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Edited by
Eugene Shoulders

sil·vics \'sil-viks\ *n pl but sing in constr* [NL *silva*] : the study of the life history, characteristics, and ecology of forest trees esp. in stands
sil·vi·cul·tur·al \,sil-və-'kəlch-(ə-)rəl\ *adj* : of or relating to silviculture — **sil·vi·cul·tur·al·ly** \-ē\ *adv*
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107 papers are presented in 13 categories: Seedling production, Site preparation, Stand establishment, Stand management, Genetics, Vegetation management, Soil-site relationships, Tree nutrition, Symbiotic relationships, Growth and yield modeling, Pest management strategies, Interactions, and Forest influences.

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Proceedings

of the

THIRD BIENNIAL SOUTHERN SILVICULTURAL RESEARCH CONFERENCE

Edited by

Eugene Shoulders

Atlanta, Georgia

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Sponsored by:

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P R E F A C E

This volume contains 107 papers presented at the Third Biennial Southern Silvicultural Research Conference held November 7-8, 1984, in Atlanta, GA. The papers are organized into 13 subject matter areas encompassing the broad array of interests of silvicultural researchers.

Initiated in 1980 and scheduled in even-numbered years therafter, Southern Silvicultural Research Conferences provide a forum for scientists actively engaged in silvicultural research to report their study results, to present new concepts and techniques, to discuss topics of mutual interest, to coordinate cooperative efforts, and to stay current on developments in the field. Nonresearchers have found the conferences and their proceedings to be valuable sources of information on current and developing trends in southern silviculture. They have contributed significantly to the success of the conferences through their participation in discussions and their informal contacts with research specialists.

The Third Biennial Conference was sponsored by the Southern and Southeastern Forest Experiment Stations of the USDA Forest Service, the Southern Region of the National Association of Professional Forestry Schools and Colleges, and the Southern Industrial Forestry Research Council. Representatives of these organizations who served on the Steering Committee are:

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John R. Toliver, Louisiana State University, Baton Rouge, LA

Special thanks are extended to the contributors who prepared and presented the research papers, and to the 17 moderators who presided over topic sessions and maintained a very strict time schedule. Thanks also go to others who submitted abstracts for consideration by the Program Committee, and to those who attended the Conference and participated in the discussions of the presented papers.

Papers have been published in this Proceedings as they were submitted by the authors--in camera-ready form. Authors are responsible for the content and accuracy of their papers. Printing and production were supervised by the Southern Forest Experiment Station, USDA Forest Service, New Orleans, Louisiana.

EUGENE SHOULDERS
Program Chairman

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SEVERE TOP PRUNING IMPROVES WATER OAK SEEDLING GROWTH[1]

John C. Adams[2]

Abstract. Two pruning and one leaf stripping treatments were applied to a uniform group of water oak (Quercus nigra L.) seedlings. The purpose was to evaluate the effect of the pruning on total height and growth of the seedling following planting. After two years, the pruned treatment had not equaled the total height of the check but were growing at a much faster rate and appeared to be in a higher state of vigor than unpruned seedlings. New growth in the first two years was 52% greater in the pruned seedlings than in the unpruned. Reduction of the size of the seedlings by pruning was noted as advantageous for handling ease.

INTRODUCTION

Water oak (Q. nigra L.) plantation establishment in the lower middle South has been rather erratic, primarily because barerooted seedlings are slow growing initially or suffer from various forms of dieback resulting in a poor competitive position in the emerging vegetation (Adams 1983).

The use of bareroot stock is desirable for many planting situations but without the establishment of vigorous, actively growing seedlings, the plantation concept for this species has little chance for success. The production of water oak seedlings in the nursery is relatively easy and inexpensive. Often 1-0 seedlings are rather large at the end of the nursery season and this large size creates two different problems. One is the physical handling of the seedlings, especially in bundles of 100 or more, and two, the root/shoot ratio may exceed an optimum for maximization of vigorous early growth of newly planted seedlings.

Water oak is a good mast producer for wildlife, grows fast once seedlings are well established, and produces desirable wood products. Because the species is versatile, water oak is in demand, especially for the small forest landowner or farm woodlot owner desiring a hardwood timber species that grows well and is productive for wildlife.

Small plantation plantings usually involve barerooted stock and planting with a dibble with little or no cultivation following seedling establishment. Therefore, the newly planted seedlings must establish good root/soil contact and produce vigorous growth to be competitive. The production of this vigorous growth in many cases is missing and to counter the effects of slow initial growth and/or dieback, several treatments were applied to a group of water oak seedlings to determine a better method of handling and planting to ensure success with a minimum of problems.

METHODS AND PROCEDURES

In January, 1982, water oak seedlings were obtained from the Office of Forestry nursery in Columbia, Louisiana. Seedlings were sorted and 246 trees approximately uniform in size (root and shoot) were selected for the study. These were planted with a dibble one by one meter spacing on a small bottom site located on the Louisiana Tech University Farm.

The planting was divided into ten blocks with four treatments per block. Each treatment/block was represented by six trees. Treatments were pruning to 2.5 cm, pruning one-half of the total height, stripping all the leaves and a check (no pruning or stripping).

---

[1]Paper presented at 3rd Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2]Dr. John C. Adams, Associate Professor, School of Forestry, Louisiana Tech University, Ruston, LA 71272.

At the end of the second growing season 40 seedlings (one seedling per plot per replication) were excavated for root development evaluations.

Experimental design was a randomized block and analysis was performed for initial height, first- and second-year height and growth, and root growth. Vigor of the seedlings was also evaluated.

RESULT AND DISCUSSION

At the beginning of the study, measurements for height and root size before application of the treatments indicated that the initial random sample was statistically equivalent. At the end of the first year there were highly significant ($P > 0.01$) differences in height. The check and the leaf stripping treatment were different from the two pruning treatments by 14.06 cm or 24.75% in height (Table 1). However, when new growth from terminal bud or from point of pruning (an advantageous bud) is considered, a completely different picture emerges. The check and leaf stripping treatments grew 11.53 cm and 6.21 cm, respectively, while the pruning to 2.5 cm grew 39.51 cm (70% greater than the check) and pruning half-height grew 22.1 cm (48% greater than the check).

At the end of the second year, the same pattern was observed. There was significant difference ($P > 0.01$) in height between the treatments but when new growth is considerd, the perspective of seedling height completely changes. Both the pruning treatments had 32 cm growth, whereas, the check and the stripping of leaves grew 26 cm or an 18 percent difference in growth (Table 1).

In the first two growing seasons, total new growth was 37.9 cm, 71.9 cm, 54.1 cm, and 32.5 cm for the check, 2.5 cm prune, half-height prune, and leaf stripping respectively. The new growth observed in the pruning treatments had larger leaves with a darker green color, and the plants generally appeared to be in a higher state of vigor and to be very competitive. The check and the leaf stripping treatment generally appeared to exhibit transplant shock with little growth in the first season and an obvious lack of vigor in the appearance of the individual plants.

The objective of this study was to determine the effect the treatments had on the growth of the seedlings. Therefore, competition from other seedling and plants was kept at a minimum and no data on survival potential of the different treatments is available. However, in several earlier plantation establishments, the low vigor associated with the first and second years of plantation life has resulted in unacceptable mortality rates, and surviving trees were very slow in responding to the competition of natural vegetation (Adams 1983). Woessner (1972) found that there was some survival problems when he root and shoot pruned and then field planted in an area of low summer rainfall. However, Hammond (1970) and Toliver et al. (1980)

Table 1. First and second year height and growth of pruned and unpruned water oak seedlings.

Treatment	Initial Height	Height 1st Season	Height 2nd Season	First Year Growth	Second Year Growth	Total Growth
	cm	cm	cm	cm	cm	
Check	47.4^{A}	58.9^{A}	85.3^{A}	11.5^{A}	26.4^{A}	37.9^{B}
Prune (2.5 cm)	45.4^{A}	40.5^{B}	72.9^{B}	39.5^{B}	32.4^{A}	71.9^{A}
Prune (1/2 height)	45.9^{A}	45.1^{B}	77.1^{B}	22.1^{B}	32.0^{A}	34.1^{AB}
Strip leaves	48.6^{A}	54.8^{A}	81.1^{A}	6.2^{A}	26.3^{A}	32.5^{B}

Means with the same letter are not significantly different.

found no significant differences in various root/shoot pruning treatments, either after the first year or the five year survival counts.

The use of a pruning treatment to 2.5 cm of height resulted in the seedlings growing at a significantly higher rate than that of the check. First-year growth was 30 percent greater than that of the check and at the end of the second year, was 50 percent greater in new growth. Although total height was less for the prune treatments, the vigor and speed of initial growth should give these seedlings a competitive advantage over those in a low state of vigor and growing very slowly.

Observation after planting and applying the treatments, indicated the pruned seedlings started sprouting as soon as leaf initiation was observed in established water oak trees. The check and seedlings with leaves removed were several weeks behind in growth initiation and growth was slow. The early growth start puts the pruned seedlings in a competitive position compared to the taller, but less vigorous, slower growing check. Larson (1975) presents some evidence that indicates a similar fast leaf initiation when northern red oaks seedlings were top pruned and planted.

Because there was a larger difference in growth between the treatments, root systems were examined. The expectation was that there would be a root size difference between the fast and slow growing treatments. However, there was no statistical difference detected for root dry weight, length, or width, and the same size root systems were supporting both the slow growing and fast growing groups of seedlings.

Whether or not the fast new growth will continue and the pruned trees exceed the unpruned in size, there is an advantage in the physical handling of the oak seedlings when they are pruned. Unlike pine seedlings which are commonly packed 1000 seedlings per bundle or bag, oak seedlings are so large that 100 per bundle is a common practice. Several thousand seedlings are difficult to handle simply because of the bulk involved. Even if growth differences are not considered, the advantage of handling ease of pruned seedlings, both in bundles for storage and in the field for planting, is considerable.

CONCLUSIONS

Pruning the top of water oak seedlings, either to 2.5 cm or one-half of the height, results in a vigorous, fast growing sprout. The sprout growth did not exceed the unpruned in total height but was much more vigorous and should be in a much better competitive position in relation to other competiting vegetation. New growth after two years was 44% greater for pruned trees. The new growth of the seedlings pruned to 2.5 cm was 52% greater than the unpruned trees.

If the growth slows on pruned trees and the unpruned start growing at a faster rate, then the net effect will be a product about the same size. However, the vigor associated with the pruned seedling sprouts may increase survival and result in more stems per acres. If growth and survival become equal over time, the advantage of less bulk and weight, plus ease of planting, will still favor the use of the pruning techniques with this species.

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A 15-DAY HYDROPONIC SYSTEM FOR MEASURING ROOT GROWTH POTENTIAL[1/]

Laura E. DeWald, Peter P. Feret, and Richard E. Kreh[2/]

Abstract.--Seedling root growth potential is correlated with field performance. A standard test to measure this parameter is time consuming and involves some special equipment. This study describes a 15-day hydroponic system developed as an alternative to the standard 24-day soil root growth potential test system for measuring loblolly pine root growth potential. The hydroponic system, which floats seedlings on top of water in fish aquariums, results in fewer numbers of new roots and less total length of new roots. However, the relative root growth potential results are comparable to the standard 24-day soil test. The 15-day hydroponic system, a viable alternative for measuring loblolly pine root growth potential, is a less expensive, simpler, and faster method than the standard soil test system.

INTRODUCTION

Decreased southern pine plantation survival has been a growing concern for the past several years. Venator (1981) attributes nearly one third of the mortality of newly outplanted seedlings to poor stock quality and improper handling procedures. Seedling quality has traditionally been evaluated by the morphological characteristics described by Wakeley (1948), which are used in many nurseries to grade the seedlings. However, these morphological grades do not necessarily correlate well with survival and field performance (Ritchie and Dunlap 1980, Wakeley 1948).

The initial survival of transplanted seedlings depends largely on the ability of their root sytems to rapidly replace the roots lost during transplanting and handling, and to regenerate new roots to re-establish contact with the soil. Stone (1955) was the first to report that tree seedlings vary widely in the ability to regenerate roots. This ability, a seedling's root growth potential (RGP), can be used as a measure of seedling physiological quality (Ritchie and Dunlap 1980) and is correlated with seedling survival and field performance (Feret et al. 1984, Sutton 1980, Burdett 1979, Stone and Norberg 1979, Jenkinson 1978, Rhea 1977, Stone et al. 1962, Stone 1955).

The degree to which a seedling possesses the ability to regenerate roots cannot be visually determined and this led to the development of a test by Stone (1955) which has become a standard test to measure seedling RGP. This test involves removing any white growing tips from a sample of seedlings, pruning the roots to a specified length, and planting the seedlings in an environment optimum for root growth. After 20 to 30 days the seedlings are carefully excavated and their new root growth is quantified.

Ritchie and Dunlap (1980) describe a need to develop a faster method for evaluating seedling RGP than this standard test and a simpler testing system would be beneficial. It is the objective of this study to develop a simpler, less expensive, and quicker test to evaluate loblolly pine (*Pinus taeda* L.) root growth potential.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Graduate Research Assistant, Associate Professor, and Research Associate, respectively, Dept. of Forestry, VPI & SU, Blacksburg, VA 24061.

MATERIALS AND METHODS

Two RGP testing systems were used in the study. A system similar to the standard test, where seedlings were grown for 24 days in soil, was compared to a 15-day hydroponic system. The seedlings used in this study were 1-0 loblolly pine seedlings grown operationally by the Virginia Division of Forestry at their New Kent Nursery, Providence Forge, Virginia. Samples of sixty seedlings were hand-lifted from the nursery on September 1, 19, October 6, 25, November 11, 22, and December 13, 1983, and on January 19, February 2, March 1, 13, and April 2, 1984. On November 22 and December 13, 1983, and February 2, 1984 an additional 240 seedlings were hand-lifted, placed into double layered polyethylene bags, and stored at 0°C, 50 percent relative humidity for 3, 6, 9, and 12 weeks. The freshly lifted seedlings on the three cold storage lift dates were used as a zero storage treatment. Following each lift or cold storage treatment, the seedlings had their root systems pruned to 12 cm below the root collar and any new white growing tips were removed. Thirty seedlings each were then placed into the two RGP test systems.

Fifteen seedlings were grown hydroponically in two replicate 37.8 liter (10 gallon) fish aquariums in a greenhouse at Virginia Polytechnic Institute and State University for 15 days. In this testing system the seedlings were suspended in tap-water by inserting them at their root collars into slots cut into sytrofoam rectangles, and then these styrofoam pieces were floated on top of the water. Air was bubbled into the water through two air stones in each aquarium using diaphragm air pumps. The water temperature was maintained at ambient air temperature (minimum of 16°C nights and up to 27 C days) and 0.5 g of 20-20-20 (nitrogen-phosphorus-potassium) was added to the water (approximately 13 ppm final concentration). The outsides of the aquariums were covered with aluminum foil to prevent sunlight from reaching the roots, to decrease algae growth in the aquariums, and to help maintain a relatively constant water temperature. The seedlings were grown under a 16-hour photoperiod (mixture of gro-lux and cool white fluorescent lights suspended 50 cm above the tops of the seedlings). Additionally, the whole system was placed under 30 percent shade cloth to help maintain more constant greenhouse temperature and light regimes.

The other 30 seedlings for each lift date and cold storage treatment were tested in a standard test system set up at the Reynolds Research Center in Critz, Virginia. Fifteen seedlings were planted into two replicate 46 X 10 X 41 cm (length X width X height) plexiglass watertight trays containing Pro-Mix BX Premier growth medium. After being planted the seedlings were well watered, allowed to drain to field capacity, and then the trays were stoppered and emersed in water baths held at 20 C. The water bath temperature was maintained with heaters (or cooling units) and water was constantly circulated around the trays with a circulating water pump. The air temperature was maintained at ambient air temperature (15-27 C). The seedlings were grown under a 16-hour photoperiod. After 24 days the seedlings were carefully excavated from the soil and their roots were washed to expose the new white root growth.

After the 15 days of hydroponic growth or 24 days of growth in the soil system the RGP of the seedlings was quantified. The new roots are easily distinguished from the old growth by their white color, and lack of periderm and secondary thickening. The RGP parameters measured on seedlings from both systems were:

1. Total number of new short roots
2. Total number of new long roots
3. Sum of the lengths of the new long roots

A short root was a new root with a length 0.50-1.49 cm, and a long root was a new root $\geq$ 1.50 cm in length. All lengths were measured to the nearest centimeter. RGP was then expressed as the total number of new roots (number of new short + number of new long roots) and as the total length of new roots (total number of new short roots + sums of the lengths of the new long roots).

The fresh lift and cold storage RGP results were analyzed separately. Analyses of variance and regression techniques were utilized to compare the two RGP test systems. The experimental design was a randomized complete block design with the test systems and lift date (and cold storage duration) the factors in the analyses. All of the analyses were based on plot means of 30 seedlings.

RESULTS

The results presented in this paper will be those relevant to the comparisons of the two RGP testing systems only. The effects of time of lift and cold storage on the RGP will not be addressed since these topics are outside the scope of the objectives of the study.

The ranges and overall mean values for the total number and total length of new roots per seedling from the lift over time and cold storage experiments for both systems are listed in Table 1. The results of the lift over time experiment are shown in Figures 1 and 2, while the cold storage results for each cold storage lift date are illustrated in Figures 3 and 4.

Table 1.--Range and mean (n=30) values of total number and total length of new roots from the cold storage and lift over time experiments.

	Cold Storage Experiment						Lift Over Time Experiment	
	November Lift		December Lift		February Lift			
	Test System		Test System		Test System		Test System	
	Soil	Hydroponic	Soil	Hydroponic	Soil	Hydroponic	Soil	Hydroponic
	Total Number							
Maximum	24.9	14.0	34.4	12.0	29.0	12.7	23.2	12.1
Minimum	11.7	4.1	5.6	4.1	15.1	3.8	1.7	0.5
Mean	18.5	8.9	20.3	9.1	21.9	7.0	12.4	4.8
	Total Length (cm)							
Maximum	89.1	30.4	102.7	23.7	64.6	26.4	66.7	21.3
Minimum	20.9	6.1	11.9	4.5	28.5	4.9	2.1	0.5
Mean	52.5	15.4	56.6	16.9	48.7	12.4	29.4	7.8

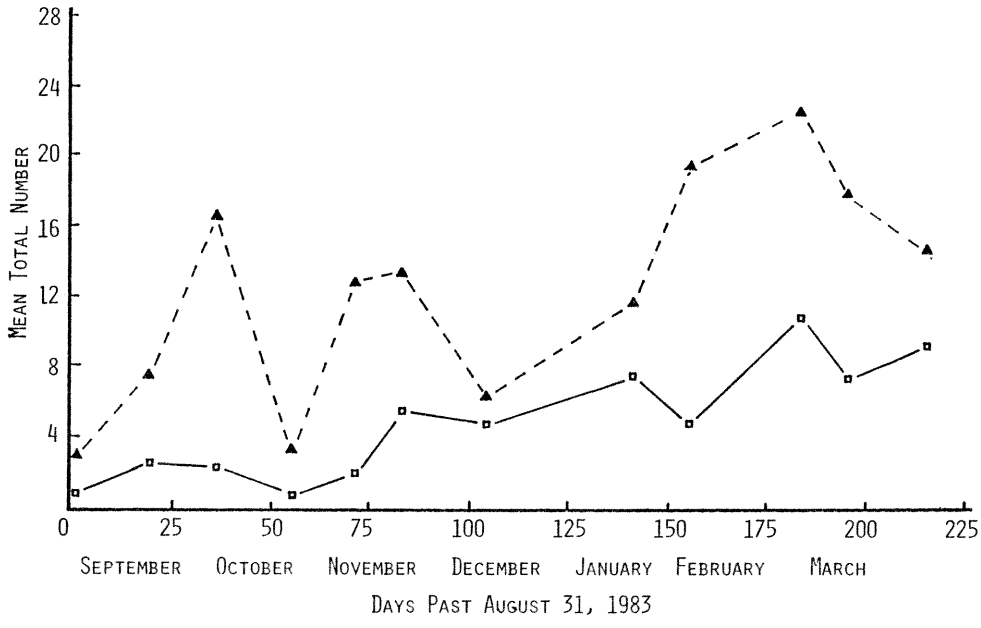

Figure 1.--Relationship between time of lift and mean (n=30) total number of new roots for the hydroponic (□—□) and soil (▲--▲) root growth potential test systems.

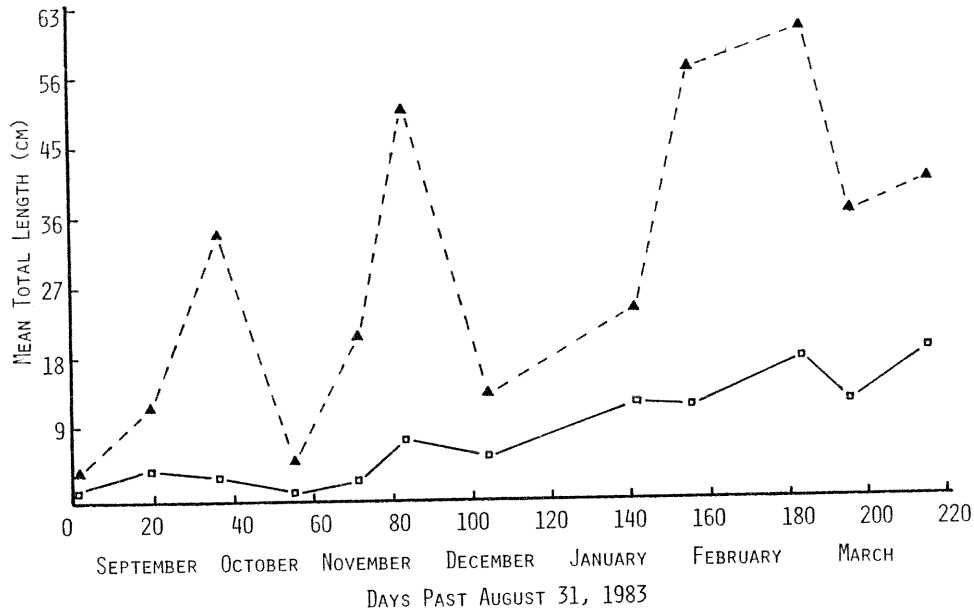

Figure 2.--Relationship between time of lift and mean (n=30) total length of new roots for the hydroponic (□ — □) and soil (▲- -▲) root growth potential test systems.

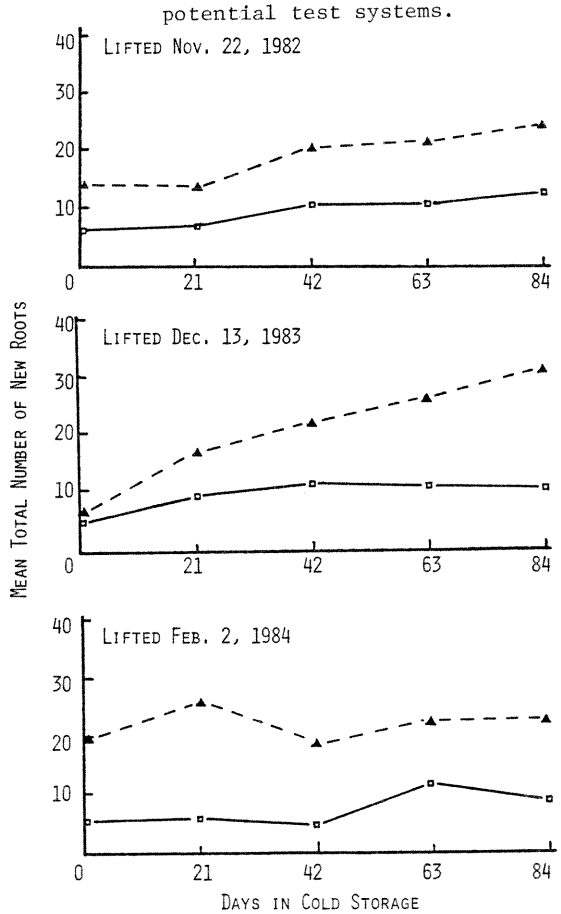

Figure 3.--Effect of time of lift and cold storage on mean (n=30) total new root number for the hydroponic (□ — □) and soil (▲- -▲) root growth potential test systems.

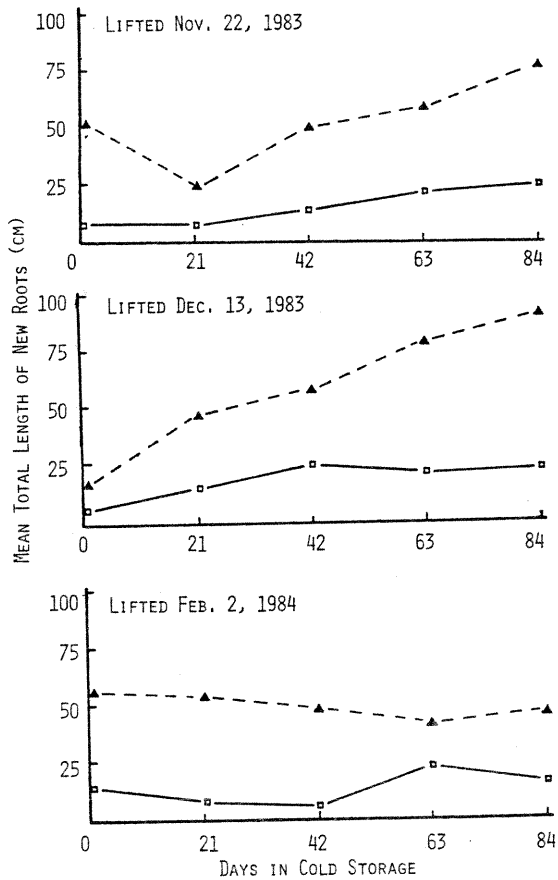

Figure 4.--Effect of time of lift and cold storage on mean (n=30) total new root length for the hydroponic (□ — □) and soil (▲- -▲) root growth potential test systems.

Each point in these four figures represents a plot mean of 30 seedlings.

The figures indicate that in both experiments number and length of new roots on seedlings from the 24-day soil test was always greater than the comparable value from the hydroponic system. The figures also illustrate that generally, when RGP was poor it was poor in both systems. However, when RGP was "good", as evidenced by abundant numbers and long lengths of roots, there was a greater difference in the absolute results between the two systems. Despite the divergence as RGP increases, both systems show relatively the same pattern from sample point to sample point as shown in Figures 1 through 4.

As would be expected after examining Figures 1 and 2, the analyses of variance for the lift over time experiment indicated that the RGP test systems differed significantly (α =0.01) for both mean total number and mean total length. This was true for the cold storage experiment as well; both mean total number and length differed significantly (α =0.01) for each of the three cold storage lift dates when analyzed separately or together.

The correlation and Spearman rank correlation coefficients between the two test systems for both experiments are listed in Table 2. The relatively low and nonsignificant coefficients for the February cold storage comparisons are due partially to the fact that RGP did not vary significantly over time in cold storage.

Table 2.--Coefficients for the correlations and Spearman rank correlations between the hydroponic and soil RGP test systems for the cold storage and time of lift experiments.

New Root Variable	Correlation Coefficient	Significance Level	Spearman Rank Correlation Coefficient	Significance Level
---------- Cold Storage Experiment ----------				
		November Lift		
Number	0.93	α = 0.01	1.00	α = 0.01
Length	0.66	α = 0.01	1.00	α = 0.01
		December Lift		
Number	0.78	α = 0.01	0.60	ns
Length	0.84	α = 0.01	0.70	ns
		February Lift		
Number	0.20	ns	0.60	ns
Length	-0.23	ns	0.60	ns
---------- Lift Over Time Experiment ----------				
Number	0.64	α = 0.01	0.66	α = 0.01
Length	0.68	α = 0.01	0.78	α = 0.01

Simple linear regressions for the model: Average Total Number = Bo + B_1(Time of Lift) were fit separately to the soil system (R^2 = 0.42) and hydroponic system (R^2 = 0.74) data sets, and the test for different slopes between these two lines was not significant (α =0.05). The same results were obtained from the simple linear regressions for average total length (R^2 = 0.42 for the soil system, R^2 = 0.77 for the hydroponic system). Since there were only five points per regression line for each of the cold storage lift dates, the test for parallel slopes was conducted on the data pooled from all three lift dates. The slopes for the model: Average Total Number = Bo + B_1 (Storage Duration) did not differ significantly (α = 0.05) between the two test systems (soil system R^2 = 0.54, hydroponic system R^2 = 0.59) Similar results were obtained from the simple linear regressions of average total length of new roots (soil system R^2 = 0.37, hydroponic system R^2 = 0.56).

In addition, analyses of variance were conducted for the lift over time and cold storage experiments where total number of new roots from the hydroponic system was compared to the total number of long roots only from the soil RGP test system. The results of this analysis indicated no significant differences between the two systems (α =0.05).

Finally, a nonparametric signs test as described by Conover (1980) was conducted on data pooled from both the lift over time and cold storage experiments. This test examined the pattern between successive points for each RGP system and tested to see if the fact that RGP increased or decreased simultaneously in both systems from point to point was random. The result of this test was not significant for both average total number and length. Therefore, the interpretation was made that both systems produced similar trends from sample point to sample point, and the similarity of these trends was not random.

DISCUSSION

Ritchie and Dunlap (1980) stress that the environmental conditions of an RGP test can substantially influence the test results. This is true in this study when the absolute values between the standard soil test and hydroponic RGP test are compared. The fact that RGP was always greater in the soil system was not unexpected since the seedlings were grown for an additional nine days in the soil system. The relationship between the results of the two systems can be interpreted from the comparison of total number of new roots in the hydroponic system to the total number of new long roots only in the soil system. The nonsignificant statistical results of the analyses for both

experiments suggests that the roots being initiated within 15 days are primarily those which rapidly elongate the following nine days. These roots, therefore, produce most of the total new root length measured in the soil system. This elongation in the additional nine days of the soil test also explains why the differences are greater between the two systems when RGP is high.

Despite the differences in absolute RGP values measured from the two systems, relative results from both experiments support the validity of the hydroponic system for measuring loblolly pine seedling RGP. When RGP was poor, it was generally poor in both systems. As RGP increased, it increased in both systems, but to a greater extent in the soil system. As previously mentioned, this greater difference when RGP is high is probably primarily due to the extra nine days of growth in the soil system. However, another contributing factor could be that the hydroponic system is less favorable for growth. Lorio et al. (1972) reported that the root systems of mature loblolly pine trees were sensitive to waterlogging and produced fewer fibrous roots in these soils. Whether this is true for loblolly pine seedlings in aerated hydroponic systems is unknown. However, even if there is some slight depression of RGP in the hydroponic test, this system can still be used if the same relative results are achieved in both tests, which was true for the data in this study.

Examination of the relative results from the two systems shows that RGP responded similarly both over time and following cold storage. Most of the correlations were significant and relatively high. Additionally, the nonsignificant difference between slopes of regressions fit separately to the data of both test systems indicates that both systems show similar overall RGP responses to time of lift and cold storage.

The pattern of RGP changes from sample date to sample date is similar in both systems for both experiments. This is visually evident in Figures 1 through 4 and is supported statistically by the lack of statistical significance in the signs analysis. The major differences in relative results between the two systems occurred primarily in late April and May. During this time of year the growth environments in the test systems were becoming unfavorable for overall seedling growth, particularly for the soil system. Air temperatures of the greenhouses were relatively high causing transpirational losses in the seedlings before new root growth began. This was true even in the hydroponic system and was evident by decreased turgor in the shoots. Stressful temperature conditions were not always uniform between the test systems (sunny, hot days in Critz coinciding with cloudy, cooler days in Blacksburg) and this probably contributed to differences in RGP changes between the two systems.

Despite statistical differences in the absolute RGP results between the two test systems, the relative RGP results are comparable. Therefore, it appears that the 15-day hydroponic system is a viable alternative to the standard 24-day soil system. The hydroponic system has several advantages over the soil system. The hydroponic system avoids losses in precision due to breakage and loss of new roots which can occur during the excavation of the seedlings from the soil system. Results can also be obtained nine days sooner with the hydroponic system. Less time is needed putting the seedlings in and getting them out of the hydroponic system. For a sample of 30 seedlings, this takes only 15 minutes for the hydroponic system but requires one hour for the soil system. Additionally, less space is required for the hydroponic system. Up to 90 seedlings can be tested in one 37.8 (10 gallon) aquarium which can easily be set up on a desk. This is in contrast to the tray and waterbath space needed for 90 seedlings in the soil test system.

Finally, the hydroponic system is simpler and less expensive to establish. Most of the supplies can be obtained from a hobby or pet shop, and the initial cost per aquarium (based on 60 seedlings per aquarium) is less than 10 dollars. This is significantly less expensive than the soil system which costs over three hundred dollars per 15 seedlings to establish. Once the test systems are established the cost of the growth medium causes greater expense for the soil system, and the costs incurred by the longer duration of the soil test and additional time required to plant the seedlings and excavate them are also higher for the soil system.

CONCLUSIONS

The results of this experiment indicate that the hydroponic system described in this paper can be used to measure loblolly pine RGP. It is a simpler, less expensive, and faster test than the standard soil RGP test system. Although fewer numbers and less total length of new roots are measured in the hydroponic system, comparable relative RGP results with the soil system are obtained. As long as test conditions are favorable for root and shoot growth, and these conditions are relatively constant, any differences in relative RGP responses between the two systems should be minimal. The disadvantage of the occasional discrepancies between the relative results of the two systems is outweighed by the many advantages of the hydroponic system.

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ROOT WRENCHING AND TOP PRUNING EFFECTS ON LOBLOLLY PINE NURSERY SEEDLING DEVELOPMENT[1/]

A. E. Miller, R. W. Rose, and K. F. Ray[2/]

Abstract.--Loblolly pine (Pinus taeda L.) seedlings growing in nursery beds were left undisturbed, wrenched once in November, or wrenched once a month for 1, 2, and 3 months consecutively before wrenching in November. Soil bulk density and seedling morphology were determined during the first week of August, September, October, November, and December. Seedling starch and nutrient content were also measured. A final measurement was made during mid-month lifting in January and included determination of root growth potential. Soil bulk density in the seedbeds declined as wrenching frequency increased. Seedling height and diameter growth were significantly reduced by wrenching compared with untreated seedlings. Root starch was significantly lower in wrenched seedlings but did not differ with wrenching frequency. There were no differences in nutrient content or root growth potential among any treatments. Overall, the results show that wrenching reduced seedling growth and starch content without altering nutrient content and root growth potential. Outplanting survival and growth will be examined after completion of a year's growth.

INTRODUCTION

A variety of cultural practices are used in forest tree nurseries. Two common cultural techniques used in the southeast are root wrenching and top pruning, which alter seedling morphology and biomass distribution. Wrenching involves passing a tilted blade under the seedbed to sever seedling roots and aerate the soil. The intended effects are to slow seedling height growth, stimulate lateral root development, and attain better balance between shoots and roots. Top pruning involves reducing seedling heights by cutting their shoots, thereby altering the influence of apical bud activity on seedling development and reducing differences in height caused by variation in the seedbed. Both of these cultural techniques are intended to promote development of seedlings that provide improved survival and growth when outplanted in the field.

Variations in final seedling size have been used to grade planting stock for quality (Wakeley 1954). Height, diameter, or shoot-root ratio have historically been used as standards due to their ease of measurement. However, the use of morphological characteristics to judge a seedling's capacity to survive and grow once it has been outplanted has been questioned for some time (Wakeley 1971). Variable survival and periodic planting failures all attest to the fallibility of morphological grades and suggest that internal physiological factors may also control growth. Seedling physiological quality may be measured by root growth after planting, but it cannot be predicted visually.

Numerous studies have shown that reductions in seedling size and growth occur after wrenching in seedbeds, but results are often mixed when compared to outplanting performance. Duryea and Lavender (1982) and Stein (1984) found reductions in size and weight of wrenched Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) nursery seedlings, but survival and growth were not improved after outplanting. Others (Tanaka et al. 1976, Koon and O'Dell 1977, van den Driessche 1983) observed similar morphological changes in

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[2/] Assistant Professor, Department of Forestry, Clemson University, Clemson, South Carolina; Research Scientist, Westvaco Corporation, Summerville, South Carolina; and former Assistant Professor, Department of Forestry, Clemson University, Clemson, South Carolina. K. F. Ray is currently Research Forester, International Paper Company, Natchez, Mississippi.

wrenched Douglas-fir which did show improved field survival and growth. Shoulders (1963) found that wrenching reduced the size of loblolly pine (P. taeda L.) and slash pine (P. elliotti Engelm.) nursery seedlings without improving field survival, while wrenched longleaf pine (P. palustris Mill.) had better survival than nonwrenched seedlings. Rook (1971) and van Dorsser and Rook (1971) reported wrenching Monterey pine (P. radiata D. Don) nursery seedlings reduces their shoot growth, produces a compact mass of fibrous roots, results in a low shoot/root ratio, and improves field survival. This study reports the effects of root wrenching and top clipping on the size, nutrient and starch content, and root growth potential of loblolly pine planting stock at lifting.

MATERIALS AND METHODS

Loblolly pine seed from Charleston County in the South Carolina coastal plain were sown in beds at the Westvaco Corporation nursery in Ravenel, South Carolina. The soil in the nursery is a Wagram loamy fine sand moderately low in pH, organic matter, and inherent fertility. The subsoil is loamy with moderate water permeability, while the surface soil exhibits rapid infiltration and is well aerated. All nursery beds were sown in early April, 1983, at a seed density which produced an average of 30 (±5) seedlings per square foot at the end of the growing season in January. Routine nursery cultural practices were applied to the beds used for this study during the rest of the growing season.

An area having six nursery beds was randomly selected during mid-June. The two beds in the middle of the selected location were separated by an irrigation pipe with sprinklers and were excluded from the study. Four beds, two located on each side of the two excluded beds, were divided into five forty-foot long plots separated by ten-foot long bed sections serving as buffer strips. Later in this study, seedlings in two of these four beds showed disease symptoms that were suggestive of Pythium spp. infection. The entire experiment was treated with Subdue™ to alleviate the disease, but this chemical seemed to have a minimal effect. The symptoms were confined to beds three and four, which are included in the analysis.

Treatments

Five wrenching treatments were applied in each nursery bed. Plots in each bed were randomly assigned one of the following treatments: (1) no wrenching; (2) wrenching once in November; and wrenching once each month in (3) October and November, (4) September, October, and November, and (5) August, September, October, and November. All wrenching treatments were applied in the afternoon near the first day of each month using a sharpened half-inch thick, 5-inch wide steel blade pulled behind a tractor. Narrow trenches were dug across the bed in the buffer strip on both ends of a plot to insert the undercutting blade to a depth of 7-8 inches below the bed surface. The blade raised the bed surface and seedlings about one inch as it was pulled through the soil, leaving cracks in the soil surface. Following wrenching, the buffer area trenches were filled with soil and the study area was irrigated for 30 minutes to reduce severe wilting.

Each wrenching treatment plot was divided further into three 13-foot long subplots, and a top-clipping treatment was applied to each subplot. A subplot was top-clipped only once. Clipping was applied mid-month about two weeks after wrenching during August, September, and October. Top clipping was done with a bushhog at a 7-8 inch height above the bed surface in August and September and a 9-10 inch height in October.

Measurements

Five seedlings were lifted from the middle area of each subplot in August, September, October, November, 1983, and January, 1984. These samples represented seedling condition one month after a wrenching treatment and were collected the day a new wrenching treatment was scheduled except for January when lifting was at mid-month. Lifting was accomplished by shoveling a ball of sod containing seedlings into a water-filled bucket. Undamaged roots were easily freed from the sod after soaking, and five visually representative seedlings were selected and placed in a previously labeled ziplock sandwich bag. The bags were put in an ice-cooled chest for transport to the laboratory. All seedling samples were placed in a laboratory freezer. The frozen bags were removed for seedling measurements which were routinely completed within a three-week period.

In addition, one soil core sample was removed from each subplot for bulk density measurement during all sample months except January. The soil bulk density core sampler (Soil Test™) used removed a 200 cc volume. This sample was placed in an airtight tin and brought to the laboratory. In the laboratory, soil samples were dried at 105°C for 5 days in a forced air oven and then weighed. Bulk density was calculated in grams per cc. The November bulk density samples were also analyzed for percent sand, silt and clay by the pipet soil texture method (Bauer et al. 1972).

Each seedling was measured for height and caliper and then separated into needles, stem, taproot and lateral roots. Dry weight of separated seedling parts was determined after 48 hours drying at 80°C in a forced air oven and weighed using a laboratory balance.

Following drying and weighing, separated seedling parts from the 5 seedlings in each subplot were combined into one composite sample and then ground to pass through a 40-mesh screen

in a Wiley Mill. Each sample was then placed in a labeled plastic ziplock bag and stored frozen for later analysis of nutrients and starch.

Ground needle tissue was examined for N, P, K, Ca, and Mg nutrient content at Westvaco's Soil and Tissue testing laboratory using standard analysis techniques. Taproots and lateral root tissues were analyzed separately for percent starch by the enzymatic method described by Haissig and Dickson (1976).

An additional twenty seedlings were collected during the January lifting for root growth potential (RGP) measurements. Five seedlings from each subplot were lifted as previously described except that they were bundled together and placed in a Kraft paper bag. The bag was placed in cold storage at 2°C (±2°) for later use. One month later, these seedlings were prepared for RGP determination as described by Ritchie and Dunlap (1980). By this method, all white, unsuberized root tips were removed from the seedlings before potting them in a 3-liter container using builders sand. One seedling from each treatment combination and bed was used, giving four seedlings per pot. There were three replications containing a total of 180 pots. Following a 30-day period of growth at 20°C with a 14-hour daylength and 375 ergs/cm/sec of light from fluorescent bulbs, the seedlings were removed from the pots and their roots washed free of sand. All new white, unsuberized root tips greater than 0.5 cm in length were counted. The counts were used as the RGP measurement.

Data Analysis

The design for Analysis of Variance was a split plot, randomized complete block. The four nursery beds served as blocks. The five wrenching treatments were whole-plots and the three top pruning treatments were split plots. Means for significant treatment effects were compared using the least significant difference procedure. The 0.05 level of significance was used in all statistical tests in this study.

RESULTS AND DISCUSSION

Soil Bulk Density

Seedbed soil bulk density was significantly reduced by the wrenching treatments (Figure 1). Bulk density averaged 1.18 g/cc among all plots in July before wrenching treatments began. By December, bulk density values reflected wrenching frequency. The lowest average soil bulk density, 1.22 g/cc, occurred in plots wrenched four times. Plots that were not wrenched showed gradual increases in bulk density up to 1.40 g/cc by December. Textural analysis of the upper 7 cm of bed surface was 86, 9, and 5 percent sand, silt, and clay, respectively. No statistical differences in texture components occurred among plots in this study.

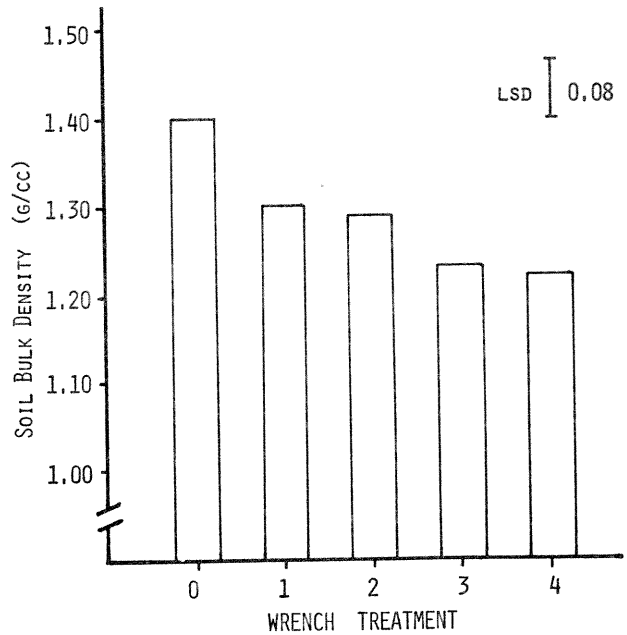

Figure 1. Soil bulk density one month following application of the final wrenching in November.

Soil bulk density of unwrenched plots appeared to become unfavorable for root growth as time progressed. In this study, a large amount of the seedling root system tended to originate from a whorl of lateral roots formed at the top of the taproot. These roots grew mostly near the bed surface and "matted" with adjacent seedling roots. Substantial reductions in root growth of pot-grown loblolly pine seedlings have been attributed to insufficient aeration and greater root mechanical impedance as bulk density nears 1.4 g/cc (Foil and Ralston 1967, Mitchell et al. 1982). It is questionable if a reduction in soil bulk density was accompanied by increased rooting at lower soil depths in this study.

Seedling Morphology

Seedling morphological features were generally reduced by wrenching (Figure 2). Both total seedling dry weight and diameter were reduced significantly by wrenching, but no consistent continued declines were associated with wrenching frequency. Seedlings wrenched two, three, and four times had significantly smaller shoot/root ratios than those that were not wrenched or wrenched only once in November. Final height in January was significantly reduced as the frequency of wrenching increased, even though all wrenching treatments had been top pruned by November. However, lack of a significant interaction between top pruning and wrenching in this study suggests final height was influenced more by wrenching than by time of top pruning.

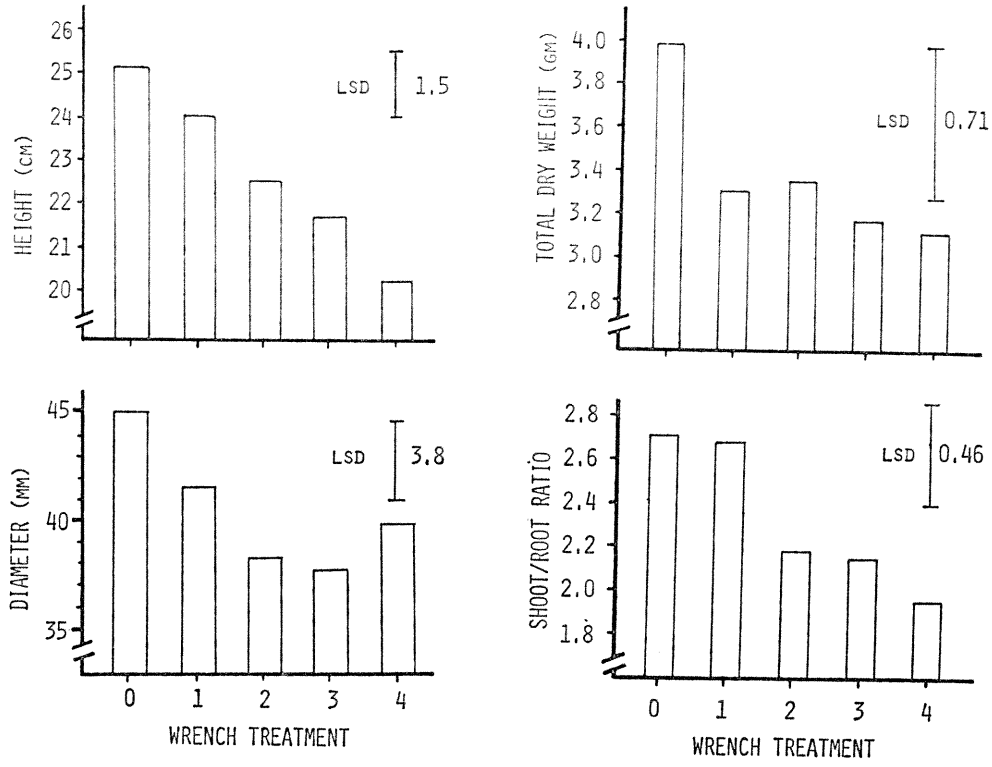

Figure 2.--Average height, dry weight, diameter, and shoot/root ratio of loblolly pine nursery seedlings in January by wrench treatment.

Top pruning did not significantly affect seedling height, diameter or shoot-root ratio (Table 1). Total dry weight of seedlings top pruned in October was significantly less than seedlings top pruned in August. Top pruning in October removed more shoot than in August and September; and coupled with the onset of a decline in vegetative growth during winter, probably caused the reduced total dry weight of seedlings in January.

Table 1. Morphological characteristics of January lifted loblolly pine seedlings for three top pruning treatments.

Time of Top Clipping	Seedling Measurement			
	Height	Diameter	Total Dry Weight	Shoot/ Root Ratio
	--cm--	---mm---	--gm--	
August	23.07	4.15	3.58	2.40
September	22.98	4.12	3.49	2.41
October	21.99	3.88	3.09	2.19
LSD	1.41	0.32	0.46	0.29

Reductions in seedling size in this study provide evidence that wrenching temporarily slows seedling growth in the seedbed. Reduc- tions in seedling size after wrenching are consistent with findings by other investigators (Rook 1971, van Dorsser and Rook 1972, Koon and O'Dell 1977, Tanaka et al. 1975, van den Driessche 1983, Stein 1984). Seedlings in each treatment have been field planted and their survival capacity will be measured after completion of one year's growth.

Seedling Physiology

Monthly increases in starch concentration were low as the growing season progressed. By December, one month after application of the final wrenching, total root starch showed no significant difference among wrenching treat- ments and averaged 9.4 percent (Figure 3). A large increase in starch content occurred in early winter between December and January. In January, total root starch was highest in the unwrenched seedlings, while wrenched seedlings generally showed reduce total root starch. Reduced starch contents were not significantly related to wrenching frequency.

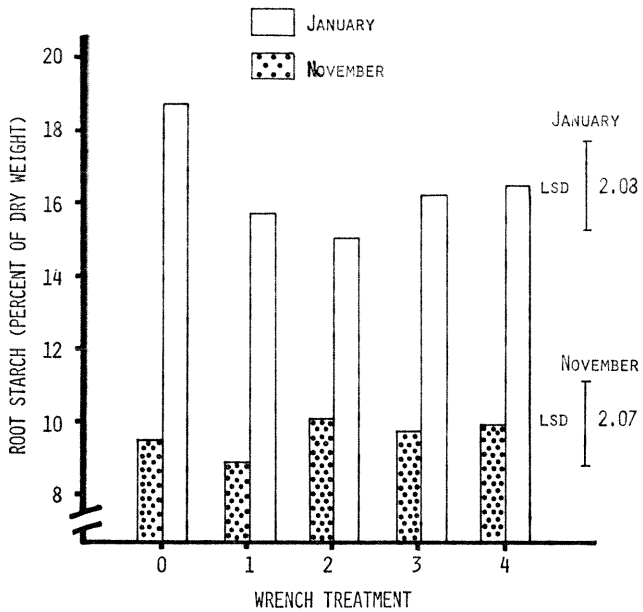

Figure 3. Root starch content of December and January lifted loblolly pine nursery seedlings by wrench treatment.

Rook (1971) found that P. radiata seedlings wrenched four times had higher total soluble sugars and starch concentrations than seedlings that were not wrenched as frequently. In this study, loblolly pine starch levels were lowered by wrenching. Unlike Rook's (1971) results, the non-wrenched loblolly pine seedlings had the highest starch levels.

Seedling nutrient content did not differ significantly with wrenching frequency or top pruning treatments (Figure 4). However, total nitrogen and potassium content did show declines with time that are probably associated with seedling growth (Figure 5). Calcium and phosphorus content of all seedlings remained relatively constant for the study period. These results show that in the absence of fertilizer applications, nutrient content can be expected to remain similar among root wrenching and top clipping treatments as applied in this study.

Root growth potential of seedlings lifted in January was not significantly affected by any of the wrenching and top pruning treatments

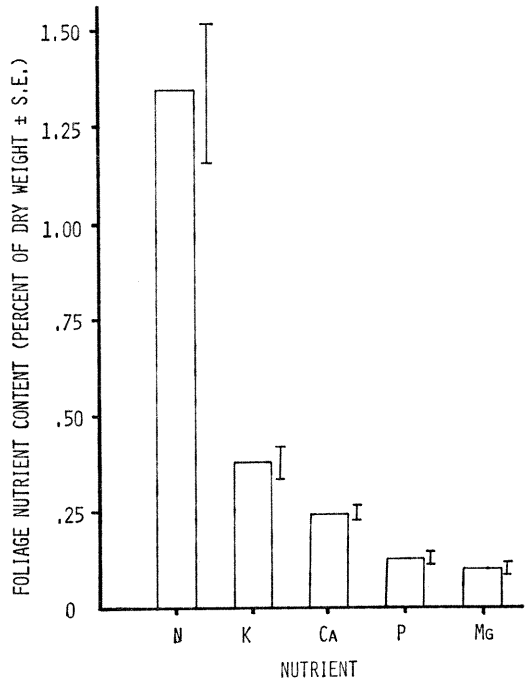

Figure 4. Nutrient content of January lifted loblolly pine nursery seedlings for all wrench treatments.

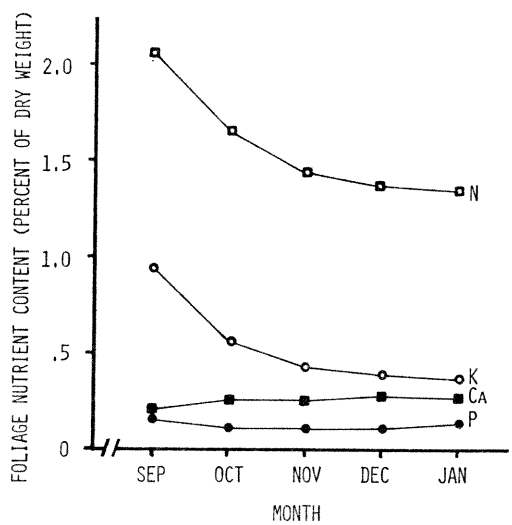

Figure 5. Average monthly nutrient content of loblolly pine nursery seedlings for all wrench treatments.

(Figure 6). The RGP data showed large between-seedling variation. Within a given wrench or top pruning treatment, the number of new root tips on any one seedling generally ranged from zero to sixty! Clearly, the wrenching and top pruning treatment effects were not strong enough to cause a consistent seedling response. Absence of a clearly dominant apical bud due to top pruning may have contributed to the lack of RGP relationships, but differences between top pruned and unpruned seedlings were not examined in this study. Starch levels of January lifted seedlings were also unrelated to RGP, as were all seedling morphological features.

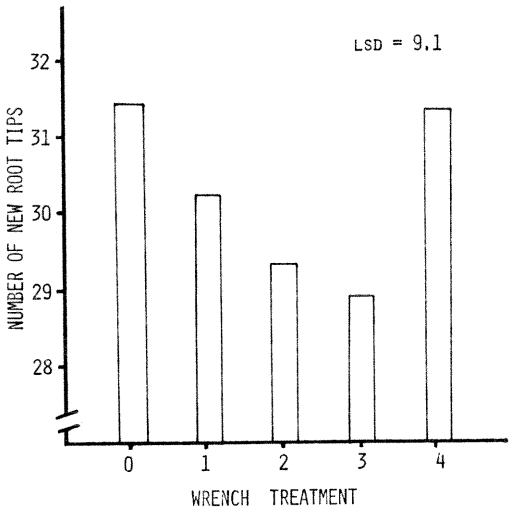

Figure 6. Root growth potential of loblolly pine nursery seedlings by wrench treatment.

CONCLUSIONS

Wrenching significantly decreased soil bulk density and generally slowed seedling growth in the nursery seedbeds. Height, diameter and total dry weight of wrenched seedlings were less than unwrenched seedlings. Wrenching also significantly reduced root starch content, but there was no correlation between starch content and wrenching frequency. Wrenching did not cause differences in seedling nutrient content or root growth potential. Top pruning does not appear to have any affect on seedling development or starch and nutrient content when applied during the late stages of seedling growth.

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ROOT GROWTH POTENTIAL OF STORED LOBLOLLY PINE SEEDLINGS[1/]

Peter P. Feret, Richard E. Kreh, and Laura E. DeWald[2/]

Abstract.--Two experiments were conducted to evaluate changes in loblolly pine (Pinus taeda L.) root growth potential (RGP) over time in storage. In Experiment I RGP changed with both time and storage temperature and was related to first-year field performance. In Experiment II RGP of stored loblolly pine seedlings fell quickly to near zero and then rebounded. RGP patterns were dependent on both storage location and duration in storage. Experiment II was designed to test the efficacy of I-Point[R] time temperature monitors for use on loblolly pine seedlings. Given certain assumptions, it was found that model 2220 may be a useful indicator of loblolly pine seedling quality.

INTRODUCTION

From the time loblolly pine (Pinus taeda L.) seedlings are lifted from nursery beds, until they are delivered to the planting site, they must pass through an array of temperatures. At lifting seedlings may be exposed to ambient outdoor temperatures until moved to cold storage. During grading and shipment seedlings may be exposed to relatively high ambient temperatures. Once delivered to the landowner, shed storage may expose seedlings to ambient temperatures for days, or weeks.

In Virginia, the Virginia Division of Forestry (VDF) has conducted a series of experiments designed to evaluate the effects of storage on loblolly pine seedlings (Dierauf and Marler, 1969; 1971a; 1971b; Dierauf, 1974; Garner and Dierauf, 1974; Dierauf, 1984). These studies have shown no consistent storage affect on field performance (Dierauf and Marler, 1969). Open shed storage may have no adverse affect on field performance (Dierauf and Marler, 1971a), and root cellar storage (vs. open shed storage) may improve seedling performance depending upon the dormancy status at time of lifting (Dierauf and Marler, 1971b). Dierauf (1974) showed a significant lifting date x storage interaction for loblolly pine seedlings but in a 1979-80 study seedlings stored for up to 99 days survived and grew well. Freezing may have no significant impact on field performance (Garner and Dierauf, 1974). The mixed results of storage temperature studies on loblolly pine seedlings suggest several factors may be important in evaluating seedling storage effects. These probably include: lift date, storage temperatures and duration, planting date and interactions among these factors (see Rhea, 1977).

Recently I-point Technologies, Limited[R] has introduced Time-Temperature-Monitors (T-T-M)[3/] for monitoring cumulative effects of storage temperature and duration on product quality. These monitors have been used for monitoring loblolly pine seedlings during shipment (C. Gramling, personal communication, W. W. Ashe Nursery, Brooklyn, MS). Their usefulness for predicting loblolly pine seedling "spoilage" has yet to be ascertained although considerable effort is currently being expended to gather such data (R. E. Rose, personal communication; I-Point Tech., Ltd., Oct. 2, 1984).

One significant problem usually associated with experiments attempting to determine the effects of storage on loblolly pine seedling survival and growth is the confounding of planting date with

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Associate Professor, Research Associate and Graduate Research Assistant repectively, Dept. of Forestry, VPI & SU, Blacksburg, VA, 24061.

3/ Mention of a company or its product implies neither approval or disapproval of product use.

treatment effects preventing analyses of storage effects alone. Recent research (Feret et al. 1984; Larsen et al. 1984, Ritchie and Dunlap 1980) shows that root growth potential (RGP) is likely a rapid and reliable parameter for estimating physiological quality of loblolly pine seedlings. Assuming this, RGP should provide a means for evaluating the relative effects of seedling storage duration and temperature on seedling physiological quality without concern for the confounding of treatments and planting dates (this is not to say these interactions are not important).

Within the context of the above, we report here the results of two experiments conducted to quantify the effects of storage temperature and duration on loblolly pine seedling RGP.

Materials and Methods

Experiment I.

Seedlings were from a commercial lot delivered to Virginia Tech by the county forester on March 1, 1984 and stored at 33°F until March 15. On March 15 seedlings from the bundle of 1000 were randomly assigned in equal numbers to each of 16 treatment combinations (Table 1). Seedlings were stored under four conditions: 1) a refrigerator at 35°F 2) a root cellar at 58°F 3) an indoor lab at 70-72°F and 4) an oven held at 88°F. For storage seedlings were wrapped in sealed polyethylene garbage bags with seedling roots within each bag wrapped in moist paper towels. As shown in Table 1, seedlings were removed from storage at varying intervals, for each storage location. Once removed, seedlings were randomly separated into two bundles: a bundle of 30 which were analyzed for RGP, and a bundle of 50 which were outplanted to an old field site. Seedlings were outplanted at the Reynolds Research Center (Patrick Co., VA) in 10 replicated 5-tree row plots at a 0.5M X 0.5M spacing.

RGP was determined by growing seedlings in trays of Promix[R] in a constant temperature water bath at 68°F for 24 days under 16 hr. photoperiod in the greenhouse. After 24 days new elongating roots >0.25 in. in length were counted. Thus, RGP was expressed as simply the number of new elongating roots.

Field planted seedlings were individually measured for height at the time of planting, and again on October 15, 1984 when survival was also recorded. These data were used to evaluate seedling field performance in relation to RGP using regression techniques.

Experiment II.

Seedlings used for this experiment were hand-lifted from the VDF New Kent Forestry Center nursery on March 1, 1984. They were held in cold storage (in polyethylene bags) for 6 weeks at 33°F. On April 15, 1984 seedlings were packaged as above and randomly assigned to one of three storage locations as follows: A) a root cellar at 58°F B) an outdoor lathhouse allowing ambient temperature fluctuations C) an indoor lab at 70-72°F.

Duration in each storage location was variable, predicated on the reaction time of two I-Point T-T-M models: 2220 and 3210. Monitors were placed on seedling bundles and when either monitor turned color (green [0] at the start of the experiment, yellow [1], rust [2], red [3]) seedlings were sampled and RGP analysis performed. Thus, for each storage location, six samples were taken. The "control" was the RGP at the start of the experiment when all monitors were "green". Table 2 summarizes treatments of Experiment II.

EXPERIMENT I

SEEDLINGS: COMMERCIAL LOT - RECEIVED MARCH 1, 1984

TREATMENTS:
A. STORED IN REFRIGERATOR AT 35°F
B. STORED IN ROOT CELLAR AT 58°F
C. STORED IN LAB AT 70°F
D. STORED IN OVEN AT 88°F

SAMPLE TIMES:

TREATMENT	DAYS
A	0, 8, 21
B	0, 8, 14, 21
C	0, 4, 8, 14, 21
D	0, 1, 2, 4, 8, 14, 21

ANALYSIS: 30 SEEDLINGS/TREATMENT/DATE - RGP
50 SEEDLINGS/TREATMENT/DATE - FIELD

TABLE 1. EXPERIMENTAL DESIGN OF LOBLOLLY PINE SEEDLING STORAGE EXPERIMENT I.

EXPERIMENT II

T-T-M MONITORS

SEEDLINGS: HAND LIFTED MARCH 1, 1984
STORED AT 32°F 6 WEEKS

TREATMENTS:
A. STORED IN ROOT CELLAR AT 58°F
B. STORED IN LATH HOUSE AT AMBIENT TEMP.
C. STORED IN LAB AT 70°F

SAMPLE TIMES: DICTATED BY T-T-M COLOR CHANGES

TREATMENT	MONITOR 2220 (DAYS)	MONITOR 3210 (DAYS)
A	0, 7, 9, 14	0, 14, 18, 20
B	0, 5, 8, 17	0, 11, 15, 21
C	0, 3, 5, 8	0, 7, 8, 12

ANALYSIS: 30 SEEDLINGS/TREATMENT/MONITOR/SAMPLE

TABLE 2. EXPERIMENTAL DESIGN OF LOBLOLLY PINE SEEDLING STORAGE EXPERIMENT II.

RESULTS

Experiment I.

The relationship between RGP and field performance is shown in Figures 1 and 2. Both field survival and height increment of living seedlings were related to RGP at the time of planting. Models were significant ($\alpha < 0.01$) and accounted for over 90% of the sums of squares.

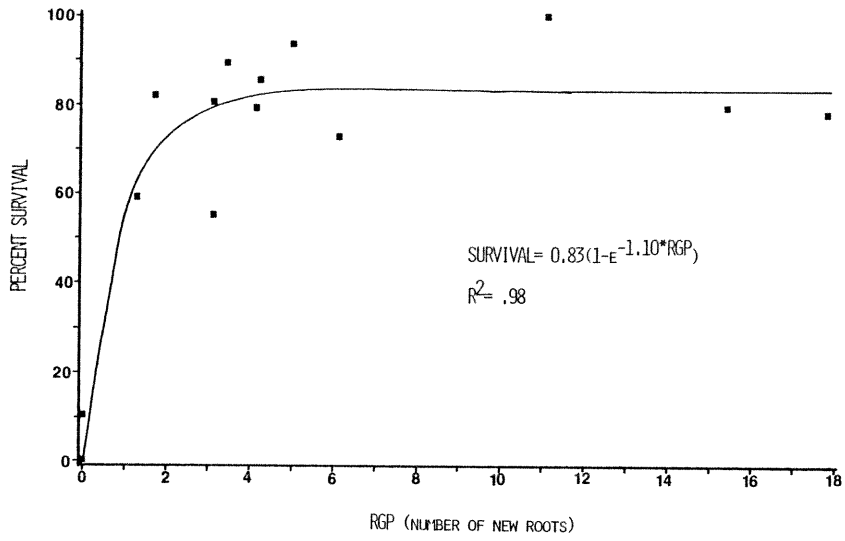

Figure 1. Relationship between number of new elongating roots and survival for loblolly pine seedling samples of Experiment I.

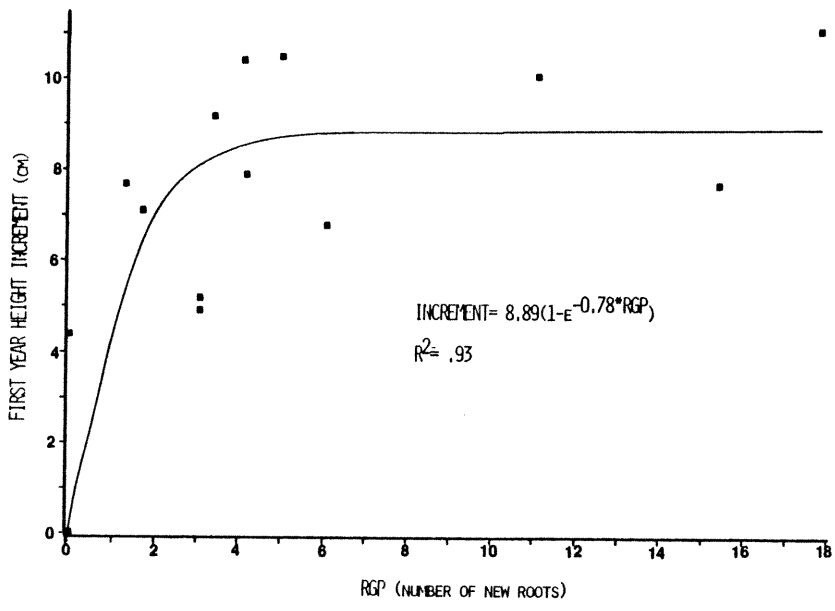

Figure 2. Relationship between number of new elongating roots and height increment for loblolly pine seedling samples of Experiment I.

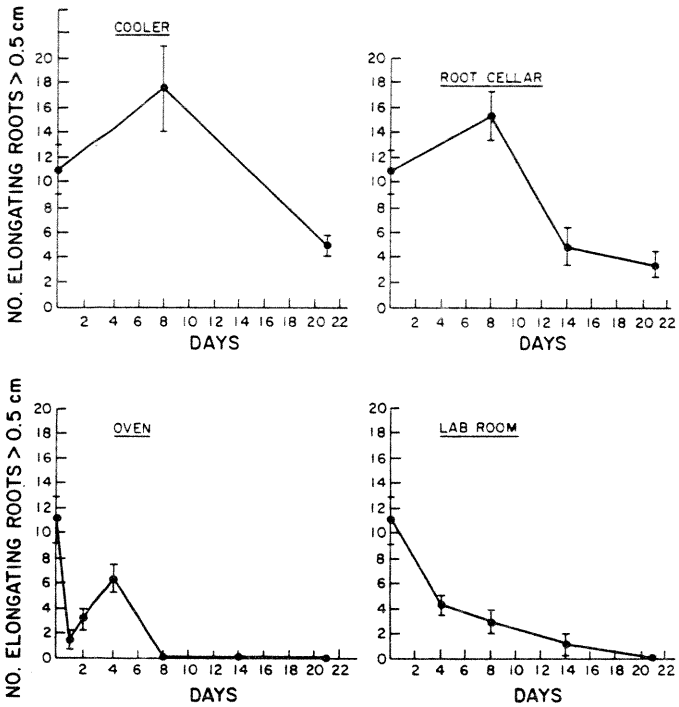

Figure 3. Results of experiment I showing changes in RGP (number of new elongating roots >0.5 cm) over time in each of the four storage locations. Vertical lines represent ± 1 std. error.

Root growth potential varied significantly both between storage locations and over time (fig. 3). In the cooler RGP was improved with 8 days of storage but after 21 days, was significantly diminished. The same trend was observed for seedlings stored in the root cellar where after 8 days RGP increased followed by a decrease after 14 and 21 days.

In the lab room (fig. 3) RGP showed a gradual decline over time with the 21 day RGP equal to 0 new roots. In the 88°F oven, RGP declined very rapidly after 24 hours, but this decline was followed by a small "burst" of RGP at day 4. By day eight, no seedlings showed new root growth.

Experiment II.

The overall results of Experiment II are plotted in Figure 4. Seedlings stored in the root cellar showed a rapid decline in RGP over the first week. This may have been followed by a small "burst" of RGP at day 14, a second decline at day 18 and another "burst" at day 21. (Two data points plotted for day 14 were plotted as the mean in Fig. 4).

In the lath house, RGP declined rapidly the first 4 days, remained low at 8 days, after which a burst of RGP was observed at days 12-16. This was followed by a second decline in RGP.

Seedlings stored in the lab gradually lost RGP until day 8. The last sample at day 12 showed a significant rise in RGP which was not statistically different from the RGP of seedlings at the start of the experiment (fig. 4).

Sample dates for Experiment II were dictated by the time-temperature-monitor reaction rates. In Figure 5, RGP is plotted by T-T-M models 2220 and

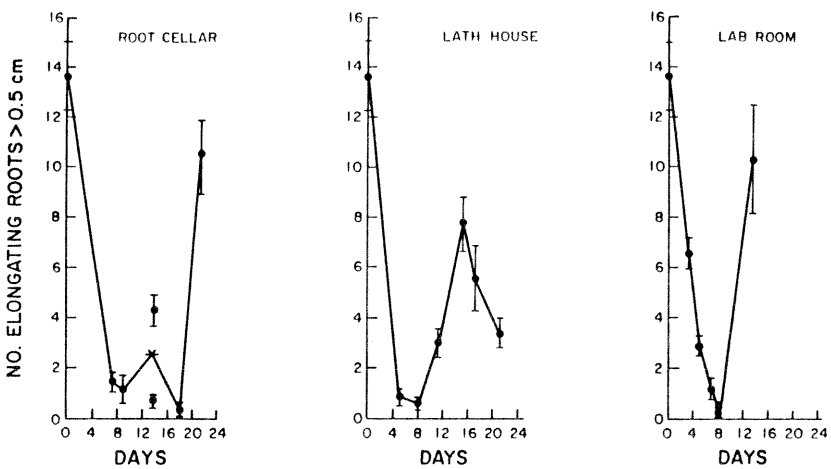

Figure 4. Results of Experiment II showing changes in RGP (number of new elongating roots >0.5 cm) over time in each of the three storage locations. (*=midpoint of two samples taken on the same day). Vertical lines represent ± 1 std. error.

3210 and storage location. The relationships between color changes of monitor 2200 and RGP appear parallel under Lab storage (Fig 5). However, for the Root Cellar and Lath House storage locations, color 3 on Model 2220 was associated with higher RGP values than either color 1 or color 2. The results using monitor model 3210 were equally as cryptic.

DISCUSSION

The relationship between RGP and first-year field performance was relatively strong and indicated that seedling samples without RGP do not survive. An RGP of from 4 to 5 new roots seemed to be sufficient for assuring survival and growth. The 1984 planting season in Patrick Co., VA was characterized by abundant moisture and cool temperatures. Thus a minimum RGP of 4-5 new roots was needed but beyond that, additional new roots did not add to the ability of a seedling to survive and grow.

Given the relationships shown in Figs. 1 and 2, only 4 storage treatments succeeded in "harming" seedlings (Oven at days 8, 14 and 21 and Lab Room at day 21). We speculate that had the planting season been drier, the relationship between RGP and first-year field performance measures would have been more linear than shown in Figs. 1 and 2 and thus other storage treatments might have also "harmed" the seedlings.

In both experiments I and II RGP appeared to be cyclical (except for the Lab Room storage of Experiment I). This RGP fluctuation may be explained several ways, recognizing that such explanations are in this report entirely speculative. First, RGP may be episoidal, with increases and decreases over time associated with "internal" rhythms of the seedlings. Such rhythms might be modified both in frequency and amplitude by storage treatments.

A second explanation for the cryptic changes in RGP over time may be that when seedlings are placed under stress in storage, they react with a "burst" of RGP. The timing and duration of the "burst" may be treatment specific. Depending on the treatment and sampling frequency, these RGP "bursts" may or may not be observed.

Physiologically these burst may be a function of growth regulator compartmentation and/or response to periods of anoxia which might occur within root tissues of stored seedlings (for literature on this topic see: Penny et al. 1974; Rowan et al. 1972; Gillbank et al. 1972; Parrish, 1976). In other words, seedlings near death (such as those in Experiment II stored in the Root Cellar for 18 days, in the Lath House for 8 days or the Lab Room for 8 days) may release actively compartmentalized growth regulators when respiration diminishes to near zero values. When this occurs, hyperelongation of new roots (measured by higher RGP) may occur. This mechanism may also explain why seedlings with low RGP (or no RGP) may

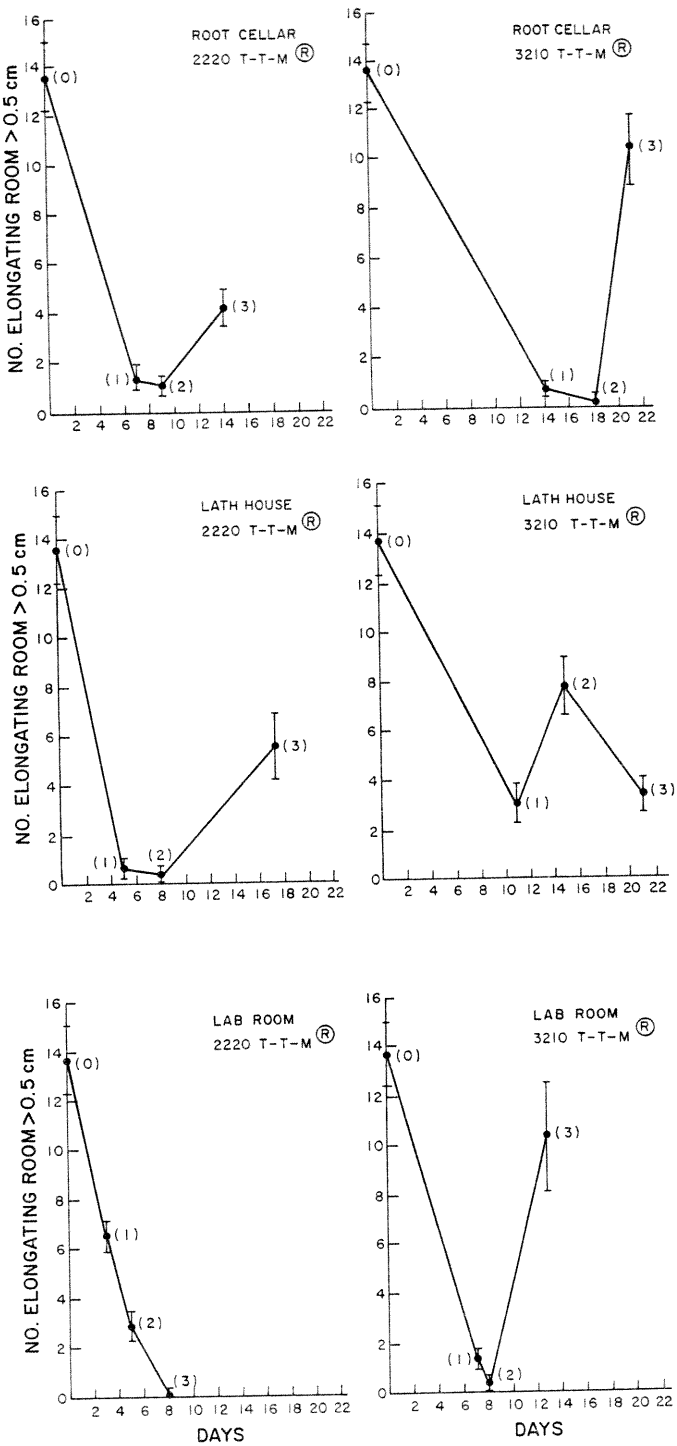

Figure 5. Results of Experiment II plotted by storage location and T-T-M model. Numbers in () correspond to T-T-M color changes where (0) = green, (1) = yellow, (2) = rust, (3) = red. Vertical bars represent ± 1 std. error.

survive and grow in the field.

A third explanation of the fluctuating values for RGP in this experiment is that both internal plant rhythms and response to anoxia may be causing the cryptic variation in RGP.

An interesting footnote to this research is that seedlings from both experiments responded differently to storage in the Root Cellar and the Lab Room (Figs. 3 and 4). The rather different patterns of RGP over time within each storage location suggest that seedling history has a major impact on RGP patterns in storage over time.

The use of T-T-M monitors cannot be judged on the basis of these results without some speculation. Specifically, if one is willing to assume loblolly pine seedlings do respond to anoxia, and prior to responding RGP must approach zero, then the use of the monitors may be justified to gauge seedling RGP status. Under each of the three storage treatments Model 2220 changed to a "1" prior to seedlings registering zero RGP. In 2 of 3 storage locations a 2220 stage "2" coincided with a nearly zero RGP. In one case (the Lab Room) a 2220 stage "3" was associated with zero RGP. Monitor 3210 only appeared to have value at stage "1" which corresponded to near zero RGP in 2 of 3 storage conditions.

CONCLUSIONS

The results of this study illustrate the following points:

1. RGP of loblolly pine seedlings changes with storage temperature and time in storage.
2. Storage RGP response may be in part a function of pre-storage events (i.e. an historical factor)
3. Storage responses may be modified by internal plant rhythms in RGP.
4. After stored seedlings reach a zero-level RGP, their RGP may rebound and this effect may be related to storage temperature, duration and seedling history.
5. The I-Point [R] T-T-M model 2220 may be useful for predicting zero RGP in loblolly pine seedlings.

Because of the complex responses to storage, it is not unexpected that the literature contains apparently contradictory data on effects of storage on loblolly pine seedlings. We are currently conducting additional storage experiments to test some of the hypotheses suggested by these data.

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ROOT GROWTH POTENTIAL AND CARBOHYDRATE SHIFTS IN PREVIOUSLY COLD STORED LOBLOLLY PINE SEEDLINGS GROWN IN HYDROPONIC CULTURE[1]

R. W. Rose[2] and R. P. Whiles[3]

Abstract.--This experiment was a preliminary attempt to determine how seedling lateral root percent starch relates to root growth potential (RGP) in loblolly pine (Pinus taeda L.) seedlings grown in a hydroponic environment. The principal findings were that initial lateral root percent starch was not a good predictor of seedling growth as measured by RGP by family. It was proven feasible to test the same loblolly pine seedlings for lateral root starch content before and after an assessment of RGP in a hydroponic tank system.

INTRODUCTION

Root growth potential (RGP) is used to measure seedling vigor after outplanting. Typically, seedlings are lifted from the nursery bed, transplanted into a suitable growing media such as greenhouse potting mix, allowed to grow for 30 days, harvested, and measured for root length. The amount of root produced is considered a measure of the physiological vigor of the seedling and indicates how the seedling will survive and grow after outplanting (6). Root growth potential in this study was defined as dry weight of new roots.

Placing the seedlings in ten-gallon tanks of water is another way to observe root growth and avoid the use of potting media†. Tanks allow daily observation of root growth and periodic weighing of individual seedlings to detect fresh weight changes. It is also possible to cut and weigh portions of new root without interference from potting media on the roots.

Since RGP is an after-the-fact morphological response measurement, it seemed important to test a tank system for evaluating seedlings for both morphological and physiological changes through time which might reveal early predictions of outplanting performance. This experiment was a preliminary attempt to determine how seedlings change in lateral root percent starch in relation to RGP over time when grown in tanks of water containing low levels of fertilizer. It was hoped that by being able to track changes over time, it would be possible to arrive at reasons why one seedling has a growth advantage over another.

PURPOSE

This experiment was a preliminary attempt to determine how seedling lateral root percent starch relates to root growth potential (RGP) in loblolly pine seedlings grown in a hydroponic environment.

PROCEDURE

Seed Sources. Five open-pollinated maternally identified seed sources were used. The five families were 7-2, 7-56, 11-9, 11-16, and 11-41.

Lifting and Storage. The seedlings were hand-lifted from the nursery bed on January 9, 1984, sealed in Kraft bags, and placed in cold storage. The seedlings were stored in the cooler until March 8, 1984. After 59 days in the cooler at 36°F, the seedlings were removed for use in the study.

Initial Measurements. Eighteen seedlings of each family were chosen at random and measured for total seedling fresh weight, height, caliper, and

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[2]R. W. Rose, Forest Regeneration Scientist, Westvaco Corporation, Summerville, South Carolina 29484.

[3]R. P. Whiles, Senior Laboratory Technician, Westvaco Corporation, Summerville, South Carolina 29484.

†Feret, P. P., Professor of Forestry, Virginia Polytechnic Institute and State University, personal communication.

root volume. A sample of fresh lateral roots was pruned prior to measuring total fresh weight from each seedling, frozen, and saved for future starch analysis. The root systems on each seedling looked reasonably uniform after pruning and not too different from the appearance of seedlings wrenched from the ground during an operational lifting. The seedlings were placed in the tank system on March 8, 1984.

Tanks. Six ten-gallon tanks filled almost to the top were fitted with templates containing 18 holes 1-1/2 inches in diameter. The water used was treated by reverse-osmosis. One tablespoon of Peter's (20-20-20) was mixed into the water. The fertilizer was added only to give the water some ions since it was believed that the water's purity could damage the seedlings. Two of the tanks were blackened on the outside and four were clear. This did not create any differences in seedling root growth. One clear tank did develop algae, but this did not interfere with the experiment. The water in the tanks was changed twice each week. Figure 1 gives an illustration of a tank.

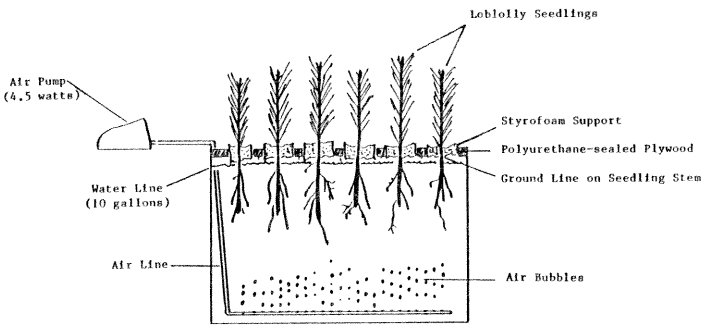

Figure 1.--Tank system for measuring root growth potential (RGP).

Interim Measurements. On March 26, 1984, (at 19 days in the tanks) the seedlings were measured for height, total seedling fresh weight, and root activity. Day 19 was chosen because most of the seedlings had some new roots. A simple root activity score index was used to evaluate seedlings: a seedling with no new roots was scored a 1, and a seedling with any new roots, no matter how few, was scored a 2.

Final Measurements. On April 6, 1984, (at 30 days) the study was terminated and the seedlings measured for height, total fresh weight, and root activity.

Destructive Sampling. At the end of the experiment each seedling was cut into several component parts, dried, and weighed. The components were new top growth (new stem + new needles), total stem, total needles, new root growth (RGP), lateral roots, and tap root. Root growth potential was measured as dry weight of new roots because there was not enough root growth to effectively measure root lengths. Putting RGP on a weight basis indicated how much biomass was produced. The samples were stored frozen and then analyzed. There were not enough pruned lateral roots per seedling to make enough sample for individual seedling starch determinations. Therefore, the three seedlings per family in each tank were composited into one sample. The same procedure was used for lateral roots per seedling at the end of the experiment.

Analysis. The needles from each seedling were sent to Westvaco's Soil and Tissue Testing Lab for nutrient analysis. The needles were measured for N, P, K, Ca, and Mg content.

The pruned lateral roots at the start of the experiment and the lateral/tap roots collected at the end of the experiment were analyzed for starch using the technique of Haissig and Dickson (3). At the end of the experiment all of the lateral roots, including new lateral roots measured as RGP, were collected and analyzed. The soluble extract from the starch procedure was saved and analyzed for five soluble sugars using high performance liquid chromatography (HPLC). The five sugars were glucose, fructose, sucrose, and two unknown sugars (UK 1 and UK 2).

Statistical Design and Analysis. The analysis of variance model was a randomized complete block having six blocks (tanks) and five treatments (families). Three seedlings of each family were randomly assigned to a tank. Tank effects were random, and family effects were fixed. The analysis of variance scheme is shown in Table 1.

Table 1. Analysis of variance model for experiment.

Source of Variation	df
Tank	5
Family	4
Error	20
Total	29

The composited lateral root samples could not be compared with any of the other variables on an individual seedling basis, so it was necessary to generate a means data set out of the other variables in the same way the lateral roots had been composited. This means data set was made up of means for each variable of the three seedlings of each family by tank combination. Therefore, each family had six means - one for each of the six tanks. This data set made it possible to compare lateral root starch levels with the other variables.

RESULTS

The results showed that initial lateral root percent starch was not a predictor of root growth potential (RGP) as measured by dry weight of new growth of lateral roots. No dependence could be found between initial lateral root percent starch

and RGP (Figure 2). The results of this experiment did not support the concept of a cause-and-effect relationship between RGP and initial lateral root percent starch.

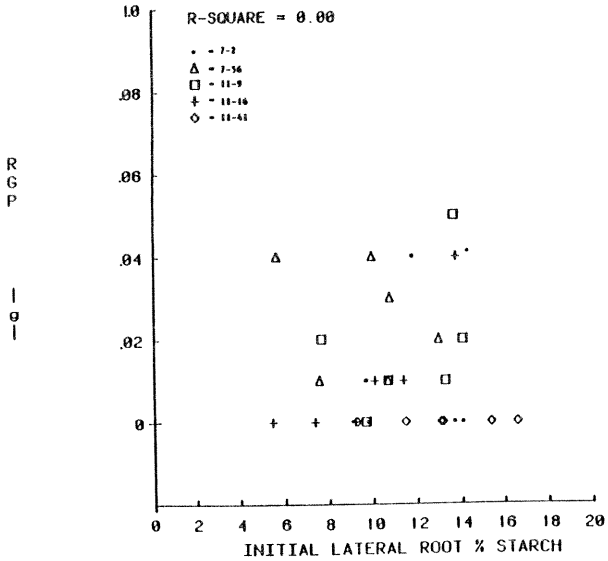

Figure 2.--Plot of the relationship between RGP at day 30 and initial lateral root percent starch at the beginning of the experiment.

A scatter plot of the relationship between RGP and lateral root percent starch at the end of the experiment (Day 30) is shown in Figure 3. The coefficient of determination (R^2) was a low .32. Family 11-41 did not produce any new roots. There was not a strong relationship between how the seedlings grew and the starch percent left in the lateral roots after 30 days.

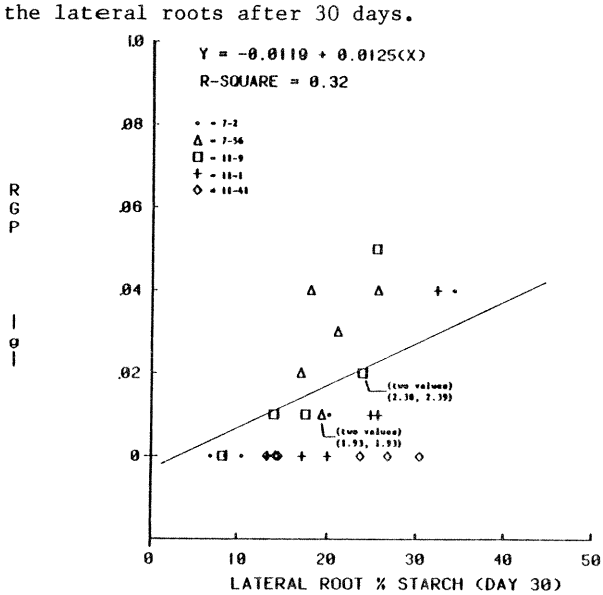

Figure 3.--Plot of the relationship between RGP and lateral root percent starch at day 30.

The analysis of variance results of the difference between percent starch on day 1 and day 30 lateral roots was not significant by family. Figure 4 depicts the results. The average difference in lateral root percent starch between day 1 and day 30 by family was 9%. This equaled an average drop in percent starch of 82% from lateral roots of the same seedlings!

The total fresh weight of each seedling in the study decreased dramatically between day 1 and day 19. From day 19 through day 30 at the end of the experiment, only Families 7-56 and 11-9 regained a portion of their original fresh weight. Figure 5 depicts this result. At the beginning of the study the families were divided into two distinct groups. The larger families were 11-16, 11-9, and 11-41, and the smaller families were 7-56 and 7-2. Figure 5 shows that the rankings for total fresh weight never changed. After day 19, only Families 7-56 and 11-9 increased in fresh weight. Seedling size did not appear to be related to shifts in fresh weight. Families 7-2, 11-16, and 11-41 continued to decrease in fresh weight between day 19 and day 30.

A positive linear relationship was found between RGP and the change in fresh weight from day 19 to day 30. Figure 6 is a scatter plot of the results. In those seedlings where new roots were produced there tended to be a positive change in fresh weight. The R^2 for these data was .68. This was to be expected since new roots increase the uptake of water.

Changes in total fresh weight after day 19 appeared to be directly related to the root activity index. This simple assessment of morphological change revealed that families 7-56 and 11-9 had the highest root activity indices of any of the families at day 19 (RA2), and at day 30 (RA3). The means are shown in Table 2. The higher the index, the greater the number of seedlings with active root systems.

The analysis of variance results of all the seedlings at the end of the experiment revealed significant differences among families for various morphological variables (Table 2). However, the statistical differences were not as important in a biological sense as the family rankings. The positive change in total fresh weight of Family 7-56 was confirmed by its highest rankings for dry weight of new top growth and RGP. Families 11-41 and 7-2 ranked lowest in these categories, having low root activity indices and negative shifts in total fresh weight throughout the study period.

Seedling morphology did not explain seedling growth. Table 2 is a tabulation of the family means and LSDs. Initial height was not a good measure of vigor since 7-56 was the shortest family and 11-9 was the tallest. Families 11-41 and 7-2 grew poorly, yet had larger tap roots than either 11-9 or 7-56. In terms of biomass, all of these seedlings appeared to have adequate distributions of needles and roots to grow well. Seedling size did not offer any particular advantage or disadvantage to growth.

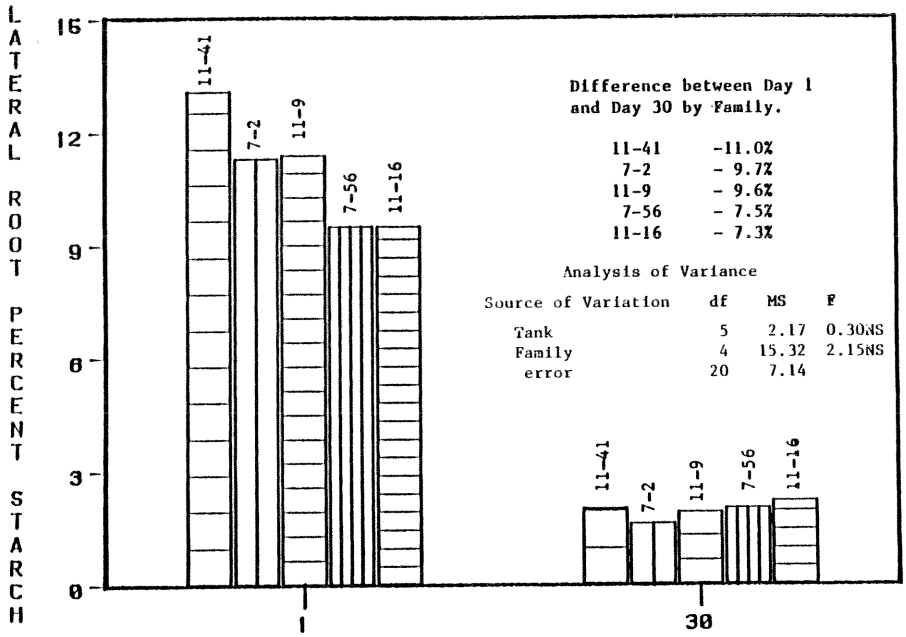

Figure 4. Change in lateral root percent starch between Day 1 and Day 30. Data from means data set.

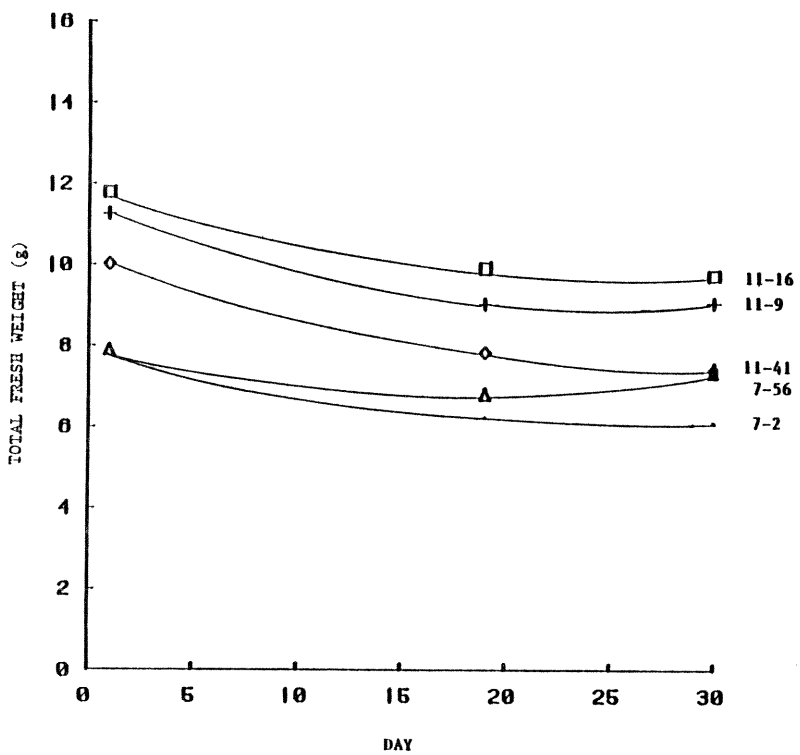

Figure 5. Total seedling fresh weights (g) over the 30 day growing period.

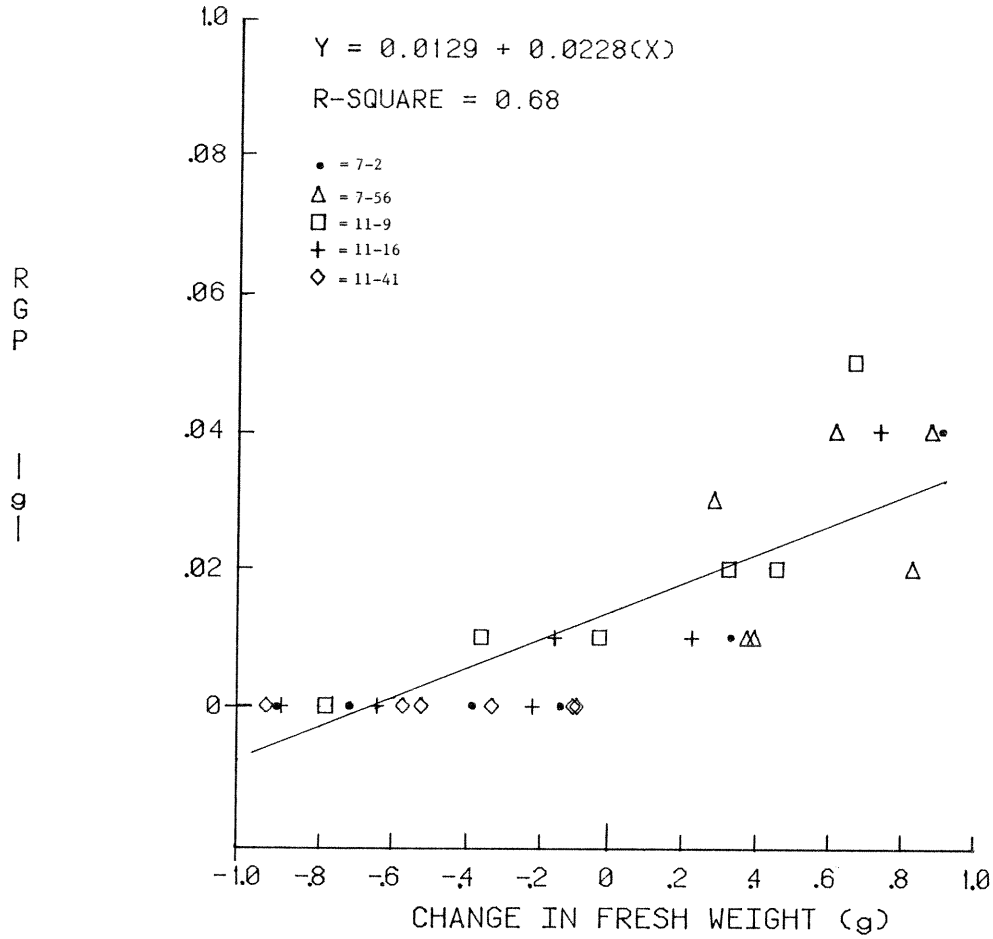

FIGURE 6. PLOT OF THE RELATIONSHIP BETWEEN RGP AT DAY 30 AND CHANGE IN FRESH WEIGHT FROM DAY 19 TO DAY 30.

Table 2. Means of measured variables by family (n = 6) and least significant differences among families. (Means with the same letter are not significantly different at the 5% level.)

Ht1 (cm)		Cali (mm)		Root Volume		Ht2 (cm)		Ht3 (cm)		NTOPWT (g)	
11-9	30.2a	11-16	4.7a	11-16	2.4a	11-9	30.3a	11-9	31.1a	7-56	.19a
7-2	27.6a	11-41	4.4a	11-41	2.3a	11-41	27.8b	7-2	29.1a	11-16	.11b
11-41	27.2b	11-9	4.4a	7-56	2.1ab	7-2	27.7b	7-56	28.8a	11-9	.10b
11-16	26.5b	7-56	3.9b	7-2	1.8b	11-16	26.9bc	11-41	28.3a	11-41	.09b
7-56	24.1c	7-2	3.9b	11-9	1.8b	7-56	25.6c	11-16	28.0a	7-2	.07b

StemWt (g)		RGP (g)		LatRTWT (g)		TapRTWT (g)		NeedWt (g)	
11-9	1.16a	7-56	.03a	11-16	.15a	11-16	.53a	11-16	1.80a
11-16	1.08a	11-9	.02ab	7-56	.14a	11-41	.46a	11-9	1.67a
11-41	0.17ab	11-16	.01bc	11-41	.12a	7-2	.36b	11-41	1.27b
7-2	0.82bc	7-2	.01bc	11-9	.12a	11-9	.36b	7-56	1.19b
7-56	0.76c	11-41	00c	7-2	.09b	7-56	.32b	7-2	1.03b

RA2		RA3		Shoot/Root		CHFRWT2 (g)		CHFRWT3 (g)	
7-56	1.89	7-56	1.89	11-9	6.06a	11-9	-2.21a	7-56	.56a
11-9	1.61	11-9	1.83	7-56	4.56b	11-41	-2.17ab	11-9	.05ab
7-2	1.50	11-16	1.67	11-16	4.43b	11-16	-1.86ab	7-2	-.14b
11-16	1.39	7-2	1.61	7-2	4.30b	7-2	-1.51bc	11-16	-.15b
11-41	1.11	11-41	1.28	11-41	4.08b	7-56	-1.09c	11-41	-.42b

Needle Nutrients

N%		P%		K%		Ca%		Mg%	
11-41	1.43a	11-41	.15a	11-41	.45a	11-41	.35a	11-9	.11a
7-2	1.26b	11-9	.13b	7-2	.43ab	11-9	.28b	11-41	.11ab
7-56	1.25bc	7-2	.13b	11-9	.41ab	7-2	.28b	7-2	.09bc
11-9	1.15cd	11-16	.13b	7-56	.39bc	11-16	.28b	11-16	.09c
11-16	1.13d	7-56	.12b	11-16	.38c	7-56	.25b	7-56	.08c

Nutrient Ratios

P/N		K/N		Ca/N		Mg/N	
11-16	.11a	11-9	.35a	11-41	.25a	11-9	.09a
11-9	.11a	7-2	.34a	11-16	.25a	11-16	.08b
11-41	.10a	11-16	.34a	11-9	.25a	7-2	.07bc
7-2	.10a	7-56	.32a	7-2	.22ab	11-41	.07bc
7-56	.10a	11-41	.31a	7-56	.20b	7-56	.07c

Tap Root Carbohydrates

Fructose (mg/g)		Glucose (mg/g)		Sucrose (mg/g)		UK1 (mg/g)		UK2 (mg/g)		Starch (%)	
7-2	20.1a	7-2	77.8a	11-41	14.5a	7-56	39.2a	7-56	1.5a	11-16	4.59a
11-41	18.8a	11-41	69.5a	7-2	12.2a	11-9	34.2ab	11-16	1.1a	11-9	4.25a
11-9	18.7a	11-16	66.7a	11-16	11.4a	7-2	27.3bc	11-41	1.1a	7-56	3.81a
11-16	16.4ab	11-9	66.5a	11-9	10.6a	11-16	23.8c	7-2	0.9a	11-41	3.39a
7-56	12.6b	7-56	46.6b	7-56	10.3a	11-41	21.7c	11-9	0.9a	7-2	3.37a

Ht1 = height at day 1
Ht2 = height at day 19
Ht3 = height at day 30
Cali = caliper at day 1
NTOPWT = dry weight of new top growth
StemWt = dry weight of stem
RGP = dry weight of new lateral root growth
LatRTWT = dry weight of original lateral roots + RGP
TapRTWT = dry weight of tap root
NeedWt = dry weight of needles
RA2 = root activity at day 19
RA3 = root activity at day 30
CHFRWT2 = change in total fresh weight between day 1 and day 19
CHFRWT3 = change in total fresh weight between day 19 and 30

Needle nutrient levels revealed some interesting trends. Family 11-41 grew very poorly and had the highest levels of N, P, K, and Ca at the end of the experiment. It had adequate levels of nutrients, yet was not utilizing them for growth. Family 7-56 grew well and had the lowest levels of P, Ca, and Mg.

The tap roots of all ninety seedlings were analyzed by high performance liquid chromotography for glucose, fructose, sucrose, and two unknown sugars. The analysis of variance results showed significant family differences for fructose, glucose, and unknown sugar #1 (UK1). Sucrose and unknown sugar #2 (UK2) were non-significant (Table 2). Tap root percent starch was non-significant due to high variation among seedlings within a family.

The rankings of the soluble sugars showed an interesting trend (Table 2). Like the needle nutrients, Family 7-56 had lower levels of fructose, glucose, and sucrose than the other families, yet had the highest levels of the two unknown sugars. As with the needle nutrients, the ranking of means by family seemed to reflect some degree of physiological activity.

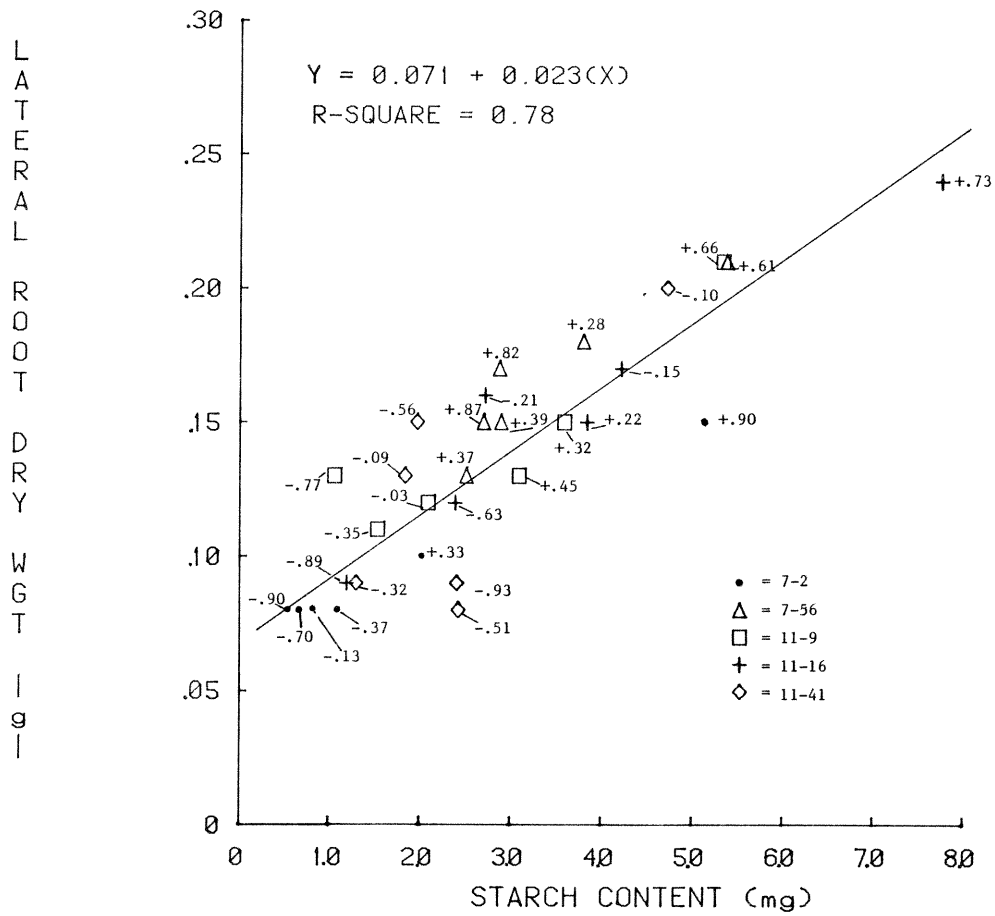

Figure 7.--Relationship between lateral root dry weight (G) and dry weight (MG) of starch in the lateral roots, numbers next to each data point are the mean negative or positive changes in total seedling fresh weight between day 19 and day 30.

DISCUSSIONS AND CONCLUSIONS

An important finding in this experiment was that it is possible to test the same loblolly pine seedlings for starch before and after an assessment of RGP in a hydroponic tank system. Instead of having to destructively sample different seedlings over time, it is possible to sample the same seedlings at two points in time.

In a study such as this one an often posed question concerns the relationship between root dry weight and the weight of the starch in the roots. Figure 7 illustrates a scatter plot of the relationship between total lateral root dry weight and lateral root starch content in milligrams. The actual family by tank means are plotted with their mean changes in fresh weight between day 19 and day 30 written along side. Milligrams of starch tend to increase with increases in lateral root dry weight. Most of the seedlings with the larger root dry weights (>.14) showed positive changes in total fresh weight. Since the new roots (RGP) were mixed with all of the lateral roots for analysis at the end of the experiment, it is not possible to state how much starch was contributed by the new roots. Marshall (5), working with Douglas Fir, suggested that starch deposition in fine roots is limited to the time when the fine roots are growing.

A major limitation of this preliminary study was the small sample size per family and the need to composite the lateral roots by family within a tank. Given the differences in growth among seedlings within a family and the need to create a means data set, it was not possible to look at lateral root percent starch among individual seedlings as it might relate to RGP. Unfortunately, seedlings with active lateral root systems had to be composited with those that were not active. The results were interpreted with this in mind.

The primary objective of research in physiological quality of seedlings is to predict growth prior to outplanting. The assessment of RGP can give an indication of future field performance, but it has the limitation of requiring up to thirty days to complete the test. This study showed that an assessment within 19 days was possible. Dewald et al (1) were able to arrive at rough estimates in fifteen days.

An immediate test would be more desirable. The results in Figure 7 draw attention to the established concept of planting seedlings with as many lateral roots as possible (4, 7). However, Family 11-41 was found to have comparable seedling root weights to the other seedlings initially, yet failed to grow any new roots.

This study showed that lateral root starch was depleted as the seedlings emerged from dormancy. It remains to be understood where the carbon from the starch was allocated in the seedlings or what triggers root growth. Every family put on top growth, but not every family grew the same amount of new roots. The carbon may have been transported from the root to the shoot, respired in response to the stress of lifting, root pruning for starch analysis and cold storage, or leached into the water in the tank.

The relationship between lateral root dry weight and weight of starch in the lateral roots points out how little is clearly understood about physiological quality in loblolly pine seedlings. It appears that physiologically active roots must maintain some amount of starch reserve. However, just having high lateral root weights or high starch contents does not guarantee good growth. Other mechanisms related to moisture stress and dormancy are certainly at work. Much needs to be learned about metabolic pathways in loblolly pine seedlings. As pointed out by Duryea and McClain (2), the few studies to focus on the relationship of RGP and carbohydrate reserves have presented conflicting results, and there are no definitive studies of the cause-and-effect relationships of nursery practices, carbohydrate levels, and field performance.

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LOBLOLLY PINE SEEDLING ETHYLENE PRODUCTION AS AFFECTED BY LIFTING TIME AND METHOD[1/]

Jon D. Johnson and Nancy J. Stumpff[2/]

Abstract.--Ethylene. a gaseous plant growth regulator, has recently been shown to be produced by pine seedlings during cold storage. The objectives of this study were to: 1) determine the effect of lifting date on ethylene production; 2) identify the origin of the ethylene to the roots or shoots; and 3) compare the effect of machine versus hand lifting on subsequent ethylene production.

Loblolly pine (Pinus taeda L.) seedlings were hand lifted monthly from November to March. Whole seedlings, roots and shoots separately, were packaged in Kraft-polyethylene bags for one week at 3°C. The ethylene concentration within the bags was measured using gas chromatography.

The results indicate that ethylene production is cyclical with a maximum concentration occurring in February. The roots and shoots on the average produced similar quantities of ethylene except for February when the roots produced twice as much as the shoots. Machine lifting stimulated ethylene production in January by 38 percent and in March by 263 percent compared to the hand lifted seedlings.

INTRODUCTION

Ethylene, a plant growth regulator, has been indirectly implicated in affecting Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) and loblolly pine (Pinus taeda L.) seedling performance (Zaerr and Lavender, 1980; Barnett, 1980, respectively) and has been detected in seedling cold storage facilities at concentrations well above those known to be physiologically active (Johnson, 1982). Fumigation of loblolly pine seedlings with ethylene has demonstrated an effect on both subsequent survival and growth (Johnson and Stumpff, 1984a,b) To further investigate the potential problem of ethylene production and accumulation during storage of loblolly pine, this series of studies was conducted. The objectives were to: 1) determine to effect of lifting date on ethylene production; 2) identify the origin of the ethylene to the roots or shoots; and 3) compare the effect of machine versus hand lifting on subsequent ethylene production.

METHODS

Loblolly pine seedlings (1-0) were hand lifted monthly from November 1982 to March 1983 from the Virginia Division of Forestry New Kent nursery, Providence Forge, Va. Machine lifted seedlings were also collected in January and March. Two hundred intact seedlings were packaged into Kraft-polyethylene bags. An additional 400 seedlings were cut at the root collar, and the roots and shoots were stored separately in K-P bags. The intact seedlings, roots and shoots were replicated twice for each lift date and stored for one week at 3°C. The ethylene concentrations within the bags were quantified with gas chromatography (Johnson, 1982) and were reported on a dry weight basis.

The amount of hormonal and wound ethylene produced was estimated by assuming that the intact, whole seedlings were producing only "hormonal" and that the "wound" ethylene was the result of cutting the seedlings in half. Therefore:

$$\text{"wound"} = (\text{shoot} + \text{root}) - \text{whole}$$

The "wound" ethylene was proportioned to the roots and shoots based on their rate of production such that:

$$\text{shoot "wound"} = (\text{shoot}/(\text{shoot} + \text{root})) \times \text{"wound"}$$

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Ga, Nov. 7-8, 1984.

2/ Assistant Professor, Dept. of Forestry, University of Florida, Gainesville, FL and Laboratory Technician, Savannah River Ecology Laboratory, Aiken, SC. Both authors were previously at Dept. of Forestry, VPI&SU, Blacksburg, Va.

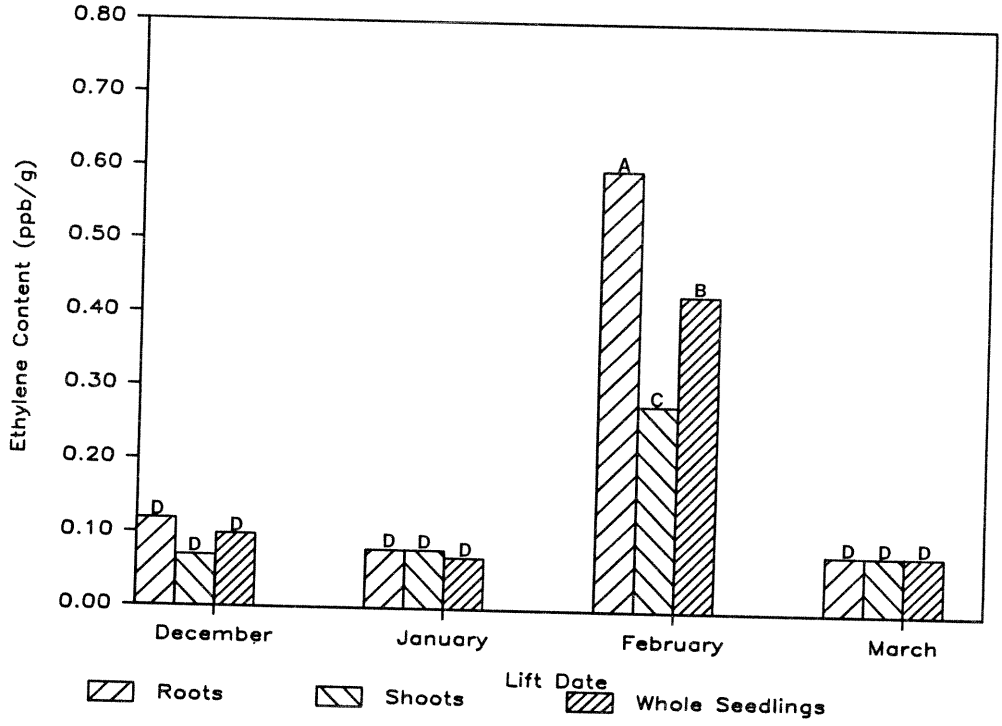

Figure 1. Ethylene content of K-P bags containing whole seedlings, roots and shoots of loblolly pine lifted monthly from December to March. Bars with the same letter are not statistcally different at a 5 percent probability level.

root "wound" = (root/shoot + root))x "wound"

RESULTS AND DISCUSSION

Ethylene content in whole seedlings, roots and shoots remained fairly constant at around 0.10 ppb/g for December, January and March (Fig.1). In February the roots produced 0.6 ppb/g, whole seedlings produced 0.42 ppb/g and the shoots produced 0.28 ppb/g. These values were statistically different from each other and all of the other lift dates (Fig. 1). A similar trend was reported in the ethylene concentration measured in the atmosphere of the cold storage facilities at the same nursery (Johnson, 1982). The peak value in that study occurred about a month earlier.

The significance of this burst of ethylene is unknown, but it may be associated with the dormancy process. The month difference in peak value discussed above can be explained by an unusually warm autumn the year the present study was conducted, delaying the normal dormancy process. Corrobative data for the involvement of ethylene in bud dormancy comes from a recently published study in which bud break was assessed monthly (Johnson and Barnett, 1984). In that study, conducted a year later with VDF seedlings, the chilling requirement for bud break was not met until after the first of February. The ethylene peak may be signaling a shift in seedling metabolism from a dormant state to a state of activity in preparation for bud break.

The absolute values for the roots and shoots reported in Fig. 1 reflect the addition of wound ethylene. In all cases, the sum of root plus shoot always exceeded the whole seedling value. The "wound" and "hormonal" ethylene was partitioned proportionately and found not to differ greatly either by lift date or by seedling part (Fig. 2). Root "wound" ethylene was consistently higher in the early lift dates (November and December) as was shoot "wound" ethylene. However, by January the differences between "wound" and "hormonal" were not consistent. The increase in ethylene in February was equal for both the "wound" and "hormonal" levels, though the roots produced more than twice that of the shoots.

Machine lifting had a significant effect on the ethylene production of whole seedlings (Fig. 3). The hand lifted seedlings did not differ significantly between January and March. However, ethylene content was increased 38 percent by machine lifting in January and by 263 percent in March. Machine lifting not only tends to break roots, but the stems of the seedlings may be compressed by the belts of the lifting machine. The large increase for the March date can be attributed to the lack of dormancy that was probably present in the January lifted seedlings.

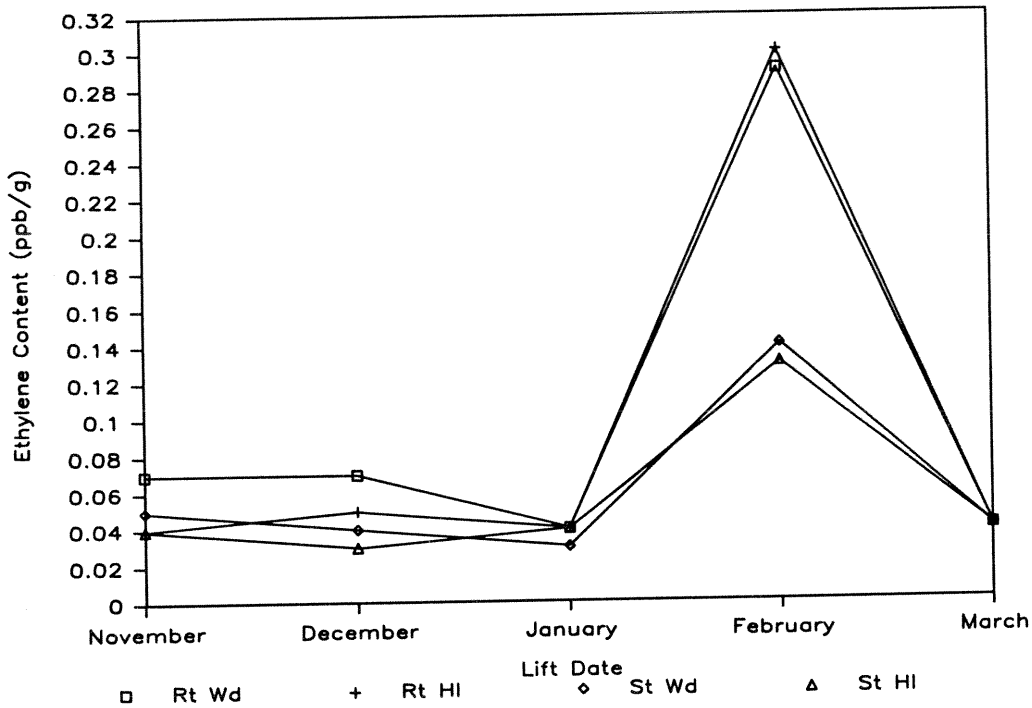

Figure 2. Ethylene content of roots (Rt) and shoots (St) of loblolly pine partitioned into "wound" (Wd) and "hormonal" (Hl) ethylene (see text).

These results further indicate that dormant seedlings can be lifted and handled with less damage than non-dormant seedlings.

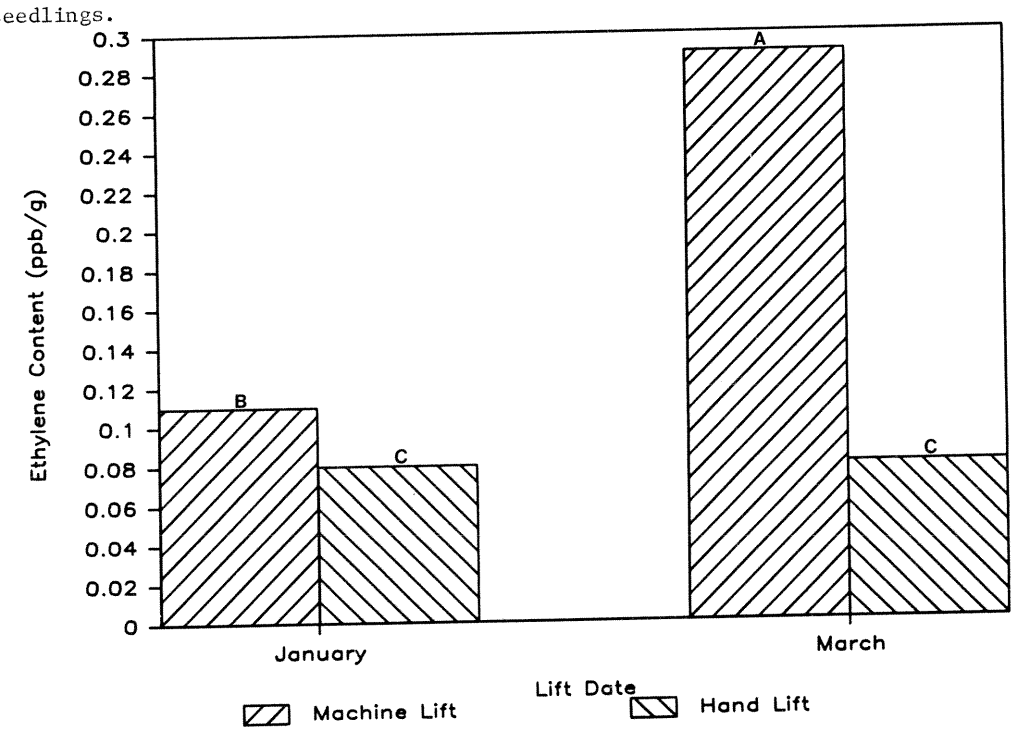

Figure 3. The effect of lifting method, machine versus hand, on ethylene content in K-P bags of loblolly pine seedlings lifted in January and March. Bars with the same letter are not statistically different at a 5 percent probability level.

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FLUID DRILLING -- A TECHNIQUE FOR IMPROVING NURSERY SEEDLING ESTABLISHMENT[1/]

James P. Barnett[2/]

Abstract.--The term "fluid drilling" is commonly used in agriculture for a technique of sowing germinated seeds directly onto soil using a gel carrier. Sowing of germinants greatly reduces the variable effects of weather and seedbed condition on germination and leads to very rapid and uniform seedling establishment. This uniformity in establishment should simplify seedling culture and reduce the percentage of cull or low quality seedlings. Fluid drilling involves techniques that obtain uniform germination in aerated water, separate germinated from ungerminated seeds, mix the germinants with a gel, and sow the gel on the nursery bed or container medium.

INTRODUCTION

Poor seedling establishment is one of the most significant problems in the nursery production of high quality bare-root seedlings. Climatic extremes, unfavorable soil conditions, and the presence of soil pathogens during and following sowing may drastically affect germination and survival. Thus, seeds do not germinate and develop as well in the field as standard laboratory germination tests indicate. Numerous attempts have been made to develop vigor or stress tests that would allow nurserymen to be able to predict field performance more accurately. However, these efforts generally have been unsuccessful, and germination tests remain the best means of estimating nursery performance (Barnett and McLemore 1984).

Problems associated with poor germination, irregular spacing, and staggered germination increase the percentage of cull or inferior seedlings and can significantly increase seedling costs. Ideally, (1) every seed sown should result in a seedling, (2) germination should be prompt and uniform, and (3) each seed should be accurately spaced within the nursery bed. Fluid drilling, a relatively new technique, offers the potential of meeting these objectives. It involves methods to obtain uniform germination in aerated water, separation of germinated from ungerminated seeds, gel suspension of germinants, and precision sowing of the gel into the nursery bed.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Principal silviculturist, USDA-Forest Service, Southern Forest Experiment Station, Pineville, La. 71360.

DEVELOPMENT OF TECHNIQUES FOR FORESTRY

Germination

Poor nursery establishment is often related to poor or slow germination. Currah and his associates (1974) at the National Vegetable Research Station in England established the advantages of using germinants over ungerminated seeds. Fluid drilling techniques allow the seeds to be partially germinated under optimum conditions, then the germinants are sowed. No allowances have to be made for poor viability or inconsistencies between laboratory and nursery germination. Seeds are germinated in aerated water with optimum temperature and light conditions.

Earlier work (Barnett 1971) with aerated water soaks as a means of stimulating germination has shown that germination of southern pine seeds in water is feasible. Even at low temperatures (about 40°F), germination will eventually occur, but it is more prompt at higher temperatures (70°F). Stratification and germination processes can be done in aerated water. However, the most prompt and uniform response is accomplished when stratification precedes germination (Barnett 1984). Our tests show that germination in aerated water is more rapid and uniform when dormant seeds such as loblolly pine (*Pinus taeda* L.) are already stratified (table 1).

Germination in water can be done with equipment as simple as an aquarium tank and aerator; however, more sophisticated and reliable equipment is now commerically available from Fluid Drilling Limited®. Units are available that aerate the water and maintain temperatures from near freezing to about 95°F. After germination,

the seed development must be arrested until it is convenient to sow. This can be done by cooling germinants to near 32°F and maintaining this temperature during storage for up to 2 weeks (Currah 1978).

Table 1.--Five-day germination[1/] of 30- and 60-day stratified loblolly pine seeds in aerated water at 72°F without light

Replication number	Stratification	
	30 days	60 days
	Percent	
1	12	49
2	6	46
3	12	53
Mean	10	49

1/ Germination based on tests of 100 seeds per replication.

Our work in developing techniques to effectively and uniformly germinate in aerated water has been primarily with loblolly pine, but the temperature and light responses should be similar in other southern pine species as well.

Temperature.--The optimum germination temperature for loblolly, slash (*P. elliotti* Engelm.) and shortleaf pine (*P. echinata* Mill.) seeds is near 75°F (Barnett 1979). The optimum temperature remained nearly the same for loblolly seeds tested in aerated water (table 2).

Table 2.--Five-day germination [1/] of 60-day stratified loblolly pine seeds in aerated water (with light) at different temperatures

Replication number	Germination temperature		
	60°F	72°F	86°F
	percent		
1	16	84	75
2	20	84	76
3	14	80	75
Mean	17	83	75

1/ Germination based on tests of 100 seeds per replication.

Light exposure.--Southern pine seeds must be exposed to light to achieve prompt and uniform germination (Nelson 1940). The quantity of light necessary to satisfy the light requirements for germination is about 150 foot-candles at a photoperiod of 16 hours (Jones 1961). Seed stratification reduces the light requirement (McLemore 1964), but even with 60 days of moist-chilling, light during the aerated-water germination improved performance (table 3). If seeds are held in a cloth bag when aerated, the intensity of the light may have to be increased to compensate for the reduction of light that reaches the seeds.

Table 3.--Five-day germination[1/] of 60-day stratified loblolly pine seeds in aerated water at 72°F.

Replication number	With light	Without light 2/	In cloth bag with light
	percent		
1	83	51	75
2	84	49	77
3	84	46	83
4	80	53	78
Mean	83	50	78

1/ Germination based on tests of 100 seeds per replication.
2/ Light was provided at an intensity of 150 foot-candles.

Seed Separation

The sorting of germinated from nongerminated seeds is an important aspect of the fluid drilling process. This is particularly necessary when germination is not uniform or when seed viability is low. Taylor and others (1978) developed a density sorting method using a sucrose solution of an appropriate specific gravity. The germinated seeds float, whereas the ungerminated ones sink. However, a specific gravity of about 1.2 is necessary to separate loblolly pine seeds. Because it is difficult to obtain such a high specific gravity solution, we are in the process of looking at other techniques that show promise in sorting seeds.

The simplest way to upgrade a seed lot is to ensure that all empty seeds are removed prior to use. Empty seeds can be 25 to 30 percent of the seedlot. This separation can be done with mechanical equipment such as gravity tables or with liquids of appropriate specific gravity. Empty loblolly seeds can be easily floated in water. Hydrocarbon liquids must be used for other pine species: i.e., slash (water-ethanol mix), longleaf (*P. palustris* Mill.) (pentane), and shortleaf (ethanol) (Barnett and McLemore 1970).

Two new methods of upgrading seed lots are under development. The first removes mechanically damaged seeds. The technique is based on the principle that liquid, under pressure, enters mechanically damaged seeds more easily than seeds

with intact coats. Called PREVAC, this method was developed by Bergston and Lestander (1983) in Sweden and requires further refinement. Experiments have shown that floating damaged seeds quickly lose their buoyancy and sink when exposed to pressure. This procedure may work with some southern pine seeds, but it would not with loblolly pine seeds since sound seeds sink in water.

The second method, IDS, separates dead from viable seeds. The IDS method is based on the principle that viable seeds, after imbibition and subsequent drying, lose absorbed moisture at a much slower rate than dead seeds (Simak 1981). This causes differences in weight and other properties between the two seed categories and allows separation based on physical principles such as flotation and specific gravity.

Extensive evaluations of these sorting methods have not been conducted with southern pine seeds. Our limited IDS tests with loblolly pine seeds show that some separation is feasible. Certainly these methods should provide for upgrading of seed lots, even though it is not yet possible to obtain clear separation of dead & viable seeds.

Gel Carrier for Drilling

Germinants from the aerated water treatment should have an exposed radicle only 2 or 3 mm in length, but even these are subject to damage. For protection, germinants are normally suspended in a viscous gel that is thick enough to protect them and provide a means of transporting and metering a given quantity of seeds. Fluid Drilling Limited® has a portable mixer that efficiently mixes a carrier powder and cold water to form a viscous gel. By mixing a known number of seeds into a quantity of gel, the seed density (number of seeds per planted area) can be determined by the rate of gel application (fig. 1).

Drilling Equipment

The seed-gel mixture has generally been applied with a planter with a single large holding tank and a number of peristaltic pumps, one pump per seed row. Each pump would extract a quantity of gel determined by the travel speed of the planter. The planter controls the seed density with reasonable accuracy, but the resulting spacing is at random. Searcy and Roth (1981) have developed a prototype precision metering system that holds considerable promise for accurate spacing of seed germinants.

POTENTIAL FOR NURSERY APPLICATIONS

Although the use of pregerminated seeds in forest seedling production has not been reported, the application of this technique could result in cost reductions in both seedbed and containerized seedling operations. Reductions should occur in

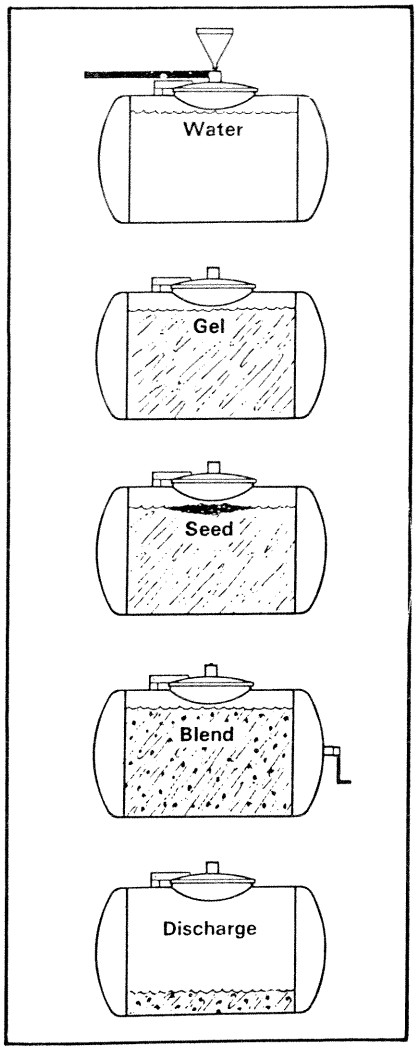

Figure 1.--Diagramatic representation of suspension of seed germinants in a gel carrier.

the number of cull plants and in the greenhouse energy and labor required for seedling production. Use of optimum germination conditions and the elimination of nonviable seeds will allow maximum yield from each seed lot. Pregermination will result in earlier seedling emergence and will allow growth to proceed over a range of temperatures, including those at which seeds may not normally germinate. Seedlings developing more uniformly should also reduce the number of cull plants due to less interplant competition. These benefits are being used in vegetable production and they should be further investigated for forest practices.

Research has shown that germination in aerated water is entirely feasible. The greatest research need is to develop practical techniques to remove either nonviable or ungerminated seeds from bulk lots. Development of more precise drilling equipment is needed before the technique can become fully operational in forest nurseries.

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MULCH AND TEMPERATURE EFFECTS ON GERMINATION OF SOUTHERN PINE SEED[1/]

J. A. Vozzo [2/]

Abstract.--Temperatures of bare soil nursery beds were compared with the temperatures of two ground covers, hydromulch and pine straw, during germination. Temperature was determined to affect germination of shortleaf, slash, longleaf, white, and loblolly pine seeds. Thermal insulation qualities of both contributed to decreased field germination. Soil temperature fluctuations must be considered as a factor in germination when selecting a ground cover for physical protection on nursery beds.

Using ground covers and mulches in southern forest tree nurseries is an established practices to control wind and water erosion (Bosch 1976, Rowan 1980). Boyer and South (1984) point out that only 1 of 51 nurseries surveyed did not use some type of mulch. The mulches used were hydromulch, pine straw, sawdust, or bark; these were originally selected for the way their physical characteristics assisted in erosion control. However, these same attributes also affect the biological interplay leading to seed germination.

Pine seeds are known to have an optimum temperature range for storage, stratification, and germination (USDA 1974). Hydromulch in particular acts as a thermal insulator with an R value of 4.0 per inch (personal communication)[3/]. The relative popularity of hydromulch and availability of pine straw suggest that their temperature effects should be considered when these two are used as a mulch for germinating pine seeds in the nursery. The findings of Rowan (1980, 1982) support continued use of both types of mulch to increase seedling production. The objective of this study is to determine what temperature effects come into play when these ground covers are used as mulches in forest tree nurseries.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Research Plant Physiologist, Southern Forest Experiment Station, Forest Service--USDA

[3/] Cincinnati Fiber, Feb., 1983.

MATERIALS AND METHODS

Pinus echinata (shortleaf), *P. elliottii* (slash), *P. palustris* (longleaf), *P. strobus* (white), and *P. taeda* (loblolly) seeds were used in the plantings. Each species was represented by 100 seeds from each of 3 different lots--for a total of 300 seeds per species. The seeds were mixed and randomly divided for treatment into three 100-seed groups.

Shortleaf, white, and loblolly seeds were stratified at 2°C for 28 days. Slash and longleaf seeds were not stratified. All seeds were planted the same day in nursery beds prepared at the Forestry Sciences Laboratory in Starkville, Mississippi. Two beds were prepared for each of 2 replications of 100 seeds for all species. The remaining 100 seeds of each species were placed on a thermogradient plate for laboratory-conditioned germination. Data from the latter test are not yet complete and will be reported later. Seeds were placed in one of three treatments: control (soil only with no mulch), hydromulch, or pine straw. Seeds were planted 10 mm deep in nursery beds with either a 10 mm layer of hydromulch or a 15 mm layer of pine straw covering.

Temperatures were observed using two methods. First, two remote thermographs with three recording probes each were used for continuous and recorded readings. Each treatment in the nursery beds had a probe buried at the 10-mm (planted seed) level. The probe authomatically recorded continuous temperatures in the soil. Each treatment replication had its separate probe and recording. In addition to the recording thermographs, an additional six soil thermometers were places alongside the process.

Seeds were planted in April 1983 and April 1984. Temperatures were recorded for 6 weeks while seeds germinated in the beds. Weather data were also collected from the National Weather Service to reflect the air temperatures. Seed germination was counted three times a week. Data reported here is the average of both the 1983 and the 1984 observations.

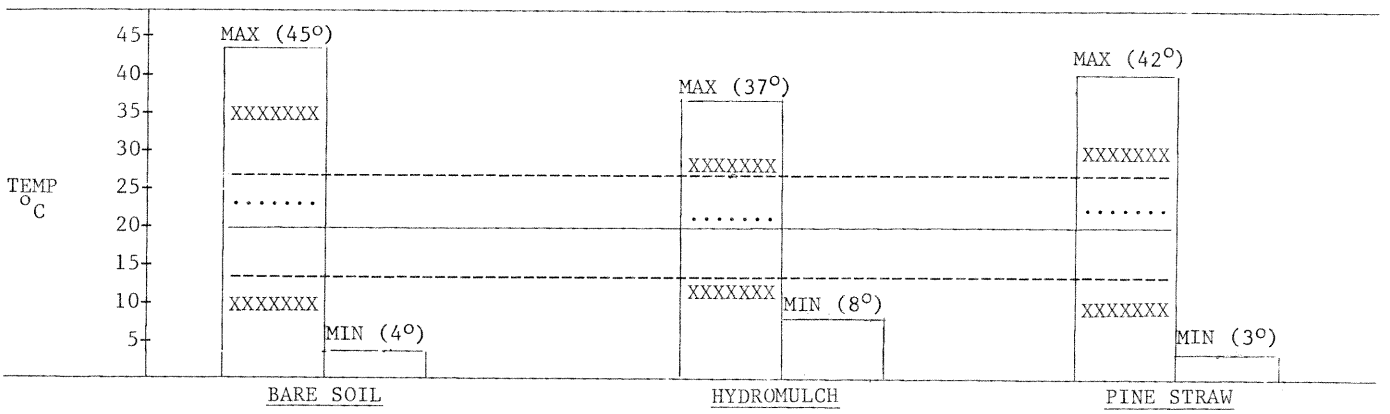
RESULTS AND DISCUSSION

Maximum and minimum absolute soil temperatures and average high and low soil temperatures for seed-level soil of each treatment were compared to average daily high and low air temperatures during the germination period (fig. 1). Germination was observed and recorded as germination capacity and peak value (table 1).

The highest germination capacity was observed in the control treatment of each species tested. With the exception of slash pine, the lowest germination capacity was always under hydromulch, while pine straw was usually intermediate. As shown in figure 1, the control treatment had the largest variation of temperature ranges, and hydromulch had the smallest ranges. All species were well within the usual 20° to 30°C recommended range for germination (USDA 1974).

Thermal insulation is specific for each treatment. This is readily compared by observing the variation of maximum and minimum absolute temperatures of each treatment from the average daily high and low air temperatures (fig. 1). The control treatment had the least insulation and the most variance (41°C). Hydromulch had the most insulation and least variance (29°C), while pine straw was intermediate with 39°C variance. The average daily air temperature for the germination period was 21°C. The average daily soil temperatures for each treatment were 23°C for control, 21°C for hydromulch, and 22°C for pine straw. Hydromulch again displayed its insulation properties by maintaining an average soil temperature that was comparable to the average air temperature.

Figure 1. Soil temperature (°C) at 10 mm (seed level) for bare soil and two nursery bed mulches.



XXX = Average high or low daily soil temp.
... = Average daily soil temp.
—— = Average daily air temp, 21°C.
--- = Average daily high (27°C), or low (14°C), air temp.

MAX = Maximum absolute temperature.
MIN = Minimum absolute temperature.

Table 1. Germination capacity (GC) and peak value (PV) of seeds from five southern pine species planted in bare soil or covered with one of two mulches.

	SHORTLEAF		SLASH		LONGLEAF		WHITE		LOBLOLLY	
Treatment	GC 1/	PV 2/	GC	PV	GC	PV	GC	PV	GC	PV
Bare Soil	23	0.82	54	1.46	48a 3/	1.80	13	0.36	35	1.01
Hydromulch	2	0.06	23	0.58	13a	0.31	2	0.07	14	0.36
Pine Straw	10	12.90	20	1.35	14	0.94	4	0.33	19	1.02

1/ GC = percent germination occurring up to time of peak or maximum germination.

2/ PV = maximum value of cumulative germination percentage divided by days of test.

3/ Signifies significant differences at 0.05 level using Bonferroni method of multiple t test.

CONCLUSIONS

Seed germination is enhanced by soil temperature variation. This has been readily shown for crop seeds (Toole, et al 1955; Thompson 1973, and Toole and Koch 1977) as well as forest tree seeds (Devillez 1978). The results reported here also support increased germination due to fluctuating soil temperatures at the seed level even though the germination values were relatively low for all species.

Protective qualities of any cover or mulch are going to affect resultant soil temperatures, which then affect seed germination. An ideal mulch would provide physical protection against wind and water erosion without interfering with seed germination. Thermal insulation qualities of any mulch may contribute to a decreased field emergence by not allowing sufficient soil temperature fluctuations. This concept is valid; however, one must also recognize other contributing factors such as physical and chemical soil composition, photoperiod requirements, micro-environments, and soil pathogenic organisms that affect seed germination and seedling emergence. If mulch is required to diminish seed loss by erosion, then you may have to decide which is more important, reduced loss due to erosion or reduced germination due to insulation. In this case, the temperature-regulating properties may be of less significance.

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SITE PREPARATION EFFECTS ON SELECTED SOIL PROPERTIES AND EARLY LOBLOLLY PINE SEEDLING GROWTH[1/]

by C.L. Tuttle, M.S. Golden, and R.S. Meldahl[2/]

Abstract.--Shear/burn, shear/single chop/burn, and shear/rake/pile/bed site preparation systems all significantly reduced competition and debris, with the bedded treatment being the most efffective. However, after two years, the shear/burn and the chop/burn treatments had significantly higher vegetation levels than did the bedded plots. Soil nutrient concentrations were not significantly different for the treatments after two years although as treatment intensity increased, nutrient concentration tended to decrease. As expected, bulk density was lower on the bedded areas following treatment and higher on the other areas. But, after two seasons, bulk densities on all three treatments were near the pretreatment levels, with the bed bulk density being significantly higher than bulk density on the shear/burn or the chop/burn systems. Loblolly pine seedling height and survival were not significantly influenced by the site preparation systems used. Ground line diameter, however, was increased on the more intensive treatments.

INTRODUCTION

Common forest practices involve clearcut harvesting followed by artificial regeneration. But, clearcutting leaves large quantities of residue and debris on the site as tops, stumps, and undesirable standing stems (Siccama et al. 1970, Murphy and Knight 1974, Howard 1978, Hart et al. 1980, McNab and Saucier 1980). This material may increase competition and reduce pine establishment because of higher seedling mortality and reduced growth.

Mechanical site preparation is used primarily to facilitate planting operations and to reduce competition (DeByle 1976, Haines and Haines 1978). Debris reduction results in increased planting efficiency and thus lower planting costs. Site preparation may also remove or destroy remaining stems and rootstocks, reducing vegetative competition for light, nutrients, and water and increasing seedling survival and growth, particularly during the establishment phase of regeneration (Clason 1978, Cain and Mann 1980).

Mechanical site preparation typically uses large heavy machines (over 20,000 kg) and these may have adverse impacts on forest land. Soils may become compacted with bulk density increases of 25% to 75%. Reduced site productivity occurs when infiltration, soil porosity, and soil aeration are reduced by compaction (Hopkins and Patrick 1969, Shoulders and Terry 1978).

The most damaging effect of mechanical site preparation, however, is surface soil disturbance and displacement. Raking and piling operations may physically remove over 8 cm of soil from the plantable area (May et al. 1973, Glass 1976, Sarigumba and Anderson 1979). Severe disturbance may also lead to increased erosion which may reduce growth (May et al. 1973, Glass 1976, Hunt and Miller 1976, Blackburn et al. 1978, Sarigumba and Anderson 1979, Wischmeier and Smith 1978).

Mechanical site preparation effects have been well documented for the Lower Coastal Plain and Piedmont regions of the Southeastern United States. However, large portions of the southern forests are located on upland Coastal Plain soils for which there is little documentation.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Authors are Research Associate, Associate Professor, and Assistant Professor, School of Forestry and Alabama Agricultural Experiment Station, Auburn University, Auburn, Alabama, respectivly.

This study was designed to compare the effects of three mechanical site preparation systems on upland Coastal Plain forest sites in Alabama.

METHODS

On each of three Hilly Coastal Plain sites, a randomized complete block design with three site preparation systems was installed during 1980 and 1981. The site preparation systems examined were shear/burn, shear/single chop/burn, and shear/rake/pile/bed. In the shear/rake/pile/bed system, the beds were placed along the contour following the piling operations. The number of replications varied from three to six per site, depending on the suitable land area available. The study areas are owned by Hammermill Paper Company. Company personnel applied the treatments in an operational manner. We gratefully acknowledge the help and cooperation of Hammermill Paper Company.

Study Sites

Study areas were located after completion of the harvesting operations. Site 1 was located in fall 1980 and four replications were established. Burning treatments, where applicable, were applied during late fall approximately three weeks after mechanical treatment. Site 1 soils are members of the Jones sandy loam series (course-loamy, siliceous, thermic Ultic Hapludalfs). Sites 2 and 3 were located in the spring of 1981. Three replications were placed on site 2 and six on site 3 during the late spring. Burning of sites 2 and 3 occurred during late May and early June 1981. Site 2 soil was a Smithdale sandy loam (fine-loamy, siliceous, thermic Typic Paleudults) and site 3 soil a Shubuta sandy clay loam (clayey, kaolinitic, thermic Typic Hapludults). Slope averaged 11%, 9%, and 7% for sites 1, 2, and 3, respectively. Site 1 was primarily on a southern aspect, while the aspect on sites 2 and 3 varied. The burning operations on all three sites were very successful. Treatment area size varied, but after treatment application 20 X 20 m measurement plots were installed with minimum 10 m buffer strips on each side. Soil and vegetation samples were collected after the conclusion of the harvesting operations prior to site preparation, after the site preparation systems were applied, and at the end of each of the first two growing seasons.

Woody vegetation located on all three sites prior to site preparation was similar in nature. The predominant hardwood species included dogwood (Cornus florida L.), persimmon (Diospyros virginiana L.), sassafras (Sassafras albidum Nutt.), sweetgum (Liquidambar styraciflua L.), blackgum (Nyssa sylvatica Marsh.), oaks (Quercus spp.), hickories (Carya spp.), sparkleberry (Vaccinium arboreum Marsh.), and sumac (Rhus spp.). Site 3 contained loblolly pine (Pinus taeda L.) as the primary conifer, while sites 1 and 2 were dominated by longleaf pine (Pinus palustris Mill.) prior to harvest.

Sample Collection and Analysis

Debris and woody stems greater than 10 cm in DBH (diameter breast high) on the study sites were measured prior to site preparation using four 3.6 m circular plots. After site preparation, woody stems over 10 cm DBH and all tops, logs, and stumps were counted on the complete 20 X 20 m measurement plot. Herbaceous competition, litter cover, debris, vines, and woody stems less than 10 cm DBH were evaluated using eight 2.3 X 2.3 m quadrats on each measurement area at all four sampling times. Herbaceous cover, vine cover, and small debris were expressed as percent ground cover, while woody stems, stumps, logs, and tops were tallied individually. Sampled values were then expanded to a per hectare basis.

Bulk density estimates were obtained for the surface soil by using a 7.62 cm diameter ring, 7.62 cm long, resulting in a core volume of 347.5 cc (Blake 1965, Terry et al. 1980). Five cores were collected from each measurement plot at each sampling time and averaged to obtain plot bulk density. These cores were randomly located on the shear/burn and the shear/chop/burn systems. On the bedded plots, the cores were collected from random placement along the upper side slope of the bed (Terry et al. 1980).

Soil samples for nutrient determinations were collected from three randomly located points per plot. Four 7.62 cm long, 7.62 cm diameter successive depth increments were collected at each point giving a total sampling depth of 30.48 cm. Collection of incremental soil samples was accomplished using a portable sample core tube (Tuttle et al. In press). The upper 30.48 cm soil zone was chosen for analysis as it represents the major rooting zone of young seedlings and supplies most of the nutrients and water used in establishment and early growth (Trouse and Humbert 1961, Hopkins and Patrick 1969, Newman and Andrews 1973, Haines and Haines 1978, Nye 1961). Soil displacement was ocularly estimated during and after site preparation treatments. Also, the degree of erosion was ocularly estimated as the percentage of the study plot affected at each sampling time.

Soil Analysis Methods

Soil samples were air-dried and passed through a 2 mm sieve screen in preparation for analysis (Jackson 1958). Soil organic matter content was estimated by the Walkley-Black wet digestion procedure (Jackson 1958, Allison 1965). Soil P was extracted using a dilute fluoric acid solution and determined using the

chlorostannous-reduced molybdophosphoric blue color method in a hydrochloric acid system (Jackson 1958) and Ca, Mg, K, and Mn were extracted with 1 N ammonium acetate adjusted to pH 7.0 and determined using atomic absorption spectrophotometery (Chapman 1965). Strontium chloride was added to the sample dilutions to reduce interference during Ca and Mg determinations (David 1960). Soil pH was determined using a 1:1 soil:water mix (Adams and Evans 1962, Peech 1965). Nitrogen content of the soil was determined by block digestion and colorimetric assay (Nelson and Sommers 1972, Cataldo et al. 1974, Isaac and Johnson 1976, Eastin 1977).

Seedling Planting and Measurement

Seedlings were planted on the three study sites during the winter following application of the appropriate site preparation system. Seedlings were grown in Hammermill Paper Company's nursery and were planted at a nominal spacing of 1.8 X 2.4 m. Seedlings planted were 1-0 improved stock and were hand planted by company crews using dibbles.

Shortly after planting, the number of seedlings planted and the total height of each seedling were recorded on each measurement plot. After the first and second growing seasons, total height and survival were again recorded. Also, after the second growing season, ground line diameter (GLD) was measured.

Data were analyzed using Analysis of Variance, General Linear Models, and Duncan's Multiple Range Tests. These procedures are part of the SAS Institute's program package (Freund and Littell 1982).

RESULTS AND DISCUSSION

Prior to bedding, 2 to 4 cm of surface soil were pushed into windrows during piling operations. This is less than that commonly reported for raking and piling operations (May et al. 1973, Glass 1976, Blackburn et al. 1978). Application of the shear/burn and the chop/burn systems resulted in little observable soil loss. After observing all three site preparation systems used, we felt it would be difficult to operationally apply these site preparation systems on these sites with less topsoil disturbance and displacement. Thus these applications represent careful, skillfully applied mechanical site preparation treatments, not poorly applied ones.

All three site preparation systems significantly reduced logging residue and debris (Table 1). The number of stumps, logs, and stems were reduced up to 90%. Pretreatment samples showed most of the debris and dead residue was from harvesting of the loblolly or longleaf pine timber. However, standing stems were primarily low value hardwoods (i.e. oaks, sweetgum, dogwood, and blackgum) and small, poor qualtity pine stems. After the site preparation systems were applied, over 80% of the remaining residue and debris and over 95% of the standing stems were hardwood.

The three systems all greatly reduced woody stems (Table 1). As expected, the more intensive chop/burn and bed systems had fewer remaining stems than did the shear/burn system. Some of the smaller stems were only pushed over by the shear/burn system and straightened up after treatment. By the second season, competing woody stems on the shear/burn and the chop/burn systems were twice that on the bedded treatment (Table 2). The raking and piling steps of the bed system removed many root stocks and seeds which produce competing vegetation. Chop/burn plots had the highest number of woody stems after two growing seasons, although not significantly more than the shear/burn treatment. Shearing action severed standing stems, producing stumps which often sprouted and the drum chopper cut the sheared stems and root stocks into segments, increasing the number of sprouting points.

All treatments significantly altered the soil surface covering. Following site preparation, all three systems had reduced the quantity of litter, small debris, and vines on the soil surface (Tables 1 and 2). Litter concentration continued to decrease on the shear/burn and the chop/burn systems, while vine cover and the number of stems both increased through the study. On these plots surface litter was partially removed during treatment and much of the remaining litter rapidly decomposed. Since there was little living woody vegetation on the sites following site preparation and planting, the litter lost could not be quickly replaced. The bed system had an extremely low litter cover after site preparation. However, litter cover increased to 21% after one season as the loose soil of the beds settled, exposing organic material incorporated in the beds. Between the first and second growing seasons, litter cover on the bedded plots decreased again due to organic matter decomposition.

As the site preparation systems reduced the quantity of debris, litter, and vine cover on a site, the amount of bare soil increased (Table 2). Bare soil on all three systems increased due to treatment. As expected, the bedding system produced the most bare soil (92.2%). Raking and piling removed most of the surface cover and the bed formation then continued to further reduce surface cover. During the first two seasons, bare soil on the bedded areas dropped 40% to 50% as vegetation began to become established. The shear/burn and the chop/burn systems both increased bare soil 20% to 25% during treatment application. These two systems had only slight decreases in the quantity of bare soil during the first two growing seasons.

Table 1.--Quantity of stems, stumps, logs, tops, and small debris for the three site preparation treatments before and after site preparation. Means within a time with the same letter are not significantly different at the 0.05 level.

Time	Site Preparation Treatment	Total Standing Stems	Total Number Stumps	Total Number Logs	Total Number Tops	Small Debris
		per ha				% cover
Pretreatment	Shear/burn	9,077 A	1,215 A	874 A	332 A	16.5 A
	Chop/burn	8,982 A	1,158 A	390 A	201 AB	12.2 A
	Bed	8,057 A	1,332 A	613 A	161 B	11.2 A
Post Treatment	Shear/burn	1,072 A	259 A	156 A	4 A	8.4 A
	Chop/burn	116 B	228 A	112 AB	2 A	7.3 A
	Bed	445 B	118 A	47 B	0 A	2.5 B

Table 2. Effect of site preparation treatment on the total number of hardwood stems and on litter, vines, and bare soil cover at each of the four sampling times. Means at a time with the same letter are not significantly different at the 0.05 level.

Time	Site Preparation Treatment	Litter	Vines	Bare Soil	Number Hardwood Stems
		%			per ha
Pretreatment	Shear/burn	79.9 A	9.2 A	8.0 A	7,975 A
	Chop/burn	76.2 A	10.5 A	9.1 A	8,073 A
	Bed	78.4 A	7.8 A	5.4 A	6,789 A
Post Treatment	Shear/burn	55.2 A	0.2 A	33.5 B	1,072 A
	Chop/burn	57.2 A	0.1 A	32.2 B	116 B
	Bed	6.5 B	0.2 A	92.2 A	445 B
1 Season	Shear/burn	45.3 A	11.3 A	30.0 B	18,825 A
	Chop/burn	44.5 A	9.7 A	34.0 B	21,074 A
	Bed	21.2 B	16.2 A	61.1 A	10,433 B
2 Seasons	Shear/burn	32.2 A	14.2 AB	25.0 B	27,165 A
	Chop/burn	36.1 A	16.2 A	25.2 B	28,304 A
	Bed	16.3 B	8.1 B	56.6 A	14,056 B

One major concern regarding intensive site preparation is that the baring of the soil surface may detrimentally affect a forest site. Removal of the litter layer opens the soil up to direct rainfall impact, which can destroy surface soil structure by reducing particle aggregation. This tends to increase erosion losses since smaller particles are more susceptible to erosion (Wischmeier 1962, Farmer and Van Haveren 1971). These small particles may also filter into surface pores and reduce infiltration and aeration. However, after two growing seasons, less than 5% of the study area had evidence of erosion. Some small rills and slight sheet erosion occurred on the treatments. The bedded plots had more rills (3% to 5% of the area) than the shear/burn or the chop/burn areas. Less than 2% of the shear/burn or the chop/burn treatment area was found to be eroding after two seasons. Erosion on the sites examined was found to be minor, but scattered small areas with more severe erosion problems were observed outside of the study plots.

Site Preparation Effects on Soil Nutrients

Site preparation system had no significant effect on soil nutrient concentrations in the upper 30.48 cm after two seasons (Table 3). As treatment intensity increased, nutrient concentration tended to decrease. The bed system (the most intense) had the lowest nutrient concentrations. The trend of decreasing nutrient concentration as site preparation intensity increased was apparently due to soil disturbance and displacement. However, soil organic matter content was increased as site preparation intensity increased. The chop/burn and bed systems incorporated portions of the litter layer into the upper soil, thus increasing the organic fraction. This extra organic matter, much of which may resist rapid decomposition, will slowly supply some nutrients as it is broken down over the next several years.

Treatment Effects on Surface Bulk Density

Site preparation system influenced soil bulk density at all sampling times (Table 4). Prior to treatment, no differences were found, but through the first two seasons, soil bulk density changed significantly. The shear/burn and the chop/burn systems compacted the soil during site preparation, but as time passed bulk density decreased as plant roots grew through the compacted layers. After one year, bulk density on both these treatments was near the pretreatment levels with further reductions during the second year. Bulk density on the bedded plots decreased after site preparation due to the bed formation. The bedding harrows disk the surface soil as it is formed into beds, thus loosening the soil. However, during the following two seasons, these beds settled, resulting in bulk density increases to approximately pre-treatment levels. Bed settling is though t to be caused by raindrop impact destroying soil structure.

At no time during the study period did soil bulk density become an obvious detrimental factor. The bulk densities found were all well below levels (approximately 1.4 g/cc for these soil textures) which reportedly reduce pine seedling growth and survival (Mitchell 1979, Halverson and Zisa 1982).

Site Preparation Effects on Loblolly Pine Seedlings

Site preparation system had no significant effect on loblolly pine seedling total height at any sampling time, but after two seasons the more intensive treatments tended to have slightly taller seedlings (Table 5). As with total height, seedling survival was not significantly affected but the more intensive treatments had slightly higher survival percentages.

Table 3.--Effect of site preparation treatment on available soil nutrient concentration, organic matter, and pH in the upper 30.48 cm of the soil at the end of the second growing season. Means with the same letter are not significantly different at the 0.05 level.

Site Preparation Treatment	Soil Nutrients						Soil Organic Matter	pH
	Ca	Mg	K	Mn	P	N		
	kg/ha						%	
Shear/burn	1631.7 A	303.0 A	180.9 A	199.8 A	6.4 A	2212.8 A	1.03 B	4.3 AB
Chop/burn	1502.7 A	289.5 A	179.5 A	198.4 A	5.3 A	2086.1 A	1.18 AB	4.4 A
Bed	1554.5 A	284.1 A	164.2 A	189.2 A	4.1 A	2020.4 A	1.28 A	4.2 B

Table 4.--Site preparation treatment effects on surface soil bulk density at each sampling time. Means within a time with the same letter are not significantly different at the 0.05 level.

Time	Site Preparation Treatment	Soil Bulk Density
		- g/cc -
Pretreatment	Shear/burn	1.19 A
	Chop/burn	1.18 A
	Bed	1.21 A
Post Treatment	Shear/burn	1.31 A
	Chop/burn	1.26 A
	Bed	1.08 B
1 Season	Shear/burn	1.23 A
	Chop/burn	1.18 B
	Bed	1.21 AB
2 Seasons	Shear/burn	1.14 B
	Chop/burn	1.12 B
	Bed	1.24 A

Seedling GLD was the only seedling measure significantly affected by site preparation system. The bed system had larger diameters than the chop/burn or the sh ear/burn treatments. Competition levels on both the chop/burn and the bed systems were lower than the level on the shear/burn system immediately after treatment application (Tables 1 and 2). However, during the latter portion of the first and all of the second season, the chop/burn system competition levels increased dramatically as stumps and roots sprouted (Table 2). The bedded plots, from which most of the hardwood stumps and roots were removed, continued to have lower competition levels. This afforded seedlings on beds more available moisture and nutrients and resulted in slightly greater height and diameter growth and lower mortality (particularly during the second year).

At this early age, evaluation of seedling heights and diameters is not necessarily indicative of future growth or volume. Young seedlings are highly susceptible to damage from insects and wildlife, which may significantly affect or alter height, making early growth measurements weak long term growth predictors.

CONCLUSIONS

The three site preparation systems studied all accomplished their two primary objectives of significantly reducing debris and residue allowing easier and faster planting operations and of reducing competition levels. However,

Table 5.--Treatment effect on total seedling height, survival and ground line diameter (GLD) at each sampling time. Means within a time with the same letter are not significantly different at the 0.05 level.

Time	Site Preparation Treatment	Total Seedling Height	Seedling Survival	Mean Seedling GLD
		---cm---	---%---	--cm--
Planting	Shear/burn	13.6 A	----	-----
	Chop/burn	14.1 A	----	-----
	Bed	13.2 A	----	-----
1 Season	Shear/burn	32.3 A	85.0 A	-----
	Chop/burn	32.5 A	89.1 A	-----
	Bed	30.8 A	87.0 A	-----
2 Seasons	Shear/burn	68.6 A	83.1 A	0.98 B
	Chop/burn	70.6 A	85.7 A	1.07 B
	Bed	69.9 A	85.3 A	1.27 A

although not significantly different, after two years, as site preparation intensity increased nutrient concentrations tended to decrease. The more intensive treatments had more soil disturbance and loss, thus reducing nutrient concentration. Bulk density on the the shear/burn and chop/burn systems increased during treatment application and then decreased over two years, while the bed system decreased when the beds were formed and then increased as the beds settled. Seedling height and survival were not influenced by site preparation used, but GLD was larger on the more intensive treatments.

Properly applied mechanical site preparation resulted in little soil loss on upland areas in the Hilly Coastal Plain. The key in limiting soil problems, even on upland slopes, is to have proper application techniques. The use of beds in upland situations may prove beneficial in that they may improve soil moisture, particularly on south facing slopes, resulting in better moisture relations and thus seedling growth. Few significant growth trends were observed during the first two growing seasons. However, the full effect of these trends and of site preparation cannot be evaluated until much later in the rotation.

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THE EFFECTS OF THREE LEVELS OF SITE PREPARATION ON PLANTED SWAMP CHESTNUT OAK ON A POORLY DRAINED SITE[1/]

J. R. Seifert, P. E. Pope, and B. C. Fischer[2/]

Abstract.--Swamp chestnut oak (1-0 bare root seedlings) were planted on a poorly drained, upland flat site following three levels of site preparation - control, disking and disking-bedding. Five-year seedling survival and total tree height were not significantly affected by site preparation. Fourth and fifth year height growth increment and diameter growth were significantly increased by either method of site preparation. Planting swamp chestnut oak in southeastern Indiana may be a feasible land use alternative on poorly drained upland sites.

INTRODUCTION

In the Central States, many acres of poorly drained upland and bottomland forests are being harvested of high quality oak sawlogs and left to naturally regenerate. The natural regeneration is usually of lower-valued nonoak species such as silver (Acer saccharinum L.) and red (A. rubrum L.) maple, sweetgum (Liquidambar styraciflua L.), sycamore (Platanus occidentalis L.), cottonwood (Poplulus deltoides Bartr. var. deltoides), boxelder (A. negundo L.), elms (Ulmus spp.) and ashes (Fraxinus spp) (Garrett, 1982). Artificial regeneration of wet-site oak species is currently rarely attempted.

In the Central States most studies on oak planting have concerned upland oaks not wet-site oaks. Studies have led to the general conclusion that oak plantings will grow slowly (Johnson, 1979), although Johnson (1984) indicates some success with underplanting northern red oak (Quercus rubra L.) in Missouri.

There is limited detailed information on the survival and growth of preferred wet-site oaks. Successful artificial regeneration research on wet-site hardwoods has revolved around sweetgum, green ash (Fraxinus pennsylvanica M.), cottonwood and nuttall oak (Q. nuttallii P.) because of these species high woody biomass yields (Gilmore and Rolfe, 1984). Johnson and Krinard (1983) found good early growth and survival for Shumard (Q. shumardii Buck), swamp chestnut (Q. Michauxii Nutt.) and water (Q. nigra L.) oaks planted in small forest openings. However, after 22 years planted yellow-poplar (liriodendrun tulipifera L.) averaged 70 feet tall, while five oak species and sweetgum each averaged less than 30 feet. Suppression by the faster-growing yellow-poplar resulted in reduced height and survival for all other species. Swamp chestnut oak had better survival and the second largest individual tree heights outgrowing water, Shumard, cherrybark and southern red oak. Francis (1983) successfully planted cherrybark (Q. falcata var. pagodiolia Ell.) and Shumard oaks on eroded ridges. After 20 years height averaged 40 feet and diameters averaged four to five inches.

The objective of this study was to evaluate the effect of site preparation on survival and growth of planted swamp chestnut oak.

MATERIALS AND METHODS

The planting site was a flat, poorly drained Avonburg-Clermont soil (Aeric Fragiaqualfs, fine-silty mixed mesic) which had been grazed prior to the establishment of the study. The association was formed in loess underlying glacial till. Depth to a fragipan varies from 30 to 40 inches and the seasonal water table varies from one to three feet. The soil is strongly acidic.

The site index (base age 50 years) is 80 - 90 feet for mixed hardwoods (Soil Conservation Service, 1976). Using the site quality rating system of Baker and Broadfoot (1979) the site has a quality rating of 70 feet for swamp chestnut oak.

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2/ Extension Forester and Associate Professors, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana.

Experimental Design and Treatments

Site preparation treatments were control, disk, and disk and bed. Disking was done with a standard agricultural farm disk. Bedding was accomplished with a moldboard two-bottom plow. The bed was formed by plowing in one direction and reversing the direction of plowing to concentrate the soil along a center ridge. This produced an elevated bed which was approximately 30 cm above the soil surface with drainage along each side. Site preparation treatments were applied in the summer of 1979 and again (disking only) in the spring of 1980.

Within each treatment four randomly selected plots were measured. Each plot contained thirty seedlings. Seedlings were measured for total height, seedling diameter at ten cm above the ground and survival. Data were tested by analysis of variance (ANOVA) and the variables found significant were subjected to Duncan's new multiple range test at the 0.05 level.

Seed Source and Spacing

Swamp chestnut oak seed was collected within a ten mile radius of the planting site and grown at the Indiana state nursery at Vallonia, Indiana. The seedlings were grown for one year (1-0). Dormant seedlings were lifted in November and stored in a cooler at 3°C through the winter. Seedlings with root collar diameters of 1.52 - 2.03 cm and top heights of 46 - 76 cm were planted in April, 1980 on a 10 ft x 10 ft spacing with a KBC planting bar.

Weed Control

Chemical weed control consisting of glyphosate (2 qt/A) and simazine (4 lb a.i./A) was applied each spring around all seedlings. For the first 2 years, the treated area consisted of 1 m diameter circle treatments around each seedling. Beginning in the third year, the chemical has been applied to 1 m wide bands over the planted row. The remaining untreated area within rows was then mowed twice annually.

RESULTS AND DISCUSSION

All the seedlings were severely browsed in the winters of 1980 and 1981 which caused the height growth data for those periods to be meaningless. Following the 1982 growing season the seedlings were too large to be browsed by rabbits. Consequently, all survival and growth data are reported beginning in 1982, the third growing season.

Plantation Survival

Third year plantation survival averaged 89% across all treatments and was not influenced by the site preparation method. Seedling survival declined to 83% by the end of the fifth growing season following two summer droughts. Although not statistically significant, survival was 15% lower for the control than either the disked or disked-bedded site treatments. These results are similar to those reported by Derr and Mann (1970) for slash pine (Pinus Elliottii Engelm.) and by Francis (1983) for cherrybark and Shumard oak. In either case flat disking and mound disking (Derr and Mann, 1970), or disking vs ditching (Francis, 1983) did not improve survival.

Total Height Growth

At the beginning of the third growing season the average seedling height across all treatments was 20 cm. Site preparation had no effect on seedling height from 1982 - 1984 (Table 1). A visual observation of the plantation would have concluded the opposite. Oak seedling growth is in general variable due to large genetic within family differences (Farmer, 1975) and seed source variation (Kriebel et al, 1976). As noted by Johnson (1979) some trees grow exceptionally well from the first year while others grow very slowly. Johnson estimated that on the average 10% of planted black oak (Q. velutina L.) seedlings exhibit exceptional growth. For this study 38% of the seedlings grew better than the plantation average (Table 2).

Table 1. Influence of site preparation on height growth of swamp chestnut oak from 1982-1984.

Site Preparation	Seedling Height (cm) 1982	1983	1984
Control	77a[1/]	112a	150a
Disked	79a	110a	165a
Disked & Bedded	65a	91a	142a
Average	73	104	152

1/ For a given year, values not followed by the same letter are significantly different by Duncan's new multiple range test at 0.05 level.

The wide range in total tree height (30 to 283 cm) recorded for 1984 was reflected by the large within-treatment coefficient of variation for each block (33-82% for the control, 35-64% for the disked, and 43-89% for the disk-bedded). The range of variation was as great between-treatments as within-treatments resulting in insignificant treatment variations in the ANOVA.

Height Growth Increment

Height growth increment was evaluated for 1983 and 1984. Height growth was significant at the 0.05 level for both years (Table 3). When compared to the control treatment, the height growth increment in 1983 and 1984 was significantly greater for the disked and disked-bedded site preparation treatments. The

Table 2. Influence of site preparation treatment on the number of individual trees growing faster than the mean plantation tree (152 cm) by size class and treatment.

Site Preparation	Height Growth Class (cm) 180	210	240	Total
Control	43(10)[1/]	22(5)	4(1)	69(16)
Disked	141(33)	69(16)	13(3)	223(52)
Disked & Bedded	124(29)	52(12)	17(4)	193(45)

1/ Values in parenthesis are the percentages of the total number of trees planted, assuming 430 trees per acre.

Table 3. Influence of site preparation on the height growth increment of swamp chestnut oak for 1983 and 1984.

Site Preparation	Height Growth Increment (cm) 1983	1984
Control	26a[1/]	34a
Disked	36b	49b
Disked & Bedded	37b	49b
Mean	33	44

1/ Values not followed by the same letter are significantly different by Duncan's new multiple range test at 0.05 level.

mean height growth increment in 1984 was 11 cm greater than 1983 (8 cm for the control, 13 cm for disked, and 12 cm for the disked-bedded treatments).

Diameter Growth

In 1984 average stem diameter for the plantation was 2.8 cm at 10 cm above the ground line and was significantly greater for the disked (3.1 cm) and disked-bedded (2.9 cm) treatments than the control (2.4 cm). No statistical difference was noted between the disked and disked-bedded plots.

Discussion and Summary

Soil cultivation, either by disking alone or by disking-bedding, increased diameter and height growth increment of swamp chestnut oak. With the selection of proper tree species, the bedding of upland flat sites may not result in increased diameter or height growth increment over disking alone. Bedding may not be necessary on upland flats in southern Indiana since periods of prolonged flooding are very rare. Site preparation by disking did cause an increase in height increment and diameter growth. Most importantly the affect of the site preparation is still evident five years after planting. Moehring (1970) noted that on silt loam soils, macropore volume was low, cultivation increased the soil air component, and reduced the mechanical resistance to tree root penetration, improving tree performance.

Swamp chestnut oak has evolved through time to the point where it can survive and grow well in high moisture content soils. However aeration of the soil through cultivation does stimulate growth. The lack of response to bedding has also been noted by other researchers working with wet-site oaks (Kennedy, 1976; 1980).

Based on the results of this study planting swamp chestnut oak on poorly drained upland sites in southeastern Indiana may be a feasible alternative land use. The potential growth of this species is promising when compared to the upland red and white oaks currently available for planting on such sites. Additional research on other wet-site oaks should be undertaken to establish growth comparisons.

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AN EVALUATION OF SITE PREPARATION METHODS FOR LOBLOLLY PINE REGENERATION ON THE PIEDMONT[1/]

C. W. Stafford, J. L. Torbert, and J. A. Burger[2/]

Abstract.--A study was conducted to quantify the effects of several site preparation prescriptions on third-year survival and growth of loblolly pine in the Piedmont Plateau of South Carolina and Georgia. Each of twelve replicate sites were treated with seven methods of site preparation. After three growing seasons, survival, height, diameter, and volume were better on mechanically-treated areas than on herbicide-burn and control areas. Treatments that included discing provided the lowest soil bulk densities and the best growth response. Foliar N levels were highest in trees on shear-rake-disc plots, but these plots had the lowest long-term N supply. Other growth limiting factors influenced by site preparation are being studied in an effort to develop site specific guidelines for prescribing site preparation treatments.

INTRODUCTION

Regeneration of intensively managed southern pine forests is accomplished primarily through clearcutting, site preparation and planting (McClurkin and Moehring, 1978). The reasons for site preparation, whether by fire, chemical or mechanical means, include 1) optimizing the soil moisture regime; 2) organic matter incorporation to increase mineralization and nutrient release to promote early growth; 3) reduce vegetative competition for soil nutrients and moisture; 4) clearing the land for ease of planting; 5) increase wood production due to both increased survival and seedling growth and 6) allow use of genetically improved planting stock. The techniques most commonly employed in the Southeast are shearing, piling, discing, bedding, chopping, burning and the use of herbicides. Although most of these site preparation methods are used in the Piedmont, there is little documentation of their differential effect on regeneration success, and short- and long-term tree growth and yield at rotation age.

Pehl and Bailey (1983) summarized results of a site preparation study on the Georgia Piedmont that was measured at ages 1, 2, 3 and 10. After the third growing season, mean tree heights on chopped, disced, and bedded plots were 11, 26 and 20% higher, respectively, than the control. By the tenth growing season, mean dbh of the trees on the disc and bed treatments were 16 and 19 percent larger, respectively, than the control, while the chop treatment did not differ significantly from the control. They concluded that (1) the height-growth advantage of intensive site preparation peaked during the third growing season, (2) was lost on the chop and bed sites by age 10, and (3) the trend suggested that the height gain will be lost on the disced plots by age 25.

On the North Carolina Piedmont, Haines and Davey (1979) studied the effects of discing, weed control by mowing, herbicides, and various combinations of fertilization, subsoiling, and irrigation. After the second growing season, heights and diameters of trees in herbicided plots were significantly greater than the control trees, but trees in the disced plots were not.

Because results from the few site preparation studies undertaken on the Piedmont are often incomplete and inconclusive, this research was conducted to quantify the effects of several site preparation prescriptions on third-year survival and growth of loblolly pine in the Piedmont of South Carolina and Georgia.

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[2/] Graduate Research Assistant, Research Assistant, and Assistant Professor, respectively, Department of Forestry, VPI & SU, Blacksburg, VA 24061.

PROCEDURES

Study Sites

Three study areas in the central Piedmont, two in western South Carolina and one in eastern Georgia, were selected. Four sites supporting natural, mature, loblolly pine-hardwood stands were selected within each area and clearcut in the summer of 1980. The prevalent hardwoods on the sites were yellow-poplar (Liriodendron tulipifera L.), post oak (Quercus stellata Wangenh.), white oak (Quercus alba L.), water oak (Quercus nigra L.), and willow oak (Quercus phellos L.). The clearcut stands ranged in age from 30 to 50 years, with site indices (base age 50) ranging from 68 to 90.

In addition to forest cover, sites were selected on the basis of similarity in soil type. The soils of the study sites were Appling, Pacolet, Cecil or Hiwassee which have minor differences in depth, color and texture of the subsoil (SCS, 1975). The soils were deep, well drained with medium fertility and moderate permeability. All were clayey, kaolinitic, thermic, Typic Hapludults except Hiwassee which was a Typic Rhodudult. The uneroded surface soils were predominately sandy loam and the subsoils ranged from sandy clay to clay. Bulk density of the surface soils ranged from 1.17 to 1.24 g/cm^3 prior to harvest.

Site Preparations

A spectrum of operationally feasible prescriptions, varying in intensity and cost, were included in the study:

1. No Preparation
2. Herbicide and burn
3. Chop and burn
4. Shear, rake-pile (2 passes)
5. Shear and disc (1-pass)
6. Shear, V-blade and disc (2-passes)
7. Shear, rake-pile, disc (3-passes)

The study was established in the summer and fall of 1980. Treatments within study sites ranged in size from three to five acres. For treatment 2, glyphosate was aerially applied at a rate of 1 gal. Roundup (R) per acre. Within six weeks the sprayed areas were burned. Shearing and discing in treatment 5 was applied simultaneously in one pass. Residual vegetation was sheared in place; however, some piling occurred when the vegetation and debris was exceptionally heavy. The shear, V-blade and disc treatment (6) consisted of shearing residual vegetation in place with the first pass, followed by a V-blade and discing with the second pass. The V-blade aligned the sheared material into small windrows between which the soil was disced. All treatment areas were planted by machine with 1-0 genetically improved loblolly pine seedlings, except for the control and herbicide plots which were hand planted. Five 0.1 acre subplots were randomly located within each treatment plot. Each subplot contained approximately 64 seedlings which provided about 320 measured trees per treatment.

Tree survival, height and diameter were measured in the winter of 1984. Foliar samples were collected from the Georgia sites in the summer of 1983. Total tissue N was determined using standard micro-Kjeldahl techniques (Bremner, 1965). A 0.5 gram subsample was ashed in a muffle furnace at 450°C for 10 hours and nutrients were extracted with 10 ml of 6 N HCL. The Murphy-Riley ascorbic acid technique (Watanbe and Olsen, 1965) was used to analyze P in the extracts. Standard procedures for a Perkin-Elmer atomic absorption spectrophotometer were used to determine K, Ca and Mg levels in the tissue extracts (Perkin-Elmer, 1980).

RESULTS

Survival has remained virtually unchanged since the first year. Over all study sites, survival in the five mechanical treatments was significantly better than in the herbicide-burn and control areas (Table 1). Within mechanical treatments, the shear-rake-disc and shear-disc treatments had significantly better survival than the chop-burn, shear-V-blade-disc and shear-rake treatments.

Overall, growth was best on the shear-rake-disc treatment. The height, diameter and volume index (d2h) of this treatment were significantly higher than the other two disced treatments, and all disced treatments had significantly better volume indices than other treatments. Height, diameter and volume indices on the control and herbicide-burn treatments were significantly lower than those on all of the mechanically prepared sites.

On mechanically prepared sites, growth responses were inversely proportional to soil bulk density; that is, the best growth response occurred on sites with lower bulk densities. All discing treatments resulted in significantly lower bulk densities than the chop-burn treatment, while the shear-rake-disc and shear-disc treatments were significantly lower than the shear-rake treatment.

Foliar nitrogen levels of trees on the shear-rake-disc treatment (1.26%) were significantly higher than that on all other treatments except the control (Table 2). There were no other differences between foliar nutrient levels except for calcium, which was significantly higher on the control than all mechanically prepared sites.

DISCUSSION

During site preparation and planting, and for some months following, the southeastern United States experienced drought conditions. In the period from June 1980 to June 1981, actual rainfall averaged 13 inches below normal. The lack

of rainfall during this critical period of seedling establishment is largely responsible for the overall poor seedling survival on these sites.

On the Piedmont, two of the factors primarily responsible for limiting pine growth are soil density and available nitrogen. Piedmont soils are usually finely textured with inherently high soil densities. With traffic, these soils can become compacted to the point that root penetration is often restricted. Nitrogen is almost always a limiting factor to pines after the first several years of rotation.

Volumes on all disced treatments in this study were significantly greater than those on all

Table 1.--Effect of site preparation method on the survival, height, diameter, volume index, and soil bulk density at plantation age 3.[1/]

Site preparation treatment	Trees planted	Survival	Trees remaining	Height	Diameter	Volume index	Bulk density
		(%)		(in)	(in)	(in^3)	(g/cm^3)
No preparation	641	43 c	276	42.32 e	0.78 d	45.19 d	1.29 c
Herbicide, burn	654	48 c	314	42.92 e	0.91 d	60.23 d	1.35 ab
Chop, burn	607	57 b	346	49.75 cd	1.23 bc	100.76 c	1.39 a
Shear-disc	597	64 a	382	53.06 b	1.31 b	119.42 b	1.29 c
Shear, V blade-disc	533	61 b	325	53.08 bc	1.31 b	122.05 b	1.32 bc
Shear, rake	618	61 b	377	47.04 d	1.16 c	85.19 c	1.37 ab
Shear, rake, disc	645	68 a	439	56.63 a	1.44 a	150.83 a	1.30 c

[1/] Different letters within columns indicate significant differences among treatments at the 0.1 level.

Table 2.--Foliar nutrient concentrations by treatment during the third growing season.[1/]

Treatment	N	P	K	Ca	Mg
	%				
No preparation	1.22 ab	.10 a	.65 a	.22 a	.10 a
Herbicide, burn	1.17 c	.11 a	.65 a	.20 ab	.11 a
Chop, burn	1.19 bc	.11 a	.67 a	.19 b	.10 a
Shear-disc	1.14 c	.11 a	.72 a	.19 b	.10 a
Shear, V blade-disc	1.16 c	.11 a	.75 a	.19 b	.10 a
Shear, rake	1.16 c	.15 a	.67 a	.20 b	.10 a
Shear, rake, disc	1.26 a	.11 a	.71 a	.18 b	.13 a

[1/] Different letters within columns indicate significant differences among treatments at the 0.1 level.

other treatments. Discing generally increases early growth on these Piedmont sites by loosening compacted surface soil (upper 10"). This relationship is most notable when comparing the shear-rake-disc treatment to the shear-rake treatment, which essentially serves as a control for the disc.

The performance of trees on the shear-V blade-disc and shear-disc treatments are lagging slightly behind those on shear-rake-disc treatments because of some soil scalping that occurred during planting. A V-blade was attached to the front of the planting tractor to move debris aside. In some cases the blade was low enough to push topsoil to the side, creating mounds between rows. Trees planted in the scalped areas did not receive the full benefit of the disc. As roots grow out into this displaced soil and organic residue, they should grow rapidly.

Foliar nutrient levels help identify obvious nutritional problems. In this study, cation levels exceeded those levels generally considered adequate for normal growth. Phosphorus levels for all treatments were at or above the 0.1% level which is often considered the critical level. In almost all cases, nitrogen levels are below the critical level of 1.2% suggesting a marginal condition.

Nitrogen levels in the shear-rake-disc plots (1.26%) reflect increased mineralization rates caused by incorporating surface material, higher surface temperatures, and less moisture competition. There is concern that there may be too much N released into the soil solution too soon which may result in N deficits at a later time. Trees in the unprepared area also had high foliar N levels, but growth of these trees is probably limited by other factors.

Raking, while useful for clearing the land to facilitate machine planting, seems to have little value for increasing productivity. As rakes travel back and forth over the surface. they compact the soil and remove nutrients from the site. Logging debris that is pushed into windrows and burned would have acted like a slow-release fertilizer, becoming available to the trees 5 to 10 years after planting. If left in place, this material would have increased the surface layer organic matter content which enhances moisture retention, cation exchange, and improves soil tilth. Two treatments in this study, the shear-disc and shear-V-blade-disc, provide the benefits of discing while allowing debris to remain on site.

Nitrogen demands are high as trees begin to grow rapidly between the ages of 3 to 10. On shear-rake-disc areas, much of the N has already been mineralized. If the nitrogen has not been captured by competing vegetation or immobilized by soil microorganisms, it has probably been leached from the soil. On the other hand, trees in the other disced treatments should start to utilize increasing levels of soil N as debris surrounding the trees decomposes.

CONCLUSIONS

Third-year results show the beneficial effect of discing on tree growth during the stand regeneration phase. To date, the best growth has resulted on the shear-rake-disc treatment. This treatment is also the most expensive. In time, the shear-V blade-disc and shear-disc treatments may prove more cost effective, particularly if retention of nutrients in slash and litter proves to be a factor significantly enhancing growth later in the rotation.

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SITE PREPARATION EFFECTS ON THE SPATIAL DISTRIBUTION OF PLANTED LOBLOLLY PINE SEEDLINGS[1/]

T. D. Needham, J. A. Burger, and D. O. Lantagne[2/]

Abstract.--The spatial patterns of loblolly pine seedlings following seven site preparation treatments were evaluated using Pielou's Index of Nonrandomness both immediately after planting and after the second growing season. Seedlings on machine planted treatment areas exhibited expected spatial patterns. As the amount of logging slash or its roughness decreased, planting patterns became more regular. Hand planted treatment areas exhibited the most regular spatial patterns even though the site preparation on these areas left difficult planting conditions. After two years, the spatial distribution of seedlings shifted from regular and random toward a more clustered pattern. The degree of change was similar in all but the unprepared and herbicide-burn treatments which exhibited the greatest change. Although significant differences in seedling spatial patterns were observed among the treatments, the importance of the differences with regard to yield and harvestabilty is yet to be determined.

INTRODUCTION

Regeneration success in southern pine plantations is often based on the number of seedlings surviving after the first year. However, the spatial distribution of trees should also be considered. A distribution that permits full utilization of a site is preferred. Therefore, among other things, site preparation should promote a pattern of well distributed trees.

A regular spatial pattern is usually sought to completely utilize a site. As either the spatial distribution shifts away from regular, or the number of trees changes, a change in yield and product is expected to occur. A guideline used by many foresters to assess the potential ability of a stand to produce an acceptable yield at rotation is 300 trees per acre assuming they exhibit a "good" spatial distribution.

The purpose of this study was to determine how several site preparation alternatives used in the regeneration of loblolly pine affected seedling spatial distribution patterns at the time of planting and after two growing seasons.

METHODS

A site preparation study was initiated in 1980 on twelve, 40 acre sites in the South Carolina and Georgia Piedmont on Champion International Corporation lands (Lantange, 1984). Each of the seven site preparation prescriptions described in Table 1 was applied to approximately 5 acres at each site. The treatments represent a range of operationally feasible site preparation prescriptions varying in cost and intensity. Following planting, five 0.1 acre plots were randomly located within each treatment area. The location of every planted seedling within the plots was identified by a row distance from a plot corner and a tree distance from the plot baseline. The second

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Graduate Research Assistant and Assistant Professor, respectively. Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, and Assistant Professor, Michigan State University, E. Lansing, MI 48824-1222.

year after planting, each plot was revisited and survival by tree location assessed.

Table 1.--Site preparation prescriptions applied at each of twelve, 40 acre sites.

PRESCRIPTION	NUMBER OF MACHINE PASSES	PLANTING TECHNIQUE	DESCRIPTION
Unprepared	0	Hand	No preparation following harvest.
Herbicide Burn	0	Hand	A 4% solution of glyphosate in water aerially applied in mid September. Burned 6 weeks later.
Chop Burn	1	Machine	An empty 3m wide double drum offset chopper behind a D7 tractor. Burned 2-6 weeks later.
Shear-disc	1	Machine	Tandem harrow (35" discs) behind a D7 tractor mounted with a KG shearing blade.
Shear V-blade disc	2	Machine	Residual vegetation sheared with a KG shearing blade. V-blade mounted to front of D7 created mini windrows while pulling a tandem harrow (35" discs).
Shear Rake	2	Machine	Residual vegetation sheared with a KG shearing blade on first pass. Slash raked into windrows.
Shear Rake Disc	3	Machine	Residual vegetation sheared with a KG shearing blade. Slash raked into windrows. Soil disced with tandem harrow (35" discs).

Pielou's Index of Nonrandomness (Pielou 1959) was used to assess seedling distribution. Research by Payandeh (1970), suggests that it is the best alternative for assessing the spatial distribution of trees. The index is based on point-to-plant distances. After the location of every planted tree was mapped, computer techniques were used to randomly locate fifty points within each plot and determine mean squared point-to-tree distances.

The spatial distribution index for each plot was then calculated as follows:

$$I = (n \cdot \pi / 43560) \cdot \bar{w}$$

where: I = spatial distribution index
$\bar{w}$ = mean of squared point-to-plant distances
n = density in trees per acre
π = 3.14159

The index was adjusted so a value of 1.00 would indicate a perfectly regular spatial distribution while larger values would indicate increasingly less regular patterns. This was achieved by creating a perfectly regular spatial pattern, determining its index value, and dividing all index values by this number. As spatial patterns become less regular they are classified as random or clustered depending on the magnitude of the index. The plots in figure 1 illustrate a range of spatial distribution patterns and give corresponding index values.

A spatial distribution index was determined for each of the 420 plots in the study and comparisons between methods of regeneration were made using analysis of variance and graphics. Analysis of covariance was used to investigate the relationship between initial and surviving seedling spatial patterns.

RESULTS and DISCUSSION

The bar chart in figure 2 shows the average spatial distribution of planted seedlings by treatment as it occurred at planting and after 2 growing seasons. No treatment promoted a clustered distribution among the trees on the average; however, several treatments tended to

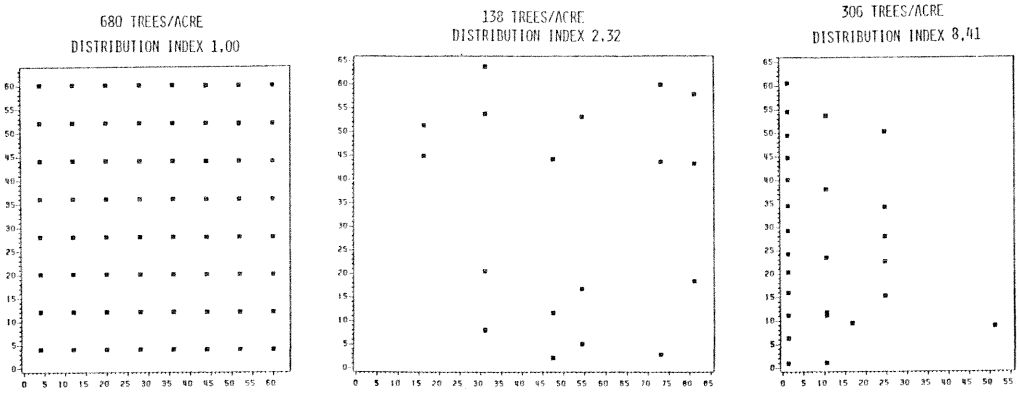

Figure 1.--Examples of spatial patterns and associated index values.

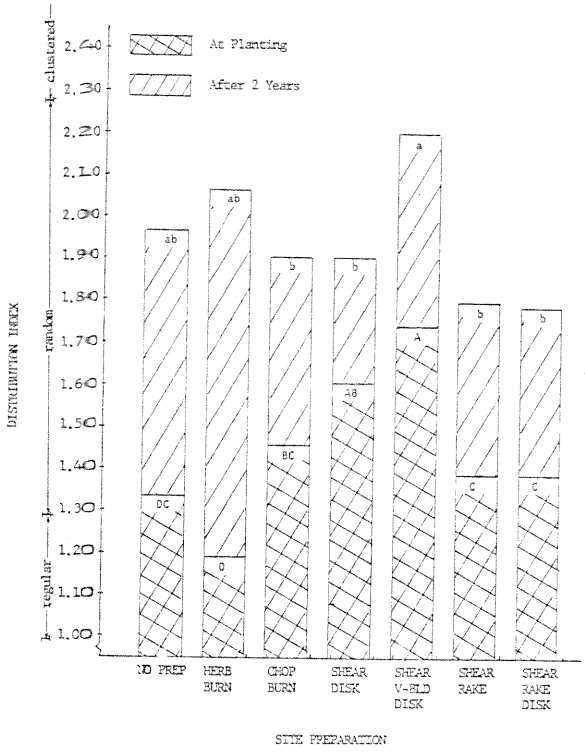

Figure 2.--Average spatial distribution of seedlings by treatment after planting and after the second growing season. 1/

1/Treatment means within each measurement period having the same letter are not significantly different at the 0.05 level.

designed to create small windrows of slash between each row of seedlings, caused a significantly more clustered distribution than the other treatments. The reason for the irregular spacing in the prescription can be attributed to irregular accumulations of slash which had be to skirted by the planter. The distribution of trees within a row was fairly regular, while the distance between rows was variable as a result. Figure 3 is an example of the type of spatial pattern exhibited by plots receiving this treatment.

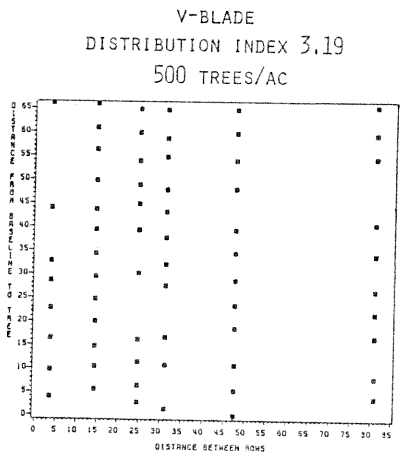

Figure 3.--An example of the spatial pattern of seedlings after planting in plots in the shear, v-blade treatment areas.

promote more clustered distributions than others. The least intensive treatments, unprepared and herbicide-burn, exhibited the highest degree of uniformity followed by the most intensive treatments, shear-rake, and shear-rake-disk. The intermediate treatments exhibited random distributions.

Spatial patterns can partially be attributed to planting technique and to the amount and distribution of logging slash and residual vegetation left on the site after harvest. Machine planting could not be used on the unprepared or herbicide-burn sites because residual vegetation and slash obstructed equipment. Consequently, hand planting was required and a relatively regular spatial distribution among seedlings resulted.

Sites that were raked provided a relatively smooth surface for the machine planter to traverse, which in turn permitted consistent and regular planting. As the amount and roughness of logging slash distributed across a site increased, planting patterns became more irregular. The V-blade treatment, which was

The distribution of trees surviving after two years (Figure 2) was highly dependent upon the tree distribution at planting. Among the machine planted treatments, the relative spatial distribution of trees remained nearly the same even though there was a large shift toward a more clustered pattern. Consequently, the V-blade treatment remained significantly different from the others. Hand planted areas exhibited a much more dramatic change from uniform toward clustered distributions. The unprepared and herbicide-burn areas exhibited extremely varible growing conditions that were largely the result of the residual hardwood distribution and the efficacy of the herbicide. Pockets of favorable and unfavorable growing conditions occurred which created clustered spatial patterns among the surviving seedlings. The other site preparation prescriptions tended to create more homogeneous site conditions and as a result, the distribution of the mortality was apparently random.

The spatial pattern of seedlings is of little consequence unless it affects yield, the product mix, or the harvestability of the future

stand. To examine the importance of spatial patterns with regard to these factors, computer simulations using the observed spatial patterns will be employed to grow and harvest trees. A distance-dependent individual tree growth simulation (Daniels and Burkhart 1975) will be used to grow trees and provide growth and yield information. A harvest simulation computer program will be used to evaluate the harvestablity of the various treatments as affected by the spatial distribution of the seedlings.

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IMPACTS OF VARIOUS INTENSITIES OF SITE PREPARATION ON PIEDMONT SOILS AFTER 2 YEARS[1/]

James H. Miller and M. Boyd Edwards[2/]

Abstract.--Six levels of site preparation were applied to replicated 0.8-hectare plots at the Hitchiti Experimental Forest on the Piedmont Plateau in central Georgia. Treatments ranged in intensity from handclearing to shearing and chopping to rootraking and disking with fertilization and herbicides. Soils were sampled before treatment applications and after 1 and 2 years. Composited bulk samples from 0-15 and 15-60cm were analyzed for texture, pH, organic matter, and available phosphorus, calcium, magnesium, potassium, and sodium. Six core samples (0-6cm) per plot were used to determine bulk density, available moisture holding capacity, and total pore space. The early trends of soil impacts are: 1) soil organic matter and available nutrients are not different among treatments; 2) pH of surface soils increased slightly with increasing intensity of treatment in the first year; and 3) bulk density significantly decreased with disking while pore space increased.

INTRODUCTION

The renewable nature of the forest resource depends on the conservation and continued productivity of the soil resource. Intensive mechanical site preparation in the rolling Piedmont needs to be examined both from the aspect of adverse impacts on sustained productivity and from longterm benefits to tree growth and volume production. Very few investigations have attempted to delve into these two crucial areas. Several presentations at this conference will discuss results of such investigations and thus make sizeable contributions to this vacant area of research. The objective of the research in this paper was to monitor changes in nutritional and physical soil properties that can influence establishment and early growth of a tree crop. Results from 2 consecutive years following site preparation will be presented. Extensive interpretation of results is not yet possible due to the paucity of comparable studies.

METHODS

Study Area

The study area is a 34-ha tract located on the Piedmont at the Hitchiti Experimental Forest, managed by the USDA Forest Service, 20 miles north of Macon, Georgia. The harvested stand was principally composed of loblolly pine (*Pinus taeda* L.) with a lesser component of mature and sapling-sized hardwoods, mainly sweetgum (*Liquidambar styraciflua* L.) and dogwood (*Cornus florida* L.). The pre- and post-harvest vegetation was sampled and described by Edwards (1982). The average site index for loblolly pine was 80 at 50 years. The pre-harvest stand was naturally regenerated on eroded cotton fields that were abandoned in the 1930's.

Soils were comprised of five series which occurred as eroded phases on this undulating terrain, and were typical Piedmont clayey ultisols except for the alluviated soils on the lower slopes:

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[2/] Authors are Research Forester, Southern Forest Experiment Station, Auburn University, Auburn, Alabama, and Research Ecologist, Southeastern Forest Experiment Station, Macon, Georgia.

	Series	Family	Subgroup
a.	Cecil	clayey kaolinitic thermic	Typic Hapludults
b.	Davidson	clayey kaolinitic thermic	Rhodic Paleudults
c.	Vance	clayey mixed thermic	Typic Hapludults
d.	Wilkes	loamy mixed thermic	Typic Hapludults
e.	Congaree	fine-loamy mixed, nonacid thermic	Typic Udifluvents

Soil series in the study area are influenced by topography and are positioned relative to three broad ridges. The ridges run generally to the southeast from a main curving ridge that is the west and northwest boundary. Wilkes series occur on the long slopes, Congaree series are along stream sides, and the others are on the uplands. The two intermittent streams separating the ridges have broad, flat streamside zones that drain into a perennial stream forming the south and southwest boundaries. Marshy areas have been excluded from the study area.

Design and Treatments

In the spring of 1980, the merchantable pines were harvested with no hardwood removal. The site laid over for a year. In the spring of 1981, a randomized complete block design was established using approximately 0.8-ha (2-a) plots with five blocks, each 4.8 ha (12 a), and six treatments.

The five blocks were located by topographic position. Two blocks were on well-drained ridges, two were positioned on side slopes, and one was located along the upland portions of an intermittent gulley and stream system. Within each block, two to three soil series occurred. Although these series were similar, much variation in surface texture and organic matter was encompassed in the study area.

The following site preparation treatments were applied:

1. Check (no site preparation)--Plots were harvested only.
2. Handclear--All trees greater than 2.5 cm d.b.h. were felled with a chainsaw in August 1981.
3. Shear and chop--Shearing was performed with a D7-sized tractor and a KG-blade in September 1981. Chopping was done with a single pass of a single drum chopper. Application was from September to November 1981. No burning was performed on treatments 3 and 4 due to poor weather conditions.
4. Shear, chop, and herbicide--In addition to the shearing and chopping of treatment 3, ½ cc Velpar® Gridball™ pellets with 10 percent active ingredient of hexazinone were applied in a grid pattern at a rate of 28 kg/ha (25 lbs/a) in March 1982. Heavy rains after application and poor infiltration caused the herbicide to smear across the plots, yielding almost total first-year control of both herbaceous and woody plants, including planted pines. Approximately 80 percent bare ground was observed on these plots during the 1982 growing season.
5. Shear, rootrake, burn, and disk--Shearing and rootraking into windrows occurred in September 1981. Good burns of the windrows were achieved in October 1981. The remaining debris and ash were scattered over the plots with a dozer blade; then, the plots were disked with an offset harrow to a depth of 15-20 cm in October 1981.
6. Shear, rootrake, burn, disk, fertilize, and herbicide--Site preparation was the same as treatment 5. In addition, ammonium nitrate (34-0-0) was applied by hand at 336 kg/ha (300 lbs/a) in March 1983, and Oust® Weed Killer with 75 percent sulfometuron methyl was applied at a rate of 0.56 kg/ha (0.5 lbs/a) in April, using backpack sprayers. Herbaceous weed control was essentially 100 percent during most of the 1983 growing season.

Improved loblolly pine seedlings (1-0 stock), obtained from the Georgia Forestry Commission nursery, were planted by hand in January and February 1982 on a spacing of 1.8 x 3 m (6 x 10 ft). Seedling growth data has not been included in this presentation.

Sampling

Composited bulk soil samples were collected for analyses of nutrients, organic matter, and texture; and undisturbed core samples were extracted for bulk density, pore space, and available water determinations. Sampling

occurred in May of 1981, 1982, and 1983, which was before site preparation treatments (after harvesting) and during the first and second growing seasons, respectively. May was considered an appropriate month for sampling because available nutrients should be at a maximum level by then to sustain uptake for the ensuing growing season. Annual sampling was repeated along two diagonal transects established across the plots, and sampling points were located every 7.6 m (25 ft). At each point, tube samples were collected and composited from the 0- to 15-cm (0- to 6-in) and 15- to 60-cm (6- to 24-in) depths. This yielded two composited bulk samples by depth per plot. At randomly selected sample points, which changed by year, six core samples (132 cm^3) per plot were extracted from the upper 6 cm. Thus, 60 composited samples and 180 core samples were collected and analyzed annually.

Analyses

Composite samples were prepared for analyses by air drying, crushing or grinding, and sieving to pass a No. 10-mesh sieve (2-mm openings). Soil nutrients were extracted from duplicate 5-g subsamples using a weak double-acid solution (Mehlich 1953), which yielded a determination of the readily available nutrients. Phosphorus analyses were made according to Watanabe and Olsen (1965), and cations (Ca, Mg, K, Na) were determined by atomic absorption spectroscopy. Organic matter was read as carbon on a carbon analyzer and converted to organic-matter content using a constant. A 1:1 soil-water mixture was used to read pH. Particle-size distribution was determined by the hydrometer method. For determining total pore space and available water-holding capacity, core samples were attached to ceramic disks, soaked to saturation, and then weighed. Following the weighing procedure, they were resoaked. Next a ground-silica slurry was used to attach the core-plus-disk to a pressure plate and a 1/3-atm run preceded a 15-atm run. Then the samples were oven dried (OD). Total pore space in cubic centimeters was calculated by subtracting the OD soil weight from the saturated weight. Available water was calculated by subtracting the soil weight at 15-atm tension from that at 1/3-atm tension. Bulk density was calculated by dividing the OD weight of soil by the ring volume.

An analysis of variance procedure for repeated-measures designs was used to compare physical and nutritional soil properties by treatment, block, year, and treatment x block. In the analyses of the physical properties, treatments were grouped (1 and 2, 3 and 4, 5 and 6) because of their similar treatment due to like equipment passes. Analyses were also performed by pooling the 2 years following treatment and are presented when significant. Probabilities less than 0.05 were considered significant. Percent values were analyzed by using arcsine transformations. Treatment and block means were compared within each year using Duncan's Multiple Range Tests.

RESULTS

Fertility Changes

Site preparation treatments, ranging from an untreated check to very intensive tillage treatments, resulted in no significant differences in soil organic matter (OM) or in available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) when compared within sample years (fig. 1 and 2). Yearly shifts in mean nutritional properties occurred irrespective of treatment during the 2 years after application.

The logical pairs of similar mechanical passes (1+2, 3+4, 5+6) do not indicate similar responses of nutritional levels; however, the weed control additions to treatments 2, 4, and 6 could have changed uptake and mineralization rates and thus separated such similarities. In this context, it is of interest to note that of all the treatments, the lowest levels in surface soils of OM, P, and Mg, although not significant, occurred on treatment 4 following the total vegetation control in the first growing season. Also, the herbaceous weed control on treatment 6 in the second growing season did not result in increases or decreases in available nutrients, except increased P (0 to 15 cm) and decreased Na (0 to 15 cm), which were not significant but apparent.

Significant differences were found in soil pH in the second and first-plus-second years, for the 0- to 15-cm depth (table 1). The pH of the soil tended to increase with increases in intensity of cultural treatment, which was not as evident at the 15- to 60-cm depth.

Block differences were significant for OM for both depths, with one upland block having the highest amounts and the block along an intermittent stream having the lowest. The same upland block had a significantly higher average pH following treatments for the 0- to 15-cm depth. The only other block difference was in the second year; a side-slope block had significantly higher Ca (both depths) and lower K (0- to 15-cm depth).

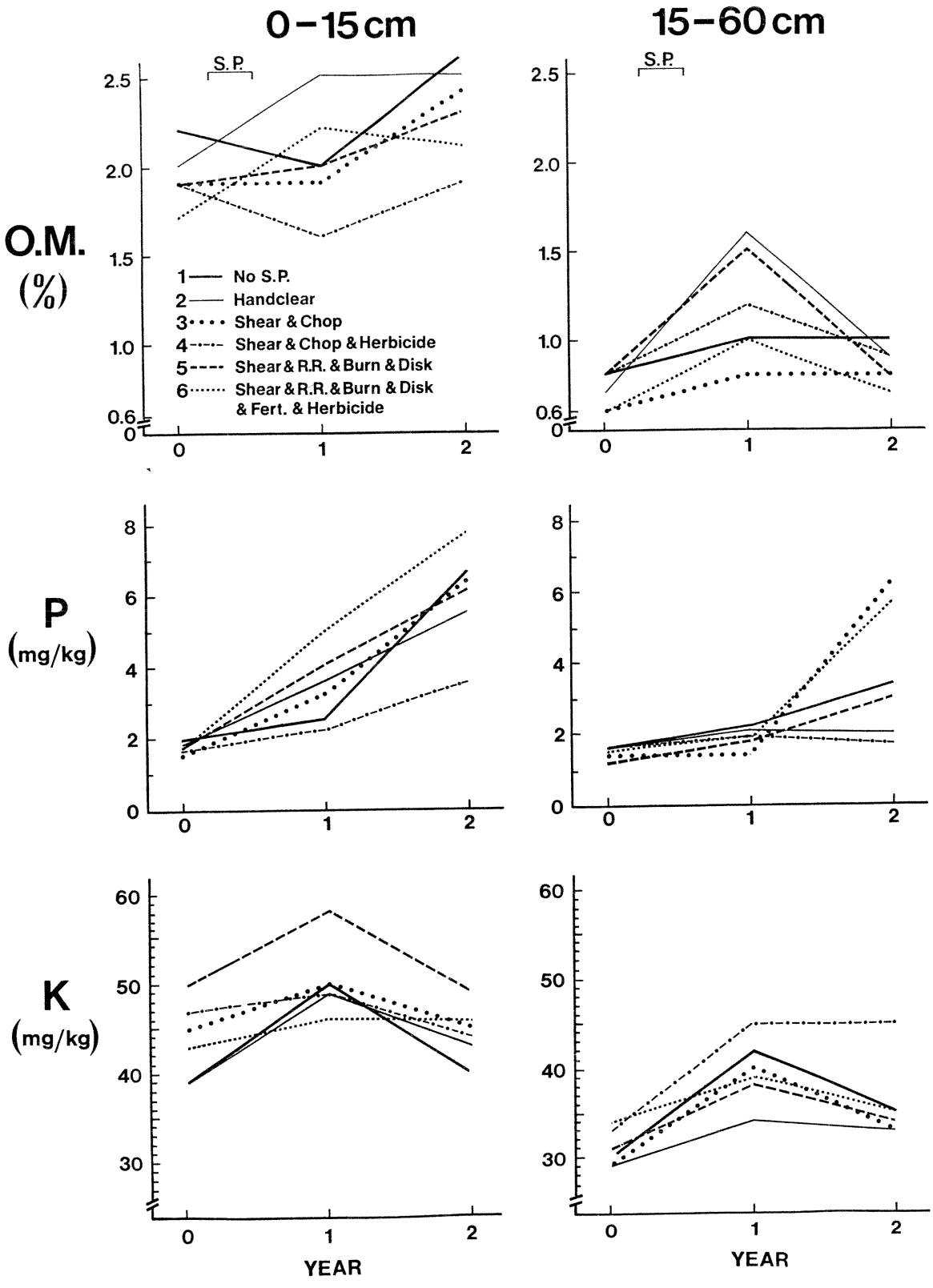

Figure 1. Organic matter and available phosphorus and potassium in soils sampled at two depths and for one and two years after site preparation (S.P.) treatments.

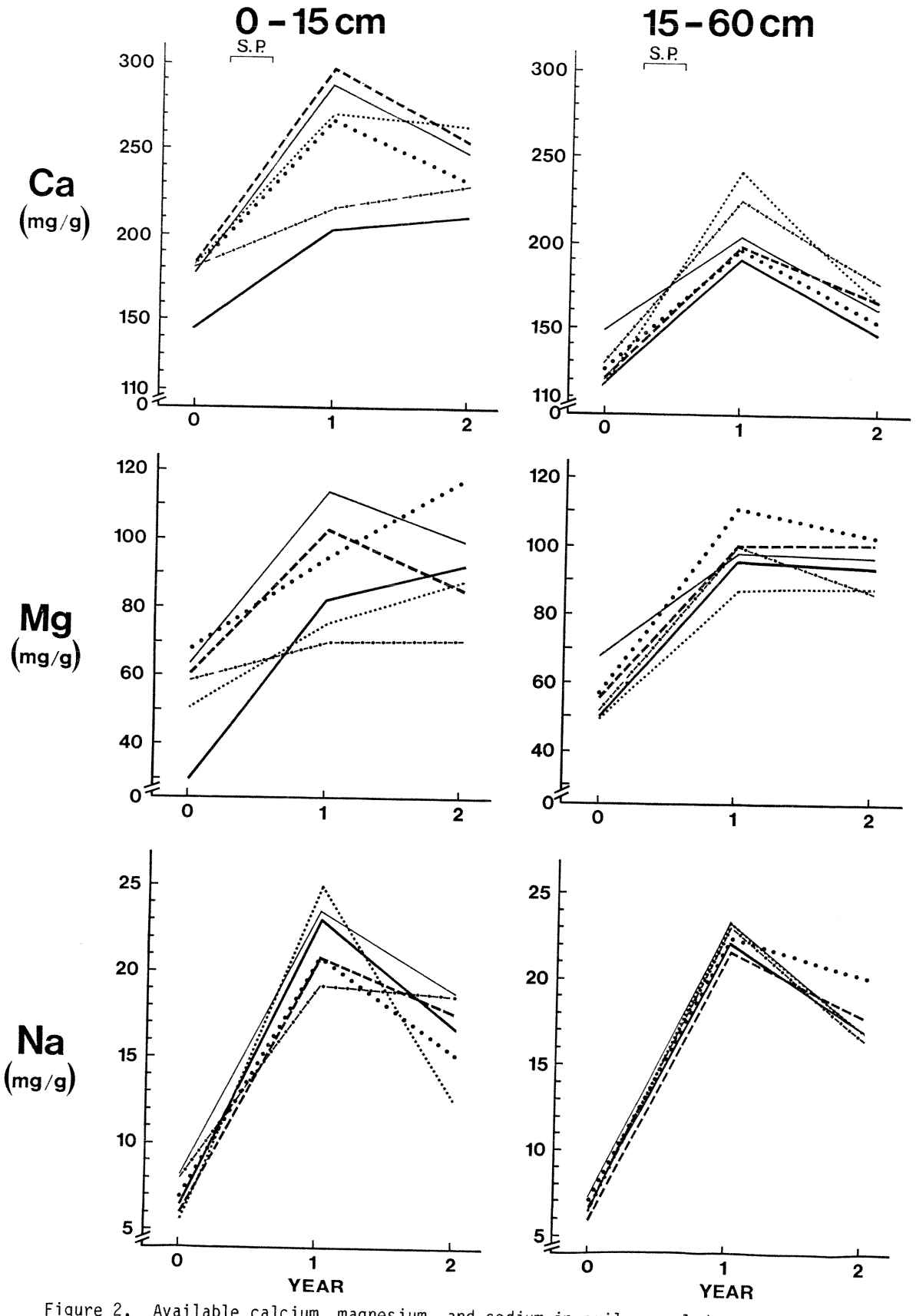

Figure 2. Available calcium, magnesium, and sodium in soils sampled at two depths before and for one and two years after site preparation (S.P.) treatments.

Table 1.--Soil pH means presented by treatment, sampling depth and year after site preparation.[1/]

Treatment	0 - 15 cm				15 - 60 cm			
	Before	1st Yr	2nd Yr	1st+2nd Yr	Before	1st Yr	2nd Yr	1st+2nd Yr
No. S.P.	4.69	4.88	5.11a	5.00a	4.71	5.03	5.26	5.15
Handclear	4.76	4.91	5.12a	5.02a	4.80	5.05	5.30	5.18
Shear + chop	4.75	4.97	5.17ab	5.07ab	4.73	5.09	5.25	5.17
S+C+Herbicide	4.78	4.99	5.33 b	5.16 bc	4.78	5.20	5.40	5.30
S+RR+Burn+Disk	4.81	5.09	5.31 b	5.20 c	4.81	5.10	5.37	5.24
S+RR+Burn+Disk +Fert.+Herbicide	4.70	5.06	5.26ab	5.16 bc	4.68	5.06	5.30	5.18

[1/] Means in a column followed by no letter or the same letter are not significantly different at the 0.05 level.

Available nutrients, organic matter, and pH changed significantly during the three sampling years (table 2). The summed values for all treatments generally show an increase for the year following site preparation treatments, and synchronized increases or decreases in the second year. Since the nontreated plots (treatment 1) follow the same trends as the site-prepared plots, these shifts are either a response to harvesting or merely to naturally occurring yearly changes in these soil properties. The 2 consecutive years of phosphorus and magnesium increases appear to be a response to harvesting and not to naturally occurring yearly changes. The same can be stated for the steady rise in pH for two years.

Physical Changes

Bulk density in the surface soils decreased with disking and was significantly less than bulk densities after chopping in the first year (table 3). Neither site preparation treatment differed significantly from the nontreated plots. A steady yearly decrease in bulk densities is apparent in the overall means, which became significantly different in the second year. As with available nutrients, this shift may be due to a harvesting response and less likely due to natural yearly changes.

Available water did not vary significantly by treatment, but there was a somewhat elevated water-holding capacity in the first year for the chopping and disking treatments. Yearly means were also significantly greater in the first year after treatment, due to all treatment means being higher.

Total pore space was significantly increased by the tillage treatments of rootraking and disking, and differences were evident for the 2 years. There also appears to be an increase in overall yearly means, probably due to the contributions to the yearly means by the disking treatments and possibly a harvesting response.

Decreases in clay and silt corresponding to increases in sand were significant in the second year following site preparation treatments (table 4). No treatment differences were significant, so these changes could also be considered a harvesting response or probably sampling variations. These changes in textural composition only resulted in minor changes in textural class designations.

DISCUSSION

Fertility Changes

Soil fertility did not vary significantly by treatment. This finding must be assessed with a full understanding of the limitations of this study. The spatial variation in soil nutrients is large and thus the limitations in sample size and intensity are ever present obstacles in this type of research. Field variation is compounded in the rolling terrain of the Piedmont due to frequent series changes and past cultural practices that have depleted topsoil by varying amounts. Still, the observed patterns of nutrient levels presented in figures 1 and 2, for the most part, show similar responses from year to year, especially in the 15- to 60 cm soil depth. These similar patterns support the idea that sampling intensity was adequate.

Table 2.--Overall yearly means of available nutrients, pH, and organic matter by sampling depth and years after site preparation treatments.

Depth	Time	OM	P	K	Ca	Mg	Na	pH
cm	yr	%	mg/kg					
0 - 15	B	1.9a[1/]	1.7a	43a	175a	59a	6.8a	4.7a
	1	2.0a	4.1b	50b	257b	90b	16.8b	5.0b
	2	2.3b	5.9c	44a	240b	92b	22.0c	5.2c
15 - 60	B	0.7a	1.5a	31a	128a	56a	7.7a	4.7a
	1	1.2b	1.9a	39b	209b	99b	22.7b	5.1b
	2	0.9a	3.7b	36b	162c	104c	20.1b	5.3c

[1/] Means within a sampling depth and in a column followed by the same letter are not significantly different at the 0.05 level.

Table 3.--Means of physical properties of samples collected before and during the first and second growing seasons after site preparation treatments.

Mechanical Treatments	Before	1st Yr	2nd Yr	1st Yr + 2nd Yr
		BULK DENSITY (g/cm^3)		
None	1.28	1.26ab	1.18	1.22ab
Shear+Chop	1.34	1.33a	1.19	1.26a
Shear+R.R.+Disk	1.30	1.22b	1.16	1.19b
	1.31A	1.27A	1.18B	
		AVAILABLE WATER-HOLDING CAPACITY (% by vol)		
None	4.7	5.6	5.5	5.5
Shear+Chop	4.9	6.0	4.7	5.4
Shear+R.R.+Disk	4.7	6.1	5.2	5.6
	4.7A	5.9B	5.1A	
		PORESPACE (%)		
None	47	47a	49a	48a
Shear+Chop	45	46a	47a	47a
Shear+R.R.+Disk	46	49b	50b	50b
	46A	47B	49B	

[1/] Treatment means listed in a column followed by no letter, or the same lower-case letter are not significantly different at the 0.05 level. Likewise, overall means in a row followed by the same upper-case letter are not significantly different at the 0.05 level.

Table 4.--Overall means of soil texture analyzed before, and one and two years after site preparation treatments

Particle Size	0 - 15 cm			15 - 60 cm		
	Before	1st Yr	2nd Yr	Before	1st Yr	2nd Yr
	----------percent----------			----------percent----------		
Sand	49a[1/]	47a	59b	37a	37a	48b
Silt	25a	24a	15b	23a	23a	18b
Clay	26a	29a	25a	40a	40a	34b
Texture Class	sandy clay loam	sandy clay loam	sandy clay loam	clay loam	clay loam	sandy clay loam

[1/] Means within a sampling depth and in a row followed by the same letter are not significantly different at the 0.05 level.

Lantagne (1984), in a similar study in the Piedmont, also found no treatment differences in the same fertility properties when analyzed by year. He noted a general trend of increasing organic matter and available phosphorus in the surface soils for all treatments. These same trends are also evident in figures 1 and 2. Increased organic matter in surface soils should translate to heightened available nutrients as mineralization occurs. Banker et. al. (1983) also reported a general increase in available macro-nutrients, especially P, following rootraking treatments in the Georgia Piedmont. Campbell (1973) found that phosphorus and calcium increased significantly during the first year after disking but not after chopping. In Texas, Stransky et. al. (1983) found that phosphorus increased mainly after burning. Treatments 5 and 6 of the current study, which included disking and burning, had the highest phosphorus levels in the first year, though not significantly different.

Another limitation of this study is that critical comparisons of within-plot variation are not obtainable because samples were composited by plot. Although this is a common procedure (also used by Lantagne 1984, Banker et. al. 1983, Stransky et. al. 1983 and Campbell 1973), the changes in microsite can not be assessed with such data, especially changes in the distribution of fertility as they may influence evenly spaced pine seedlings. Redistribution of topsoil and organic matter characterizes most site preparation treatments, particularly windrowing and bedding. But composited samples merely provide an assessment of the average fertility for a treatment, combining the high and low values. Thus, the variation in fertility, that especially should occur with windrowing, is masked. Glass (1976) examined windrows on a Piedmont site in North Carolina and found that the 0- to 6-cm layer had 340% more phosphorus, 325% more calcium, 117% more magnesium, 36% more potassium, 21% more organic matter, and 20% more sodium than the inter-windrow layer. Concentrated topsoil and nutrients have also been reported for windrows in the flatwoods (Morris et. al. 1983). Thus, further studies are needed to describe microsite variation and changes in frequency of fertility levels as they influence early pine establishment.

The slight increases in pH, found with increasing intensity of site preparation (table 1), should translate into increased availability of macro-nutrients (Pritchett 1979). As acidity or hydrogen-ion concentrations decrease, exchangeable macro-nutrients (N, P, K, Ca, Mg, and Mg) become more available and mineralization rates of organic matter are increased.

The absence of an uncut control stand is another limitation of this study, because yearly changes under untreated conditions in both fertility and physical properties can not be ascertained. The changes in overall yearly means for most properties and for both depths in table 2 must be assumed to be caused by a combination of the harvesting influence, site preparation treatments, and natural year-to-year changes. For the most part, the unprepared treatment 1 shows the same pattern of change (fig. 1 and 2) and thus lends more weight to the

harvest influence. Removal of the overstory canopy at harvest adds logging debris and changes all input variables to the soil by increasing precipitation and decreasing litterfall, while temporarily decreasing transpiration and nutrient uptake. For a plot-average study approach, these changes due to harvest may mask the site preparation impacts. Obviously, an ecosystem approach, with careful descriptions of the nutrient budgets and how they vary on microsites, is required to fully understand the complex processes taking place after site preparation treatments.

Physical Properties

The decreases in bulk density and increases in pore space found with disking have been shown to improve growth of loblolly pines (Hatchell, 1970; Foil and Ralston 1967). Root growth is enhanced because of the prevalence of accessible pores and the absence of resistance found in compacted soils. Campbell (1973) also reported that chopping did not increase average bulk density when compared to the untreated check, but disking did result in a significant decrease.

Available water-holding capacity was not drastically altered by the mechanical treatments. Banker and co-workers (1983) showed that infiltration was decreased by rootraking on a Piedmont site. However, if infiltration is altered by treatments, then the amount of soil water recharge is altered and deserves closer study. Again, there is some indication that overstory removal during harvest may influence the soil physical properties, since decreases in bulk density from year one to year two and changes in available water occurred irrespective of treatment.

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FIRST-YEAR SURVIVAL OF PLANTED LONGLEAF PINE BARE-ROOT AND CONTAINER STOCK AS AFFECTED BY SITE PREPARATION AND RELEASE[1/]

William D. Boyer[2/]

Abstract.--The effect of field conditions on first-year survival of both longleaf pine 1-0 bare-root and container-grown seedlings was studied at five locations in Georgia, representing a variety of Coastal Plain sites. Two intensities of pre-planting site preparation were each combined with two post-planting release treatments (release with a herbicide or no release). Planting was done in early March 1983. All treatments significantly affected survival. Survival was better for container (80%) than bare-root stock (59%). Survival was better with the higher (77%) than with the lower (62%) intensity of site preparation. Release 4 months after planting reduced survival (61%) from that of unreleased seedlings (79%). None of the treatments significantly affected seedling root-collar diameter after 1 year in the field.

INTRODUCTION

Poor survival of planted longleaf pine has been a problem in Georgia, where planting failures are all too common. Longleaf pine has long had a reputation as a difficult species to regenerate, either naturally or artificially. Repeated longleaf planting failures have reinforced this reputation, even though it may be largely undeserved (Mann 1969, Farrar and White 1983). As a result, other species have been favored over longleaf, despite the many favorable attributes of the species.

The poor survival of planted longleaf pine most likely can be attributed to one or more of three factors. These are: Quality of nursery stock; care in handling, storage, and planting; and field conditions at the time of planting and during the critical first year. Successful planting of longleaf pine requires careful attention to details beginning at the nursery and continuing through planting, as outlined by several authors (Mann 1969, White 1979, Farrar and White 1983).

This study is concerned with the effect of field conditions, particularly the degree of pre- and post-planting competition control, on the survival of longleaf pine on a wide range of coastal plain sites in Georgia.

METHODS AND PROCEDURES

Location

Five sites in Georgia were selected for this study, as follows:

1. Butler (Taylor County). A sandhills site with a sandy surface soil > 36" in depth. A turkey-bluejack oak type.
2. Soperton (Treutlen County). A sandy, moderately well-drained middle coastal plain site. Sandy surface soil underlaid by sandy clay loam at 22"-24" depth.
3. Waycross (Ware County). A sandy, poorly drained flatwoods site with high water table. Sandy surface soil underlaid at 20"-22" by sandy clay loam. Lower coastal plain palmetto-gallberry type.
4. Valdosta (Lowndes County). A deep sandy site, sandy surface soil > 36" in depth, with high water table. Lower coastal plain hardwood bay type.
5. Albany (Doughetry County). A sandy middle coastal plain site. Sandy surface soil underlain at 8"-10" depth by sandy loam to sandy clay loam subsoil, grading to compact sandy clay at 20"-24".

[1/] Paper presented at Southern Silvicultural Research conference, Atlanta, Georgia, November 7-8, 1984.

[2/] The author is Principal Silviculturist at the George W. Andrews Forestry Sciences Laboratory, Auburn, AL, maintained by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with Auburn University.

Treatments

Four treatments were established at each study location except Albany. These treatments included two intensities of pre-planting site preparation, designated:

1. Low. Complete removal of all trees, hardwood and pine, plus one mechanical pass (chop or harrow) for residual brush control.

2. High. Same as above, plus additional mechanical pass (chop or harrow) for improved competition control.

Each of the two site preparation treatments were split, for application of two post-planting release treatments, as follows:

1. Release. Velpar® L applied as a spray at a rate of one pound a.i. per acre, (0.75 pound on Butler sandhills site) in water, to make about 30 gal. of spray per acre. Plots were sprayed from the ground, using a small crawler tractor equipped with a cluster nozzle. All spraying was done during the period July 6-8, 1983.

2. No release.

At each location, about three acres were set aside for the study, with one-half (1½ acres) for each of two intensities of site preparation. Each of these was split for application of the two post-planting release treatments. Sites were prepared in the fall-winter of 1982-83, as follows.

1. Butler
   a. Low site prep. Clearcut, single chop.
   b. High site prep. Clearcut, sheared and piled, double-chop.

2. Soperton
   a. Low site prep. Clearcut, burn, single chop.
   b. High site prep. Clearcut, burn, double harrow.

3. Waycross
   a. Low site prep. Clearcut, single chop.
   b. High site prep. Double harrowed (old field, not cutover).

4. Valdosta
   a. Low site prep. Clearcut, sheared and piled, single harrow.
   b. High site prep. Clearcut, sheared and piled, double harrow.

5. Albany
   a. Low site prep. Hot fall burn only.
   b. High site prep. None.

The Albany site has a residual longleaf pine overstory averaging about 20 ft^2 basal area per acre. A burn was the only site preparation treatment. This location was omitted from the experimental design, although it was split for release treatments, and marked seedlings were periodically examined.

Planting

Longleaf pine 1-0 bare-root and container stock were both planted on all study plots.

About 10,000 1-0 bare-root seedlings, all from E.A. Hauss (Atmore) Nursery in Alabama, were used in this study. These seedlings were lifted February 24, and transported to the study area on February 26, 1983. All nursery seedlings were machine planted with a Whitfield planter pulled by a crawler tractor.

About 1,900 container-grown seedlings were obtained from a Southern Station Research Work Unit (RWU-1102) at Pineville, LA, and were about 25 weeks old when planting began. They were grown in 10 cubic inch RL Single Cells® filled with a 1:1 peat-vermiculite medium. Seedlings were removed from the plastic tubes in the field, and the plugs were hand planted using a dibble.

All seedlings were planted at a spacing of about 6 x 12 feet (600 trees/acre). In each of the four treatment plots per location (two plots at Albany), about 500 bare-root and 100 container seedlings were planted.

Planting in a normal, operational manner began March 1 and was completed March 10, 1983. All bare-root and container stock were planted, with no intentional culling based on size or condition. Within each treatment plot, 100 bare-root and 50 container seedlings were marked for observations of survival and growth. Five 20-seedling row segments of bare-root stock and five 10-seedling row segments of container seedlings were identified in each plot. The first seedling in each sample row segment was marked with a pin and tag identifying the row segment. Each sample seedling within row segments was marked with a flag pin.

Measurements

Survival of all marked seedlings (100 bare-root and 50 container stock per treatment-combination) was checked a total of six times during the first year from planting; five times from April through September 1983 and, finally, February 1984.

Seedling root-collar diameter was measured and recorded for all sample seedlings in one row segment out of five for both bare-root and container stock to permit growth comparisions among treatments. No sample seedlings were in active height growth (0.5 ft or more in height to base of terminal bud) in February 1984, after one year in the field. Only a 20 percent subsample of all sample rows was taken, since root collar measurements can disturb both the seedling and its immediate environment.

The percent of vegetative cover on a 6-ft wide belt centered on each sample row segment was estimated to the nearest 10 percent. These estimates, made in September 1983 at all locations except Butler, were completed in October 1983.

Analysis of variance, with significance at the 0.05 level, was used to determine effects of treatments on recorded variables in this split-split plot experiment.

RESULTS

Seedling Survival

Seedling survival at end of the first growing season in the field was significantly affected by all treatments. Overall survival of longleaf pine seedlings averaged 69.8 percent. Among the eight treatment combinations, however, average seedling survival ranged from a low of 48.8 percent for bare-root stock with low site prep sprayed for release to a high of 97.5 percent for container stock with high site prep not sprayed for release (Table 1). Survival differed most between container (80%) and bare-root stock (59%). Seedling survival was better with high site prep (77%) than with low (62%). Seedling release with liquid Velpar® adversely affected seedling survival, which averaged 61 percent compared to 79 percent for seedlings without release. None of the interactions in the analysis were significant. Transforming survival percents (arcsin $\sqrt{\text{percent}/100}$) did not change the results.

Despite the broad range of site conditions represented in the study, differences among the four locations in seedling survival were not great enough to be significant for bare-root and container stock separately or for both combined. Survival was consistently better for container than for bare-root stock at all locations, including Albany that was omitted from the analysis (Table 2). Mortality associated with release varied considerably among locations, but was worst for both types of planting stock on the sandhills site at Butler, even though the herbicide rate had been reduced to 0.75 lb a.i./acre at this location.

The best treatment combination was high site preparation without release. Under these conditions, survival was satisfactory everywhere (over 75%) except for bare-root stock on the sandhills site at Butler (Table 3).

Table 1.--First-year survival of planted longleaf pine according to seedling type, site preparation, and release.

Seedling type	High site prep.		Low site prep.		Average
	Release	No release	Release	No Release	
	(percent)				
Bare-root stock	50.8	74.5	48.8	63.0	59.2
Container stock	85.5	97.5	58.5	79.5	80.2
Average	68.2	86.0	53.6	71.2	69.8

Table 2.--First-year survival of planted longleaf pine at each study location.

Location	Bare-root stock		Container stock	
	Release	No Release	Release	No Release
	(percent)			
Butler	32	62	53	94
Valdosta	51	64	83	94
Waycross	52	76	60	79
Soperton	64	74	92	87
Albany	51	54	90	92
Average	50	66	76	89

Table 3.--First-year survival of planted longleaf pine with best treatment-combination (high site prep-no release).

Location	Bare-root stock	Container stock
	----------(percent)----------	
Butler	60	94
Valdosta	82	100
Waycross	76	98
Soperton	80	98
Average	75	98

A major factor affecting first-year survival of any planted pines is drought during the growing season. Severe spring and summer droughts, widespread in Georgia during 1984, affected some study locations much more than others.

The most severe rainfall deficiencies were recorded near Butler and Soperton. At Butler, rainfall was only about 30 percent of normal in May, 20 percent in July, and 53 percent in September. There were 21 consecutive days in May with a total of only 0.10-inch of rain, 14 consecutive days in July without rain and, later, 29 consecutive rainless days beginning August 5. On sandhills sites, with deep, excessively-drained sandy soils, the effects of drought are expected to be more severe than on other coastal plain sites, especially those with high water tables. At Soperton, rainfall was only about 18 percent of normal in May, 25 percent in July, and 72 percent in August. From late April to mid-May, there were 21 consecutive days without rain. July had 19 consecutive days with a total of only 0.11-inch of rain, and August had 15 consecutive rainless days.

Rainfall at Waycross was 22 percent of normal in May and 67 percent in August. In May there were 18 consecutive days with a total of just 0.11-inch of rain. July had 14 consecutive rainless days.

Valdosta did not have any month deficient in rainfall, although there were 16 consecutive days without rain in July. At Albany, only July was deficient in rainfall, at 52 percent of normal, although there were 14 consecutive days without rain in July, and 16 consecutive rainless days in August.

Except for bare-root stock at Butler, differences among locations in drought severity did not appear to influence seedling survival.

Some seedling mortality occurred at the Valdosta location due to flooding and ponding of water for relatively long periods. All flooded seedlings were in the low site prep portion, and all died. Five percent of the seedlings at that location were affected.

Poor planting of bare-root seedlings (too shallow or too deep), and also the prolonged flooding at Valdosta, affected an estimated 10 percent of all seedlings, with associated mortality of about 4 percent. Poor planting and flooding, together, accounted for about 10 percent of all mortality recorded through the first year.

Some mortality may also be associated with seedling size and vigor, as all living seedlings were planted with no attempt to cull or grade by size. Most of the recorded mortality, however, appears to be associated with site/treatment conditions. In the analyses (with survival percents transformed $\arcsin\sqrt{\text{percent}/100}$) recorded site/treatment conditions accounted for 72 percent of the total observed variation in survival.

Seedling Size

After one year in the field, average seedling root-collar diameter was 0.52-inch, with container-grown slightly larger (0.55-inch) than bare-root stock (0.49-inch). The difference was not significant. None of the treatments had a significant effect on seedling root-collar diameter at end of first year in the field.

Vegetation Density

Vegetative ground cover percent associated with each treatment and location was estimated in the fall of 1983. Release was the only treatment significantly affecting ground cover, which averaged 19 percent for released plots and 38 percent for unreleased plots. The intensity of pre-planting site preparation had no effect on cover, which was primarily herbaceous vegetation. Vegetative ground cover on unreleased plots ranged from a low of 19 percent on the sandhills site at Butler to a high of 62 percent at Waycross.

CONCLUSIONS

The survival of containerized seedlings during the first year was far superior to that of bare-root nursery stock. The differential was greatest on the dry sandhills site, where 94 percent of the unsprayed container stock survived compared to 62 percent of bare-root stock. These seedlings survived severe May and July-August droughts. The superior survival of container over bare-root stock on sandhills sites has been observed elsewhere (Goodwin 1980). Containerized

seedlings seem better able to withstand environmental stress than bare-root stock during the first year after planting. If this is so, containerized seedlings should be preferred over bare-root seedlings for planting on severe sites.

Intensive advance preparation of the planting site can improve the first-year survival of longleaf pine seedlings, according to results of this study. The degree of response to more intensive site preparation varied among locations, being entirely absent on the sandhills site for both types of planting stock.

Release spraying with Velpar® L reduced longleaf seedling survival considerably. Except for the sandhills site, containerized seedlings suffered relatively light mortality from the herbicide compared to bare-root stock. It may prove desirable to defer herbicide treatment until the second year after planting, particularly for bare-root stock. By then, surviving seedlings should be well established and better able to withstand the spray.

While the herbicide treatment reduced seedling survival, it had not significantly improved the growth of survivors by year end. The treatment did significantly reduce herbaceous competition. Whether this will improve seedling growth during their second year remains to be seen.

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SUSTAINED RESPONSE OF PLANTED SLASH PINE TO SPACING AND SITE PREPARATION 1/

Terry I. Sarigumba 2/

Abstract.--In 1958 a study was made to test the effects of different spacings and site preparation treatments on the productivity of slash pine (Pinus elliottii var. elliotti Engelm.) planted on different southeastern coastal plain soils. Results obtained 25 years after installation showed that bedding and harrowing had significantly increased the productivity of the soils involved and that the latter was more effective than the former. This study also showed that planting spacing is a highly important aspect of effective plantation management.

During the 1950s, the growing interest in intensive forest management was seriously impeded by uncertainties about the management tools needed for effective plantation establishment (Worst 1964). Practitioners during that period wanted to know: 1) the initial density at which pine trees should be planted for optimum stocking, 2) effective site preparation methods that would ensure good survival and growth, and 3) the influence of soil properties on the effectiveness of spacing and site preparation.

To address these questions, a uniform study was installed on six separate areas representing the range of pine sites found on the lands controlled by the Brunswick Pulp Land Company (BPLCO) in southeast Georgia. Soils involved in this study are shown in Table 1.

Each site was partitioned into 1-acre blocks and randomly assigned to seven tree spacings. Each block was evenly divided into four sub-plots and each of these was assigned a particular site preparation treatment. The seven spacings, replicated twice in each location, were (in feet): 6 x 6, 6 x 10, 8 x 8, 6 x 12, 8 x 12, 10 x 10, and 12 x 12. Site preparation treatments included:

A. CONTROL - No treatment

B. SCALP - After burning in December, 1957, a Mathis fireline plow pushed out debris and 1 to 2 inches of top soil.

C. BED - After burning in May, 1957, the ground was plowed in strips using a D-4 Caterpillar tractor and Mathis fireline plow which created deep furrows. The furrowed strips were then pulled back with an Athens fireline harrow to form a planting bed with a raised center.

D. HARROW - Similar to C except the ground was harrowed twice with a 7-foot Rome offset harrow.

Table 1. Some southeastern coastal plain soils and their selected properties.

Soil	Bh *	Bt	Drainage class
	-- inches --		
Orsino	16-24	-	moderately well
Chipley	-	-	moderately well
Leon	14-30	-	somewhat poor
Mascotte	16-28	30-36	poor
Olustee	12-16	12-20	poor
Pelham	-	26-36	poor

* Bh = organic pan or spodic horizon
Bt = clay or argillic horizon

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2/ Research Forester, Brunswick Pulp Land Company, P. O. Box 860, Brunswick, Georgia 31521.

Slash pine seedlings, 1-0 stock, were dibble-planted in January, 1958. Measurements were made 4, 10, 14, 20, and 25 years after installation. Because the test on the Chipley soil was damaged by wild fire and the one on Olustee was harvested before age 25, results from these tests are excluded from this report.

As shown in Table 2, volume yields at age 20 in some spacing groups were not significantly different. For instance, volume yields in the 6 x 10, 8 x 8, and 6 x 12 were not statistically distinct and the same was true for those in the 8 x 12 and 10 x 10 spacings. Therefore, only the spacings selected to represent each distinct group are included in this paper. Furthermore, this report is confined to the spacings that represent a progressive doubling in planting density: 6 x 6, 6 x 12, and 12 x 12.

Table 2. Main effects of spacings of slash pine volume at age 20.

Spacings (feet)	Volume (cords/acre)
6 x 6	28 a *
6 x 10	23 b
8 x 8	24 b
6 x 12	23 b
8 x 12	20 c
10 x 10	19 c
12 x 12	16 d

* Values bearing different letters are significantly different at .05 level.

Measurements made at age 4 showed large height variations caused by soil and site preparation treatments (Table 3). At later ages, the F-values declined but at age 25, they were still very highly significant, indicating that what proved to be significant at age 4 had remained the same through age 25. The interaction between soil and spacing started weakly but became stronger at age 25. On the other hand, the interaction between soil and site preparation treatment lost its significance from age 20 to 25, after starting strongly at age 4.

In terms of the average tree height across all spacings at age 4, the tallest trees were observed on the Orsino soil while the smallest ones were found on the Leon soil (Table 4). On the other hand, the main effects of spacing showed no significant difference at all. On the Orsino soil, the best spacing in terms of height growth was 6 x 12, 12 x 12 on the Leon, and 6 x 6 on the Pelham.

After showing no significant response to spacing earlier, height growth became more sensitive to spacing as age increased. By age 25, trees in the 12 x 12 spacing were considerably taller than those in the 6 x 6 or 6 x 12. Except on the Orsino soil where the tallest trees were in the 6 x 12 plots at age 25, the tallest trees were observed in the 12 x 12 spacing on the other soils.

The main effects of site preparation treatments were only 1 ft. apart at age 4 (Table 4). But at age 25, height range had increased from 48 ft. for the scalp treatment to 54 ft. for the harrow.

Table 3. The effects of soil, spacing, and site preparation on slash pine height at different ages.

SOURCES OF VARIATION	AGE MEASURED 4	10	14	20	25
	F-VALUES				
SOIL (A)	95.0**	104.9**	34.6**	10.4**	14.4**
SPACING (B)	2.7	3.1*	0.4	5.7*	45.0**
A x B	3.1*	5.2**	2.4	2.8*	8.9**
SITE PREP (C)	253.8**	122.4**	85.4**	31.1**	21.4**
A x C	31.5**	9.2**	2.9*	2.0	2.0
B x C	1.9	2.1	1.3	1.0	0.7
A x B x C	1.3	2.2	1.7	1.7	1.4

Levels of significance: *=.05 **=.01

Table 4. The effects of soil, spacing, and site preparation treatments on slash pine height at age 4 and 25.

SOIL	SPACING 6x6	SPACING 6x12	SPACING 12x12	SITE PREPARATION A *	SITE PREPARATION B	SITE PREPARATION C	SITE PREPARATION D	AVE
	feet							
AGE 4								
ORSINO	7 awx	8 aw	6 ax	5 ay	4 ay	8 ax	9 aw	7 a
LEON	4 bwx	4 bcx	5 bw	4 awx	4 bx	5 cw	4 cx	4 b
MASCOTTE	3 cw	3 cw	3 bw	3 cw	2 cx	3 dw	3 dw	3 c
PELHAM	5 bw	4 bw	4 bw	4 bx	4 bx	5 bw	5 bw	4 b
AVE	5 w	5 w	5 w	4 x	4 x	5 w	5 w	
AGE 25								
ORSINO	47 bcy	55 aw	52 cx	49 aby	47 by	52 awx	55 aw	51 ab
LEON	49 ax	51 cx	57 aw	51 awx	50 ax	54 awx	55 aw	52 a
MASCOTTE	46 cy	53 bwx	55 bw	49 abx	48 abx	54 aw	54 aw	51 b
PELHAM	48 abx	47 dx	52 cw	47 bx	47 abx	53 aw	49 bx	49 c
AVE	47 y	52 x	54 w	49 x	48 x	53 w	54 w	

* Site preparation treatments: A=CONTROL; B=SCALP; C=BED; D=HARROW

Values bearing different letters are significantly different at .05 level. Use a, b, c, d to compare column-wise; w, x, y to compare row-wise.

Height variations at age 25 were even wider at the interaction level which showed that the best response to site preparation had been consistently observed on the Orsino soil. For the Orsino, Leon, and Mascotte soils, harrowing appeared to be the best treatment while for the Pelham soil, bedding had stimulated the best height growth. This is an expected result from such a poorly drained soil. The scalp treatment produced the smallest tree regardless of soil. In fact, effects of the scalp treatment were worse than those of the control.

As shown in Table 5, the effects of soil on slash pine volume were highly significant at age 10 but were reduced to near non-significance at age 25. Variations in volume caused by spacing were highly significant at age 10 and remained the same through age 25. However, there is some kind of bias in the effects of spacing. The significance of the F-values are not due to spacing *per se* because stocking levels associated with the different spacings ranged from 250 to 1000 trees per acre. The main effects of site preparation treatments were initially very strong and remained strong until age 25. Significant interactions between soil and site preparation on the one hand and between spacing and site preparation on the other were observed during the 10th to 14th year but these effects had disappeared afterwards.

Table 5. The effects of soil, spacing, and site preparation on slash pine volume at different ages.

SOURCES OF VARIATION	AGE MEASURED 10	14	20	25
A 1/	163.3**	54.4**	23.2**	5.2*
B	62.7**	21.6**	59.1**	53.6**
A x B	15.3**	4.1*	2.7*	2.8*
C	127.2**	89.7**	76.6**	26.7**
A x C	36.6**	6.3**	2.6	1.9
B x C	8.5**	2.6	1.6	0.4
A x B x C	4.1*	1.2	2.3	1.0

1/ A=soil B=spacing C=site preparation

In terms of average volume across all soils, the effects of the three spacings were highly distinct (Table 6). Plots with 6 x 12 spacing produced 9 cords/acre more than those with 12 x 12. This was certainly due to the fact that, as will be shown later, the surviving trees in the 6 x 12 spacing exceeded by 244 trees/acre those in the 12 x 12. However, although the surviving trees in the 6 x 6 spacing exceeded by 381 trees/acre those in the 6 x 12, the yield difference was only 5 cords/acre. This is a strong indication that a near optimum stocking was attained in the 6 x 12 spacing, that trees in the 6 x 6 had succumbed to over-crowding, and that in the 12 x 12 spacing, growing space was not fully utilized.

At the interaction level, the spacing effects on the Leon, Mascotte, and Pelham soils followed the same trend as the main

effects. On the Orsino soil, however, the 6 x 12 plots had exceeded in volume yield the 6 x 6 plots. The drainage characteristics (Table 1) of this soil may have accentuated the severity of competition due to crowding.

The main effects of site preparation on volume yield were also sharply distinct (Table 6). The trees in the bedded plots produced 4 cords/acre more than the control while the harrowed plots yielded 6 cords/acre more than the control. On the other hand, the plots receiving the scalp treatment were 3 cords/acre inferior in productivity to the control.

At the interaction level, harrowing was the best treatment on the Orsino, Leon, and Mascotte soil while bedding appeared to be slighly better on the Pelham soil. Because of poor drainage, the Pelham and Mascotte soils should have benefited more from bedding. Probably, the trees, especially those on the Mascotte soil, responded more to reduction in weed competition accomplished by harrowing.

The effects of the scalp treatment bear some important implications. If moving a small portion of the top soil over such a small distance, as was done in this study, had made a big reduction in productivity of the planted slash, then pushing big chunks of top soil farther away from the planted trees, as is done in some windrowing activities on unsuitable sites, could be more damaging, especially when the top soil is limited or does not exist.

Projection curves based on the volume growth trend observed through age 20 on the Orsino soil indicated that by age 25, the trees in the plots receiving the harrow treatment would outyield those in the 6 x 6 plots receiving the same treatment (Fig. 1). The curves also indicated that the trees in the 12 x 12 plots would pull even in volume yield with those in the 6 x 6 plots by age 25. As shown on Table 7, the 6 x 12 curve did go over the 6 x 6 curves but the 12 x 12 curve failed to make it to the projected intersection point.

In Fig. 2, volume yields of plots that received the harrow treatment on the Orsino soil are shown by spacing and diameter classes. The total volume yield at age 25 in the 6 x 6 spacing was 5 cords less than in the 6 x 12. Since the majority of the surviving trees in the 6 x 6 spacing were in the 5-6 inch size range while those in the 6 x 12 spacing were on the 7-9 inch size range, better product quality further enhanced the superiority of the 6 x 12 spacing over the 6 x 6. The volume yield in the 12 x 12 spacing was 32 cords/acre, 6 cords less than in the 6 x 6 but more than half of this yield was accounted for by trees that were 9 inches in diameter or larger.

Table 6. The effects of soil, spacing, site preparation on slash pine volume at age 25.

	SOIL				
	ORSINO	LEON	MASCOTTE	PELHAM	AVE
	cords/acre				
SPACING					
6 x 6	35 ax *	40 aw	34 ax	39 awx	37 a
6 x 12	36 awx	32 bx	32 ax	27 by	32 b
12 x 12	22 bw	25 cw	24 bw	22 cw	23 c
SITE PREPARATION					
CONTROL	27 cdwx	31 abw	26 bx	27 bcwx	28 c
SCALP	24 dxy	29 bwx	21 cy	25 cxy	25 d
BED	30 bcx	35 aw	33 awx	31 abwx	32 b
HARROW	36 aw	35 aw	35 aw	29 abcx	34 a
SOIL AVE	30 xy	32 wx	29 y	28 y	

* Values bearing different letters are statistically different. Use a, b, c, and d to compare column-wise; w, x, and y to compare row-wise.

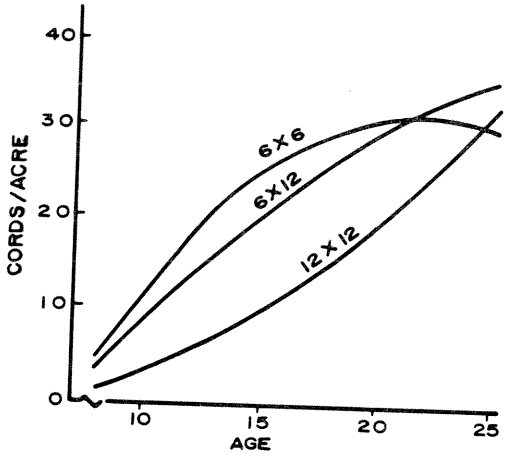

FIG. 1. VOLUME TREND OF PLANTED SLASH PINE RECEIVING HARROW TREATMENT ON AN ORSINO SOIL.

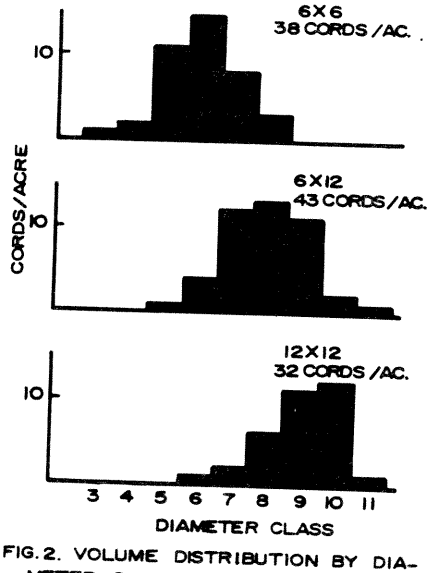

FIG. 2. VOLUME DISTRIBUTION BY DIAMETER CLASSES OF 25-YEAR-OLD PLANTED SLASH PINE ON ORSINO SOIL RECEIVING A HARROW TREATMENT.

At age 14, response to the harrow treatment in the 6 x 6 spacing was 6 cords per acre (Table 7). At age 25, such response completely disappeared. In the 6 x 12 spacing, response started with 13 cords at age 14, climbed to 15 cords at age 20, and went back down to 10 cords at age 25. This is a clear indication that the trees in the 6 x 12 plots had started to succumb to crowding shortly after age 20 on this Orsino soil. In the 12 x 12 spacing, responses to the harrow treatment were 11, 16, and 17 cords/acre at age 14, 20, and 25 respectively. Availability of growing space apparently had continued to stimulate volume growth response to the harrow treatment through age 25.

Table 7. The effects of spacing on the volume response of slash pine planted on an Orsino soil at different ages.

SPACING	SITE PREPARATION	AGE MEASURED 14	20	25
		cords/acre		
6 x 6	CONTROL	12	32	38
	HARROW	18	33	38
6 x 12	CONTROL	12	21	33
	HARROW	25	36	43
12 x 12	CONTROL	3	10	15
	HARROW	14	26	32

The effects of spacing on survival are shown on Table 8. At age 4, survival percentages were 88, 90, and 89 for the 6 x 6, 6 x 12, and 12 x 12 spacings, respectively. However, survival rate is a misleading parameter for analysis particularly when initial stockings are dissimilar. In this case, dead trees at age 25 were 145, 60, and 33 trees/acre for the 6 x 6, 6 x 12, and 12 x 12 spacings, respectively, despite the fact that the survival percentages were nearly identical.

Survival in the 6 x 6 spacing declined to 72% by age 20 and remained the same through age 25, reflecting a total mortality of 339 trees/acre. In the 6 x 12 spacing, 81% of the planted trees survived and 115 trees/acre were in the mortality column. Only 54 out of the initial 300 trees/acre died by age 25 in the 12 x 12 spacing.

Table 8. Survival rates of planted slash pine at different spacings and ages.

SPACING	--- AGE MEASURED --- 4	10	20	25	TREES/AC. LIVE	DEAD
	------ percent -----					
6 x 6	88 a*	87 a	72 b	72 b	871	339
6 x 12	90 a	87 a	84 a	81 a	490	115
12 x 12	89 a	84 b	82 a	82 a	246	54

* Values for each age with unlike letters are statistically different at .05 level.

Both the bed and harrow treatments showed favorably significant effects on survival at age 4 (Table 9). During the 4th to 10th year period, however, more trees died in the bedded and harrowed plots while the survival percentage in the control plot remained the same. By age 25, the control, bed, and harrow treatments were all virtually even in terms of number of surviving trees.

Table 9. Survival rates of planted slash pine receiving various site preparation treatments

TREATMENT	--- AGE MEASURED --- 4	10	20	25	TREES/AC. LIVE	DEAD
	----- percent ------					
CONTROL	86 b*	86 b	80 a	79 a	557	148
SCALP	84 b	80 c	74 b	74 b	522	183
BED	93 a	90 a	82 a	80 a	564	141
HARROW	90 a	88 b	82 a	80 a	564	141

* Values in each column bearing different letters are significantly different at .05 level.

As noted earlier, the scalp treatment accounted for the worst, in some cases negative, response in height and volume. In terms of survival, the scalp treatment also accounted for the lowest rate from age 4 through 25.

CONCLUSIONS

This study strongly showed that such site preparation treatments as bedding and harrowing had significantly improved the productivity of slash pine planted on some southeastern coastal plain soils. The scalp treatment was apparently a mistake that could cause some serious decline in site productivity.

Between bedding and harrowing, the latter proved to be more effective than the former, even on the poorly drained Mascotte and somewhat poorly drained Leon, both of which could have benefited more from bedding. This is probably because the beds constructed in 1957 were not of the same intensity and quality as today's beds which have been constructed using more modern equipment.

It had been reported in literature that response to bedding may disappear after age 10 (Haines and others 1975; Outcalf 1984). One such report, however, which did not include a control treatment to measure response, compared bedding and disking, which is tantamount to comparing bedding and harrowing in this study. As has been mentioned earlier, harrowing was a superior treatment to bedding but it must be noted, however, that the bedding treatment was significantly better than the control, an indication that if constructed properly on the right site, bedding can be an effective tool for slash pine plantation establishment.

This study also showed that spacing had a significant influence on the amount of response to site preparation and that control of plantation density can be a highly critical factor in the production of quality timber products.

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EFFECTS OF SUBSOILING AND DISCING ON THE PERFORMANCE OF LOBLOLLY PINE GROWING FOR THREE SEASONS ON THE PIEDMONT[1/]

J. A. Burger, J. L. Torbert, and D. O. Lantagne[2/]

Abstract.--The effect of discing and subsoiling on loblolly pine were evaluated after three growing seasons. Four low, medium, and high quality sites were included in this study in the Piedmont of South Carolina and Georgia. Discing and subsoiling treatments were imposed individually and together on areas that were KG bladed and raked. Discing clearly resulted in significant increases in tree heights and diameters whereas the effects of subsoiling were more subtle.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Assistant Professor and Research Assistant, respectively, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, and Assistant Professor, Michigan State University, E. Lansing, MI 48824-1222.

YIELDS, STAND STRUCTURE AND ECONOMIC CONCLUSIONS FROM A 22-YEAR-OLD SITE PREPARATION STUDY WITH PLANTED LOBLOLLY AND LONGLEAF PINES[1/]

Barry L. Beers and Robert L. Bailey[2/]

Abstract.--In October 1960, a site preparation study was planted with 726 trees per acre to loblolly and longleaf pine on loblolly site index 65 (base age 25) land in Polk County, Georgia. Data from nine replications of each species established following each of four site preparation methods indicates that age-22 yields (inside bark to a 2-inch top) are significantly less for longleaf (1,203 cu ft/ac) than for loblolly (3,094 cu ft/ac). Analyses of site preparation effects were restricted to loblolly. Across the four site preparation treatments, (1) shear and pile, (2) disk, (3) bed, and (4) subsoil and bed, loblolly survival was excellent and ranged from 81.8 to 88.5 percent. Dominant height averaged from 52.4 to 51.1 feet across treatments. Volume yield for the subsoil and bed treatment (3,352 cu ft/ac) was significantly greater than for bed (3,064 cu ft/ac), shear and pile (2,999 cu ft/ac) and disk (2,962 cu ft/ac). An economic analysis based on these yields indicates that none of the other three treatments applied after shearing are likely to be cost effective.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georiga, November 7-8, 1984.

2/ Manager of Data Processing, F and W Forestry Services, Albany, GA, and Associate Professor, University of Georgia, Athens, GA.

PINE AND HARDWOOD REGENERATION ALTERNATIVES FOR HARVESTED BOTTOMLAND HARDWOOD STANDS[1/]

Charles A. Gresham[2/]

Abstract.--A 400ac tract of bottomland hardwoods in the Santee River swamp, South Carolina, was harvested and roughly half of the area allowed to regenerate naturally. The other half was sheared, bedded and planted with loblolly pine tublings.

Stocking inventories before and three growing seasons after harvest indicated that natural hardwood regeneration was dominated by sugarberry. Loblolly pine survival was high (78%) and height and caliper at three years was good.

INTRODUCTION

Bottomland hardwood stands are naturally productive for several reasons. The soils of these areas are generally alluvial and hence rich in macronutrients. The clay to clay loam soils have high cation exchange capacities which further increases site productivity. Annual flooding deposits more alluvium on the area which provides annual fertilization. Finally the vegetation very rarely experience severe drought during the growing season because of the low topography, annual spring flooding and high water holding capacity of the soil.

Landowners in South Carolina who wish to manage bottomland stands generally harvest the merchantable timber, then let the area regenerate naturally. This has the advantage of being economical in that the harvest produces an income and the regeneration does not require capital investment. Sprouts will grow from stumps created during harvest, and seed is blown or washed into the area. Although economical, this method does not allow the landowner to control the timing of regeneration, nor the species composition and distribution of the resulting stand. The unstable nature of the market for hardwood timber further complicates management, because the species that are valuable at the time of regeneration might not be so valuable at the time of harvest. The market for hardwood pulpwood is weak at best.

An alternative to managing bottomland hardwood stands for some mixture of hardwood is to prepare the site and plant loblolly pine. The first and major disadvantage to this alternative is the initial early cost of clearing the logging residue and preparing planting microsites for the pine. Advantages of site conversion include producing a product for a stable market and realizing an earlier return on the investment by a thinning or early final harvest. The demand for pine pulpwood is reasonably stable and the landowner can be assured of a market for his timber. Pines are fast growing pioneer species that take advantage of the inherent productivity of a bottomland site. Thus a commercial thinning at an early age will start the cash flow much sooner than could be realized in hardwood management.

The purpose of this report is to present the results of a case study comparing natural hardwood regeneration and pine plantation establishment. Although this report deals with a case study, the results provide an indication of how similar stands in other regions can be managed.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Assistant Professor of Forestry, Belle W. Baruch Forest Science Institute of Clemson University, P. O. Box 596 Georgetown, SC 29442.

STUDY AREA

The study was located in the upper section of the Santee River Swamp, just downstream from the Lake Marion dam in Clarendon County, South Carolina. A 400ac tract of the upper terrace of the swamp was identified and divided into two roughly equal sections. The area had been selectively logged from 1930 to 1950, and since then had not received any management. The soil throughout the swamp was a Tawcaw silty clay loam, a deep, somewhat poorly drained soil formed in alluvial sediment. The site floods annually in the spring for a week or two. Just prior to the study the entire tract was cruised and marked for patch clearcutting. Approximately 100ac were marked for harvest in each section.

METHODS

A preharvest inventory of the portions of the tract marked for harvest was conducted with 25 randomly located sampling points. Around each point, a set of concentric circular plots were located and tallied according to the following design. Small regeneration, defined as woody stems less than 3 ft tall, were tallied by species in four 10.8 ft^2 quadrats located sixteen feet in each of the cardinal directions from plot center. Stems taller than 3 feet and less than one inch DBH, called medium regeneration, were tallied by species in a circular plot of radius 8.2 ft. Large regeneration, stems between one and five inches DBH were tallied by species within 16.4 ft of plot center. Stems 5 to 13.7 inches DBH within 33 ft of plot center were recorded as pulpwood by noting species and DBH. Trees larger than 13.7in. in DBH were considered sawtimber with DBH and species recorded for such stems within one chain of plot center.

A composite soil sample, to a depth of 12 inches, was taken at each sampling point and four pictures were taken of each plot.

Both sections of the tract were logged by chainsaw felling and topping, skidding and loading at a deck. Residuals were not felled. Section A was harvested in the summer and fall of 1979 while section B was harvested in the winter and spring of 1980. Section A received no further treatment following logging, while section B was cleared by rootraking and the debris piled around the edges of the clearing and in a few interior windrows. Following rootraking, this area was bedded and planted with containerized loblolly pine (Pinus taeda l.) at a spacing of 6 x 8 ft during April 1981.

Post harvest procedure consisted of reinventorying section A with more intense methods than were used in the preharvest inventory, and establishing and periodically tallying plots in the planted area.

Section A was reinventoried after the third growing season with 43 clusters each of which was four contiguous plots with an area of 76 ft^2. All woody stems greater than 3 ft tall were tallied by species in the plots and all stems less than 3 ft tall were tallied in a 10.8 ft^2 subplot within each plot.

Six plots, each three rows wide by approximately 33 planting spaces long were established in the pine planted area, and all three rows were tallied to determine survival. Seedling height and caliper data were taken on 25 seedlings located in the middle row. Survival and growth data were taken annually for three years following planting. The occurrence of browsing, tip moth damage, flooding and degree of competition were also noted.

PREHARVEST INVENTORY

Sweetgum (Liquidambar styraciflua), sugarberry (Celtis laevigata), ash (Fraxnus spp), laurel oak (Quercus laurifolia) and water oak (Q. nigra) accounted for 72% of the 140 ft^2 of preharvest basal area (table 1.). The approximately equal division of the basal area in the two size classes reflects the previous cutting which left a few larger unmerchantable trees and caused multi-stemmed growth of the remaining smaller trees. The understory was composed of sugarberry seedlings with few larger stems of other species present (table 2).

HARDWOOD NATURAL REGENERATION RESULTS THREE GROWING SEASONS AFTER HARVEST

The hardwood regeneration in the seedling size class was dominated by sugarberry with an estimated 2,753 stems per acre (table 3). This accounted for 62% of the seedling regeneration. Other species present in the seedling size class include green ash, red maple (Acer rubrum) and sweetgum. Sapling regeneration was estimated at 2,867 stems per acre also dominated by sugarberry. Green ash, red maple, sweetgum, and cottonwood were also present in the sapling size class. The highly desirable species, the oaks and hickories were not very abundant in the seedling nor sapling size classes.

The origin of the regeneration was different between the seedling size class and saplings in that the seedling sized stems were mostly of seed origins, with very few sprouts, whereas the stems in the sapling size class were mostly of sprout origin.

The spatial distribution of the regeneration was poor. Sixty one percent of the 172 subplots tallied did not contain a seedling (table 4). Distribution of saplings was not much better with 31 and 86 percent of the plots inventoried being void of samll and large saplings respectively.

Table 1.--Pre-harvest basal area by species and DBH class.

Species	DBH class 5 to 13.9 in	13.9 in +	Both classes
	ft^2 /ac		
Sweetgum (*Liquidambar styraciflua*)	17.8	9.7	27.4[1]
Sugarberry (*Celtis laevigata*)	17.9	7.5	25.4
Ash (*Fraxinus spp*)	11.6	6.9	18.5
Laurel oak (*Quercus laurifolia*)	0.8	14.2	15.0
Water oak (*Q. nigra*)	2.2	11.5	13.7
Swamp chestnut oak (*Q. michauxii*)	0.7	6.0	6.7
Cottonwood (*Poplus spp*)	0	6.3	6.3
Red oak (*Q. falcata*)	2.1	3.9	6.1
Red maple (*Acer rubrum*)	5.2	1.0	6.2
Elm (*Ulmus americana*)	0.7	4.4	5.1
Water hickory (*Carya aquatica*)	0.3	1.9	2.2
Cypress (*Taxodium spp*)	0	0.4	0.4
Undesirable species[2]	4.4	2.4	6.8
Total	63.6(6.0)[3]	75.9(7.1)	139.6(8.0)

1/Basal areas may not add to indicated total due to rounding.
2/Undersirable species include Overcup oak (*Q. lyrata*), American holly (*Ilex opaca*) and American hornbeam (*Carpinus carolinia*).
3/Standard error of total.

Table 2.--Pre-harvest regeneration stocking by species and size class.

Species	Size Class: Seedlings (less than 3 ft tall)	Saplings (less than 1 in DBH)	Saplings (1-5 in DBH)
	stems/ac		
Sugarberry	3288	52	60
Sweetgum	84	0	34
Ash	84	0	0
American elm	0	17	26
Red maple	0	0	17
Red oak	0	0	9
Tupelo (*Nyssa spp*)	0	0	4
Undesirable species[1]	1686(523)[2]	635(173)	330(88)
Total	5143(1215)[3]	704(178)	480(102)

1/Undesirable species include holly (*Ilex spp.*), American hornbeam and dogwood (*Cornus spp.*).
2/Total and standard error.
3/Columns may not add to indicated total due to rounding.

Table 3.--Reproduction by spacing and size three growing seasons after harvest on section A.

Species	Seedlings (less than 3 ft tall)	Saplings (3 ft tall to 1 in DBH)	Saplings (1-5 in DBH)
	stems/ac		
Sugarberry	2,753	835	44
Ash	424	228	26
Red maple	235	313	26
Sweetgum	212	199	56
Cottonwood	94	160	3
Cypress	47	6	0
Water hickory	47	117	0
American elm	24	64	20
Water oak	24	79	6
Red oak	24	9	0
Swamp chestnut oak	0	3	0
Persimmon	0	79	0
Tupelo	0	0	3
Undesirable species[1]	565(171)[2]	544(77)	44(15)
Total	4,447(537)[3]	2,639(186)	228(65)

1/Includes American holly (Ilex opaca), American hornbeam, black willow (Salix nigra and Vaccinium).
2/Total and standard error.
3/Columns may not add to indicated total due to rounding.

Table 4.--Reproduction stocking by size class three growing seasons after harvest on section A.

Desirable species stocking level	Size class: Seedlings	Size class: Saplings (3 ft tall to 1 in DBH)	Size class: Saplings (1-5 in DBH)
Stems/plot	percent of plots		
0	61	31	86
1 to 5	36	46	13
6 to 10	3	9	0
11 plus	0	14	1

PINE PLANTATION ESTABLISHMENT RESULTS

Survival and growth of the planted loblolly pine was good. After three growing seasons the average survival was 76% of original planting, which at a 6 x 8 ft spacing is 690 trees per acre. The survival percent has remained essentially unchanged since the beginning of the second growing season (figure 1). Average seedling height at the end of the third growing season was 5.7 ft with a maximum height of 12 ft. Average caliper was 1.1 in with a maximum caliper of 2.6 in.

Seedling survival and growth overcame browsing by deer, loss of terminal shoots by tip moth, competition from herbaceous vegetation and annual flooding. Browsing by deer was heavy during the first winter with 40% of the inventoried seedlings exhibiting browsing of one or more terminal shoots. During the second winter the browsing was lighter with only 14% of the seedlings showing browse damage, and by the third growing season the terminal shoots of the seedlings had grown above the browse line.

Tip moth (Rhyacionia spp.) damage was noticed on one or more terminal shoots of 66% of the seedlings inventoried after the second growing season. This was the only time that tip moth damage was significant.

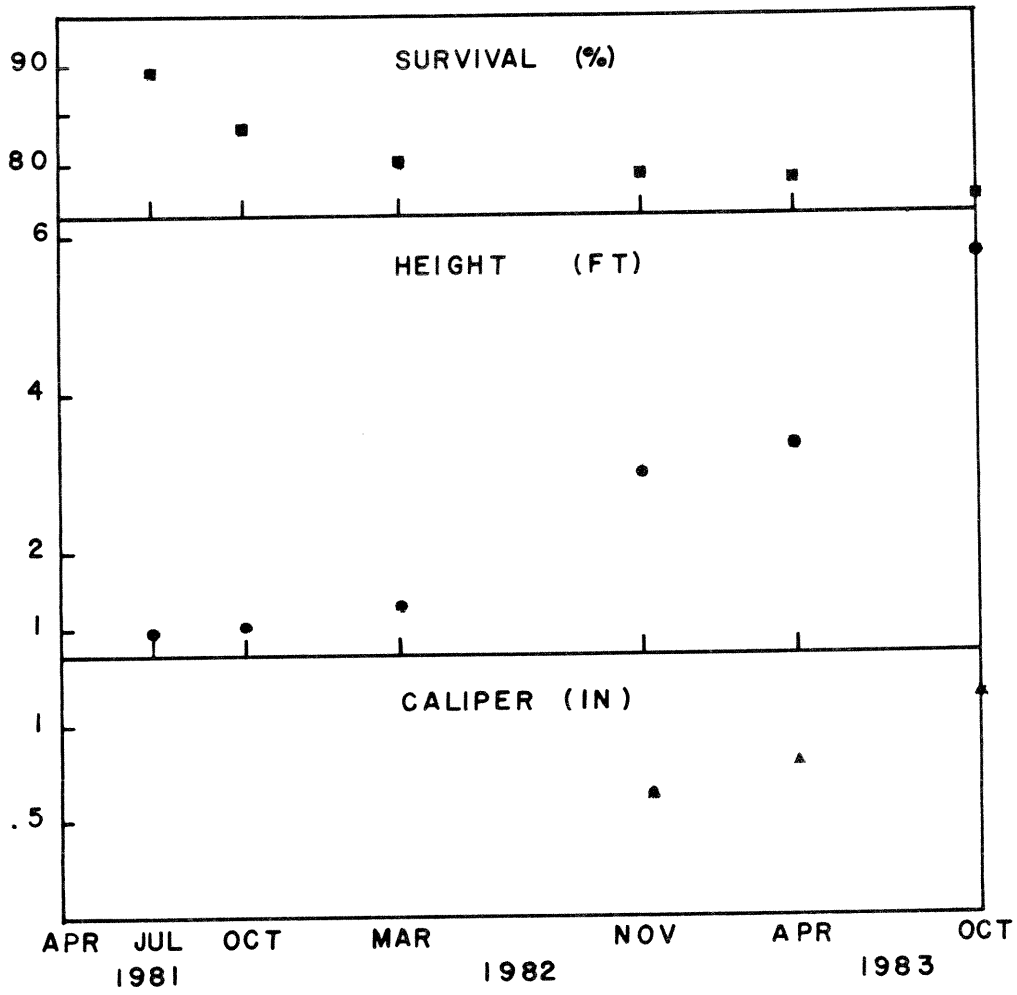

Figure 1. Pine seedling survival, height and caliper averaged over six plots in section B for three growing seasons since planting in April 1981.

Competing vegetation quickly invaded the cleared area and at the end of the first growing season there was a cover of horseweed, blackberry, pokeweed and other herbaceous species. The planted pine was able to grow through the herbaceous canopy during the third growing season.

The study site flooded annually during the study in the months of March and April when the seedlings were still dormant. Observations of the area and examination of the river level records at the dam indicated that the flooding was for only a week or two and that water depth at the study site was not great.

MANAGEMENT ALTERNATIVES

Examination of the two management alternatives and the results after three growing seasons indicate that clearcutting without any post harvest treatment will produce a stand of light seeded hardwood species with uneven spatial distribution. The future canopy species of the area studied will be sugarberry, ash, maple and sweetgum. Oak seedlings (estimated at 48 stems per acre) could survive below the closed early canopy and contribute to the canopy of the mature stand. However the moderately intolerant to intolerant nature of the oaks may prevent the stems from surviving to enter the canopy. The 91 sapling oak stems less than one inch DBH may survive and increase the value of the stand, but will the oak stocking at rotation be acceptable?

A better hardwood stand probably results when the logging residue and unharvested residuals are felled, chopped and burned. This enables all species to start at the same height and eliminates the physical support that allows vines to completely shade the ground. Such minimal post harvest treatment not only increases the uniformity of size of regeneration, but also decreases the patchy distribution of the regeneration.

Establishing loblolly pine on the upper terrace of the swamp was successful. Average survival after three growing seasons was 76% of initial planting density, which may be considered a little low, but still produced a stand of

satisfactory stocking. Whatever the loss due to relatively low stocking was more than compensated by the excellent height and caliper growth. The 5.7 ft average height and 1.1 in average caliper reflects the high quality of the site and its productivity. This is further indicated by the size of the largest of 150 pine seedlings measured which was 12 ft tall and 2.6 in at ground line. These growth figures are in spite of deer browse and tip moth damage that killed many terminal buds. Furthermore, the effects of competing vegetation and flooding could hardly have been beneficial to pine seedling growth: therefore, in the absence of these factors, one could reasonably expect more and larger seedlings after three growing seasons.

LOBLOLLY PINE REGENERATION AND OVERSTORY DENSITY[1]

Boris Zeide[2]

Abstract.--On a 24-year-old loblolly pine plantation a seedling is affected by the trees situated within a distance equal to 25 times their diameter. Reliable regeneration can be obtained if the number of these trees does not exceed five, a quantity which corresponds to a basal area of 85 square feet per acre. These results were achieved by the point sampling of canopy trees performed from a seedling position using successive basal area factors.

INTRODUCTION

What is the minimum size of a forest opening sufficient to secure reliable regeneration of loblolly pine (Pinus taeda L.)? What is the maximum canopy density which will obtain the same end? These questions, with their many theoretical and practical implications, have attracted much research. Although the questions are often discussed separately, they may be considered as two aspects of the same problem because density is closely related to the number and size of openings per unit area.

Regarding the question of forest opening size, the search has been focused on the minimum size because it maximizes the amount of available seeds, minimizes the loss of canopy tree growth and encroachment of undesirable vegetation. Based on their observations of loblolly pine in Duke Forest in central North Carolina, Toumey and Korstian (1947) found that an opening size of about one acre or less is required to secure reproduction. Wahlenberg (1948), working with same species at Crossett, Arkansas, concluded that the removal of a single mature tree, which created an opening 15 to 30 feet wide, was sufficient to produce reliable regeneration providing that selective cuts are made about every 5 years. This provision is indeed crucial because Wahlenberg's data show that at 5 years of age the seedlings from larger openings (0.1 acre or more) had eight times greater volume than those from the single tree openings. Without subsequent thinning, pine reproduction can be obtained by the group selection method when clusters of two or more neighboring trees are removed (Wahlenberg 1960).

At first glance, the single-tree selection method seems reasonable: a spot sufficient for a mature tree should be adequate for a small seedling with its much lower requirements. The problem here is that the crown of the mature tree, being lifted to the canopy level, is exposed to full sunlight while the seedling, situated near the forest floor, is shaded by the remaining overstory. Thus, the problem is whether the abundance of room for a seedling compensates for the deficiency of light. Numerous observations indicate that, in general, this compensation does not occur. Only the most tolerant species, such as European silver fir (Abies alba Mill.), can be perpetuated by selection of a single tree (Smith 1962). The majority of species require larger openings (Roach and Gingrich 1968, Smith 1977, Fischer 1981), the size of which depends on site, species, and especially height of the surrounding overstory.

Another approach to the problem of obtaining reliable regeneration is to specify overstory density, not the size of the openings. Seedlings and saplings, even of intolerant species such as loblolly pine, are regularly found growing directly under canopy trees (Reynolds 1959), especially when there is plenty of side light. The problem here is to determine the maximum density of canopy trees which will allow regeneration of desirable species. Although any practicing forester has a feeling of this threshold, quantitative information is

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[1] Paper presented at the Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984 by Dr. J. M. Guldin.

[2] Associate Professor, Department of Forest Resources, University of Arkansas at Monticello, AR 71655.

rather sparse even for well-studied species such as loblolly pine. In a comprehensive monograph devoted to this species, Wahlenberg (1960, p. 176) indicated that "most seedlings come in under overwoods of 225 or less." The "225" is the stand density index which corresponds to a basal area of 123 square feet per acre when the average diameter is 12 inches (assuming that the slope of the stand density index line is equal to -1.6) and to 144 square feet per acre when the diameter is 15 inches.

According to Wahlenberg (1960), subsequent survival of the newcomers is low under these extreme densities (four years on the average). The seedlings have better chances to survive (life expectancy 10-20 years) when overstory density is 70-80 square feet per acre. My colleague Dr. B. F. McLemore, specialist in the management of loblolly pine, comes up with a similar estimate. His opinion (personal communication) is that loblolly pine regeneration can persist indefinitely in groups scattered between mature trees provided that the overall density of canopy trees does not exceed 75-80 square feet per acre. In addition to density, the species composition of the overstory is also important. In southeastern Arkansas, for example, 55% of loblolly pine seedlings survived 5 years under dense canopy (90% cover) of pure pine, and none under hardwoods of the same cover (Wahlenberg 1960).

The cited figures, however, cannot be applied everywhere because the critical size of openings and level of overstory density are likely to vary with area, site, overstory composition and homogeneity, as well as with other factors. Further research is required to specify these important relationships and to clarify methodological problems. This article reports the effect of a parent canopy on loblolly pine regeneration which was investigated with application of point sampling.

MATERIALS

A 24-year-old loblolly pine plantation, situated in southeastern Arkansas, four miles southeast from the University of Arkansas at Monticello, was selected for this study because, as a single-species plantation, the stand was highly uniform with respect to species, age, site, slope, etc. The terrain is level (0-3% slope) and the soil is predominantly Tippah silt loam and some eroded Sacul soils. At the same time, the stand, the subject of a thinning study, was extremely diverse with respect to both studied variables (amount of regeneration and overstory density) due to four different levels of thinning which have been randomly applied to forty 0.1-acre study plots established within the stand. This diversity was further enhanced by two severe ice storms which took place two and seven years prior to our measurements performed in 1981. At that time basal area of planted trees varied (on 0.1-acre plots) from 39.5 to 148.1 square feet per acre, the average diameter was 11.8 inches, and the average height 62.6 feet.

In the fall of 1972 all undergrowth and regeneration was removed. At the time of our measurements nine years later, patches of pine regeneration, highly variable in density, were present throughout the plantation. The average age of regeneration was 5-7 years.

METHODS

Survival and growth of a seedling is affected by its immediate neighbors depending primarily on their number, distance, and size. These three variables can be combined into one measurement, basal area of trees growing in a certain vicinity around the seedling. This local density is more important for the seedling than the average density per unit area derived mostly from remote trees which are unrelated to the survival of a given seedling. Therefore, by providing the estimate of local density, point sampling performed from a seedling position is appropriate, both technically and biologically, for predicting regeneration success (Zeide 1985). Point sampling is convenient technically because it is an efficient method for estimating local basal area. This method is suitable biologically because it selects trees according to their number, distance from the sample point (in this case from the seedling), and size (diameter, closely correlated with height and volume, is a good representative of size), that is, those variables which determine seedling's success. The basal area factor (BAF) determines the spatial reach of sampling which is of crucial importance for the method.

On the described plantation success of regeneration was estimated by basal area of young pines which was determined by measuring diameters of seedlings at the level of 4.5 inches from the ground on small circular plots (radius 5 feet). Twenty four plots, representing the entire range of regeneration density (from 0 to 54 square feet per acre), were established in the plantation. Point sampling of canopy trees was performed from the center of each plot. At each point the overstory basal area was determined for twelve basal area factors -- from 4.36 to 52.27 (from 1 to 12 in metric). This was done by measuring the distances to and diameters of all overstory trees which could be counted with BAF 4.36 (1 in metric). The number of trees countable with other BAF's was calculated from these measurements.

When BAF increases, both the number of sampled canopy trees and the average distance to them decreases. The relationship between BAF and regeneration density is more complicated. The decrease of the number, associated with

the increase of BAF, is positively correlated with the regeneration density, while its correlation with the concomitant decrease of the average distance is negative. As a result of these opposing changes, the correlation between regeneration density and BAF first increases with the increased BAF, reaches a maximum, and decreases.

The trees sampled with that "peak BAF" are those which significantly affect the growth and survival of seedlings around point. Comparing the number of these influential trees with the regeneration density makes it possible to find the maximum density of canopy trees compatible with a reliable regeneration at a given point. This maximum can be detected by a sharp drop of the regeneration density. The correlation coefficient at the peak BAF (or rather its square, the coefficient of determination) shows the proportion of the variance in regeneration density due to the effect of overstory and can be considered as a measure of the overstory influence on the growth and survival of seedlings.

RESULTS AND DISCUSSION

The relationship between regeneration and overstory densities is shown in Figure 1. The wide scatter of points can be explained by the fact that, in addition to the effect of overstory, regeneration is affected by other factors, such as the amount of forest floor litter, predation, diseases, and fire. The scatter of points suggests that these other factors are responsible for poor regeneration on some plots when the number of overstory trees counted with BAF 17.4 (4 in metric) is less than six (basal area less than 105 square feet per acre).

Correlation between regeneration density and basal area of canopy trees reaches its maximum around BAF = 17.4 (Figure 2). It means that in this case the trees situated around a seedling within the distance equal to 25 times their diameters exert a decisive effect on the seedling. This effect is a decisive compared with the effect of the trees located outside that distance. As compared with other factors affecting regeneration success, the effect of overstory is modest: the variation of its density explains only about 20% of the total variation of the regeneration basal area. This proportion is likely to increase with the age of regeneration because the effect of canopy is more consistent and less random than that of other factors. A sharp decline in regeneration takes place when the number of overstory trees counted with the peak BAF (= 17.4) exceeds six to seven trees (Figure 1). It means that as far as the overstory density is concerned, in order to obtain reliable regeneration up to nine years old, the stand should be thinned to leave four to five trees countable with BAF 17.4 (70-87 square feet per acre).

The actual regeneration is usually less than that possible under given overstory conditions. If one is interested solely in the effect of overstory, it might be appropriate to use only a portion of all plots, those which are least affected by the other factors and have a larger density of reproduction. These plots are represented by dots situated at the outer edge of

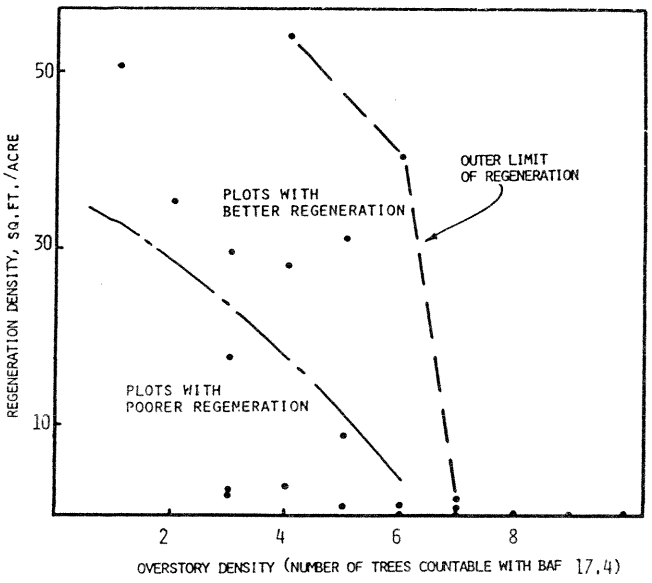

Figure 1.--Relation between regeneration and overstory densities.

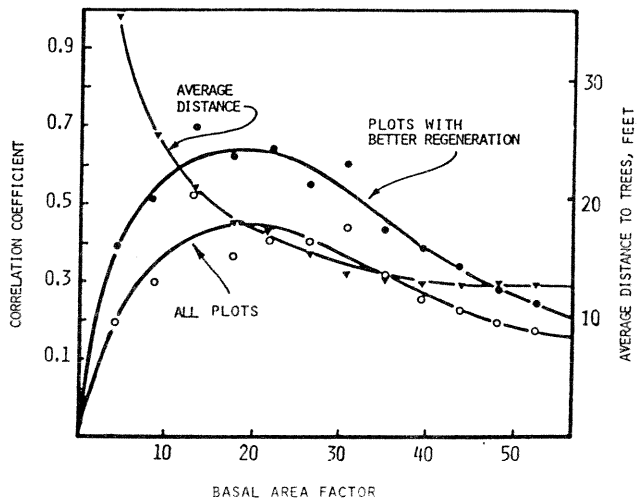

Figure 2.--Overstory - regeneration density correlation and distance to point-sampled trees as a function of basal area factor.

the point scatter (Figure 1). The division between plots with better (16 plots) and poorer (8 plots) reproduction was made using judgement rather than calculations. The division did not affect the peak BAF which in both cases (for all 24 plots and for 16 of them with better regeneration) is close to 17.4 (Figure 2), although the correlation between basal area of regeneration and that of overstory trees is greater for plots with better regeneration.

These results answer both opening questions for a rather typical loblolly pine plantation at the stage of approaching maturity. The answer concerning the minimum of a forest opening is formulated in terms of the size of and distance to the immediate neighbors decidedly affecting seedling growth and survival. The number of these neighbors corresponding to the sharp decrease in regeneration density answers the second question dealing with the maximum canopy density.

ACKNOWLEDGEMENTS

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COMPARISON OF THREE METHODS FOR REGENERATING HONEYSUCKLE-INFESTED OPENINGS IN UNEVEN-AGED LOBLOLLY PINE STANDS [1]

B. F. McLemore [2]

Abstract.--Planting, direct seeding, and natural seedfall were used to regenerate openings in an uneven-aged loblolly pine (Pinus taeda L.) stand infested with Japanese honeysuckle (Lonicera japonica Thunb.) Site preparation consisted of bushhogging. Survival of planted seedlings was best, at 69 percent, after 2 years. Seedlings averaged 1.9 ft in height and were free-to-grow. Only 22 percent of the direct-seeded spots were successful. These seedlings averaged only 0.6 ft after 2 years and were suppressed by honeysuckle regrowth. Milacre stocking of naturally regenerated plots averaged 22 percent. These seedlings also averaged 0.6 ft in height and were suppressed. In a supplemental side test of natural regeneration, disking was used to reduce the honeysuckle. After 2 years this resulted in a 100 percent milacre stocking with 4,600 seedlings per acre averaging 1.9 ft in height.

INTRODUCTION

Natural regeneration is commonly employed by foresters in managing uneven-aged loblolly pine (Pinus taeda L.) stands. For a variety of reasons, however, it is sometimes difficult, if not impossible, to obtain natural regeneration following selection cutting. If failures in natural regeneration continue over extended periods of time, the land manager must turn to artificial means of regenerating the openings, usually with planting or direct seeding.

Campbell and Mann (1973) compared different methods of regenerating loblolly pine clear-cut areas in Texas and Louisiana over an 8-year period. They concluded that planting was most reliable and that direct seeding was preferable to natural seeding.

In uneven-aged loblolly pine stands, a silviculturist can expect natural seedfall to be much greater than in a clearcut situation, but site preparation in an uneven-aged stand is much less intensive, resulting in a less thorough control of competing vegetation. On areas infested with Japanese honeysuckle (Lonicera japonica Thunb.), establishment of natural regeneration may fail, especially if there is inadequate site preparation. The options for the silviculturist then become artificial regeneration and/or a more intensive site preparation.

This study was installed to compare planting, direct seeding, and natural regeneration in honeysuckle-infested openings of an uneven-aged loblolly pine stand.

METHODS

Study Area

The study was installed in an uneven-aged loblolly pine stand on the Crossett Experimental Forest in Ashley County, Arkansas. Soil on the area is Bude silt loam, a member of the fine-silty family of Glossaquic Fragiudalfs, and the topography is flat. Site index for loblolly pine is 90 ft at age 50. The stand consisted of approximately 70 ft^2 of basal area, with volumes of 1,900 ft^3, (6,000 board feet Doyle) per acre in trees with at least a 4-inch d.b.h. Very little pine reproduction or hardwoods were present. Although there were many 0.05- to 0.1-

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2] Principal Silviculturist, Forestry Sciences Laboratory, Monticello, Arkansas, Southern Forest Experiment Station, USDA Forest Service in cooperation with the Department of Forest Resources and the Arkansas Agricultural Experiment Station, University of Arkansas at Monticello.

acre openings in the stand, a dense growth of Japanese honeysuckle appeared to be preventing adequate natural regeneration.

Treatment

Ten circular openings, ranging from about 0.05 to 0.1 acre, were bushhogged in September of 1981. Each of the 10 openings (blocks) was divided into 3 essentially equal "pie-shaped" plots by lines running from the center of the circular block to the perimeter. One of the following techniques was used to regenerate each of the three plots: (1) hand planting of 1-0 loblolly pine seedlings (2) direct seeding of stratified, repellent-treated seed in spots, and (3) reliance on natural regeneration from surrounding overstory trees. Treatments were randomly assigned to plots on each block.

The same seed source was used for the seedlings as for direct seeding. Seed was from the Georgia-Pacific seed orchard located adjacent to the Crossett Experimental Forest. Morphological grade 1 seedlings (Wakeley 1954) were hand planted, using a dibble, in December 1981, at a spacing of approximately 6- by 6-ft. Direct seeding was in spots prepared with a hoe at a spacing of 6-by 6-ft, and was accomplished in early March of 1982. Five stratified, repellent-treated seed were placed in each spot. Seeds were treated with the standard arasan-endrin-latex coating prescribed by Derr and Mann (1971).

All planted seedlings and direct-seeded spots were marked with wire pins to facilitate relocation and to distinguish them from natural seedlings. Different numbers of seedlings and seeded spots were required for the different sizes of openings, but the same number of seedlings and spots were used for each individual block, ranging from 24 to 35 per plot. The third plot on each bushhogged block was dependent on natural seedfall for regeneration. Seed traps were used to monitor seedfall during the fall and winter of 1981-82.

In addition to the 10 bushhogged openings, 2 openings were disked in a supplementary side test of natural regeneration. No planting or direct seeding was done on these two disked openings; regeneration was completely dependent on natural seedfall.

Measurements

A 100-percent inventory of planted seedlings and direct-seeded spots was conducted at the end of the first and second growing seasons. Heights of seedlings were recorded to the nearest 0.1 ft. For the direct-seeded spots, a successful spot consisted of one or more seedlings, but only the largest seedling on each spot was measured.

Four circular milacre plots, located at random, were used to evaluate natural regeneration on the plots assigned this treatment within each block and also for each of the two supplemental disked openings. Number of seedlings per acre and percent milacre stocking were determined from these inventories.

The study design provided for a statistical comparison between treatments, but a subjective evaluation of the results indicated that such an analysis would be meaningless.

RESULTS

Natural seedfall during the fall and winter of 1981-82, as determined by seed traps, ranged from 30,000 to 100,000 and averaged 64,000 sound seeds per acre. This moderate seedfall resulted in an average of 1,250 naturally established seedlings per acre after the first year, but less than one-third of the milacre plots were stocked with at least one seedling (Table 1). The height of these seedlings averaged 0.4 ft after one growing season. The number of natural seedlings per acre had declined to 675 after two growing seasons, with only a 22-percent milacre stocking. Seedling heights averaged only 0.6 ft after 2 years. Moreover, a dense growth of honeysuckle reoccupied the plots the first growing season following bushhogging and effectively suppressed the seedlings. Hence, dependence on natural regeneration of openings where Japanese honeysuckle has been bushhogged appears highly questionable.

Direct seeding trials did not have any better results than natural regeneration. Observations of spots soon after seeding indicated heavy losses of seed to birds and/or rodents. Fragments of seed coats were found on spots that had been scraped clean for site preparation. It is known that birds and rodents will sample repellent-treated seed, often taking a sublethal dose before rejecting them. In the present case, there were only a few seeds in each bushhogged opening--a maximum of 175 (35 spots with 5 seeds per spot). Even with only a few being sampled, the number of seed was substantially reduced. Consequently, only 28 percent of the seeded spots had one or more seedlings at the end of the first year (Table 1). These seedlings averaged 0.4 ft in height, exactly the same as natural seedlings. The percentage of spots with seedlings had declined to 22 percent after 2 years, with seedlings averaging 0.6 ft in height. Even after 1 year, however, honeysuckle had reinvaded the cleared direct-seeded spots and was shading out the seedlings.

Survival of planted seedlings averaged 88 percent after 1 year (Table 1). Despite heavy browsing by deer, these seedlings averaged 1.1 ft in height and were almost three times as tall as natural seedlings or those resulting from direct seeding. Of course, honeysuckle had reinvaded the area. Survival had declined to 69 percent after 2 years, but was deemed acceptable. In spite of continued browsing by deer, these seedlings

Table 1.--Summary of seedling data after one and two growing seasons

Seedling data	Disked Plots[1/] Natural regeneration	Bushogged plots Natural regeneration	Direct seeding	Planted seedlings
First Year				
Seedlings (per acre)	11,750	1,250	338	1065
Milacre stocking (percent)	100	32	--	--
Success/survival (percent)	--	--	28	88
Height (feet)	0.4	0.4	0.4	1.1
Second Year				
Seedlings (per acre)	4,125	675	266	835
Milacre stocking (percent)	100	22	--	--
Success/survival (percent)	--	--	22	69
Height (feet)	1.9	0.6	0.6	1.9

1/ Average of two plots; all other data represent an average of ten plots.

averaged 1.9 ft in height after 2 years, and the tops of most were above the encroaching honeysuckle.

In the supplemental side test where two openings were disked and no planting or direct seeding was done, control of the honeysuckle was still effective after 2 years. At the end of the first year, there was an average of 11,750 seedlings per acre, with 100 percent milacre stocking. This was a direct result of an enhanced seedbed and reduction of honeysuckle competition. These seedlings averaged 0.4 ft in height----the same as natural seedlings on the bushhogged plots. After 2 years, there were 4,125 seedlings per acre, and 100 percent of the milacres were still stocked. Because of the additional site preparation and control of the honeysuckle, these seedlings averaged 1.9 ft in height after 2 years, the same height as planted seedlings after 2 years.

CONCLUSIONS

The key to successful natural regeneration of openings in uneven-aged loblolly pine stands infested with Japanese honeysuckle is effective control of the honeysuckle. Bushhogging is not an effective means of controlling honeysuckle since its profuse growth will reinvade the area after only 1 year. Natural regeneration and direct seeding were both unsuccessful on bushhogged areas. After 2 years, planted seedlings had become established on plots that had been bushhogged and were capable of competing with the honeysuckle. Disking controlled the honeysuckle on two plots, permitting natural seedlings to become established. The larger number and greater height of natural seedlings on disked plots compared to natural seedlings on bushhogged plots after 2 years was the result of better seedbed preparation and control of honeysuckle by disking.

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RESULTS OF A QUESTIONNAIRE ON REGENERATION OF PINE SITES IN THE SOUTHEAST[1/]

J. A. Burger, R. A. Kluender, and R. L. Izlar[2/]

Abstract. A questionnaire was sent to forest managers of APA-member companies to determine how forest regeneration prescriptions are made, what factors affect the prescription process, and how site preparation might change in the future. Based on the results, economic and legislative constraints are having an effect on regeneration management, but the silvicultural needs of forest sites are still fundamental in making regeneration prescriptions. An increasing amount of mature plantations and fewer hardwood-to-pine conversions will require less intensive site preparation in the future. The availability of new herbicides and the high cost of mechanical site preparations are also partly responsible for a trend toward less intensive operations. There was little indication that harvesting and regeneration activities were coordinated to maximize regeneration efficiency. Overall better communication is needed between procurement and regeneration personnel.

INTRODUCTION

Forest managers in the southeast are committed to the successful regeneration of pines. During the past twenty years most regeneration on industry lands has been accomplished by planting 1-0 pine seedlings after clearcutting and site preparation. Ideally, site preparation would be prescribed based primarily on silvicultural needs; however, regeneration prescriptions are more difficult to plan now than they were ten years ago. Changes in harvesting methods, management objectives, limited capital, fuel allocations, restrictive legislation, and environmental awareness have created problems for forest managers who attempt to balance many concerns in their prescriptions. As a result, the forest being regenerated on industry lands today is being shaped by economic, legislative, and environmental concerns as well as the silvicultural needs of the forest site.

The questionnaire was part of a survey sponsored by the American Pulpwood Association (APA) in its continuing effort to obtain information that can be used by forest managers in their planning. The purpose of the questionnaire was to determine who makes regeneration prescriptions, what factors affect the prescription process, and how site preparation might change in the future.

RESULTS

All APA-member forest companies located in both the Southeast and Southwest Technical Divisions, as well as other cooperating companies, were asked to participate. The answers to the questions are based on the responses of forty-six participants making assessments of their regeneration programs during 1982.

Question 1: Who (management level title) normally makes the site preparation prescriptions for your company?

(1) A paper presented at the Third Biennial Silvicultural Conference, November 7-8, 1984, Atlanta, GA.

(2) Assistant Professor, Forestry Department, Virginia Polytechnic Institute and State University, Blacksburg, VA; Assistant Professor, Forestry Department, University of Arkansas at Monticello; and Executive Director, Mississippi Forestry Association, Jackson, MI.

Response 1: Figure 1 depicts a typical woodlands organization. The highest level is a woodlands manager, possibly a corporate vice-president. At the other end of the organizational diagram is the district forest manager who usually has considerable experience in a local area. The average reported level at which prescriptions were made was just slightly lower than the division level manager, but was higher than that of the district level manager.

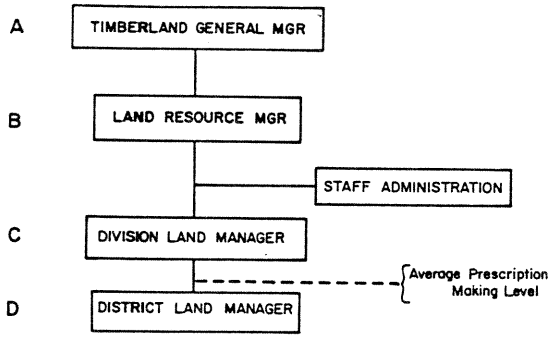

Figure 1.--Typical forest management organizational structure.

Question 2:

Listed below are various factors which could influence a manager in making regeneration prescription decisions. Please read the entire list and then number in order of importance, with #1 being the most important. Do not repeat a number (e.g., there should not be two #1's or three #7s).

_____ Growth optimization
_____ Ease of planting
_____ Time since harvest
_____ Total acres to be prepared this year
_____ Local labor supply (contractors, etc.)
_____ Management desires
_____ Last month's profit and loss statement
_____ Equipment available
_____ Capital ($) available
_____ Silvicultural needs of tract
_____ Desired end products
_____ Residual material left on tract
_____ Hardwood component of previous stand
_____ Total cost
_____ Terrain limitations
_____ Stand nutritional requirements
_____ Soil type
_____ Soil drainage requirements
_____ Non-point source pollution considerations
_____ Previous stand species
_____ Competition control
_____ Survival
_____ Other _____

Response 2:

The 18 most important factors are presented in Table 1 in descending order. The factors were further separated into two broad categories: Those that address the silvicultural needs of the tract, i.e., establishment, productivity, and yield, and those that address more immediate management concerns such as cost, production, and availability of manpower.

Table 1.--Importance ranking of site preparation criteria.

Order	Factor	Average Importance	Maximum	Minimum	Standard Deviation
1	Silvicultural needs of tract	4.39	1	14	3.28
2	Growth optimization	6.51	1	18	5.46
3	Terrain	7.67	1	17	4.31
4	Survival	7.44	1	22	6.39
5	Residual material	8.11	1	21	5.45
6	Competition control	8.72	1	20	5.21
7	Total cost	9.00	1	21	5.68
8	Management desires	9.24	1	22	6.32
9	Capital available	9.55	1	20	6.63
10	Percent hardwood	10.14	3	19	4.72
11	Soil type	10.73	3	20	5.23
12	Equipment availability	12.59	2	22	5.05
13	Drainage requirements	12.62	2	22	5.84
14	Total acres to plant	12.77	3	21	5.52
15	Time since harvest	12.83	1	20	4.31
16	Ease of planting	12.88	1	22	5.60
17	Previous stand species	13.29	6	22	4.92
18	Non-point pollution	13.78	4	22	5.22

The factors associated with silviculture in descending order of importance were:

1. Silvicultural needs of the tract
2. Growth optimization
3. Terrain
4. Survival
5. Competition control
6. Percent hardwood
7. Soil type
8. Drainage requirements
9. Time since harvest
10. Previous stand (species)

Those factors that addressed management/capital/money resources in descending order of importance were:

1. Residual material left on tract
2. Total cost
3. Management desires
4. Available capital
5. Equipment availability
6. Total acres to plant
7. Ease of planting (production)
8. Point, non-point pollution requirements

Of the 18 factors considered, four of the first five ranked highest in priority were silviculturally oriented; however, only six of the first ten factors were silvicultural concerns.

An analysis was made to determine if managers at different levels considered different criteria (Figure 2). The first five factors identified by management Level B (refer to Figure 1), in descending order of importance were:

1. Growth optimization
2. Terrain
3. Silvicultural needs of the tract
4. Survival
5. Residual material left on tract

Those factors identified by management Level C, in descending order of importance were:

1. Silvicultural needs of the tract
2. Terrain
3. Capital available
4. Growth optimization
5. Total cost

Those factors identified by management Level D, in descending order of importance were:

1. Silvicultural needs of the tract
2. Survival
3. Growth optimization
4. Residual material
5. Competition control

It is apparent from the responses that many of the same factors are considered at different management levels, and that silvicultural concerns are especially important in decision making at all levels. Therefore, if capital resources are available, silvicultural needs of the tract will probably control regeneration decisions at all management levels.

Question 3:

In the future, do you plan to increase, decrease, or stay the same in regard to the number of acres treated by different site preparation methods?

Response 3:

Responses to this question show that site preparation will change rather dramatically. Ditching and micro site preparation will increase slightly in the future (Figure 3). Of the conventional treatments, use of herbicides will increase the most, while disking and chopping will increase moderately. Only slight increases will be made in the number of acres burned, scarified, and bedded. A slight reduction will be made in the number of acres sheared, with a moderate to strong decrease in raking.

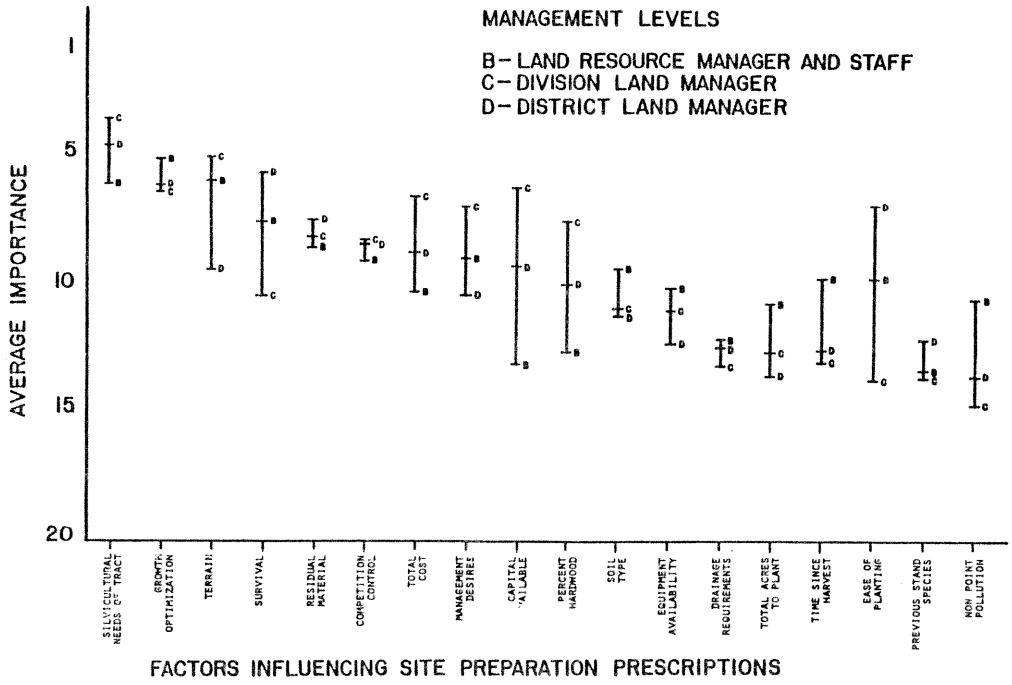

Figure 2. Average Importance of Site Regeneration Prescription Factors by Management Level

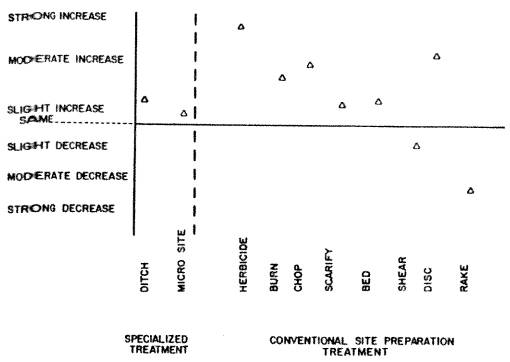

Figure 3. Anticipated changes in the use of various site regeneration treatments.

Conventional treatments are ordered (left to right) on the graph in increasing intensity of treatment. The general downward trend of the data indicates that less intensive treatments that cause less site disturbance will become more prevalent in the future. Except for discing, treatments that move organic material and disturb the soil surface will be used less. As more and more acres are established in plantations, less heavy conversion work will be needed. Forest managers are also becoming more aware of the possible reductions in site quality that very intensive site preparation treatments may cause.

Question 4:

What percentage of your harvest-plant conversion is done in the following categories:

Previous Stand	New Stand
Hardwood	to Pine plantation
Natural pine	to Pine plantation
Mixed pine hardwood	to Pine plantation
Pine plantation	to Pine plantation

Response 4:

Conversion from mixed pine hardwood stands accounted for over 35% of the acres harvested and regenerated while conversion of natural pine to pine plantations accounted for almost 36% of the total (Table 2). Hardwood to pine conversions were performed on 14%, and pine plantations that followed pine plantations accounted for 15% of the total.

Question 5:

Has the suspension of 2,4,5-T affected your site preparation activities?

Table 2. Proportion of various stand types being converted to pine plantations

Previous Stand	Average % of Total Site Prep	Standard Deviation	Minimum	Maximum
Hardwood	14.27	15.47	0	59
Natural Pine	35.80	21.55	5	90
Mixed Pine Hardwood	35.02	21.07	3	82
Pine Plantation	15.00	22.01	0	90

Response 5:

Respondants were in two clearly different camps on this question. One group had not been affected or felt that restriction of the chemical was minimal. This group accounted for 25 of the 46 responses (54%).

The second group consisted of individuals who had either used 2,4,5-T to one degree or another, or needed to begin using this herbicide. Of those who indicated that the restriction of 2,4,5-T would make a difference, the most frequently cited problem was reduced flexibility in the regeneration process. Often more intensive mechanical treatments were prescribed in place of the herbicide to insure competition control. Other alternatives to an increase in mechanical operations were more expensive, newly registered chemicals.

Question 6:

How have section 208 and 404 of PL 95-500 (non-point source pollution and dredge fill requirements) changed your site preparation activities, if at all?

Response 6:

Several respondants (5 out of 46, 11%) reported that their companies had been little affected by the advent of point and non-point planning requirements since their own company policy had long stressed the same protective measures imposed by the law.

Of those companies that reported changing philosophies (78%), the single most significant change was the addition of buffer strips along streams (streamside management zones), and a subsequent slight loss of plantable land. Apparent benefits of the legislation were better planning, contour operations on slopes, and generally increased corporate understanding of the environmental hazards of broadscale operations. Some reports indicated a shrinkage in the average size of tracts being treated, while some land was pulled out of production because of an inability to provide the degree of protection demanded by the spirit of the law.

Other general trends were stabilization attempts such as use of water bars, seeding open areas, and buffer zones. While more costly in many ways, pine regeneration in the South will become more diversified as a result of this legislation. Planning will include site specific prescriptions that accomodate both regeneration and protection requirements.

Question 7:

If an area is exceptionally well harvested and utilization is high (e.g., a clean whole tree chip operation), is an accounting credit given to site preparation?

Yes _____ No _____

How is it applied?

If harvesting costs are higher with greater utilization, is this extra cost all, or in part, underwritten by site preparation accounts?

Response 7:

Of the 46 respondants, only 4 reported a credit to site preparation operations for good harvesting. Credit was recognized either directly by a dollar exchange between accounts, indirectly in the form of less intensive site preparation treatments, or by a formal realization by management of reduced cost in site preparation due to increased cost in harvesting.

Question 8:

In your opinion, how can harvesting and regeneration operations be combined or otherwise managed to reduce total woodlands division or departmental cost?

Response 8:

Most respondants had a number of ideas of how total cost could be lowered. Most frequently mentioned was better utilization of all harvestable material. This was especially true of the hardwood component. Various methods of liason were suggested, but all mentioned the need for better communication between procurement and regeneration personnel within a company. Some took an administrative hard-line approach and suggested that high level administrators impose standards, while others felt the job could be done at a much lower level.

Another suggestion was to shift the problem outside of the organization, thus requiring contractors to do both harvesting and site preparation within very tight guidelines.

Probably the best suggestions included the liason activities mentioned above. Others specified that site-specific regeneration needed to include prescriptions for harvesting operations as well as site preparation.

DIRECT SEEDING SLASH PINE BEFORE CLEARCUTTING[1]

Earle P. Jones, Jr.[2]

Abstract.--Four separate sawtimber stands in the middle coastal plain of Georgia were prescribed burned and furrow seeded with slash pine (Pinus elliottii Engelm. var. elliottii) before clearcutting. Despite logging over the seeded furrows, empirical observations of established stands at ages 16 to 22 showed that they were only slightly less productive than in adjacent areas in the same clearcuts that had been site prepared and planted with seedlings after cutting. Due to much lower establishment costs, estimated net returns on merchantable volumes favored the direct-seeded stands.

INTRODUCTION

During the 1960's there was considerable interest and research in direct seeding slash (Pinus elliottii Engelm. var. elliottii), longleaf (P. palustris Mill.), and loblolly (P. taeda L.) pines. This was a result of the development of reliable repellents for coating seed in the late 1950's. Through research and field trials by industry and State and Federal agencies, the technology for successful direct seeding was developed and documented (Anon. 1965, Derr and Mann 1971). Methods included broadcast and row seeding, and several tractor-mounted row seeders were developed for use on woodland sites.

In 1963, a different application of direct seeding was conceived, which was to direct seed beneath a stand before it was clearcut. As opposed to the removal or reduction of logging debris for intensive site preparation, the rationale is that if seeding can be done while the trees are still on the stump then the debris is not a hinderance to direct seeding. In addition, if logging is completed soon after seeding, the seed will germinate and seedlings will develop as logging debris deteriorates--in fact, the debris affords some protection to the seed bed. If this method proved successful, time and cost for heavy site preparation could be saved.

Some exploratory field trials of direct seeding before clearcutting were installed during the 1960's on the Holt Walton Experimental Forest.[3] But as interest in direct seeding waned, this work was not pursued.

In recent years there has been a disturbing trend of clearcutting small forest properties without provision for pine regeneration. The Georgia Forestry Commission has embarked on a commendable program to counter this trend by demonstrating all the regeneration options available to landowners, with the hope that every landowner will find some method or cost range that will suit his or her need. Thanks to cooperating forest industries in the State, the Commission can also provide seed for direct seeding, at no cost, to qualified landowners.

Prompted by this new interest in direct seeding, I thought it would be instructive to measure these areas that were direct seeded before clearcutting, now at ages 16 to 22, and compare them with the adjacent areas that were clearcut at the same time but site prepared and planted by conventional methods.

STUDY AREA

The study was installed over a 6-year period, from 1962-1969, on the Holt Walton Experimental Forest in Dooly County, in the middle coastal plain of Georgia. The areas used each year were 50-acre square tracts designated for operational clearcutting under the routine management plan for the forest. Under the area control scheme employed in the plan, these 50-acre tracts are one-fourth of a surveyed land lot and do not conform to stand boundaries or topographic features. They contain mostly slash and longleaf pines on gently sloping terrain with intermittent streams bordered by

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[1] Paper presented at Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2] Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, Macon, Georgia.

[3] Near Cordele, Georgia; operated by the Southeastern Forest Experiment Station in cooperation with the H. E. Walton Estate and St. Regis Paper Company.

narrow bands of scrubs and small hardwoods.

Soils on the study areas are mostly loamy sands of the Gilead, Lakeland, and Susquehanna series, characterized by rapid surface and internal drainage, and with a slash pine site quality of 70 to 80 (base age 50). Three of the four areas used for direct seeding had patchy, natural stands of slash and longleaf pine, 40 to 50 years old, and the other was a 29-year-old widely spaced plantation.

TREATMENTS

One-fourth of each area was direct seeded before clearcutting and the remaining three-fourths was site prepared and planted after clearcutting. In this exploratory work, both slash and longleaf were seeded separately, but only the slash pine portion is reported in this paper. The details associated with each treatment and in each year varied a little, according to the particular conditions of time and place.

Generally, for direct seeding, the area was first burned to remove ground litter. This improved the seedbed by reducing litter and exposing mineral soil, it killed back the small hardwood competition, and it made it easier for the tractor driver to see obstacles such as stumps, holes, or other hazards which might be under the litter.

Immediatedly before clearcutting, the stand was underseeded by a furrow seeder attached behind a farm tractor. Seed were stratified and repellent-treated with thiram and endrin, and coated with aluminum flakes (Mann and Derr 1964). Seeding rate was based on a germination test of unstratified seed, a target establishment of about 800 to 1,000 seedlings per acre, and the hope that about one out of five germinated seedlings would survive the first summer--really a guess. Seeding rates ranged from 0.5 to 1.1 pounds per acre. The highest rate was on one area that was not planted until late in May, beyond the recommended season for sowing slash pine seed in south Georgia (Jones 1971). Other areas were seeded in February and March.

Two different types of row-seeding machines were used in different years. The H-C Furrow Seeder was used in three of the areas discussed here. It was developed by the Southern Forest Experiment Station at Brewton, Alabama (Croker 1964). It is basically a stock corn seeder modified by a heavy frame for rough woods seeding, and attached behind a small fire plow. The whole unit is mounted by a 3-point hitch behind a farm wheel tractor. The other row seeder, also on a 3-point hitch, was a prototype of a row seeder then being developed at the USDA Forest Service's Equipment Development Center at San Dimas, California (Richardson 1967). It employed a vacuum seed dispensing mechanism which was intended to correct the problem of irregular seed distribution caused by rough woods operation. Each machine was equipped with a small soil cultivation device to prepare a continuous, though narrow, seedbed just ahead of the seed drop, a drag device to cover the seed, and a press wheel to firm over the top of the planted bed.

Seeded rows were installed more or less on contour. The driver tried to keep them as parallel as possible and at the prescribed distance apart. However, it was not unusual for rows to converge, or occasionally to cross, as the driver tried to manipulate around trees. In the three natural stands in this study, density ranged from 93 to 160 trees per merchantable acre, which seldom caused much of a problem. Thickets of pine saplings presented the main problem; they would interrupt several adjacent rows, and it was usually impossible to drive through them with a small farm tractor. In the one plantation seeded, rows were merely installed between standing rows of trees.

After seeding, the entire 50-acre tract was clearcut in the same operation by commercial logging crews using ordinary procedures. In these tests, all merchantable pines were felled, limbed, and trimmed to a 4-inch top by chain saw at the stump. Tree lengths were skidded to a log ramp on the site. Poles, sawtimber, and pulpwood were separated, worked up, and loaded for haul at the ramp. Logging crews were instructed to ignore the seedbeds and work right over them. After logging was completed, the furrow seeder returned to the area, and the loading ramp, truck haul road, and major skid trails were reseeded. This ended the direct seeding treatment. Logging debris was left where it had fallen on the seeded furrows. Follow-up hardwood control by individual stem treatment could be applied in the first spring or summer after seeding, although none was used on the test areas carried to completion in this study.

After clearcutting, the remaining three-fourths of the clearcut 50 acres was left fallow for a year or more, or at least through one summer, to allow the tops and limbs to dry out. The planting site was then prepared by burning, single or double chopping, and bedding on 11-foot centers. Slash pine 1-0 nursery stock was planted at a 5- by 11-foot spacing, or 792 trees per acre. St. Regis Paper Company is one of our cooperators on the Experimental Forest and all site preparation and planting was according to their operational standards, and was done mostly by contractors.

MEASUREMENTS

Of the six annual installations of slash pine, only four areas could be used for a final comparison in 1984. Of the two excluded, one had been installed in an area where too many small pine trees had survived burning and clearcutting, and by 1984 it was impossible to distinguish between the residuals and the seeded trees; the other direct-seeded area excluded had very poor survival at age 3, so it was site prepared and planted along with the other three-fourths of the clearcut.

On each of the four study sites remaining, merchantable stands occupied from 43 to 83 percent of the total area, and 40 to 73 percent of the trees were sawtimber. Stocking in these merchantable stands ranged from 4.5 thousand board feet (Int. 1/4-inch rule) plus 2 cords, up to 8.5 thousand board feet plus 10.6 cords per acre. The heaviest stocking was in the plantation.

Table 1.--Stand data for direct-seeded and planted treatments in four annual study areas

Area	Age[1]	Trees per acre		Basal area per acre		Volume per acre		Crown classes			Trees with rust[4]		Trees with sawtimber potential[5]	
		Total[2]	Merch.[3]	Total[2]	Merch.[3]	Total[2]	Merch.[3]	Sup.	Int.	D+C				
	Yrs.	--Number--		Square feet		-Cubic feet-		---Percent---			Tpa	Pct.	Tpa	Cu. ft.
						DIRECT SEEDED								
1	22	686	371	102	82	1914	1535	33	24	43	196	29	208	984
2	21	294	183	53	47	935	828	26	24	46	80	27	101	544
3	18	247	155	41	35	608	511	24	23	53	52	21	107	390
4	16	414	199	58	47	992	798	44	25	31	99	24	104	550
						PLANTED								
1	20	455	359	96	91	1736	1634	15	23	62	108	24	222	1179
2	20	357	276	72	66	1253	1151	17	30	53	83	23	149	740
3	17	451	284	67	57	970	806	20	24	56	120	27	166	503
4	15	352	167	40	29	484	310	27	33	40	107	30	92	181

1 For direct seeded, age is from seed; for planted, age is from outplanting of 1-0 seedlings.
2 All slash pine having a d.b.h.
3 Trees having 4.6-inch dbh, and above.
4 Trees per acre (Tpa) and percent of total trees having rust cankers in lower 17 feet of stem, or in crown if severe enough to threaten loss of one-half or more of crown before tree reaches maturity.
5 Trees per acre (Tpa) and cubic volume of trees currently merchantable, in the dominant or codominant crown classes, and without rust as defined in note 4, above.

Comparative measurements of direct-seeded and planted stands were made in August.[4] In each annual test area, five one-fifth-acre plots were established for each treatment so that the samples of direct-seeded and planted treatments were in close proximity.

In each plot, all pine trees were measured for d.b.h., and judged for crown class and rust condition. Two trees in each diameter class were measured for total height. Height samples were combined for the five plots in each treatment area and a combined height over diameter curve was fitted to a model using a logarithm of total height and reciprocal of age. These height estimates and diameter measurements were then used to accumulate merchantable and total cubic-foot volume estimates for each plot by available equations for merchantable volume (McGee and Bennett 1959) and for trees less than 4.6 inches d.b.h.[5]

Unfortunately, there were no replications of the slash pine treatment within a given year, and the annual installations of the direct seeding tests did not constitute legitimate replications in time. Therefore, it was not possible to apply meaningful statistical tests to the data. However, the empirical results of direct seeding in comparison with planting provide the basis for some conclusions as to the success or failure of direct seeding before clearcutting.

RESULTS AND DISCUSSION

Establishment surveys made on the direct-seeded stands at age 3 showed seedling establishment ranged from 412 to 1,270 seedlings per acre over the four study areas. In comparison, the planted areas averaged 470 to 630 trees per acre at age 2, or 60 to 80 percent survival of planted trees. Direct seeding rows had been spaced about 6 to 10 feet apart, and a few irregular rows could still be detected in 1984 at ages 16 to 22.

Estimated site index (base age 25) varied by only 1 or 2 feet between the direct-seeded and planted treatments, except on one area where the direct-seeded treatment averaged 9 feet greater than the comparable planted area. This discrepancy was at least partly due to a few trees left as residual seedlings or saplings from the previous stand. Despite the confounding effect of residuals in the data, it could be considered an advantage in utilization of advance reproduction, rather than a loss that would occur by complete mechanical site preparation.

Ages of the direct-seeded plots range from 16 to 22 years (table 1). The planted stands were usually planted 1 year later. On Area 1, however, there was a 2-year delay before site preparation and planting due to administrative reasons. A 1-year delay, of course, means that the

[4] The Georgia Forestry Commission provided field assistance for taking measurements.

[5] Personal communication with Douglas R. Phillips, Southeastern Forest Experiment Station, Clemson, South Carolina, 1982.

direct-seeded and planted areas are actually the same age from seed because 1-0 nursery stock was used.

About 200 to 600 well-spaced trees per acre is an acceptable range of stocking for a slash pine plantation, depending on whether the management objectives are for pulpwood only or include sawtimber (Bennett and Clutter 1968). The average stocking was less than 200 merchantable trees per acre on three of the four seeded areas compared with only one of the planted areas having less than 200 (table 1). Because of crowding in the seeded rows, not all of the smaller trees will be available for ingrowth.

Crowding of trees is often a problem of row seeding caused by irregular seed flow from the hopper to the furrow. For example, a jolting seeder sometimes causes no seed drop for 10 feet, followed by a dozen seed dropping in a couple of feet. If most of these seed establish seedlings, the resulting clumping effect is evident in the distribution of diameters and crown classes. In this study, poor spatial arrangement in the direct-seeded plots resulted in a lower proportion of the total number of trees attaining merchantable sizes at their respective ages (table 1). An average for the four direct-seeded areas shows that 55 percent of the trees are in merchantable size classes compared with an average of 67 percent for the planted areas. The efficiency of spacing for planted trees is also seen in diameter distribution (table 2) in which the four study areas average 33 percent of the planted trees less than 5 inches d.b.h., and 45 percent of the direct-seed trees still nonmerchantable. Area 4 includes one plot on which seven trees must have been nonmerchantable residuals from the previous stand, based on the fact that they were much taller than the other trees on the plot. Futhermore, in the planted areas, an average of 53 percent of the trees are in the dominant and codominant classes, but only 43 percent of the direct-seeded trees are in the dominant stand (table 1).

Table 2.--Diameter distributions for direct seeded and planted treatments on four annual clearcut areas

Area and treatment	Diameter class (inches) <5	5-8	9	10	11	12	16
	----Number of trees per acre----						
1 Seeded	315	353	13	5			
Planted	96	324	23	8	3	1	
2 Seeded	111	157	18	4	2	2	
Planted	81	255	15	6			
3 Seeded	92	147	6	2			
Planted	167	280	4				
4 Seeded	215	189	2	3	3	1	1
Planted	185	167					

There was little difference between planted and direct-seeded treatments in the incidence of severe rust (table 1). Rust was recorded only for trees with a stem canker in the lower 17 feet of the stem, or a canker in the crown if it threatened to cause more than half of the crown to break out before maturity.

Total cubic volume production on the direct-seeded areas was not consistently in favor of either treatment (table 1). Two of the direct-seeded stands had more total volume than the planted stand on the same clearcut area. Average merchantable volume has averaged slightly better on the planted area, but the difference is only about 57 cubic feet per acre, or about 0.6 cord.

There were very few trees in the sawtimber class at these ages (table 1). Sawtimber potential, however, was estimated on the merchantable size trees in the dominant and codominant classes that were free of rust, as defined above. The direct-seeded areas compared closely with the planted stands, averaging 130 trees and 617 cubic feet per acre sawtimber potential compared with 157 trees and 650 cubic feet per acre on the planted stands.

A simple analysis of cost and returns shows that direct seeding before clearcutting had a financial advantage as of the 1984 measurements (table 3). Accurate cost records were not kept for the work, so cost values for the mid-1960's were estimated. These values were adjusted to be generous for direct seeding and on the low side for site preparation and planting. Mann and Derr (1964) estimate $4.30 per acre for the cost of burning, seed, and furrow-seeding open areas. I raised this to $8 to allow for the additional time needed to operate among standing trees. Consensus among practitioners of the time suggests that $40 per acre was a conservative total charge for burning, chopping, bedding, seedlings, and planting on cutover sites in the mid-1960's.

Costs were compounded at 7 percent from the date of direct seeding or planting. A pulpwood

Table 3.--Net returns in 1984 for direct seeding before clearcutting versus site preparation and planting on four clearcut areas, with 1965 estimated costs per acre of $8 for the seeding treatment and $40 for the planting treatment, both compounded at 7 percent annually; and 1984 stumpage rate of $25 per cord

	Direct seeded			Planted		
Area	Cost[1]	1984 value	Net	Cost[1]	1984 value	Net
	----Dollars----					
1	35	418	382	155	445	290
2	33	225	192	155	312	157
3	27	138	111	126	220	94
4	24	218	194	110	85	<-25>

[1]Compounded for respective periods under "Age" in Table 1.

stumpage value of $25 per cord is $1 below the low side of the range reported for stumpage in south Georgia in September 1984 (Timber Mart South, Inc. 1984). Annual charges for management and taxes were omitted as being the same for both treatments.

Differences in net return for the two treatments range from $17 to $92 in favor of the direct seeding treatment, not including Area 4 which, at age 15, is just on the threshold of merchantability and does not yet show a profit for the planted treatment. Of course, this reflects the heavy impact of the eightfold greater establishment cost for site preparation and planting.

A basic consideration in this idea of direct seeding before clearcutting is that if logging is completed before seed germinate, they may still germinate after having been logged over, although they may be relocated somewhat in the process. A germinated seed, with radical and sprout extended out of the protective seed coat, would not fair as well, nor would a seedling.

In these trials, the trees were topped and limbed at the stump, and the tree-length logs were bunched and skidded across the beds. Skidding bunches of 6 to 10 whole trees, with tops, would sweep a wider swath, but the fact that the trees are moved in the vertical position to the bunching point may cause less damage to the beds. This might be and interesting point for further investigation.

CONCLUSIONS

Statistically sound conclusions cannot be drawn from this empirical study of direct seeding before clearcutting. However, these final points can be stated:

1. For some small slash pine tracts, direct seeding in rows before clearcutting may be a practical and inexpensive way to regenerate.

2. Clearcutting must be timed to coincide with the proper season for direct seeding, preferably the winter and early spring season.

3. Proper timing between direct seeding and logging is essential so logging will be completed before significant germination starts.

4. Direct seeding before clearcutting should not be used where intensive hardwood control measures are needed.

5. Open understory conditions are more suitable for direct seeding before clearcutting, and this condition can be maintained by regular prescribed burning before the time for harvest.

6. This application of direct seeding is not suggested as a general substitute or improvement over the planting of nursery seedlings, but it may be considered a regeneration option under the conditions and restrictions described above

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A METHOD FOR EVALUATING SURVIVAL ADEQUACY IN YOUNG PLANTATIONS[1/]

T. G. Matney and J. D. Hodges[2/]

Abstract.--A method based on the negative binomial (NB) distribution and area potentially available (APA) concept is described for objectively evaluating the need to replant. The NB parameter P, planting spacing, and numbers of living trees are estimated from sample data. Using these estimates a distribution of APA's is simulated and essentially open grown trees are excluded from the stand. The residual stand is then projected, and an economic analysis performed to assess the benefits of replanting.

INTRODUCTION

Forest managers are constantly plagued with the problem of assessing the adequacy of first year survival in plantations to meet management objectives. Surviving seedling counts on plots randomly or systematically distributed in a plantation provide a good estimate of the numbers of survivors per unit area, but no information is gained on the spatial distribution of survivors or the proportion of trees surviving. It is distinctly possible that unless a plantation is carefully stratified into survival classes, poor survival and good survival in differing areas in the plantation may average out to an acceptable number of survivors per unit area. In this paper we discuss and illustrate a method based on the negative binomial probability distribution that provides the manager with information on numbers of survivors and their distribution. We also demonstrate an objective decision criterion for answering the question "Should I replant or not?"

The field procedure of the sampling technique, called the runcount method, is first described as a starting point for discussion. Then the theory on which the technique is based, and the possible use of the area potentially available (APA) concept (Brown, 1965) to derive expected yields for the sampled plantation are described.

FIELD PROCEDURE

Following stratification of the plantation into (1) potentially similar survival strata and (2) the selection of random points, in each strata (see figure 1):

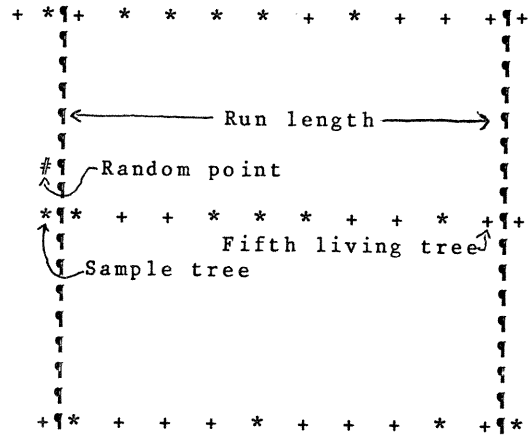

Figure 1.--Illustration of the run count method using a run length of five living trees. A plus (+) represents a living tree and an astrick (*) represents a planting position without a living tree. WS and WE are the distance between the midpoints of adjacent rows and L is the length of the run.

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[2/] The authors are Associate Professor, and Professor, respectively, in the Department of Forestry, Mississippi Agricultural and Forestry Experiment Station at Mississippi State University, Mississippi State, MS 39762.

1. Locate the row closest to the point. If the point is equidistant between two rows, select one of the rows with 50 percent probability by tossing a coin.

2. In the row, select the planting position closest to the point located on the ground and record whether a living tree is present in the planting position or not.

3. Select a direction to travel in the row at random by tossing a coin.

4. Locate a point halfway between the previously identified planting position and the first planting position in the direction of travel.

5. At the halfway point between planting positions, measure the distance between the midpoints of the adjacent rows. The measurement lines should be perpendicular to the measurement row.

6. Proceed down the row counting the number of planting positions until n living trees are counted. The n selected will depend on the spacing and survival percentage, and should be chosen so that the length of the run is not much greater than 150 feet. The quantity n will be referred to as the living count.

7. At the nth living tree along the length, locate the halfway point between the nth tree living and the next planting position; and measure the distance between the midpoint of the two adjacent rows.

8. Finally, measure the length of travel along the row traversed by measuring the distance between the points established in steps 5 and 7.

THEORY

At best in a plantation we may expect that the probability (P) of a planting position having a living tree present is constant throughout the plantation. In general, however, the probability P will vary from location to location in a plantation producing clumps of better than average survival and clumps of worse than average survival. Another possibility, and one that is highly unlikely, is that survival is more regular than expected.

When P is constant, the run counts are distributed as the negative-binomial distribution.

$$f(x) = \binom{x-1}{n-1} P^n (1-P)^{x-n} \quad , x = n, n+1, \ldots$$
$$= 0 \quad , \text{elsewhere.} \qquad (1)$$

where: $f(x)$ = the probability of a run-count being x planting positions in length,

x = a random variable representing run-count length,

P = constant probability of a planting position having a living tree present, and

n = fixed number of living trees in each run count.

Given P, the expected average length (X) of run-count and the expected variance (S^2) of run-count lengths are, respectively,

$$X = \frac{n}{P} \quad , \text{and} \qquad (2)$$

$$S^2 = n \frac{(1 - P)}{P^2}. \qquad (3)$$

Sample estimates from the field data collected for each stratum are,

$$x = \frac{\sum_{i=1}^{N} R_i}{N} , \qquad (4)$$

$$s^2 = [\sum_{i=1}^{N} R_i^2 - (\sum_{i=1}^{N} R_i)^2/N]/(N - 1), \text{ and} \qquad (5)$$

$$p = \frac{COUNT}{N} , \qquad (6)$$

where: R_i = value of the ith sample run-count,

N = number of sample run-counts, and

COUNT = the number of living trees present at each of the planting positions closest to each randomly located point.

Because of the way COUNT is obtained, and because the total number of planting positions is very large, the distribution of COUNT is approximately binomial with parameters N and P.

$$f(COUNT) = \binom{N}{COUNT} P^{COUNT} (1 - P)^{N - COUNT},$$
$$COUNT = 0, 1, 2, \ldots N \qquad (7)$$

The expected value of p is thus P and the variance of P is

$$Var(P) = P(1 - P)/N. \quad (8)$$

On taking the square root of the ratio of the approximation to the theoretical run count variance obtained from equation 3 by substitution of p from equation (6), and the sample estimate of the runcount variance from equation 5, an index (I) or measure of the degree the sample plantation departs from having a constant P is formed:

$$I = \sqrt{s^2/S_A^2}, \quad (9)$$

where

$$S_A^2 = n(1 - p)/p^2. \quad (10)$$

If the index I is greater than one, P varies from location to location in the plantation. If I is less than one, P is less variable than would be expected when surviving trees are randomly distributed to planting positions. When I is exactly equal to one, then we may accept the hypothesis that surviving trees are randomly distributed. The index is similar to a measure of aggregation based on the possion distribution discussed by Pielou (1977).

The index I provides a measure of the degree to which a plantation's survival pattern departs from the best expected, but in itself the index I cannot be used to decide whether to replant or not. One possible approach to making use of the index I for deciding whether to replant or not is to generate the distribution of area potentially available (APA), for a given planting spacing, and estimates of P and I. The APA of trees considered too large to meet management objectives can be used to reduce the amount of land stocked. The growth of the remaining stocked area per acre can then be simulated (or forecast) with a yield model, and an economic analysis applied to the result to determine if replanting is justified.

To investigate this method, a simulator was written in FORTRAN 77 to estimate the distributions of APA given P, I, and planting spacing. The program locates sample points in the plantation. At each sample point a value of P is selected from a normal distribution with mean P and a variance S^2, and the run-count and APA is obtained for the point. When sufficient points have been sampled, I is calculated and compared with the desired I. If the simulated I and desired I are the same, the distribution of APA is printed. If the two I's do not match, the variance of the normal distribution is adjusted and another run is performed with the process being iterated until the I's match.

As an illustration of this approach, suppose a loblolly plantation of site index 60 on site prepared land is sampled at age 3, and from the data we find the average spacing of the plantation is 7' x 8', the number of trees per acre surviving is 300, the proportion of planting positions with living trees is .3875, and the index I is 6.5. The distribution of APA calculated by the FORTRAN program for the conditions is in Table 1.

Assuming that any tree that will not exhibit crown closure before reaching a DBH of 6.5 inches will be low value material unsuitable for our management objectives, we can treat the areas of trees having APA greater than 150 square feet as unstocked.[3/] That is, we will have from Table 1 approximately on the average:

$$180*32.2 + 200*16.6 + 220*5.6 + 240*3.4$$
$$+ 260*2.0 + 280*1.0 + 300*0.8 + 320*0.8$$
$$= 12{,}500 \text{ square feet}$$

of unstocked area per acre, and

$$300 - 32.2 - 16.8 - 5.6 - 3.4 - 2.0 - 1.0$$
$$- .8 - .8 = 237 \text{ trees}$$

growing on a stocked area per acre of

$$43{,}560 - 12{,}500 = 31{,}060 \text{ square feet.}$$

The growth of this stand can be forecast as that of a stand with

$$\frac{43{,}560}{31{,}060} * 237 = 322 \text{ trees per acre,}$$

and predicted yield can then be reduced by

$$\frac{12{,}500}{43{,}560} * 100 = 28.7\%$$

to approximate the expected yields of the stand per acre. The assumption here is that we can ignore the yield of the trees having large APA's.

Performing this yield estimation operation using a loblolly pine simulator developed by Matney and Sullivan (1982), and modified to predict the yields of loblolly pine on cutover sites, the expected yield with thinning at age 20 is in Table 2 and Table 3.

With a site preparation and planting cost of $120 per acre, a cost of $60 per acre at age 7 for brush control, an interest rate of 13% and stumpage prices of $17 per cunit, and $170 per MBF doyle, the net present value (NPV) of the stand harvested at age 35 is -$98.81. At this interest rate we can certainly not afford to grow trees, but will replanting improve things?

[3/] The open grown crown area of the 6.5" tree was approximated using the predicted crown radius from the equation in Strub 1975.

Table 1.--Distribution of APA for a loblolly pine plantation with poor survival.

APA Class (ft^2)	Proportion	Number Per Acre
$56 \leq X \leq 90$	.0513	15.4
$90 < X \leq 130$	.1353	40.6
$110 < X \leq 130$	.2033	61.0
$130 < X \leq 150$	.2107	63.2
$150 < X \leq 170$	.1907	57.2
$170 < X \leq 190$	.1073	32.2
$190 < X \leq 210$	.0560	16.8
$210 < X \leq 230$	.0187	5.6
$230 < X \leq 250$	.0113	3.4
$250 < X \leq 270$	.0067	2.0
$270 < X \leq 290$	.0033	1.0
$290 < X \leq 310$	.0027	.8
$X > 310$	.0027	.8

To answer the question we must look at the net present value of a successful replant, recognizing that if the second planting fails we are in trouble.

So, rerunning the yields and net present value for the stand assuming 80% survival and a replant at age 3, the net present value is -\$171.58. This assumes a replanting cost of only \$100 and one additional thinning.

The conclusion for our case, since the NPV of the replanted stand is less than the NPV of the original stand, is that we should not replant. Indeed with these NPV's we would not have planted trees. We did not, however, include taxes, and other factors that may have considerable influence on forest management decisions.

Approximations of the numbers of trees per acre ($\overline{TPA}$), average spacing between rows ($\overline{RS}$), average spacing between planting positions within rows ($\overline{CS}_P$) and the average spacing between living trees within rows ($\overline{CS}_L$); and their variance [Var(.)] are readily estimated from the data. These estimators are listed below:

$$\overline{TPA} = (\sum_{i=1}^{N} TPA_i)/N \tag{11}$$

$$VAR(\overline{TPA}) = [\sum_{i=1}^{N} TPA_i^2 - (\sum_{i=1}^{N} TPA_i)^2/N]/(N)(N-1) \tag{12}$$

$$\overline{RS} = \frac{1}{2}[\sum_{i=1}^{N} (WS_i + WE_i)^2 - [\sum_{i=1}^{N} (WS_i + WE_1)]^2]/N/(4)(N)(N-1) \tag{13}$$

$$\overline{CS}_P = (\sum_{i=1}^{N} L_i/R_i)/N \tag{14}$$

$$VAR(\overline{CS}_P) = [\sum_{i=1}^{N} (L_i/R_i)^2 - (\sum_{i=1}^{N} L_i/R_i)^2/N]/(N)(N-1) \tag{15}$$

$$\overline{CS}_L = \frac{1}{n}[\sum_{i=1}^{n} L_i]/N \tag{16}$$

$$VAR(\overline{CS}_L) = \frac{1}{n^2}[\sum_{i=1}^{N} L_i^2 - (\sum_{i=1}^{N} L_i)/N]/(N)(N-1) \tag{17}$$

In these equations,

$TPA_i = (2)(43560)(n)/[(WS_i + WE_i)L_i]$,

WS_i = distance (feet) between midpoints to adjacent rows at the ith sample point and at the start of the run,

WE_i = same as WS_i except the measurement is taken at the end, of the run, and

L_i = length of run in feet.

FIELD TEST

Field testing of the method was conducted to primarily determine if the technique would give a good estimate of numbers of surviving trees per acre and to evaluate the amount of field time required to sample a plantation. Four hand planted loblolly pine plantations were selected for sampling, ranging from 1 to 4 years old. In each plantation 50 run count plots and 50 one-hundredth acre count plots were established randomly. The run count length (n) used for each plantation was 10.

Comparison of the number of trees estimated by the two methods using a two sample t test resulted in no significant differences even at the .30 level. Examination of the differences between estimates also showed no consistent under- or over-estimation by the method.

Table 2.--Adjusted yields for a loblolly pine plantation with poor survival.

	Standing Volumes After Thinning			Volume Removed in Thinning		
Age	Pulpwood ft^3 (ib)	Chip & Saw Doyle bd. ft.	Veneer Doyle bd. ft.	Pulpwood ft^3 (ib)	Chip & Saw Doyle bd. ft.	Veneer Doyle bd. ft.
15	235	859	35			
20	98	911	514	110	675	489
25	79	985	1697			
30	72	951	3011			
35	65	1018	3840			

Table 3.--Yields for a loblolly pine plantation with better than average survival.

	Standing Volumes After Thinning			Volume Removed in Thinning		
Age	Pulpwood ft^3 (ib)	Chip & Saw Doyle bd. ft.	Veneer Doyle bd. ft.	Pulpwood ft^3 (ib)	Chip & Saw Doyle bd. ft.	Veneer Doyle bd. ft.
15	821	595	0			
17	433	613	1	406	556	1
20	382	1302	265			
23	329	1658	735			
25	160	1244	872	151	623	262
30	141	1414	2434			
35	124	1531	3606			

The time required for the run count method was greater than for the plot count method, by about 10%. This could have been reversed however if we had used a shorter run count length.

Example Computations

The run count data for a hand planted three-year-old loblolly pine plantation shown in Table 4 will be used to demonstrate the computations involved with the run count method.

An estimate of the negative binomial parameter P is calculated from the status column of Table 4.

$$p = \frac{\text{Count of Living Trees Present}}{N} = \frac{31}{40} = .775$$

This estimate of P has an estimated variance and a large sample 95 percent confidence interval, respectively of:

$$Var(p) = p(1 - p)/[N(N - 1)]$$

$$= (.775)(.225)/[(40)(39)] = .011$$

and

$$CI95: \quad p \pm (t)\sqrt{VAR(p)} = .775 \pm (2.020)(.1049)$$

$$= .775 \pm .2119$$

where t is the value from Students-t table for a two-tailed test at the .05 level with N - 1 = 39 degrees of freedom.

Under the hypothesis that living trees are randomly distributed in planting positions, the variance of the run count would be equal to

$$s^2 = \frac{n(1 - p)}{p^2}$$

which is approximately equal to

Table 4.--Run count data for a three year old loblolly pine plantation on a cutover prepared site. The living trees in each run count was fixed at 10.

Point (i)	First Tree Status (S_i)[1/]	Run Length In feet (L_i)	Run Count In Number (R_i)	Distances Between Midpoints to Adjacent Rows At Beginnng (WS_i)	At End (WE_i)
1	P	103	14	9.1	9.4
2	P	112	15	9.4	9.5
3	P	265	18	9.5	9.4
4	P	115	11	9.4	9.1
5	P	89	10	9.1	8.0
6	P	103	13	8.0	8.5
7	P	105	14	8.5	9.6
8	P	104	13	9.6	8.0
9	P	139	17	8.0	8.1
10	P	91	12	8.2	8.6
11	P	159	20	10.8	9.1
12	P	119	16	9.1	9.9
13	P	144	19	9.9	7.5
14	M	129	15	9.3	8.3
15	P	141	16	8.6	7.5
16	P	175	19	8.7	10.5
17	M	276	25	9.2	9.7
18	P	236	26	11.1	8.2
19	P	126	15	8.7	9.1
20	P	92	11	9.1	8.4
21	P	184	18	10.0	10.9
22	M	301	31	10.8	10.0
23	P	87	13	10.0	10.3
24	M	100	13	10.3	10.4
25	P	136	16	10.4	9.7
26	M	141	18	9.7	10.2
27	P	121	16	10.2	8.7
28	M	90	12	8.7	10.5
29	M	376	50	10.5	9.3
30	M	155	21	9.2	10.3
31	M	300	50	8.0	8.3
32	P	139	23	9.8	9.2
33	P	99	16	9.1	10.4
34	P	118	19	10.5	9.3
35	P	113	18	9.3	10.1
36	P	166	27	10.7	12.1
37	P	189	31	12.1	8.4
38	P	178	19	9.0	12.4
39	P	94	16	11.8	7.4
40	P	132	21	7.4	10.2

[1/] Status of planting position closest to random point. If S_i = P a living tree is present and if S_i = M the position a dead tree is present or no tree is present.

$$S_A^2 = \frac{n(1-p)}{p^2} = \frac{10(1-.775)}{(.755)^2} = 3.75,$$

on substitution of p for P in equation 3.

On the other hand the estimate of S^2 from actual runcounts taken in the field is obtained from the runcount column in Table 4 and equation 4.

$$s^2 = [14^2 + 15^2 + \ldots + 21^2 - (14 + 15 + \ldots 21)^2/40]/39 = 76.7639$$

Taking the square root of the ratio of S_A^2 to s^2 forms the index I, which measures the degree to which the actual plantation's surviving trees depart from a random allocation to planting position.

$$I = \sqrt{s^2/S_A^2} = \sqrt{\frac{76.7639}{3.75}} = 4.52$$

The required estimate of the number of trees per acre and its variance are given by:

$$\overline{TPA} = [457.2 + 411.6 + \ldots + 375.0]/40$$

$$= 355 \text{ trees per acre, and}$$

$$VAR(\overline{TPA}) = [457.2^2 + 411.6^2 + \ldots + 375.0^2 - (452.2 + 411.6 + \ldots + 375.0)^2/40]/(40)(39) = 123.21 \text{ [trees per acre]}^2$$

where

$TPA_1 = 457.2 = (2)(43560)(10)/[(9.1 + 9.4)103]$ trees per acre,

$TPA_2 = 411.6 = (2)(43560)(10)/[(9.4 + 9.5)112]$ trees per acre,

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$TPA_{40} = 375.0 = (2)(43560)(10)/[(7.4 + 10.2)(132)]$ trees per acre.

A 95 percent confidence interval on the number of surviving trees per acre can thus be expressed.

$$CI95: \overline{TPA} \pm (t)\sqrt{VAR(\overline{TPA})} = 355 \pm (2.020)(19.48) = 355 \pm 39.4 \text{ trees per acre}$$

In a similar manner the average, variance of the average, and 95 percent confidence intervals for spacing between ROWS ($\overline{RS}$), spacing between planting positions within ROWS ($\overline{CS}_P$), and spacing between living trees within rows (CS_L) can be calculated as follows:

$\overline{RS}$

$$\overline{RS} = \frac{1}{2}[(9.1 + 9.4) + (9.4 + 9.5) + \ldots + (7.4 + 10.5)]/40 = 9.6 \text{ ft.}$$

$$VAR(\overline{RS}) = [(9.1 + 9.4)^2 + (9.4 + 9.5)^2 + \ldots + (7.4 + 10.5)^2 - [(9.1 + 9.4) + (9.4 + 9.5) \ldots + (7.4 + 10.5)]^2/40/](4)(40)(39) = .48 \text{ ft}^2.$$

$$CI95: \overline{RS} \pm (t)\sqrt{VAR(\overline{RS})} = 9.6 \pm (2.020)(.69) = 9.6 \pm 1.4 \text{ feet}$$

$\overline{CS}_P$

$$\overline{CS}_P = (103/14 + 112/15 + \ldots + 40/21)/40 = 7.99 \text{ ft.}$$

$$Var(\overline{CS}_P) = [[(103/44)^2 + (112/15)^2 + \ldots + (40/21)^2] - [103/14 + 112/15 + \ldots + 40/21]^2/40]]/(40)(39) = .07 \text{ ft}^2$$

$$CI95: \overline{CS}_P \pm t\sqrt{VAR(\overline{CS}_P)} = 7.99 \pm (2.020)(.27) = 7.99 \pm .54 \text{ ft.}$$

$\overline{CS}_L$

$$\overline{CS}_L = \frac{1}{10}(103 + 112 + \ldots + 132)/40 = 15.1 \text{ ft.}$$

$$VAR(\overline{CS}_L) = [(103/14)^2 + (112/15)^2 + \ldots + (40/21)^2 - (103/14 + 112/15 + \ldots + 40/21)^2/40]/[(40)(39)(100)] = 1.16 \text{ ft}^2$$

$$CI95: \overline{CS}_L \pm (t)\sqrt{VAR(\overline{CS}_L)} = 15.1 \pm (2.020)(1.04) = 15.1 \pm 2.18 \text{ ft.}$$

DISCUSSION

The authors' feel the run-count method for sampling survival adequacy of young plantations presented in the paper, has great potential as a technique for making the decision between the two alternatives of replant or don't replant. Refinements and additional field testing of the procedure are necessary by users of this method to tailor it to their own management objectives and economic situation.

The advantages of the method are that it is easy to implement in the field, it is readily programmable for small computers, and it is amenable to establishing objective decision criteria to answer the important questions of whether a plantation should be replanted.

The main disadvantage of the method is that it can only be applied in plantations with reasonable row integrity. A method based on composite binomial distributions that overcomes the need for row integrity is now being investigated by the authors.

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MACHINE APPLICATION OF HERBICIDES FOR HARDWOOD SPROUT CONTROL--A CONCEPT[1/2/]

Clyde G. Vidrine[3/]

Abstract. A method for selectively applying herbicides to the stump of undesirable hardwoods for sprout control combined with the operation of a feller-buncher is presented. Potential advantages of the proposed system result from the herbicide being applied only to the stump surface and at the time period when an application is most effective. The amount of herbicide required for sprout control is thus minimized, the need for subsequent aerial spray applications to suppress hardwood growth may be eliminated, and the intensity of mechanical site preparation for reforestation may be reduced. Results from short term observation of a feller-buncher equipped with a spray system indicate additional time requirement for spraying of about 5 seconds per stem.

INTRODUCTION

Site preparation for reforestation is a major expense in the forest management practice Mechanical site preparation by conventional methods is accomplished by shearing, windrowing, or chopping and burning. According to Johnson (1977), site preparation is the most costly item in forest management practice. Diesel fuel consumption alone has been reported to average 15.2 gallons per acre to prepare and plant harvested land (APA, 1978).

With increasing fuel prices, there has been growing interest in using whole tree chippers to convert undesirable timber into fuel. This is advantageous since undesirable trees are removed and the site is left clean for reforestation purposes, thus eliminating some of the conventional site preparation operations. The hardwoods are commonly harvested by a feller-buncher and soil is less disturbed in relation to mechanical site properties. Terry and Campbell (1981) have stated that severe erosion and environmental problems may develop from conventional site preparation.

In the early stages of pine growth in chip harvest areas, competition from hardwood sprouts has often been observed to be more severe than on areas prepared conventionally. Smith (1979) reported hardwood stems of stump sprout origin in non-herbicide treated sites amounted to 40 to 50% of the stand population in even-aged managed hardwood stands while in herbicide treated sites stems of sprout origin accounted for 15 to 20% of the population. Studies show that stump treatment with herbicide can provide an effective and inexpensive means of controlling sprouting, and that treatment at harvest reduces the expense of eliminating sprouting (Lewis et al., 1984). In the Lewis study, stump sprout control of up to 96% was achieved using the herbicide Picloram.

A spray system mounted on the feller-buncher could effectively apply a prescribed amount of herbicide to each stump as each hardwood stem was harvested. For herbicides to be used for stump application, it is required that application be made shortly after cutting. Applying herbicides only to the cut stump surface would minimize the quantity of herbicide required, reducing both expense and potential environmental pollution. Herbicides listed for hardwood sprout control include Picloram + 2,4D, 2,4D ester + 2,4-DP ester, and Dicamba (USDA, 1983).

1/2/ Paper presented at the Third Biennial Silvicultural Research Conference, Atlanta, GA, November 7-8, 1984. This project was supported by the McIntire-Stennis Cooperative Forestry Research Program under Public Law 87-788.

3/ The author is Clyde G. Vidrine, Professor, School of Forestry, and, Department of Agricultural Engineering, Louisiana Tech University, Ruston, LA 71272.

OBJECTIVES

The objectives of this study were to:

(1) Design a spray system to be mounted on a feller-buncher for immediate herbicide application to the sheared stump.

(2) Evaluate spray equipment performance.

(3) Determine added time required for spraying.

(4) Determine limitations of the system.

SYSTEM DESIGN

The design of the spray system included component selection, design and fabrication of protective shields and housings, and the selection of mounting locations for the components on the feller-buncher.

Major components selected for the spray system included a reservoir, a solenoid operated valve, a spray nozzle, a surge tank, hose, and a pump. The herbicide reservoir was a 5 gallon, rectangularly shaped, fuel can. The solenoid valve used to control the spray application was a Hypro model 2525* with an accompanying remote control, single-pole single-throw (SPST), normally off, push button switch. The spray nozzle chosen was made of hardened stainless steel, produced a 60 degree full cone spray pattern, and was complete with a drip proof check valve. It was rated for 0.57 gpm at 40 psig pressure. A Hypro model 3375-0003 surge tank was used in the spray system to reduce pump cycling and reduce system pressure drop during spraying. The tank was rated for a maximum pressure of 500 psig and was approximately 10 inches tall and 4 inches in diameter. The hose used for the system was 3/8 inch ID, type EPDM and capable of withstanding pressures of 200 psig. The sprayer pump selected was a Shurflo model 2123-09-922-14, diaphram type pump powered by a 12 volt dc, self-contained motor. It had built-in pressure switches which kept pump operation between 40 psig and 60 psig. An on-off, SPST toggle switch was used for system start-up.

An enclosure to protect the pump and solenoid valve was constructed out of 6 x 4 x 5/16 inch steel angle. The dimensions of the housing was 16 x 8 x 6 3/4 inches. The surge tank was mounted on the outside of the housing because of the tank's size and durability. The plumbing for the system was fixed to the sturdy housing to provide strain relief should any external hoses become snagged and pulled. This protected the pump and solenoid valve ports. Strain relief connections were also provided for the electrical wiring, with barrier strip terminals fixed to the housing. With the pump and solenoid valve secured inside the housing and the surge tank mounted outside, the assembly provided a convenient package for easy mounting on the feller-buncher.

A bracket was fabricated out of 3 x 2 x 3/16 steel angle for mounting the nozzle. A shield was made to protect the nozzle and bracket.

A cradle was fabricated out of 2 x 2 x 1/8 steel angle for carrying and mounting the herbicide reservoir to the tractor. A quick-attach coupling was installed on the bottom of the reservoir for easy detachment of the hose from the reservoir to the pump inlet. This gave the option of removing the reservoir from the tractor mounted position for easy filling. A schematic diagram of the components is shown in Figure 1.

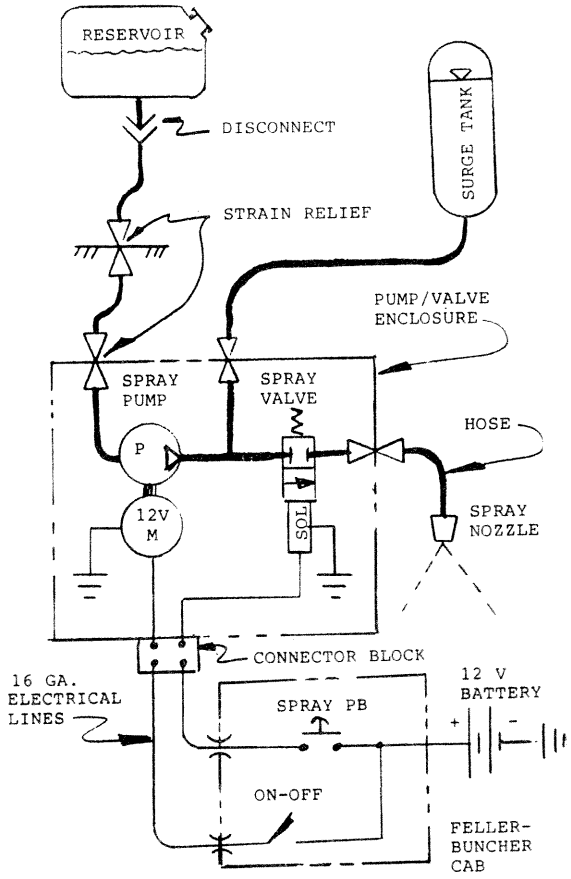

FIGURE 1. HERBICIDE SPRAY SYSTEM SCHEMATIC.

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*The use of trade names in this paper does not imply endorsement of the products named, nor criticism of similar ones not mentioned.

Proper placement of components on the feller-buncher was necessary to ensure protection from limbs and snags, avoid mechanical interference with the harvesting operation, effectively apply herbicide to the stump with minimum increased operation time, and allow adequate observation.

The nozzle was installed at the back of the shear head on the main structural beam. This placed the nozzle approximately 1-2 feet behind the tree that was in shearing position. The nozzle was positioned at an angle so that the spray area would cover the stump with minimum extra lifting or tilting of the feller-buncher head. The nozzle was positioned above the bottom of the shear to keep it free from soil and debris, since trees are often sheared at ground level. The positioning of the nozzle behind the shear also kept the nozzle and hose away from the mechanical action of the shear. The nozzle was well protected from limbs and trees because of its location and shield.

The external hoses and electrical wires for the system were tied in with the feller-buncher hydraulic lines along the inside of the feller-buncher lift arms for protection.

The pump and solenoid valve enclosed in a framed housing was between the feller-buncher lift arms and behind a structural circular beam located between the operator and the nozzle. The housing, located within the framework of the harvesting machine,was protected from the working environment. The housing and surge tank were in full view of the operator but did not interfere with vision required for normal harvesting operations.

The reservoir was mounted in the front of and below the cab and operator's vision. It was mounted on the tractor, between the feller-buncher lift for protection, and in a position above the pump, giving the herbicide a a pressure head and permitting gravity flow to the pump inlet, which eliminated potential pump starvation problems.

The remote control push button switch for the solenoid valve and the toggle switch for system start up and shut down were located in the cab - to the front and right of the operator for easy access.

RESULTS AND DISCUSSION

With the spray system mounted on a feller-buncher, a harvest operation was observed. A dyed-water solution was used to see the area of spray application and effectiveness of the system.

The operator manuevered the tractor into position for cutting, the tree was sheared, the shear was lifted and tilted to point the nozzle at the stump, and the remote control push button switch was pressed for 1-2 seconds for sufficient spray application to the stump.

The system components operated satisfactorily. The volume of spray delivered in 1-2 seconds at 40-60 psig appeared sufficient for wetting the stump and was adequate for the spray pattern. The added operational time to position the nozzle and spray the stump was small (about 3-5 seconds), particularly as the operator becomes familiar with the proper technique for effective application. The higher the shear was raised, the larger the area of application, but the less concentrated the spray droplets were. At a level of 2 feet above the stump, the spray area was more than enough to cover 10 inch diameter stumps, and the amount of spray contacting the stump appeared adequate. Stumps sheared at ground level often had debris thrown on them by the shearing action. This interfered with proper stump wetting and complete application. Cutting the trees 2-4 inches above ground reduced the severity of that problem.

No problems developed with regard to component mounting and placement during the short term test. All components were well protected from the environment.

The overall observation time was about 3 hours and only approximately 2 gallons of spray solution were used in harvesting more than 100 trees. The positioning of the nozzle and the spray application time added little to total production time. The system was very effective at consistently and thoroughly wetting the entire stump.

SUMMARY AND CONCLUSION

A feller-buncher mounted spray system may help to reduce site preparation costs in chip harvested sites. It is felt that sprout control can be accomplished by the combined shearing-spraying operation. In limited tests with a feller-buncher equipped with a spray system, stump surfaces were consistently wetted by the sprayer and system operation was simple. The harvesting production time was delayed only about 5 seconds per cycle with the addition of the spraying process. Component selection and placement on the feller-buncher were adequate. The items were well protected from the environment and free from mechanical interference with the machine.

As fuel chip use becomes more popular, the added advantages from combined harvesting and herbicide stump application operations with a feller-buncher mounted spray system may become even more apparent. The system could be a good option for clearing and preparing sites for reforestation and may reduce expenses required

by conventional site preparation methods. Also, since often times an area is harvested and a period of time allowed to elapse for sufficient sprouting to occur for burning, this sprout control method may allow pine to be planted sooner.

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DIRECT SEEDING VERSUS PLANTING FOR ESTABLISHMENT OF PINES ON WEST FLORIDA SANDHILLS [1/]

Kenneth W. Outcalt [2/]

Abstract.--Survival and growth of direct-seeded longleaf, slash, and Choctawhatchee sand pines were compared with that of nursery-grown 1-0 seedlings on a typical sandhills site. Nursery seedlings of all species grew faster initially, but by age 8 growth rates were similar for trees on both planted and seeded areas. Trees on the planted areas, however, are still significantly larger than those on seeded areas because of the advantage gained in the early years. Direct-seeded slash and longleaf pine plots are now understocked and, because of mortality from brown-spot needle blight, planted longleaf plots are also poorly stocked. Planted slash pine plots are fairly well-stocked but growth rates have been poor. Sand pine had the best rate of growth and was the only species successfully established by direct seeding.

INTRODUCTION

About 8 million acres of sandhills are scattered throughout the southeastern coastal plain of the United States. These marine deposits from the Pleistocene epoch are an important physiographic feature of central and northwest Florida. They also occupy significant areas of Georgia, South Carolina, and North Carolina in the transition zone between the upper coastal plain and the piedmont (Burns and Hebb 1972). Sandhills soils are typically acid, infertile, and droughty. Because of sorting action during deposition they are largely quartz sands, ranging from a few feet to more than 20 feet deep.

The sandhills were once dominated by relatively open stands of longleaf pine (*Pinus palustris* Mill.) but only scattered patches and isolated trees remain. Most sites were claimed by a scrub oak-wiregrass understory following removal of the longleaf in the early 1900's. This scrub vegetation is principally turkey (*Quercus laevis* Walt.), bluejack (*Q. incana* Bartr.), and sandpost (*Q. stellata* var. *margaretta* (Ashe) Sarg.) oaks, and wiregrass (*Aristida stricta* Michx.).

The Chipola Experimental Forest was established in northwest Florida by the USDA Forest Service in the early 1950's to develop methods for making sandhills more productive forest sites. Initial observations indicated that direct seeding might be used to establish pine plantations on these areas. Direct seeding is cheaper than planting nursery-grown seedlings. The objective of this study was to compare the survival and growth of direct-seeded longleaf, slash (*P. elliottii* Engelm.), and Choctawhatchee sand (*P. clausa* var. *immuginata* Ward) pines with nursery-grown 1-0 transplants on site-prepared scrub oak sandhills.

METHODS

Study Site

The study site is 1.3 miles west of the Chipola Experimental Forest headquarters (NW 1/4 of Sec. 5, T 1 S, R 10 W) in Calhoun County, Fla. The soil is a typical droughty, deep sand of the Lakeland series. The site was burned in May, chopped in July, and rechopped in August 1958. Plots established in 1963 were disked in November 1962; plots established in 1964 were disked in November 1963.

Experimental Design

A randomized block, split-plot design with treatments replicated over time included four blocks with 12 plots within each. Within each block, species were randomly assigned to a group of four plots, i.e., the main plots. These four

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Kenneth W. Outcalt is Soil Scientist, Southeastern Forest Experiment Station, Gainesville, Florida 32611.

plots were randomly selected for direct sowing or planting, two in 1963 and two in 1964. Plots were 16 by 200 feet and contained 50 seed spots or transplants, two rows of 25 each.

Establishment

Seeds were collected from natural stands of longleaf and slash pine on the Chipola Experimental Forest in the fall of 1960. Sand pine seeds were collected on the Eglin Air Force Reservation in the fall of 1961. Germination averaged about 70 percent in tests of all seed lots before and after study establishment.

A repellent coating of Arasan® and endrin was applied to direct-sowed seeds. Twelve seeds were sowed at each seed spot with spots at an 8- by 8-foot spacing. Seeds were covered with 1/4 to 3/8 inch of soil and a hardware mesh cone was placed over the seed spot for protection from predators. Some type of seed protection is necessary on small areas cleared in scrub oak sites but would not be required on larger operational-scale areas. One year after sowing, the cones were removed and all but the largest seedling was removed from spots with multiple seedlings.

Seedling stock was grown in the Chipola Experimental Forest Nursery. After 1 year in the nursery, seedlings were lifted and dibble planted in the field at an 8- by 8-foot spacing. Direct seeding and planting 1-0 stock was done in February for both the 1963 and 1964 plots. Fall or winter is the recommended season for direct sowing longleaf, slash, and sand pine in this area (Burns and McReynolds 1975), but a February date was used to coincide with the date seeds were sowed in the nursery for the planting stock.

Data Collection and Analysis

Heights and survival were recorded annually on all plots from ages 1 to 10 years. Tree diameters were measured on all plots at age 10. Heights and diameters were measured on the sand pine plots only at 20 years of age. Initial survival for direct-seeded plots was based on the 12 seeds planted at each seed spot. Survival data after 1 year were based on the number of planting or seed spots. Other than the initial survival of direct-sowed seedlings, there were no significant differences between the 1963 and 1964 plots so data were combined for analysis and presentation.

RESULTS AND DISCUSSION

Based on the 12 seeds planted at each seed spot, survival at the end of the first planting season was 19, 14, and 58 percent for longleaf, slash, and sand pine, respectively, for the 1963 planting, and 75, 69, and 79 percent, respectively, for the 1964 planting. The difference in initial survival was largely due to a dry period in March and April of 1963 when total rainfall for the 2-month period was less than 2 inches. Even though survival was low for direct-seeded plots in 1963, at least one seedling survived at each planting spot. Thus, all plots for both years were fully stocked after 1 year.

Between ages 1 and 10, mortality was rather high on the direct-seeded longleaf and slash pine plots, and both were understocked at age 10 (Table 1). Plots direct seeded to sand pine had an acceptable density of 325 trees per acre after 20 years. Plots planted to longleaf were understocked due to losses from brown-spot needle blight (Scirrhia acicola (Dearn.) Siggers). Planted slash and sand pine each had more than 80 percent survival after 10 years.

Table 1.-- Stocking and growth of direct-seeded and planted longleaf, slash, and sand pines on a west Florida sandhills site.

Establishment method	Stocking	Diameter[1/]	Height	Volume[2/]
	No./acre	Inches	Feet	Ft.^{3} /acre
		LONGLEAF PINE (age 10)		
Direct seeded	210	1.7	3.0	8
Planted	245	2.5	6.2	30
		SLASH PINE (age 10)		
Direct seeded	180	1.2	11.5	28
Planted	555	3.1	17.2	255
		CHOCTAWHATCHEE SAND PINE (age 10)		
Direct seeded	350	3.1	18.1	220
Planted	630	4.7	24.5	1045
		CHOCTAWHATCHEE SAND PINE (age 20)		
Direct seeded	325	5.4	40.6	1100
Planted	625	6.9	47.8	3450

1/ All differences in growth attributed to method of establishment are statistically significant at the 0.05 level.

2/ Volumes are for the entire bole inside bark. Longleaf and slash pine volumes are based on equations from Schmitt and Bower (1970).

During the early years of the study, planted stock grew at a faster rate than direct-seeded trees (Fig. 1). Since about age 8, however, height-growth rates have been nearly equal for both establishment methods. The initial advantage of the planted trees was still evident after 10 years, with planted sand pine averaging 6.4 feet taller, planted slash pine 5.7 feet taller, and planted longleaf pine 3.2 feet taller than the direct-seeded trees of the same species (Table 1). Average diameters at age 10

were also greater for the trees established by planting. These height and diameter advantages of the planted stock continued for sand pine through age 20.

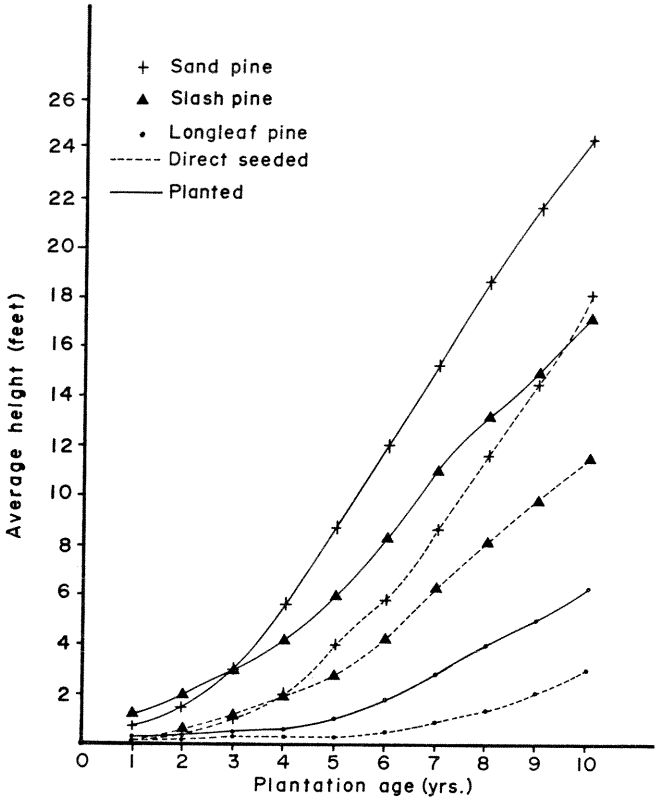

Figure 1.--Average tree heights by species, age, and establishment method.

Because of poor survival and lower growth rates, direct-seeded plots produced much less wood than the planted stands at 10 years of age (Table 1). Plots planted to longleaf and sand pine contained about four times as much wood as direct-seeded plots while planted slash pine plots contained nine times as much wood as direct-seeded plots. The difference in volume between direct-seeded and planted sand pine had diminished somewhat by age 20, but planted plots were still superior.

Some of the observed height advantage was because planted trees were 1 year older than direct-seeded trees. The height of direct-seeded trees, however, lagged 2 or more years behind the planted stock. Thus, planted trees had more than just an age advantage. Because of their initial height, planted trees were better able to deal with competing vegetation and suffered less growth loss. Because these sandhills sites tend to be infertile, some of the difference in growth was likely due to nutrients that the planted stock accumulated while in the nursery. Once both types of trees were above the competition and dilution effects had mediated the nutrient differences, an equalization in mean annual height growth would be expected. Sand pine height growth between ages 10 and 20 averaged 2.25 and 2.3 feet per year on direct-seeded and planted plots, respectively, while diameter growth was 0.23 and 0.22 inches per year. Thus, as expected, growth rates did equalize.

Even though all plots were fully stocked at the end of the first growing season, poor stocking at age 10 was a significant problem with the direct-seeded longleaf and slash pine plots. For longleaf pine this was primarily because of brown-spot disease, which could be controlled to reduce mortality. Seeding rates could also be adjusted to compensate for expected mortality. However, even when adequate stocking was obtained, as it was in the planted longleaf and slash pine plots, growth rates were still inferior to that of sand pine.

CONCLUSIONS

Choctawhatchee sand pine had the best growth in both direct-seeded and planted plots. This would be expected since Choctawhatchee sand pine has consistently outperformed all other species tested on these sandhills sites (Brendemuehl 1981). In addition, sand pine was the only tested species where adequately stocked stands were established by the direct-seeding method of regeneration. Even though successfully established by direct seeding, because of the limited seed supply and the slower initial growth compared with planted seedlings, planting in most cases would be preferred. The only advantage of direct seeding is lower establishment cost.

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RELATING ROOT GROWTH POTENTIAL TO SURVIVAL AND GROWTH OF LOBLOLLY PINE SEEDLINGS[1/]

Charles R. Venator and James P. Barnett[2/]

Abstract.--Loblolly pine seedlings were lifted monthly from October 1979 to April 1980 to determine any relationships of root growth potential to survival and height growth. Root growth potential varied by the different lifting dates, but it was not significantly correlated to field performance. The best root growth was found when seedlings were lifted in January, February, and March. Seedlings lifted prior to dormancy survived poorly in the field. The study found evidence that "lifting windows" can be related to improved field performance.

INTRODUCTION

Increasing the field performance of southern pine seedlings during the first year following outplanting is one of the greatest needs in forestry across the South. To accomplish this would lower both nursery production and plantation establishment costs. One means of improving this first-year performance could be the determination of optimum lifting and planting dates. Timeliness of these events appears to influence seedling survival. However, there is no general agreement on the most favorable dates.

Venator (1985) found that loblolly pine seedlings lifted in December or January survived and stored better than those lifted later in the lifting season. Dierauf (1978) reported in a review of loblolly planting practices in Virginia that late winter and early spring planting gave better seedling survival than did later planting. In a related paper, Gardner and Dierauf (1976) found that loblolly seedlings' root systems steadily increased in weight through the winter which indicates seedlings continue root growth in the colder months.

In another study to determine the effect of planting date on regeneration and development of roots of loblolly pine seedlings, Bilan (1961) lifted and planted seedlings at 2-week intervals between November and March. Seedlings planted early grew substantially larger root systems than seedlings planted late. His conclusion was that late planted seedlings were more likely to succeed only when favorable soil moisture conditions occurred in the growing season that followed.

In a recent publication Brissette and Roberts (1984) studied the effect of seedling size and lifting date on root growth potential of loblolly pine seedlings of two Arkansas nurseries. Larger seedlings exhibited significantly more root regeneration potential than small seedlings, perhaps because larger root systems had more sites for root growth or more food reserves. Also, seedlings lifted in November had less root growth potential (RGP) than those lifted in January or March. However, no statistically significant correlation between RGP and field survival of seedlings was found.

In this study, root growth potential was related to field survival and seedling heights over a period of several months between early fall and late spring.

METHODS

Seedlings were lifted from a research nursery at the Alexandria Forestry Center. Liftings were made near the first of each month, between October 1978 and April 1979. Five plots of 20 seedlings each were outplanted each month in a randomized block design. All of the 1-0 seedlings were planted by hand at a 2' x 2' spacing. Only mycorrhizal seedlings were outplanted. Site preparation prior to outplanting consisted of disking to minimize variation due to competing vegetation.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984

2/ Research Plant Physiologist and Principal Silviculturist, Southern Forest Experiment Station, USDA-Forest Service, Pineville, LA 71360.

Root growth potential measurements were made on 25 seedlings from each lifting date. These were potted five each in 8-inch plastic pots filled with washed sand. The pots were placed in an environmental chamber with a constant temperature of 20°C and a 14-hour light photoperiod. Number and length of new roots exceeding 5 mm were measured after 30 days.

The field survival data after 1 and 2 years were converted to arcsine $\sqrt{\text{proportion}}$ values for correlations with root growth potential. Seedling heights were measured to the nearest centimeter. Correlation coefficients of RGP and field performance and Duncan's multiple range tests of lifting date means were evaluated for statistical significance at the 0.05 level.

RESULTS

Root Regeneration

The number of new roots ranged from 20 per seedling with an average length of 2.3 cm to 134 with an average length of 2.8 cm (table 1). Root regeneration was highest for the January, February, and March lifted seedlings with the peak occurring in February. The highest RGP coincided with the period when cold hardiness or dormancy seemed greatest.

Average root length was quite uniform regardless of lifting date, although a peak did occur during January. The coefficient of determination relating numbers to length of new roots was 0.415, which was not statistically significant.

Survival

First-year survival averaged 75 percent or more in only three plantings (February, March, and April) (table 1). Survival of seedlings planted in October averaged only 42 percent. There was a 30-percentage point drop in overall survival between the first and second years in the field. The maximum survival rate was reached by the March plantings, and these averaged only 51 percent. This major drop in overall survival reflected the severe drought of 1980. Monthly rainfall from May through September averaged only 5 inches, compared to a 30-year average of 21 inches for the same period.

Correlation coefficients between RGP (numbers of new roots) and survival after 1 and 2 years was 0.679 and 0.611, respectively. Only 46 and 37 percent of the variation in survival was accounted for by root growth potential.

Heights

Seedling heights averaged from 52 to 63 centimeters after 2 years in the field (table 1). Seedlings planted in October were smaller than those planted the other dates. Heights were not significantly related to RGP. The correlation coefficient between numbers of new roots and second-year height was 0.552.

DISCUSSION

The RGP data indicate that loblolly pine seedlings have a period during the lifting season

Table 1.--Root growth potential, survival, and heights of loblolly pine seedlings lifted and outplanted monthly between October 1979 and April 1980[1/]

Lifting/planting date	Root growth potential: New roots	Root growth potential: Avg. length	Survival: 1st year	Survival: 2nd year	Height: 2nd year
	---number---	----cm----	-----percent-----		------cm-----
October	20 a	2.3 bc	42 a	27 a	52 b
November	63 b	2.0 b	68 ab	23 a	61 a
December	21 a	1.5 a	69 ab	32 a	59 a
January	105 c	3.3 e	71 b	40 a	56 a
February	134 c	2.8 d	81 b	42 a	63 a
March	108 c	2.7 cd	79 b	51 a	62 a
April	43 ab	2.7 cd	75 b	43 a	60 a

1/ Means within columns followed by the same letter are not significantly different at the 0.05 level.

when root growth is better than at other times. This confirms the recent report (Venator 1985) that a "lifting window" exists for loblolly pine and that it coincides with the period when seedlings are considered to be most dormant.

It is generally assumed that RGP is closely related to field survival. However, a statistically significant relationship between numbers or lengths of new roots and survival was not found. Others have reported the same results (Brissette and Roberts 1984). An even poorer relationship existed between RGP and seedling growth. The relationship between RGP and field performance could probably be improved by more closely grading seedlings by morphological characteristics prior to installation of a study comparing root development and seedling performance.

Even when a close relation exists between RGP and field performance, climatic conditions following outplanting may control performance more than the morphology and physiology of the plants.

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SURVIVAL OF PINES ON DROUGHTY SOILS: TWO YEAR RESULTS [1/]

James C. Kroll,[2/] William C. Deauman,[3/], C. Darwin Foster,[4/], David L. Kulhavey,[2/] and David Tracey[2/]

Abstract.--Three species of pines (loblolly, slash and longleaf) were planted with four treatments (loblolly and slash = bareroot, clay dip slurry and Terrasorb®; longleaf = containerized) to test survival on droughty, typic quartzipsamments soils. At the end of the first season, survival was significantly better for the containerized longleaf and Terrasorb® treated loblolly pine (81 and 85%) followed by untreated loblolly pine (51%), clay-treated loblolly (50%), then Terrasorb® treated slash (48%), untreated slash (41%) and clay-treated slash (36%). At the end of the second growing season, longleaf had 56% survival, Terrasorb® treated loblolly (51%), clay-dip slurry loblolly (31.9%), Terrasorb® treated slash (21%), untreated loblolly pine (20%) and clay-treated slash and untreated slash (17%). Pest management recommendations and management considerations are presented.

INTRODUCTION

During the last twenty years clear-cutting, followed by intensive site preparation and planting with genetically improved seedlings, has become a widely used method for southern pine regeneration. Such techniques, when applied on a broad scale, "one-size-fits-all" manner often produce less than satisfactory results. This is particularly the case when ecologically sensitive sites are involved. We encountered one such problem while attempting to regenerate pines on droughty soils (=Tonkawa Series) near Nacogdoches, TX.

Tonkawa soils are Typic Quartzipsamments, characterized by low fertility and high permeability, especially in uplands. These soils make up approximately 23,000 acres in Nacogdoches, Panola, Rusk and San Augustine counties. Tonkawa soils are formed in sandy deposits, with slopes ranging from 0-20 percent. Typical site index is 55 (base 50 years). The original forest cover type was probably dominated by shortleaf pine (*Pinus echinata* Mill.) with some longleaf pine (*P. palustris* Mill.) intermixed. Dominant hardwood species were sandjack (bluejack) oak (*Quercus incana* Bart.).

From 1973 to 1975, approximately 5,200 acres were clearcut, followed by either chopping, burning and/or shearing and windrowing with V-blades. In some areas a whole-tree chipper was used for hardwood removal. Essentially, this was removing organic matter from the surface and exposing bare mineral soil to the sun and wind, greatly decreasing the moisture holding capacity of the soil, as well as, increasing surface temperature. Subsequently, several attempts were made to reforest the area (1974-1981), using both machine planting and hand planting methods. Planting stock was generally slash 1-0 seedlings, with some drought hardy loblolly also being planted. Sources of seedlings included Texas Superior seedlings from the Texas Forest Service and seedlings from Florida and Oklahoma. All of

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[2/] Respectively, Professor of Forest Wildlife, Associate Professor of Forest Entomology, and Lecturer, Center for Applied Studies, School of Forestry, Stephen F. Austin State University, Nacogdoches, TX 75962.

[3/] Soil Conservationist, USDA Soil Conservation Service, Nacogdoches, TX 75961.

[4/] Director of Administration, Temple-EasTex Inc., Diboll, TX 75941.

these plantings were failures (i.e., less than 10 percent survival) due primarily to droughty conditions. Other factors included rabbit and town ant damage. Town ant predation is common on such sites (Moser 1984).

This study was initiated in 1983 in order to ascertain the fate of pine seedlings given various root treatments, planted on Tonkawa soils. Results reported herein represent two years of survival data.

METHODS AND MATERIALS

Study plots were established on Tonkawa (Typic quartzipsamments) soils (Dolezel 1980) 6 miles west of Garrison, Nacogdoches Co., TX. Seven treatments with eight replications (Fig. 1) each were established. Within each replicate, 48 seedlings were planted on an 8 x 8 foot spacing in four rows of 12 seedlings each. A buffer zone, equal in size to the replicates was planted with bare rooted loblolly pine seedlings between replicates. Replicates were 208 by 104 ft., each containing the same seven treatments randomly arranged (e.g., Replicate 5, Fig. 1).

The seven treatments were:

1. bare rooted loblolly pine,
2. Terrasorb® treated loblolly pine,
3. clay-slurry treated loblolly pine,
4. bare rooted slash pine,
5. Terrasorb® treated slash, and
6. containerized longleaf pine.

Terrasorb® is an organic compound which, when mixed with water, forms a hydroscopic substance used as a root dip to increase moisture holding capacity. Clay-slurry is a similar but inorganic compound that also forms a hydroscopic substance when mixed with water. Planting stock was 1-0 seedlings. Replicates were hand-planted using standard methods in January 1983. The study was replicated in January 1984, but failed due to excessively low winter temperatures, followed by high rabbit predation.

Survival counts were taken at approximately three month intervals throughout the year. At each count, surviving seedlings were flagged for ease of relocation. Data for all replicates were grouped by treatment to compare the effects of each treatment on survival and growth. We are in the process of taking height and diameter measurements on surviving seedlings for comparison of growth rates for each treatment.

RESULTS

First Year Survival.--First year data (Fig. 2) indicated a drastic decrease in survival between the period June-October, reflecting the below normal rainfall during that period (H. Reeves, pers.

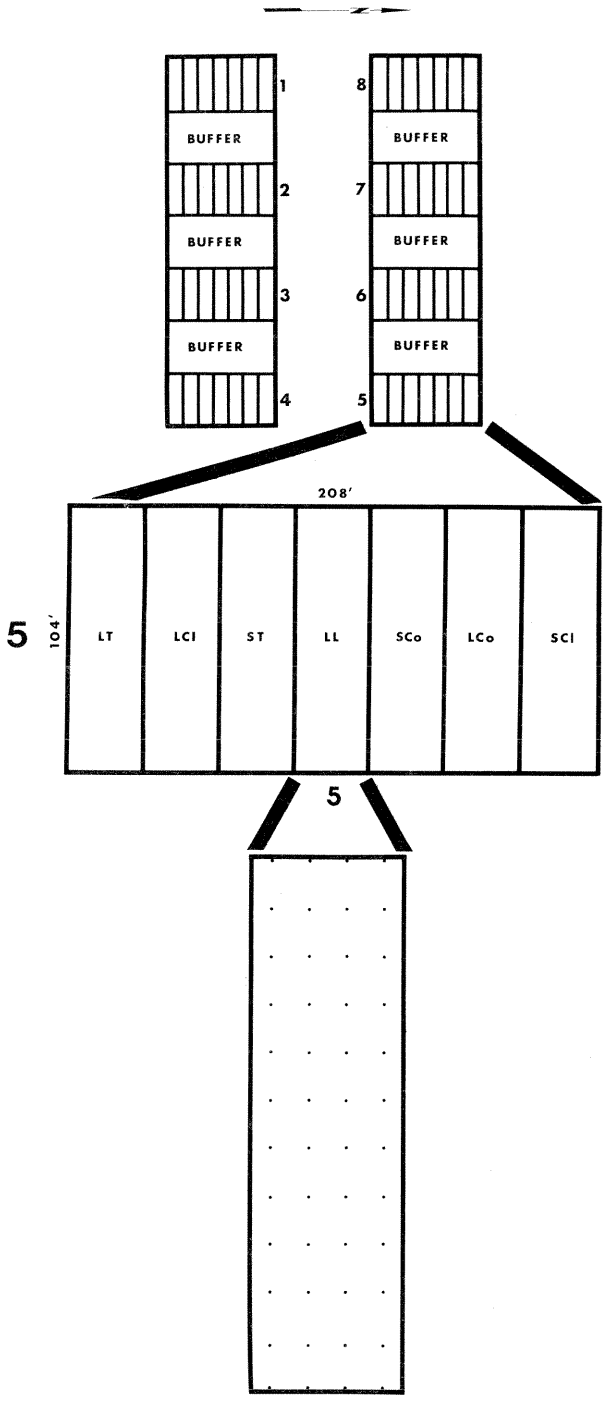

Figure 1. Experimental design for the Tonkawa pine seedling survival study. Each of the 8 replicate plots were randomly assigned 7 treatments. Abbreviations for treatments are those given in Fig. 2.

comm.). For the remainder of the year, both the longleaf and loblolly Terrasorb® treatments showed much higher survival rates (greater than 80%) than the other five treatments (50% or less). The entire study was repeated in December 1983, but due to extremely low temperatures (8°F.) for an extended period of time, that planting was a total loss.

Second Year Survival.--Second year data (Fig. 2) indicated another drastic decrease in survival between August and October, reflecting another severe drought. At last count (October, 1984), the longleaf and loblolly Terrasorb® treatments still showed significantly higher survival rates (56.6 and 50.8%, respectively), while the other five treatments showed unacceptable levels of survival (32% or less). The slash treatments all had very low survival, which indicates that this species is unsuitable for growing on droughty sites. Within some replicates, there was often less than 10% survival of the slash treatments.

DISCUSSION

Containerized longleaf and Terrasorb® treated loblolly pines had better survival than the other treatments. Management considerations for these deep sandy soils include:

1) minimizing clearcutting (followed by intensive site preparation as these methods

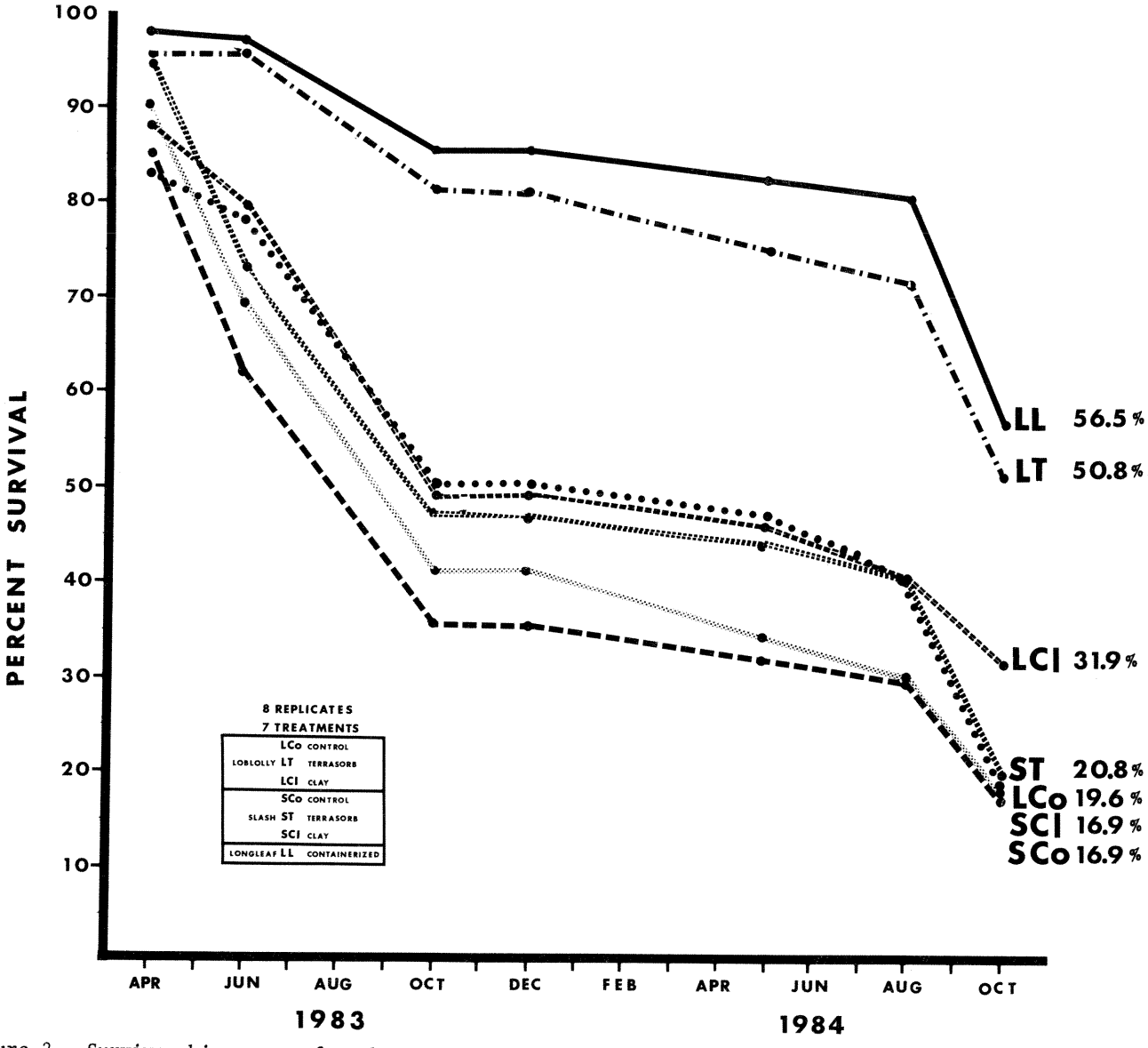

Figure 2. Survivorship curves for the 7 seedling treatment types during the period April, 1983 to October 1984. Plotted values represent means of 8 replicates.

cannot be economically justified due to the low productivity of the site;

2) considering underplanting with delayed hardwood removal, as this method leaves cover and shade for the seedlings. The key idea is to leave some cover and organic matter on the site to prevent exposure to the sun and wind.

The USDA Soil Conservation Service (Nacogdoches, TX) reports excellent success in regenerating sites on droughty soils by underplanting followed by injection. The problem of regeneration on deep sandy soils emphasizes the importance of root treatments for loblolly pine and the consideration of longleaf pine for planting.

Future project plans include:

1) continued monitoring of the existing replicates;
2) field operation tests of containerized longleaf, barerooted loblolly and shortleaf pine with and without Terrasorb®;
3) soil tests for moisture holding capacity and temperature combined with monitoring of wind speed;
4) monitoring of precipitation including amount and periodicity;
5) examination of survival in relation to topographic position, slope and aspect; and
6) study of mortality through time to ascertain cause and degree of each mortality factor (i.e., summer drought, winter low temperatures, pests, including town ants and rabbits).

In conclusion, we feel that Terrasorb® treatments and longleaf pine should be considered when planting seedlings on exposed droughty soils.

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COPPICE PRODUCTION FOLLOWING THE HARVEST OF A POLE-SIZE SYCAMORE PLANTATION[1]

E. J. Schmeckpeper and R. P. Belanger[2]

Abstract.--A high percentage of stumps sprouted during the first growing season following harvest of an 11-year old sycamore plantation. Subsequent mortality and total yields were significantly influenced by the length of coppice rotations. The highest yielding sprout clumps resulted from long coppice rotations. A 3 + 3-year cutting cycle produced 41.38 tons per acre of green weight material compared with 17.43 tons per acre for a 1 + 1 + 1 + 3-year rotation. There was a direct relationship between the stump diameter of the parent tree and the production of coppice growth. More mortality resulted from frequent cuttings than from longer rotations. There was no evidence of root or stem disease in the sprout regrowth.

The primary objective of short-rotation hardwood management is high yields of wood fiber from harvests of the parent stand and subsequent coppice regrowth. Two methods of producing maximum hardwood fiber yields have been tested: (1) rotations of 1 to 6 years to produce whole-tree chip material, and (2) rotations of 10 to 15 years to produce conventional stemwood (Saucier *et al.* 1972, Steinbeck *et al.* 1972, Zobel and Kellison 1972, Belanger and Saucier 1975). On good sites, American sycamore (Platanus occidentalis L.) appears well suited to both systems of management.

The purpose of managing short-rotation sycamore is to ensure high yields of coppice growth over repeated harvests. Guidelines have been developed to assure a high degree of sprouting, increase coppice yields, and maintain stump vigor for 4- to 6-year-old plantations (Belanger 1979). There is no information related to the sprouting response of older sycamore stands. The harvest of an 11-year-old pole-size sycamore plantation in the Georgia piedmont provided the opportunity to study the sprouting characteristics of larger and older stumps.

MATERIALS AND METHODS

Study Area

The sycamore study plantation was located on a well-drained piedmont flood plain in Greene County, Georgia. The 4-acre planting site was disk plowed and then hand-planted with 1-0 seedlings during the winter of 1960-1961. Seedlings were planted at an 8- x 8-foot spacing, the plantation thinned to reduce competition at age 7, and harvested after leaf fall at age 11.

The parent stand contained an average of 472 stems per acre at the time of harvest. Average d.b.h. in the plantation was 5.8 inches; average tree height was 63 feet. Trees were cut at ground level with a chain saw. Average stump diameter of the felled trees was 7.8 inches and ranged from 3.3 to 13.0 inches. Total tree yield (green weight--stem and branchwood) averaged 92.6 tons per acre.

Mean annual increment had not culminated in the stand at age 11. However, power-dam construction had begun to impound the river adjacent to the plantation. The parent stand was harvested and short coppice rotations scheduled to determine the sprouting response of older stumps before the site was inundated. The study area was flooded by Lake Oconee after 6 years of coppice growth--17 years from planting.

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[2]Research Assistant, North Carolina State University, Raleigh, North Carolina 27650, and Principal Silviculturist, Southeastern Forest Experiment Station, Athens, Georgia 30602.

Study Design and Measurements

Three coppice rotations were randomly assigned to 54 study plots. Cutting schedules were 1 + 1 + 1 + 3 years (Treatment 1), 2 + 4 years (Treatment 2), and 3 + 3 years (Treatment 3). The sequence indicates age of the sprouts when harvested. All cutting was done during the dormant season. Study plots were square and consisted of 16 planting spaces plus an outer row of border trees. Average number of study trees per plot was 11 and ranged from 8 to 16 depending on survival and degree of thinning. Stand and individual tree characteristics of the 11-year-old plantation were not statistically different among the assigned treatments.

Individual sprout clumps were weighed in the field at each harvest to determine green weight production. Additional measurements were made after the final (6th year) coppice cut to determine the basal diameter of individual sprouts, total height, and number of live sprouts per stump. Analysis of variance was used to determine if sprouting characteristics and total green weight production were significantly different among treatments. Duncan's new multiple range test with the Statistical Analysis System (Ray 1982) was used to separate treatment means.

RESULTS

Stump Survival

A high percentage of the first-generation stumps sprouted. Only 4 of the 596 selected study stumps did not produce measurable coppice growth. A total of 53 stumps died during the study. Stump mortality was significantly influenced by cutting treatments (Table 1). More mortality resulted from frequent cuttings (Treatment 1) than from longer rotations (Treatments 2 and 3). Average diameter of the dead stumps was 7.2 inches and ranged from 3.5 to 10.0 inches. There was no significant difference between the average size of the dead stumps and the mean of all stumps.

Sprouting Characteristics

The importance of coppice rotations was significantly reflected in the sprouting characteristics of individual stumps at final harvest (Table 2). Frequent cuttings (Treatment 1) adversely affected the number of sprouts, basal diameter, total height, and green-weight yields of coppice growth. Larger and heavier sprout clumps resulted from longer coppice rotations.

Table 1.--Stump survival and mortality following different coppice rotations of American sycamore. The parent stand was an 11-year-old pole-size plantation

Coppice rotations †	Live stumps: Initial sample	1st year	2d year	3d year	6th year	Mortality
	.....Number per acre.....					..Percent..
1 + 1 + 1 + 3	466 a	466	463	449	387 a ††	17.0
2 + 4	466 a	--	466	--	435 b	6.7
3 + 3	478 a	--	--	468	449 c	6.1

† Sequence indicates age of sprouts when harvested.

†† Within-column means not followed by the same letter are significantly different (P = > 0.05).

Table 2--Sprouting characteristics at final harvest (6th year) resulting from different coppice rotations of American sycamore. The parent scand was an 11-year-old pole-size plantation

Coppice rotations †	Average per stump							
	Live sprouts		Diameter		Height		Green weight	
	Total	Dom. & Codom.	All	Dom.	All	Dom.	All	Dom.
	.....Number.....		....Inches....		.....Feet....		....Pounds.....	
1 + 1 + 1 + 3	4.4 a ††	3.1 a	2.0 a	2.4 a	23.7 a	26.1 a	54.3 a	22.4 a
2 + 4	5.2 a	4.2 b	2.6 b	3.4 b	28.9 b	33.3 b	121.6 b	46.3 b
3 + 3	7.5 b	5.1 c	2.4 b	3.1 b	26.6 c	30.6 c	107.3 b	36.1 c

† Sequence indicates age of sprouts when harvested.

†† Within-column means not followed by the same letter are significantly different (P = > 0.05).

Diameter of the stump also influenced the amount of coppice production. Regression analysis indicated a direct linear relationship between initial stump size and total yield over the rotation (Fig. 1). Belanger (1979) reported similar growth responses after harvesting a 5-year-old sycamore plantation. Results may be related to more carbohydrate reserves and the greater nutrient-water foraging capacity of large root systems over small ones.

Coppice Production

Stump mortality and sprouting characteristics of individual stumps combined to influence total coppice yields (Table 3). Longer rotations produced more aboveground biomass than shorter rotations. The balanced 3 + 3-year cutting cycle produced 41.38 tons per acre of green weight material compared with 17.43 tons per acre for the 1 + 1 + 1 + 3-year cutting cycle. Trends are consistent with studies on repeated coppicing in younger sycamore plantations (Kormanik *et al.* 1973).

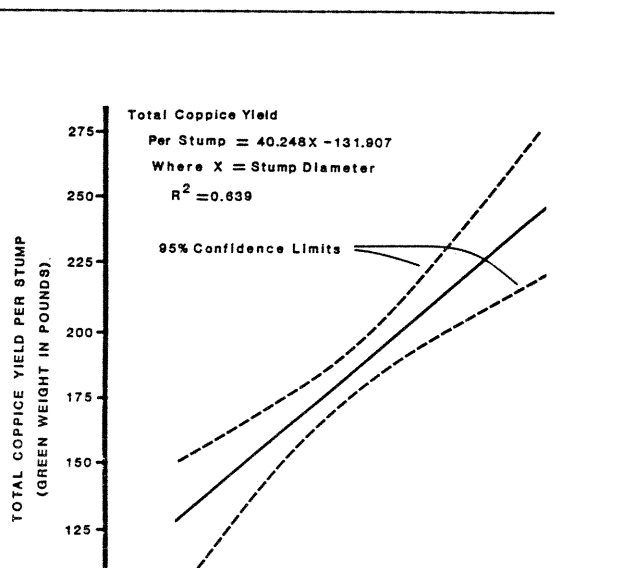

Fig. 1.--Total coppice yield of sycamore related to stump diameter of the parent tree.

Table 3.--Green-weight yields from different coppice rotations of American sycamore. The parent stand was an 11-year-old pole-size plantation

Coppice rotations †	1st year	2nd year	3rd year	6th year	Total	Annual
	.....	.....	Tons per acre	.....	.....	.....
1 + 1 + 1 + 3	2.04	2.10	2.11	11.18	17.43 a ††	2.91
2 + 4	--	7.96	--	26.19	34.15 b	5.69
3 + 3	--	--	17.89	23.49	41.38 c	6.90

† Sequence indicates age of sprouts when harvested.

†† Within-column means not followed by the same letter are significantly different (P = > 0.05).

Frequent harvest inhibits the maximum growth and development of stump sprouts. Study plots harvested each of the first 2 years after cutting the parent stand (1 + 1) produced 4.14 tons per acre of green-weight material compared with 7.96 tons per acre for plots harvested after 2 years. Three successive years of cutting (1 + 1 + 1) produced 6.25 tons per acre compared with 17.89 tons per acre for plots harvested after a 3-year interval.

Stumps harvested annually did not recover as well as stumps harvested over longer rotations. Total green weight yield in the 3-year period following annual cuttings (Treatment 1) was 11.18 tons per acre compared with 23.49 tons per acre for the final 3-year period in Treatment 3. Frequent cutting may partially deplete the amount of carbohydrate reserves in the root systems.

DISCUSSION

There were no serious problems associated with the initiation, growth, and development of stump sprouts following the harvest of an 11-year-old pole-size sycamore plantation. Sprouting did not appear to be hindered by the annual flooding of the river adjacent to the plantation, or the accumulation of leaves and other debris on the cut surface of the stumps. Although the above-ground portion of the parent stumps had decayed by the final harvest, there was no evidence of root or stem disease in the sprouts.

Longer coppice rotations produced larger dominant and codominant stems than short rotations. Tree sizes are relevant to the choice of harvesting equipment and quality of the final product. Most harvesting equipment requires a minimum tree size and/or volume per acre to operate economically. Larger stems also contain lower proportions of bark and impurities in the chip mix than smaller stems (Saucier *et al.* 1972).

Several sprout clumps were not cut during the study. These stumps were located in border rows at the edge of the plantation and usually contained two, three, or four dominant and condominant stems. Most of the intermediate and suppressed sprouts had died due to natural competition. Growth and vigor of the dominant sprouts were excellent, indicating that rotations greater than 6 years are certainly possible for the coppice management of sycamore plantations.

Maximum green weight production of coppice material was similar to growth of the original plantation. The parent stand had produced 40.7 tons per acre of stem and branchwood through age 6 compared with 41.4 tons per acre of coppice growth from the 3 + 3-year rotation. This is excellent growth and equivalent to approximately 3 cords per acre per year. However, this was an extremely fertile bottomland site. Growth and yield would be less for most plantings.

CONCLUSIONS

Sycamore plantations can be managed on rotations of 10 through 15 years for fiber or fuel production. Careful choice of planting areas, thorough site preparation, graded planting stock, and intensive cultural treatments are essential for the successful establishment and early growth of the planted stand (Belanger and Saucier 1975). Results from this study showed proper management practices can produce acceptable yields of coppice material without losses from insects or diseases following the harvest of pole-size trees. Balanced rotations of 5 years or longer are recommended to reduce stump mortality, sustain stump vigor, and maximize the production of wood fiber over repeated harvests.

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SEASON OF HARVEST AND SITE QUALITY EFFECTS ON HARDWOOD REGENERATION IN THE VIRGINIA PIEDMONT[1/]

J. S. Kays, D. Wm. Smith, and S. M. Zedaker[2/]

Abstract.--The effects of season of harvest and site quality after two growing seasons on sprout production of oaks, yellow-poplar, red maple, sourwood, and other species are evaluated. Clearcutting utilizing whole-tree harvesting was performed on six similar pairs of plots ranging from site index 48 to 75 (base age 50) for white oak. Pairs of plots received dormant season harvest, or growing season harvest. Stands selected spanned a typical range of upland hardwood Piedmont site conditions; characterized by low quality stems and poor species composition. Pre-harvest frequency, density, and species composition were measured in tree, shrub, and herb strata. Changes in frequency, density, and species composition from pre-harvest levels are reported. Silvicultural strategies for increasing oak composition are discussed.

INTRODUCTION

In the Virginia and North Carolina Piedmont, past abusive agriculture practices followed by unmanaged reversion to forest cover, high-grading, and wildfire have propagated stands characterized by low quality stems and poor species composition. Many of these poor and medium quality Piedmont sites support oak populations composed primarily of chestnut oak (*Quercus prinus* L.), scarlet oak (*Quercus coccinea* Muenchh.), and white oak (*Quercus alba* L.). Higher quality sites found on steeper hillsides of favorable aspects contain primarily white oak, northern red oak (*Quercus rubra* L.), and yellow-poplar (*Liriodendron tulipifera* L.). A significant amount of undesirable species such as; red maple (*Acer rubrum* L.), sourwood (*Oxydendron arboreum* L. D.C.), and blackgum (*Nyssa sylvatica* Marsh.), compete directly for site resources with desirable oaks and reduces the probability of successful oak regeneration after harvest. Many oak species sprout more frequently and productively during a dormant season harvest (Roth & Hepting 1943, Johnson 1977), however, the relative response of other species over a range of site qualities has not been reported for Piedmont sites. Using whole-tree harvesting the effect of different seasons of harvest on the growth potential and species composition should be manifested during the early stages of stand regeneration. Because of the potential problems of not obtaining adequate oak regeneration (Holt and Fisher, eds. 1979) and the possibility of favoring oak composition using a dormant season harvest, the response of different origins of desirable and undesirable regeneration to whole-tree harvesting was investigated. Number of stems, frequency, and mean height of different origins of regeneration was used to assess the density, distribution and dominance of oak species in the context of stand development on different site qualities.

STUDY AREA

The study area is located at the Virginia Polytechnic Institute and State University's Reynolds Homestead Research Center near Critz, Virginia. Soils are leached, eroded Ultisols developed mainly from granitic and metamorphic bedrock. Slopes range from 2-20 percent with 6-8 percent being most common. Annual precipitation averages 125 cm. per year and is well-distributed throughout the year. The frost free season is 196 days.

Six similar pairs of regeneration plots were located along a gradient of site productivity that also differed in terms of vegetation composition. The plots were situated in 50- to 80- year-old

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2/ Research Assistant, Associate Professor of Silviculture and Forest Soils, and Assistant Professor of Forest Ecology, Virginia Polytechnic Institute and State University, Blacksburg,Va.24061.

second growth oak-hickory forest on site qualities ranging from site index 48 to 75 (base age 50) for white oak. Differences in vegetation composition, based on the presence and absence of site specific species, enabled division of stands into two ranges of site quality, those stands below white oak site index 65 (base age 50), and those above (Table 1). Pairs of plots received dormant and growing season harvests. Whole-tree harvesting was employed with all stems greater than one-inch DBH cut to within 6 in. of the ground. The dormant season harvest was completed between February 21 and March 23 of 1983 and growing season harvests between June 21 and July 25 of 1983.

Table 1 - A summary of pre-harvest species, basal area (BA) and stems per acre attributes by season of harvest and site class, Critz, Va.

SPECIES	DORMANT SEASON HARVEST		GROWING SEASON HARVEST	
	POOR SITE CLASS 1/ (AV. SI = 54)	GOOD SITE CLASS (AV. SI = 72)	POOR SITE CLASS (AV. SI = 57)	GOOD SITE CLASS (AV. SI = 68)
OAKS 2/				
BA/acre	68	42	58	37
Stems/acre	198	111	151	100
RED MAPLE				
BA/acre	18	16	12	17
Stems/acre	102	106	91	130
YELLOW-POPLAR				
BA/acre	2	30	1	14
Stems/acre	23	90	11	46
SOURWOOD				
BA/acre	14	11	14	16
Stems/acre	174	93	207	148
OTHER WOODY				
BA/acre	12	25	13	27
Stems/acre	109	111	48	142
TOTAL				
BA/acre	114	124	98	111
Stems/acre	606	511	508	566
Mean Ht. 3/	48	58	49	52
Vol/acre	3,781	4,988	3,320	3,918

1/ Site index given is for white oak (base age 50) and is the average of three plots.
2/ BA = basal area in square ft. per acre
3/ Mean height in feet of dominants, codominants, and intermediates

METHODS

Each of the twelve regeneration plots were 98.4 ft. X 98.4ft. (30m X 30m) and contained three levels of nested subplots to enable sampling of the three strata comprising the original stand; the tree strata, shrub strata, herb strata. 1) The tree strata contained nine 32.8ft. X 32.8ft. (10m X 10m) subplots. Prior to harvest, all stems greater than 16.4 ft. in height were permanently marked, inventoried, and located on a coordinate grid. 2) The shrub strata was measured on a subset of the 36 possible 16.4ft. X 16.4ft. (5m X 5m) subplots. A 25 percent random sample was selected from each 32.8 ft. X 32.8 ft. subplot and stems 3.3 ft. to 16.4 ft. in height were inventoried but not tagged. 3) the herb strata was measured on one 3.3 ft. X 3.3 ft. (1m X 1m) subplot within each 32.8 ft. X 32.8 ft. subplot. This 1 percent sample inventoried all stems under 3.3 ft. in height by species.

After two growing seasons all twelve plots were again inventoried according to the three strata. The origin and height of each individual based on its position or absence in the pre-harvest stand was recorded. Four distinctive classes of regeneration were delineated:
1) stump sprouts - sprouts originating from stems in the pre-harvest tree strata (over 16.4 feet in height),
2) advance regeneration - sprouts originating from stems in the pre-harvest herb and shrub strata (under 16.4 feet in height),
3) root sprouts - sprouts originating from tree roots following harvest,
4) seedlings - individuals originating from seed following the harvest.
This procedure enabled a characterization of the new stand by the sources of regeneration.

The three quantitative measures chosen to assess stand condition were height of the tallest sprout as a measure of competitive ability in the new stand, stems per acre as a measure of density and ultimately stocking, and frequency of occurrence in the total number of cells sampled as a measure of distribution of stump sprouts in the new stand. Significance of differences in the height of regenerants in the same site class of different harvests was determined with a non-parametric Wilcoxon Rank Sum Test (alpha=.05). Statistical tests for differences in the density of stems were possible, but the large variation due to small sample size yielded no significant effects.

Assessing changes in the density of stems of different plots is meaningful only if the pre-harvest density is considered. To correct the post-harvest density of stump sprouts and advance regeneration for the pre-harvest density, analysis of covariance was employed. The main effects were season of harvest and species with post-harvest density as the dependant variable, and pre-harvest density the covariate. Unfortunately, the relatively large variability due to the clumpy stand structure resulted in many species having higher post-harvest densities, rather than pre-harvest densities. This resulted in negative residual values for some species, therefore, the covariance analysis could not be meaningfully interpreted. To give some indication of changes in species composition, the percent change in the pre- and post-harvest densities of stump sprouts and advance regeneration were used and presented in Tables 9 and 10, respectively.

PRE-HARVEST STAND ATTRIBUTES

The pre-harvest stand characteristics shown on Table 1 are presented for the five major species groups. All the stands were well-stocked, with oak species comprising about 60 percent of the basal area on the poor sites and 40 percent on the good sites. While basal area of red maple is similar on both site classes, yellow-poplar is significant only on the good sites. The poorer site classes contained a canopy composition of chestnut oak, scarlet oak, red maple, and sourwood along with scattered Virginia pine (Pinus virginiana Mill.) and White pine (Pinus strobus L.). Canopy composition of the good site classes contained a large component of white oak, yellow-poplar, red maple, and northern red oak with varying amounts of scarlet oak and American Beech (Fagus grandifolia Ehrh.). The poor site classes were characterized by a rather open canopy compared to the good sites resulting in an extensive ground cover of mountain laurel (Kalmia latifolia L.), rhododendron (Rhododendron maximum L.), and greenbriar (Smilax spp.). Oak advance regeneration is mostly small (under 3.3 feet) and in competition with sourwood, blackgum, red maple and the forementioned ground cover. Overstory dominants on the good site classes had an acceptable stocking resulting in a fairly closed canopy. Oak advance reproduction is of larger stature but in competition with an abundant understory of flowering dogwood, American beech, red maple, and others.

RESULTS AND DISCUSSION

Whole-Stand Regeneration

The height of stems from different origins of regeneration for all species (Table 2) documents the superior height growth of the larger, better established stump sprouts. Advance regeneration, root sprouts, and seedlings are progressively smaller in size. The signifigant increases in height of all origins on the dormant harvest is most likely a reflection of the superior stored carbohydrate root reserves (Roth and Hepting 1943), and the abundant spring regeneration which acts as "trainers" to redirect height growth and increase competitive success (Ross 1982). Both site classes within each harvest show a consistent increase in the density of stems from stump sprouts to seedlings, except for the smaller number of root sprouts in the poor site classes. This reflects the absence of prolific root sprouting species, such as black locust, dogwood, sassafras, and honeysuckle.

Oak stump sprouts (Table 3a) were significantly taller in both site classes of the dormant season harvest compared to the growing season harvest. Advance regeneration in the good site class was also taller with a dormant season harvest. Stump sprouts on poor sites decreased in height from 8.1 to 5.1 ft. on the dormant and growing season harvests, respectively, while stem height on good sites decreased in height from 6.6 to 5.2 ft. Although oak species are not known as root sprouters, some did occur, mostly for chestnut oak. The prominent increases in the density of oak stump sprouts with a dormant season harvest reflects the increase in sprouting frequency (Roth and Hepting 1943). Although no references support the increase in sprouting frequency of advance regeneration with a dormant season harvest, the increases shown in Table 3a indicate the sensitivity of this desirable form of regeneration to season of harvest. The decrease in seedling density with a growing season harvest for each site class may reflect the hot, dry conditions that result in desiccation of acorns. Whole-tree harvesting results in the removal of brush and leaf litter that would normally shade germinating acorns. Chestnut oak is responsible for the significant increases in height of stump sprouts on the poor sites of the dormant season harvest, while white oak is responsible on the better sites (Table 3b). Increases in density of stump sprouts and advance regeneration follows the same pattern. Although stump sprouts are the smallest in number, they will be the main competitors in the new canopy due to their superior height growth when compared to other origins (Table 3a). Stems of advance regeneration, although subordinate in height to stump sprouts, have large densities that enables them to compete for advantageous canopy openings. Seedlings generally grow too slow to be of significance (McQuilken, 1975; Ross, 1982).

Yellow-poplar stump sprouts were taller with a dormant season harvest in both site classes, however advance regeneration was not (Table 4). The density of all yellow-poplar classes of regeneration were also increased. Comparison of the heights of yellow-poplar stump sprouts with that of the oaks in Table 3a reflects the competitive advantage of yellow-poplar (McGee and Hooper 1970). The low density of stump sprouts reported on good sites indicates that yellow-

Table 2 - A summary of all regeneration by origin, season of harvest, and site class after two growing seasons, Critz, Va.

REGENERANT ORIGIN	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Stems per acre	Mean 1/ Height (feet)	Stems per acre	Mean 1/ Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
Stump Sprouts	450	8.8 a	432	8.1 a	378	5.9 b	407	5.7 b
Advance regeneration	12,427	3.7 a	11,648	4.1 a	17,625	2.5 b	7,554	3.2 b
Root Sprouts	6,612	2.8 a	19,831	2.8 a	13,968	2.1 b	17,877	2.3 b
Seedlings	15,299	0.7 a	49,745	1.0 a	9,897	0.5 a	44,812	0.4 b
Total Regenerants	34,788		81,656		41,868		79,650	

1/ for each origin in the same site class of different harvests, means followed by the same letter indicate harvests are not significantly different at alpha = .05 (Wilcoxon Rank Sum Test).

Table 3a - A summary of oak regeneration by origin, season of harvest, and site class after two growing seasons, Critz, Va.

REGENERANT ORIGIN	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Stems per acre	Mean 1/ Height (feet)	Stems per acre	Means 1/ Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
Stump sprouts 2/	156	8.1 a	132	6.6 a	102	5.1 b	72	5.2 b
Advance regeneration	9,928	1.9 a	5,809	2.9 a	6,570	2.1 a	2,926	2.0 b
Root sprouts	618	1.9 a	467	2.1 a	510	2.9 a	300	0.5 a
Seedlings	1,049	0.6 a	749	0.4 a	450	0.3 a	300	0.3 a
Total Regenerants	11,751		7,157		7,632		3,598	

1/ for each origin in the same site class of different harvests, means followed by the same letter indicate harvests are not significantly different at alpha = .05 (Wilcoxon Rank Sum Test).

2/ number in parenthesis is the frequency of occurrence in this class of regenerant in samples subcells.

poplar will only become a part of the species mix with the oaks and other species. There are very few Piedmont sites under site index 75 (base age 50) for white oak where yellow-poplar is capable of making up a large component of the stand (Olson and Della-Bianca 1959). The ability of yellow-poplar to produce large numbers of seedlings is evident (Beck and Della-Bianca 1981). This study confirms that the best survival and height growth of yellow-poplar seedlings is found following a dormant season harvest (Trimble and Tryon 1969). A dormant harvest allows for the spring germination of seeds which are capable of competing with the flush of new vegetation. Although seedlings on the poor sites may succumb in the near future (Weaver and Robertson 1981), vigorous yellow-poplar seedlings on the better sites of both harvests will likely fill some canopy openings.

Red maple stump sprouts in both site classes and advance regeneration on better sites were significantly taller with a dormant season harvest (Table 5). Similar to yellow-poplar, the height of red maple makes it an ardent competitor of the oaks on all sites. Comparison of the height of stump sprouts and advance regeneration with that of the oak species (Table 3a) indicates the competitive advantage of red maple in the new stand. Red maple forms large, expansive sprout clumps that utilize large amounts of site resources and limits the establishment of desirable species. This capability of red maple to maintain this large area through crown closure has been noted in the Southern Appalachians (McGee and Hooper 1970, 1975), and poses a formidable barrier to attaining desirable oak stocking. The dormant harvest does not appear to result in large gains in density, except for the four-fold increase in red maple advance regeneration in the poor site class; however, the height of these stems were shorter. The numerous red maple seedlings are short and very spindley, thereby, potentially incapable of contributing to the new stand. The larger density and higher distribution of stump sprouts in the good site class of each harvest, indicates red maple will be more of a problem on the better sites. However, heights of the stump sprouts will be similar, regardless of site quality.

Table 3b - A summary of oak regeneration by species; origin, season of harvest, and site class after two growing seasons, Critz, Va.

Species	Origin	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
		POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
		Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
White Oak	Stump sprouts	24	5.2 a	60	6.2 a	51	4.4 a	39	4.3 b
	Advance regeneration	911	2.0 a	2,608	2.4 a	491	3.0 a	1,091	2.3 a
	Root sprouts	300	0.9 a	450	0.5 a	300	0.3 a	300	0.5 a
	Seedlings	449	0.3 a	749	0.4 a	150	0.2 a	300	0.3 a
	Total white oak	1,684		3,867		992		1,730	
Chestnut Oak	Stump sprouts	114	8.9 a	24	7.2	32	5.7 b	--	--
	Advance regeneration	6,601	2.1 a	1,462	3.4 a	3,968	2.2 a	13	3.8 a
	Root sprouts	318	2.4 a	19	3.7	60	3.7 a	--	--
	Seedlings	300	0.3 a	--	--	300	0.4 a	--	--
	Total chestnut oak	7,333		1,505		4,360		13	
Red Oaks	Stump sprouts	18	6.9 a	48	6.9 a	19	6.3 a	33	5.9 a
	Advance regeneration	2,416	1.0 a	1,739	2.9 a	2,111	1.4 a	1,822	1.6 b
	Root sprouts	--	--	--	--	150	0.6	--	--
	Seedlings	300	0.2	--	--	--	--	--	--
	Total red oaks	2,734		1,787		2,280		1,855	
	Total Oak Regeneration	11,751		7,157		7,632		3,598	

Table 4 - A summary of yellow-poplar regeneration by origin, season of harvest, and site class after two growing seasons, Critz, Va.

REGENERANT ORIGIN	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Stems per acre	Mean 1/ Height (feet)	Stems per acre	Mean 1/ Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
Stump sprouts 2/	36 (7%)	11.1 a	60 (18%)	10.9 a	18 (4%)	7.8 b 3/	24 (11%)	6.8 b
Advance regeneration	60	6.7 a	378	5.4 a	6	3.5 a	180	4.3 a
Root sprouts	48	3.9 a	24	4.6 a	0	0	0	0
Seedlings	6,157	0.8 a	26,065	1.0 a	2,404	0.6 a	19,183	0.3 b 3/
Total regeneration	6,301		26,527		2,428		19,387	

1/ for each origin in the same site class of different harvests, means followed by the same letter indicate harvests are not significantly different at alpha = .05 (Wilcoxon Rank Sum Test).

2/ number in parenthesis is the frequency of occurrence of this class of regenerant in sampled subcells.

3/ significant at alpha = .058

Table 5 - A summary of red maple regeneration by origin, season of harvest, and site class after two growing seasons, Critz, Va.

REGENERANT ORIGIN	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Stems per acre	Mean1/ Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
Stump sprouts2/	72	9.7 a	114	9.4 a	36	6.9 b	138	6.3 b
Advance regeneration	977	4.2 a	869	5.7 a	240	5.5 a	641	4.5 b 3/
Root sprouts	6	3.9 a	467	2.5 a	0	0	243	2.8 a
Seedlings	2,998	0.4 a	5,395	0.4 a	2,248	0.3 a	5,695	0.3 b
Total regenerants	4,053		6,845		2,524		6,717	

1/ for each origin in the same site class of different harvests, means followed by the same letter indicate harvests are not significantly different at alpha = .05 (Wilcoxon Rank Sum Test).
2/ number in parenthesis is the frequency of occurrence of this class of regenerant in sampled subcells
3/ significant at alpha = .051

The lack of sourwood seedlings (Table 6) shows the reliance of this species on existing rootstocks for regeneration. The dormant harvest resulted in taller stump sprouts on both site classes and taller advance regeneration on the poor site class when compared to the growing season harvest. The density of stump sprouts and advance regeneration on the good site class was halfed with a dormant season harvest. On the poor sites stump sprouts were slightly reduced and advance regeneration was increased five-fold. These results indicate that large decreases in the density of sourwood stems on the good sites are possible with a dormant season harvest due to the failure of sourwood to compete effectively for resources with the denser, more prolific sprouts of other species. The increase in sourwood height and density with a dormant season harvest on the poor sites causes concern due to its sprouting character in the early post-harvest stand. Sourwood produces a wide zone of lateral sprouts around a few central leaders that uses considerable site resources and limits the establishment of more desirable oak species.

Other woody species (Table 7) include blackgum, dogwood, black locust, and sassafras. Contrary to the other species groups, stump sprouts are not taller with a dormant season harvest. The low density and height of these stump sprouts indicates that the major competitors for the oak species will come from yellow-poplar, red maple, and sourwood. The large density and competitive stature of root sprouts on the dormant season harvest warrants attention. Vigorous and stout species like black locust may become a problem on better sites (McGee 1975), while blackgum is numerous and common to all sites. Important to note is the significant decline in advance regeneration and root sprout densities in the poor site class with a dormant season harvest. These species may not be able to compete effectively with the rapid flush of vegetation of the other species groups.

While subordinate in density and height the relative position of oaks to its competitors is affected by the season of harvest (Table 8). The difference in height of oak stump sprouts and other species is 1.1 ft. on the poor site class for both the dormant and growing season harvest. Therefore, there appears to be no harvest-site class interaction on the poor sites. On the good sites the relative difference in stump sprout height of oaks and all others for dormant and growing season harvest is 2.2 and 0.7 ft., respectively. Thus, the oaks are in an undesirable strata position on the dormant season harvest. Applying this comparison to advance regeneration indicates no difference on the good sites, but an advantage on the poor sites with a growing season harvest. Although the growing season harvest may have some advantages with relative height, the dormant season harvest would still be recommended due to the increase in density of oaks resulting from increased sprouting frequency and sprout production.

Table 9 shows the relative percent change in the number of stumps with at least one live stem between the pre-harvest tree strata and the post-harvest stand. A two percent increase in oak composition was found on the poor sites of the dormant harvest, but the largest gain is on the better sites with a 9 percent increase. This larger increase on the better sites is due to the higher sprouting frequency of white oak stumps that make up the largest oak component. Oak advance regeneration (Table 10) registered larger gains on both site classes with a dormant season harvest. The approach of using percent changes in the number of stems to quantify changes in species composition is helpful, but not final. It should be realized that gains registered may be the result of large decreases in another species group and not a real change in the density of stems of the specie of interest. Use of analysis of covariance to correct sample

Table 6 - A summary of sourwood regeneration by origin, season of harvest, and site class after two growing seasons, Critz, Va.

REGENERATION ORIGIN	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Stems per acre	Mean1/ Height (feet)	Stems per acre	Mean1/ Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
Stump sprouts2/	180 (41%)	8.8 a	60 (29%)	8.8 a	204 (52%)	6.0 b	108 (41%)	5.9 b
Advance regeneration	432	5.8 a	180	4.4 a	102	4.7 b	348	4.3 a
Root sprouts	6	3.8 a	0	0	18	5.8 a	0	0
Seedlings	0	0	0	0	0	0	0	0
Total regenerants	618		240		324		456	

1/ for each origin in the same site class of different harvests, means followed by the same letter indicate harvests are not significantly different at alpha = .05 (Wilcoxon Rank Sum Test).

2/ number in parenthesis is the frequency of occurrence of this class of regenerant in sampled subcells.

Table 7 - A summary of other woody regeneration by origin, season of harvest, and site class after two growing seasons, Critz, Va.

REGENERATION ORIGIN	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Stems per acre	Mean1/ Height (feet)	Stems per acre	Mean1/ Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
Stump sprouts2/	6	5.8 a	66	5.8 a	18	5.1 a	66	4.7 a
advance regeneration	1,031	4.6 a	4,412	4.1 a	10,707	1.9 b	3,459	2.8 b
Root sprouts	5,935	2.8 a	18,872	2.8 a	13,441	1.9 b	17,415	2.3 b
Seedlings	5,096	0.8 a	17,535	1.3 a	4,796	0.5 a	19,633	0.6 b
Total regenerants	12,068		40,885		28,962		40,573	

1/ for each origin in the same site class of different harvests, means followed by the same letter indicate harvests are not significantly different at alpha = .05 (Wilcoxon Rank Sum Test).

2/ number in parenthesis is the frequency of occurrence of this class of regenerant in sampled subcells.

Table 8 - A summary of oak regeneration and all other regeneration by origin, season of harvest, and site class after two growing seasons, Critz, Va.

SPECIES	REGENERATION ORIGIN	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
		POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
		Stems per acre	Mean1/ Height (feet)	Stems per acre	Mean1/ Height (feet)	Stems per acre	Mean Height (feet)	Stems per acre	Mean Height (feet)
Oaks	Stump sprouts	156	8.1 a	132	6.6 a	102	5.1 b	72	5.2 b
	Advance regeneration	9,928	1.9 a	5,809	2.9 a	6,570	2.1 a	2,926	2.0 b
All Other	Stump sprouts	294	9.2 a	300	8.8 a	276	6.2 b	336	5.9 b
	Advance regeneration	2,500	5.1 a	5,839	4.6 a	11,055	2.7 b	4,628	3.6 b

1/ for each origin in the same site class of different harvests, means followed by the same letter indicate harvests are not significantly different at alpha = .05 (Wilcoxon Rank Sum Test).

Table 9 - Comparison of pre- and post-harvest stand composition by season of harvest and site class, Critz, Va.

	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Percent of stems	Percent change	Percent of stems	Percent change	Percent of stems	Percent change	Percent of stems	Percent change
OAKS								
1/ Pre-harvest	33		22		30		18	
2/ Post-harvest	35	+2	31	+9	27	-3	18	0
RED MAPLE								
Pre-harvest	17		21		18		23	
Post-harvest	16	-1	26	+5	10	-8	34	+11
YELLOW-POPLAR								
Pre-harvest	4		18		2.		8	
Post-harvest	8	+4	14	-4	5	+3	6	-2
SOURWOOD								
Pre-harvest	29		18		41		26	
Post-harvest	40	+11	14	-4	54	+13	27	+1
OTHER WOODY								
Pre-harvest	17		21		9		25	
Post-harvest	1	-16	15	-6	4	-5	15	-10

1/ based on number of pre-harvest overstory stems (over 16.4 ft.)
2/ based on number of pre-harvest overstory stumps that produced at least one sprout greater than 3.3 ft. two growing seasons after harvest.

Table 10 - Comparison of the pre- and post-harvest advance regeneration component of stand composition by season of harvest and site class, Critz, Va.

	DORMANT SEASON HARVEST				GROWING SEASON HARVEST			
	POOR SITE CLASS		GOOD SITE CLASS		POOR SITE CLASS		GOOD SITE CLASS	
	Percent of stems	Percent change	Percent of stems	Percent change	Percent of stems	Percent change	Percent of stems	Percent change
OAKS								
1/ Pre-harvest	40		17		26		13	
2/ Post-harvest	80	+40	50	+33	37	+9	39	+26
RED MAPLE								
Pre-harvest	26		41		31		29	
Post-harvest	8	-18	7	-34	1	-30	8	-21
YELLOW POPLAR								
Pre-harvest	1		1		1		1	
Post-harvest	1	0	3	+2	1	0	2	+1
SOURWOOD								
Pre-harvest	1		2		1		1	
Post-harvest	3	+2	2	0	1	0	5	+4
OTHER WOODY								
Pre-harvest	32		39		41		56	
Post-harvest	8	-24	38	-1	60	+19	46	-10

1/ based on number of pre-harvest stems less than 16.4 ft. in height.
2/ based on number of post-harvest stems not originating from the stumps of per-harvest overstory and not post-harvest seedling.

values for pre-harvest density would be desirable and would allow for direct comparisons of density values in Tables 2-8. Use of this approach in future studies will require larger samples to eliminate the variation caused by the clumpy distribution of this type of regeneration.

SUMMARY AND CONCLUSION

The superior height of stump sprouts will enable them to become the dominant component of the new canopy, while advance regeneration will probably fill what holes remain. Root sprouts and seedlings, because of their smaller stature, will probably contribute little. The dormant season harvest resulted in taller stump sprouts of the oaks and yellow-poplar, as well as taller sprouts of the undesirable competitors, red maple and sourwood. Although the density of red maple stump sprouts was increased on the poor sites with a dormant season harvest, there was little change on the better sites. Sourwood density can be effectively reduced on better sites with a dormant season harvest, but will increase on the poorer sites. Advance regeneration of red maple and sourwood are both competetive with oak advance regeneration and

will provide significant competition regardless of season of harvest. The relative dominance of oaks may suffer somewhat with a dormant season harvest, but their potential advantage is the increase in the density of stump sprouts and advance regeneration.

Favorable oak stocking can only be accomplished if the stems are present there to begin with. Silvicultural treatments such as stump treatment with herbicides at time of harvest (Lewis 1984) can be utilized to reduce competing stems of red maple, sourwood, and if desired, yellow-poplar. Future results of this study will indicate on what site qualities competition control may be advantageous. However, the larger densities of canopy species (red maple and yellow-poplar) on the better sites, and large component of less vigorous white oak, may require that treatment be directed to these sites. From an economic standpoint, silvicultural treatments would also be more justified on these better sites since they are capable of producing high-quality red and white oak sawtimber.

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DESIGN PARAMETERS FOR A BIOMASS HARVESTER FOR SHORT-ROTATION, HARDWOOD STANDS[1]

Harry G. Gibson[2]

Philip E. Pope[3]

Abstract.--Design parameters for a short-rotation, hardwood biomass harvester were developed from field tests and mathematical simulations methods. Severing methods, tires versus tracks, and compaction were evaluated from field tests. Power, weight, tractive effort and speed requirements were determined from simulation methods.

INTRODUCTION

Wood is the largest biomass energy resource in the United States and its importance as an alternate of supplemental fuel is dramatized by recent fossil fuel shortages. A report from the Office of Technology Assessment (1980) indicates woody biomass, in addition to its traditional uses, will play a major role in future energy production through gasification or conversion to liquid fuels. In the short run, most of the energy resource needs from biomass is expected to come from residues in conventional harvesting but an increase in the intensity of forest management, including the establishment of biomass/silage plantations, may be essential to achieve the projected energy yield from wood while maintaining the supply of material to forest industries.

Numerous studies have been undertaken, and many completed, regarding practices, economics, and production of short-rotation, intensively cultured (SRIC) tree plantations (Pope and Gibson, 1984; P.C. Jones and S-Y. Shen, 1982; A.D. Vyas and S-Y. Shen, 1982). Information on technology to harvest SRIC tree plantations is more limited (Pope and Gibson, 1983) and, in general, discusses biomass harvester designs that are outgrowths of conventional timber harvesting machines.

Belanger (1979) and Machado (1981) note that the method of harvest can have a significant impact on the productivity of the remaining stump. Scientists have recognized the importance of *stump management* in sustained coppice productivity for some time. Research plantings are usually harvested manually during the dormant season and care is taken to maintain a 15 cm stump height, minimize disturbance of the root system, and make smooth stump cuts -- all of which minimizes the likelihood of stump fracture or splitting which reduces coppice productivity (Hansen and Baker, 1979; Belanger, 1979). When SRIC plantations have been harvested mechanically (Dawson et. al., 1976; Perala, 1979) there have been no data presented for stump damage and/or subsequent coppice productivity.

Some developments have been made towards harvesting low quality hardwoods through the use of a tracked harvester/chipper (Koch and Savage, 1980). This type of harvester was not designed for SRIC plantation use, however, and indications are that the weight and track carrier of this type of machine would seriously damage the root stock. In fact, the machine is promoted for site conversion where hardwood root stock mortality is beneficial. Scandinavian efforts toward SRIC biomass harvester developments are relatively new (Crafood, 1980) and are directed towards Scandinavian species and site conditions. Brazilian efforts toward mechanizing SRIC plantation harvesting have been minimal (Machado, 1981), mainly due to low labor costs and plentiful labor.

Presently, technology for mechanized harvesting of single and multiple stems of the size attainable in a 3-5 year rotation is lacking. Paramount in developing a harvesting system will be *cost effectiveness, minimization of detrimental impacts* on the site and *assurance of survival and continued productivity* of the stumps remaining after harvest. Productivity data are available for successive rotations of American sycamore (*Platanus occidentalis* L.) and eastern cottonwood (*Populus deltoides*, Bastr.) for root stocks of varying age but these plantations were harvested manually and care was taken not to damage the root stocks. Previous research indicates that conventional equipment is too costly, causes soil compaction and may injure the remaining stumps to the extent that biomass yields can be significantly reduced (Machado, 1981). The objectives of this study were to determine the influence of mechanical stem severing techniques on the coppice productivity of biomass plantations and to develop parameters for the design of a harvester for SRIC coppice biomass tree plantations. An assessment of soil compaction influence on coppice productivity was also an objective of the study.

PROCEDURES

Study Site

Short rotation intensive culture (SRIC) biomass plantations of black locust (*Robinia pseudoacacia* L.) and European black alder (*Alnus glutinosa* L.) were established at Martell Forest in the spring of 1979. Prior to planting, the site was characterized by soil type, slope, aspect, estimated tree productivity and soil nutrient status.

1 Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2 Associate Professor, Agricultural Engineering Department, Purdue University, West Lafayette, IN 47907.

3 Associate Professor, Dept. of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907.

One-year-old bareroot seedlings of each species were planted in pure stands equivalent to 5,000, 10,000 and 20,000 plants per hectare (ha), representing spacings of 2 x 1, 1 x 1 and 0.5 x 1 m, respectively. The study plots were limed and fertilized as specified in the study plan, and competing herbaceous and woody vegetation was controlled by cultivation. The experimental design for each tree species consisted of two fertilizer treatments (for another study reported on separately) randomly assigned over three blocks forming six main plots. Three spacings were randomly assigned to subplots within each main plot. Each subplot was 12 x 12 meters. The study was arranged in a randomized complete block design with three replications and analyses based on unequal sample size.

Harvesting Method Evaluation

After three growing seasons, alternate rows of the original 12 x 12 m net plots were harvested by sawing or guillotine shearing at a standard 15 cm stump height. Border rows, to be used for an assessment of the impact of soil compaction on coppice growth and rows allocated to determine the influence of vehicle track damage on coppice growth, were excluded from the measurement plots. In total, 90 m^2 of the original 144 m^2 was evaluated to assess the influence of harvesting technique on coppice productivity. The cut stumps were coded by the method of harvest, stump diameter, and stump condition. Stump condition was classified by the evenness of cut, the amount of compressed wood and the extent of bark damage (Table 1).

Table 1. Classification of stump damage caused by the method of harvesting sawing or guillotine shearing.

Component Evaluated	Method of Evaluation
Stem Diameter	Average of 3 diameter measurements were recorded. Point of measurement was 6 cm below the point of detachment.
Compression Wood	1 = no compression wood 2 = compression wood in > 0-25% of the exposed stump surface 3 = compression wood in 26-50% of the exposed stump surface 4 = compression wood in 51-75% of the exposed stump surface 5 = compression wood in 76-100% of the exposed stump surface
Cambial Tissue Injury	1 = no separation of cambial tissue from woody tissue 2 = 1-25% of the cambium separated from the woody tissue 3 = 26-50% of the cambium separated from the woody tissue 4 = 51-75% of the cambium separated from the woody tissue 5 = 76-100% of the cambium separated from the woody tissue

Fertilizer was applied to one-half of the harvested area to include both harvesting techniques. Coppice productivity was evaluated for each stem severing technique for four fertilizer treatments. At time of planting, soil samples were collected from 24 locations, in each of the main plots.

Coppice productivity for all stumps was assessed by the number of sprouts per stump, and the height and diameter of the dominant stem. The coppice on 10 percent of the stumps was removed after the first growing season and total dry weight determined. Regression analysis was used to predict (estimate) the standing coppice biomass.

The study was arranged in a randomized complete block factorial design with 5 replications of each treatment. For each tree species, locust and alder, the factors are 3 spacing densities, 4 fertilizer treatments and 2 methods of harvesting. A total of 630 stems were harvested for each tree species. For each tree species, 45 trees were harvested by each stem severing technique on the 2 x 1 m plot, 90 trees by each technique on the 1 x 1 m plot and 180 trees on the 0.5 x 1 m plot. Border row trees served as a buffer and were not measured.

A two-wheel-drive, rubber-tired tractor, having a ground pressure of 16 psi, was driven between rows of alder and locust harvested by shearing or sawing to simulate the effect on the soil of harvesting equipment. Treatments included 0, 2, 6 or 10 passes over the soil. Compaction treatments were conducted when the soil moisture was approximately 15.5 percent. Based on a previous study (Gaultney, 1980), the potential for soil compaction is greatest in the range of 17 to 18 percent soil moisture for this Fincastle silt loam soil. Immediately following the compaction treatments, soil compaction was determined between rows (in the vehicle track) and within rows of stumps (not in the vehicle track). Compaction, as measured by a cone penetrometer, was taken at three depths, 0-7 cm, 9-15 cm and 27-33 cm with three replications for each sample depth.

Compaction and Stump Damage Evaluation

To measure the influence of compaction on stump productivity, data was collected on the number of sprouts per stump and height of the dominant sprout. The statistical design was a completely randomized design with 3 replications for each compaction treatment with 10 observations per replication. Data was analyzed by analysis of variance and mean values for significant variables were separated by Duncan's new multiple range test. Damage to stumps may be caused by the tires or tracks of the carrier. To assess this damage and its impact on stump productivity, designated rows of alder and locust harvested by each of the stem severing methods were subjected to four passes by either a tracked vehicle or a rubber-tired tractor. Damage was assessed immediately and placed into one of four categories (Table 2). The number of sprouts per stump and the height of the dominant stem of each stump were used to estimate the influence of stump damage on productivity. Data were analyzed by analysis of variance and means of signficant treatments were separated by Duncan's new multiple range test.

To saw the trees a standard chainsaw was used. Shearing required construction of a prototype shear that would sever the tree (fig. 1). Rows of trees within a plot being harvested by the same method, chainsaw or shear, were cut at approximately six inches (15 cm) above ground level (fig. 2). Fresh weights were determined for all trees within a plot being harvested by the same method.

Table 2. Rating scheme for damage inflicted on harvested stumps caused by rubber-tired or track vehicles.

Code	Type of Damage
0	No Damage
1	Slight Damage (minimal damage to stump)
2	Moderate Damage (up to 50% of the bark lossened or removed, stump moveable)
3	Heavy Damage (more than 50% of the bark loosened or removed, stump split, and dislodged and/or roots uplifted.

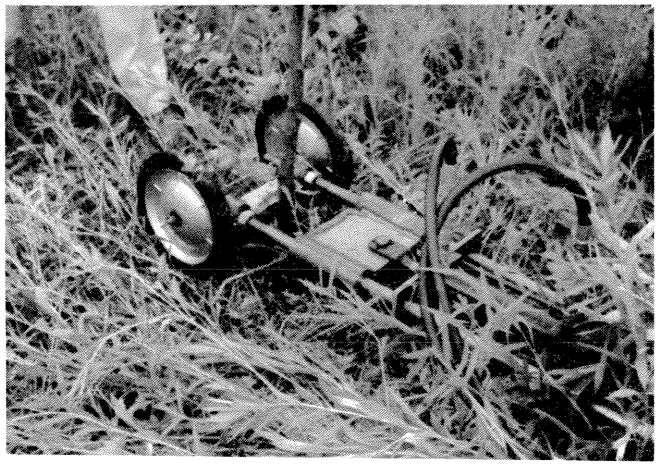

Figure 1. Hydraulic shear used to sever stem 15 cm above the ground.

Figure 2. Stump from tree that has been sheared at 15 cm height.

Stumps in selected rows were intentionally damaged by a small, steel tracked, dozer. A pass down the row and back was used to simulate movement of the machine in a harvesting operation. Similarly, stumps in other rows were scraped or run over with the rubber tires of a medium-sized Ford tractor. Again, a pass down the row and back was used to simulate movement during harvest.

Harvester Simulation

Seven variables were selected as representing the important parameters that govern the performance of a self-propelled woody biomass harvester. These variables are: speed, width, weight, price, power, tractive effort, and hours of operation per year. An optimizing simulation model was developed for a woody biomass harvester using successive linearization as per the method used by Griffith and Stewart in their OPTLIB model. This simulator was used to determine optimum general harvester specifications.

RESULTS

Chainsaw Versus Shearing

Method of harvest had no significant influence on coppice dry matter production of individual stumps or the stem:foliage weight ratio which averaged 0.54 kg per stump and 1.58, respectively. However, total coppice dry matter produced per stump tended to be greater for the sheared stumps at the 1 x 1 (0.53 vs 0.32) and 0.5 x 1 m (0.47 vs 0.36) spacings. A summary of the influence of chainsawing and shearing on growth parameters of alder coppice is presented in Table 3.

Injuries from Tractors

Tracked vehicles caused more stump injuries than rubber-tired vehicles for both tree species tested (Table 4). Black locust tended to incur more damage than alder for each of the treatments tested but a χ^2 goodness of fit test indicated no significant difference. The trend for more stump injury in locust may be a result of an inherently lower wood moisture content which can cause the bark and stemwood to split under stress. The alder stumps were not as easily dislodged as the locust but did experience more separation of the cambial tissue from the wood.

Productivity of the stumps were inversely related to stump damage though productivity significantly declined only for stumps assessed as being *heavily damaged* (Table 5). The productivity of a stump within a damage category was not influenced by the method used to inflict the damage. Consequently, productivity within a particular damage category is averaged for tracks and rubber tires. The injury inflicted on the stumps resulted from four passes with a metal tracked or rubber-tired vehicle. It is unlikely that such deliberate and extensive damage will occur in an operational mode. However, it is apparent from the data that damage must be in the *moderate* to *heavy* category before a reduction in stump productivity is observed.

Table 3. Summary of the influence method of harvest on the growth parameters of coppice for European black alder.

Spacing 0.5 x 1m

Variable	Method of Harvesting *Chainsaw*	*Shear*
Sprout Height (cm)	127.4	168.2
Number of Sprouts	14.0	14.3
Dry Wt (Stem) kg	0.179	0.273
Dry Wt (Fol) kg	0.098	0.127
Total (Dry Wt) kg	0.277	0.400
Stem/Foliage	1.82	2.14

Spacing 1 x 1 m

Variable	Method of Harvesting *Chainsaw*	*Shear*
Sprout Height (cm)	145	135
Number of Sprouts	16.1	18.4
Dry Wt (Stem) kg	0.306	0.236
Dry Wt (Fol) kg	0.169	0.143
Total (Dry Wt) kg	0.475	0.379
Stem/Foliage	1.81	1.65

Spacing 2 x 1 m

Variable	Method of Harvesting *Chainsaw*	*Shear*
Sprout Height (cm)	111	116
Number of Sprouts	18	20
Dry Wt (Stem) kg	0.18	0.18
Dry Wt (Fol) kg	0.15	0.12
Total (Dry Wt) kg	0.33	0.30
Stem/Foliage	1.20	1.50

Table 4. Influence of metal-tracked or rubber-tired vehicles on the damage inflicted on 15 cm stumps of locust and alder. Values represent the frequency (%) that a particular level of damage is present.

Damage Classification	*Metal Tracks* Locust		*Rubber-Tires* Alder	
None	--	--	10	15
Slight	20	20	50	55
Moderate	30	35	25	20
Heavy	50	45	15	10

Soil Compaction

Compaction results from cone index readings, figures 3 and 4, and bulk density measurements, figure 5, give general indications that soil strength (cone index) and soil density (bulk density) increased with the number of passes made by the agricultural tractor tire. Different soil conditions existed initially at different depths on Plot 6 (fig. 3) as the cone index readings dropped from 2 inches (5.1 cm) down to 6 inches (15.25 cm) but a higher reading was found at the 12 inch (30.5 cm) depth. The soil condition at the 12 inch depth is attributed to agricultural plowing of the soil in prior years that developed a compressed pan of soil at that depth.

On Plot 6 all soil depths showed an increase in penetration resistance as recorded by the cone penetrometer with increased passes of the agricultural tractor over the soil with two exceptions: At the 6 inch depth and 6 passes and at the 12 inch depth and 6 and 10 passes.

The soil in Plot 7 was of different physical condition than Plot 6 as evidenced by lower penetration resistance. Initial cone index readings were lower, ranging from 125 to 144 psi for the 2, 4, and 6 inch depths as compared to 190 to 268 psi for the same depths in Plot 6. With succeeding passes over the soil by the agricultural tractor tire, cone index readings increased (fig. 4) as they did in the previous area, Plot 6. The 12 inch depth again had higher readings indicating a hard pan.

Soil bulk densities, figure 5, showed the general trend of soil compaction with increasing passes.

Increased soil compaction from multiple passes of the agricultural tractor over the plantation soil is reflected in reduced height of one year old coppice (Table 6). Zero and two passes showed no significant difference in number of sprouts or sprout height, nor did six and ten passes. However, six and ten pass sprout height was less when compared to zero and two pass growth. In effect, compaction did reduce sprout height after more than two passes. From a design standpoint, production will be reduced after more than two passes, hence ground pressure from the harvester tractive component (tires or tracks) and repeated travel over the site should be minimized. Put another way, the contact patch with the ground of tires or tracks should be maximized up to the point of incurring damage from limited maneuverability due to the tractive component width. Tracks, due to their larger contact patch, would be the logical choice *if only compaction* were considered.

Harvester Simulation Results

The optimization model OPTLIB was used with selected harvester operating variables to determine different combinations of design parameters for such a machine.

Variables used:

X1 = Harvester Speed
X2 = Width
X3 = Weight
X4 = Price
X5 = Horsepower
X6 = Tractive Effort
X7 = Hours of Operation (annual)

The overall strategy is to produce wood chips at the lowest possible cost. To do this a machine must be matched to the optimum operating conditions. With the seven variables defined an equation describing cost of producing chips with a harvester is formulated. This equation is:

MINIMIZE: Machine Cost Per Year/Tons Harvested Per Year

Table 5. Influence of stump damage on the productivity of 1 year-old coppice of locust and alder.

Damage Classification	*Locust* Stem Ht. (cm)	*Locust* Number of Sprouts/Stump	*Alder* Stem Ht. (cm)	*Alder* Number of Sprouts/Stump
None	146a[1]	10a	157a	15a
Slight	143a	7a	161a	16a
Moderate	107ab	9a	117ab	14a
Heavy	49b	4b	69b	8b

[1]Values for a particular tree species and productivity variable not followed by the same letter are significantly different by Duncan's new multiple range test ($\alpha = 0.05$).

Table 6. Effect of soil compaction(number of passes) on the productivity (height and number of sprouts) of 1year old coppice of black locust and European black alder.

	Number of Passes							
	0		2		6		10	
	Locust	Alder	Locust	Alder	Locust	Alder	Locust	Alder
Height (cm)	137a[+]	151a	130a	149a	87b	101b	56b	91b
Number of Sprouts	9a	15a	7a	15a	10a	12a	8a	11a

[+]Values for a particular characteristic for each species not followed by the same letter are significantly different by Duncan's new multiple range test ($\alpha = 0.05$).

NOTE: There was not an influence of harvesting as a main or interactive variable.

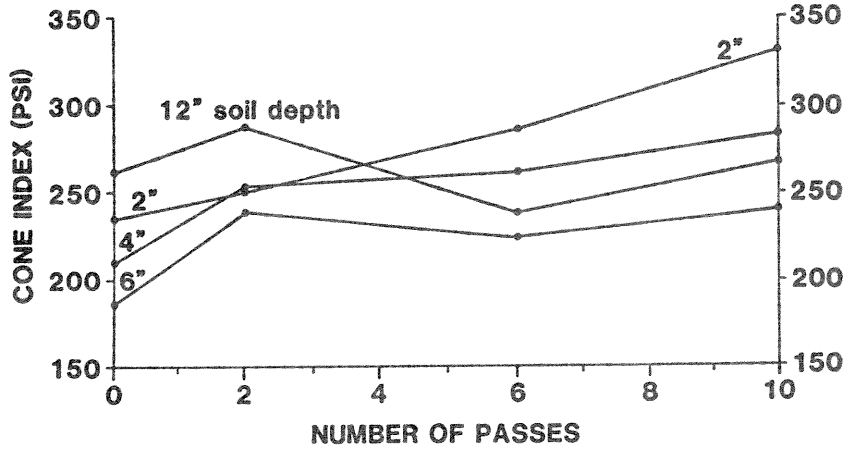

Figure 3. Soil compaction as indicated by cone index values for multiple passes over the soil by an agricultural tractor (Plot 6).

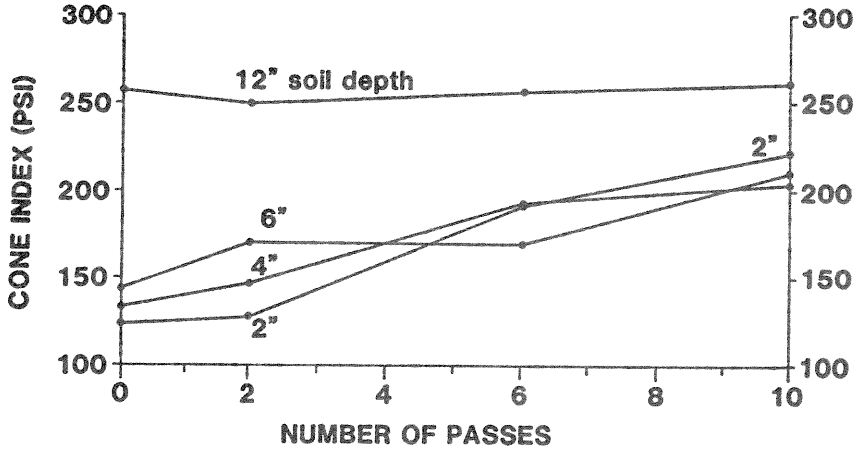

Figure 4. Soil compaction as indicated by cone index values for multiple passes (Plot 7).

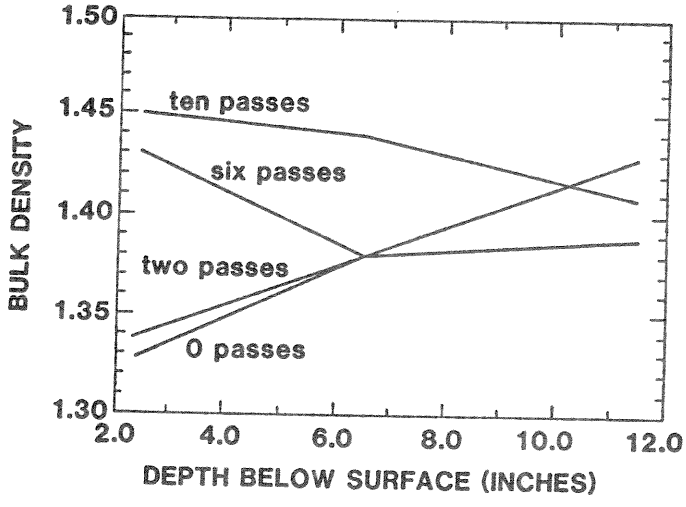

Figure 5. Effect of machine passes on bulk density of the soil.

This basic equation results in $/ton and can be rewritten in terms of the variables giving the objective function to be optimized.

OBJECTIVE FUNCTION = MIN:
(0.11483*X4+0.015*X5*X7+3.373*X7)
- (X1(X2*X7))

Using the relationships described above the objective function is subject to the following constraints:

a. WEIGHT = 109.6 * HP

b. HP=.00267*TE*SPEED+35.1647*SPEED*WIDTH
+.606097*WIDTH

c. TE = 0.22 # WEIGHT

d. PRICE = 250. # HP

Initially five starting points were determined to make sure the program would converge on the global optimum if there was one. The five points picked were scattered throughout the feasible regions defined for the objective function.

Initial runs indicated there were several local optima and the algorithm converged differently depending on the initial starting point. Although several optima were found, obvious trends in SPEED and WIDTH were discovered. Slow speeds resulted in the optimum solution throughout all horsepower ranges. Similarly wide machine widths were present in all results. This indicates the best machine should incorporate a cutting head that is as wide as possible and be designed to harvest at a slow speed near one mile per hour.

Other parameters like weight, price and tractive effort increased with horsepower as their defining equations dictate. Hours operating per year were the same for all runs indicating a minimum for hours in the objective function. Horsepower at the optimum differed depending on input conditions indicating the objective function contains many optimum points which the algorithm converged on depending on initial proximity to the point. The most important result is the net cost per ton to produce wood chips. A trend of decreasing production cost with increasing machine size is present and was somewhat expected since this is a common phenomena in agricultural operations. The initial results indicated a machine width much too wide to travel on a conventional highway so the upper bound on width was lowered to eight feet.

Results of the second analysis were identical to the first except in variables SPEED and WIDTH. At the limited width of eight feet in this run, the speed was increased to satisfy the constraints and the same horsepowers were found to be optimum even at these different speed and width combinations. The net result of imposing narrower width restrictions than found optimum was a higher cost per ton of wood chips produced.

Investigation of possible tire combination to work with the above machine parameters produced a limitation on machine weight below the initial estimate. Combining this restriction with tire performance charts the maximum weight of an eight foot wide harvester must be limited to 26,600 lbs.

The program converged on the same solution as before instead of finding another feasible local optimum between 220 HP and 254 HP. This indicates there is no other optimum solution between these values. The selection of the following design parameters is suggested based on this analysis.

1. SPEED: .73 mph
2. WIDTH: 8.0 feet
3. WEIGHT: 24189 lbs.
4. PRICE: 55176 dollars
5. H.P.: 220
6. TRACTIVE EFFORT: 5321 lbs.
7. HOURS: 1167 operate per year
8. PREDICTED COST: 2.07 $/TON

The alternatives considered in this study - tracks vs. wheels, saws vs. shears, and combinations of weight, horsepower, and speed - result in general specifications for a harvester for short rotation, intensively cultured (SRIC) tree species for energy plantations. While these specifications should be used with caution, they do give indicators for design of a harvester to be used on SRIC energy plantations composed of alder or black locust, planted on one meter spacings, in silt loam soils in mid-western locations. General specifications for such a harvester are given in Table 7.

Table 7. General Harvester Specifications.

Severing Method:	Saws or Shears
Vehicle Traction Method:	Pneumatic Tires
Tire Section Width:	24.5 in. (62 cm)
Tire Design Diameter:	71.0 in. (180 cm)
Vehicle Operating Speed:	0.73 mph (1.17 kph)
Harvesting Width:	8 ft. (2.4 m)
Machine Weight:	24,189 lbs. (10,536 kg)
Machine Power:	220 Hp (164 kw)

For a harvester with a cost of $55,176.00, this unit would produce energy wood at a cost of $2.07 per ton ($2.28 per tonne). Severing method could be either by chainsaw or by shear though a sawing method would be more conclusive to continuous motion of the machine through the plantation (shearing would necessitate stopping the machine or a complex relative motion shearing head design).

CONCLUSIONS

Method of harvest (sawing or shearing) had no significant influence on coppice dry matter production of individual stumps, however, shearing of the 1 x 1 and 0.5 x 1 meter spacing produced more dry matter from sprouts than shearing at other spacings or sawing at any spacing.

Tracked vehicles caused more stump damage than rubber-tired vehicles for both species tested. Productivity of the stumps was inversely related to stump damage though productivity significantly declined only for stumps assessed as being **heavily** damaged.

Succeeding passes of the pneumatic tired tractor over randomized subplots resulted in increased soil strength and density down to 15.2 cm. Compaction did not effect the number of sprouts produced at 0, 2, 6, or 10 passes but did significantly affect (reduce) sprout height at 6 and 10 passes.

Using an optimization technique OPTLIB, an analysis was made to determine parameters for the design of a SRIC biomass harvester. The results of this optimization analysis gave the following design parameters:

Speed:	0.73 mph (1.17 kph)
Width:	8.0 feet (2.4 m)
Weight:	24,189 lbs. (10,536 kg)
Price:	55,176 dollars
Horsepower:	220 (164 kw)
Tractive Effort:	5.321 lbf (23,668 N)
Operating Hours:	1,167 per annum
Predicted Cost:	2.07 $/green ton (2.28 $/tonne)

The analysis showed that the best tractive means was by pneumatic tires, though this is a compromise.

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EARLY RESULTS OF OAK ENRICHMENT PLANTINGS IN BOTTOMLAND HARDWOODS OF SOUTH CAROLINA[1/]

L. E. Nix, J. L. Haymond, and W. G. Woodrum, III[2/]

Abstract.--Enrichment plantings of cherrybark oak on bottomland tracts in South Carolina were followed through four growing seasons. One and two-year-old oak seedlings were planted in clearcut and shelterwood cut blocks which were disked prior to planting. Some seedlings were released from understory competition by herbicide spraying. Seedlings planted in areas initially clearcut are now under heavy competition regardless of early attempts at competition control. Competition was effectively controlled for only two years by the herbicide treatment. A small proportion (20%) of the seedlings planted in clearcut areas are tall enough (12-15 ft) to appear to be holding their own among the competition. Seedlings planted in the shelterwood cut areas are 3-6 ft tall but many are overtopped by competition where the overstory was removed early (after a year). Seedling survival averages about 50% for all treatments.

INTRODUCTION

Although there is an abundant supply of hardwoods in the United States today, the supply of quality hardwoods appears to be diminishing while the demand for quality hardwood products is increasing (McGarity 1980, White 1980). Many hardwoods are suitable only for species-specific markets while those quality hardwoods that are generally suitable for a variety of markets are becoming scarce or less accessible (Dutrow 1980).

In the United States, 14 billion cubic feet of wood is consumed each year. The hardwood component of this consumption is 25 percent. An increasing demand for wood has been filled mainly by relying on softwoods (Knight and Hilmon 1978). A decline in softwood regeneration and an expanding market for hardwoods, i.e., fuel, chemical and fiber products, will place an increasing demand on the hardwood resource (Dutrow 1980).

In the South, 55 to 58 percent of the commercial forests are hardwood and over half of the hardwoods harvested are from bottomlands (Linde 1980). Hardwood-using industries of the South have found that over the past 15 years, while the need for quality hardwoods has increased, local sources have decreased due to past cutting practices and land use changes (McGarity 1980). The lack of quality hardwoods, especially the oaks, is of increasing concern (Dutrow 1980) and current regeneration practices in bottomland stands, consisting primarily of clearcutting or group selection cutting, are not consistently providing for establishment of quality oak stems.

When advanced oak reproduction or quality oak sprouting is inadequate, bottomland stands formerly containing an appreciable oak component are regenerating to fast-growing, light-seeded species such as elm, ash, hackberry, cottonwood, and sweetgum after clearcutting. Many stands on bottomland sites capable of supporting quality oak growth no longer have an oak component in the overstory. Artificial regeneration of oaks may be necessary where there is inadequate advance reproduction present, where a poorly stocked stand already exists, or where it is not practical to wait until advance reproduction takes place (Johnson 1979, Russell 1971). However, planting such stands to oak after clearcutting is feasible in only a few situations where intensive management is economically practical. Only 12 to 15 percent of the Coastal Plain hardwood forest area is suitable for intensive hardwood culture (Linde 1980).

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[2/] Associate Professor, Instructor, and Former Graduate Student, Department of Forestry, College of Forest and Recreation Resources, Clemson University, Clemson, South Carolina.

Since the slow early growth of planted oak seedlings and the intense competition of sprouts, vines and weeds on the typical bottomland site usually necessitate rigorous and expensive competition control, other methods of establishing quality oaks in these stands need to be evaluated. One method that might solve the competition problem involves planting oaks under an overstory or partial overstory, such as shelterwood, prior to final harvest of the stand. Such planting imitates the natural development of advanced reproduction in the understory which is important for regeneration of oaks (White 1980, Johnson 1979, Clark and Watt 1971). This type of planting is intended to "enrich" the species composition of the stand with quality oaks, rather than to establish a pure oak stand. "Enrichment" plantings might provide a viable oak component at stand maturity without the high expense of intensive competition control associated with an oak "plantation." To enrich the species composition of a stand the survival to maturity of 15-20 well-spaced oak trees per acre may provide an adequate quality sawtimber component (Johnson 1980).

The overall objective of this study was to evaluate the potential of enrichment planting of oak seedlings in bottomland stands for improving the quality of species composition where a viable source of oak reproduction is no longer present. Additional objectives were to evaluate low-cost competition control methods such as preharvest disking, herbicide application and leaving a partial overstory (shelterwood) in establishing the planted oaks as a permanent stand component.

STUDY DESCRIPTION

The study area consists of a first bottom stand of 70 to 80-year-old hackberry, elm, sycamore, boxelder, and green ash with an understory of dense grasses, switch cane, and scattered privet hedge adjacent to the Wateree River in Kershaw County, South Carolina. The site is a red river bottomland that was once pastureland, but that has reverted to a dense hardwood forest with few understory trees or shrubs over the past century. The soil is a deep, well-drained, fertile Congaree series (a fine-loamy, mixed, nonacid, thermic typic Udifluvent) subjected to occasional flooding of short duration and having considerable microsite variation due to changes in surface soil texture and drainage features such as sloughs, old drainage ditches, shallow basins and low ridges. Soil pH (top 6 inches) ranges from 6.0 to 6.3 and organic matter from 7 to 11 percent. The site is well-suited for growing bottomland oaks and other valuable hardwoods. The study area is owned by Mr. Francis Biedler, Jr. and managed by the Milliken Forestry Company of Columbia, South Carolina, key cooperators in the study.

Four experimental conditions were imposed on the stand in 5-acre blocks. Two blocks were clearcut and two blocks were cut to a shelterwood with 40-50 ft^2 basal area (BA) of residual overstory. One of the clearcut blocks and one of the shelterwood blocks were disked prior to cutting to interrupt the well-established grass sod and overstory root mat. Four circular one-fifth acre plots were systematically established in each of the four 5-acre blocks for evaluating the natural regeneration following cutting. After cutting, one half of each fifth-acre plot was bar-slit planted in March, 1979 with 2,0 bare root cherrybark oak seedlings (Quercus falcata var. pagodaefolia) obtained from the Mississippi State University Nursery at Starkville, Mississippi. The seedlings were planted at a 15 by 15 foot spacing resulting in twenty seedlings per tenth-acre or an approximate simulated stocking of 200 seedlings per acre.

Height, basal diameter and survival of the planted seedlings were measured after two growing seasons. At this time, a herbicide competition control study was initiated to release seedlings from overtopping competition (Woodrum 1982). In May, 1981 a 2 percent v/v mixture of commercial glyphosate herbicide and water was direct sprayed on the foliage of competing vegetation in a 1-meter radius around one seedling of each of 15 pairs of seedlings selected in each of the four treatment blocks. The seedlings were paired according to apparent vigor (height) and one of each pair chosen for herbicide release by coin toss. The seedlings were protected with a plastic shield and herbicide solution was applied with a pressurized hand sprayer to full wetting of the foliage of competing vegetation around the seedling, requiring an average of 270 ml of herbicide and water per seedling. At the planting density of 200 seedlings per acre simulated by this study, approximately 1.1 liters (.28 gal) of commercial glyphosate herbicide would be used per acre. At the end of the growing season (October, 1981), seedling height, basal diameter and growth were measured and comparisons were made among the results of overstory treatments and the mechanical and chemical vegetation control treatments. Analysis of variance and Chi-square contingency testing were used to statistically test treatment mean differences.

Concurrent with the above treatments, four other 5-acre treatment blocks were installed in another part of the same tract; two were cut to a dense shelterwood (80-90 ft^2 BA) and two were disked prior to cutting to a shelterwood and a large adjacent area was clearcut. Again, four one-fifth acre plots were established in each treatment block, except that 1,0 instead of 2,0 bare root cherrybark oak seedlings were planted at 15 x 15 foot spacing on one-half of each plot in March, 1980. The residual overstory was removed from all the shelterwood blocks after three growing seasons. Seedling height and survival were measured after one and four growing seasons (one year after planting and one year after overstory removal, respectively). Comparisons of seedling heights and survival were made only among the shelterwood treatments (both disked and

undisked) as the clearcut area was already one growing season in the "rough" at the time of planting and was not planted.

RESULTS AND DISCUSSION

After two growing seasons, both the overstory and understory treatments significantly affected the growth and survival of planted 2,0 cherrybark oak seedlings (Table 1). Preharvest disking improved survival of the 2,0 seedlings dramatically with disked plots averaging 79 percent survival compared to 39 percent for plots not disked. Seedling height was also improved by preharvest disking with disked plot seedlings averaging 87 cm total height and undisked seedlings averaging 75 cm total height irrespective of overstory treatment. Complete removal of the overstory significantly improved seedling basal diameter growth, but only on plots that had preharvest disking. Clearcutting seemed to improve seedling height growth over that of shelterwood conditions in the undisked blocks, 79 cm versus 72 cm, respectively, but the difference was not statistically significant.

Table 1. Height, Diameter and Survival of 2,0 Planted Cherrybark Oak Seedlings After Two Growing Seasons on a Red River Bottomland Site in South Carolina.[1/]

Preplanting Treatment[2/]	Height[3/] (cm)	Basal Diam. (mm)	Survival (%)
SW	71.7a	8.2a	38.8a
SD	86.0b	9.5a	72.5b
CC	79.2a	9.7a	40.0a
CD	88.5b	11.7b	86.3b

[1/] Means are of 80 seedlings per treatment.
[2/] Treatment codes are as follows: SW - shelterwood, SD - shelterwood with preharvest disking, CC - clearcut, CD - clearcut with preharvest disking.
[3/] Column values adjacent to same letter are not significantly different at the .05 level.

After the third growing season, differences in seedling development among treatments were striking, with both disking and complete overstory removal (clearcutting) contributing substantially to seedling response (Table 2). Seedling total height was significantly greater in the clearcut plots than in the shelterwood plots, 164 cm versus 103 cm, respectively, and though not statistically different, the disked shelterwood appeared to permit greater seedling height, 191 cm, than did the disked clearcut, 179 cm. Nevertheless, the disked treatments significantly improved overall seedling height growth over that of undisked treatments.

Table 2. Height, Diameter and Growth of 2,0 Planted Cherrybark Oak Seedlings During and After Third Growing Season on a Red River Bottomland in South Carolina.[1/]

Preplanting Treatment[2/]	Height[3/] (cm)	Height Growth (cm)	Diameter (mm)	Diameter Growth (mm)
SW	103.5a	23.2	11.3a	2.8
SD	190.9b	59.6	19.5b	6.9
CC	163.9c	46.9	20.1b	8.5
CD	178.8b	58.4	21.2b	8.3

[1/] Means are an average of 24 seedlings per treatment.
[2/] SW - shelterwood, SD - shelterwood with disking, CC - clearcut, CD - clearcut with disking.
[3/] Column values adjacent to same letter are not significantly different at the .05 level.

However, the disked shelterwood treatment retained an overstory for only one year after the seedlings were planted as a tornado resulting from a coastal hurricane nearly completely leveled the residual overstory on these plots. This perhaps explains why all treatments showed much better seedling diameter and height growth than did the shelterwood without disking as it was essentially the only 2,0 seedling treatment with an overstory for any substantial time period (three years).

Herbicide competition control proved to be a mixed blessing as release from competing vegetation inhibited height growth of planted seedlings while improving diameter growth, irrespective of overstory treatment (Table 3). Herbicide-released seedlings exhibited a discernible increase in lateral branch and foliage development and, although no actual measurements of these parameters were made, the significant increase in basal diameter of released seedlings would seem to verify the development of a greater photosynthetic activity. A few seedlings were killed by herbicide drip from overtopping vegetation and released seedlings were more frequently browsed by deer than were unreleased seedlings. For these reasons, 12 of the 60 seedling pairs were eliminated from the experiment. Casual observation indicates that the herbicide treatment effectively reduced competition for only 2 growing seasons after application, as competing vegetation rapidly reoccupied the small treated area around the seedlings.

The results of the 1,0 seedling planting trials were a great surprise as survival after one growing season averaged 85 percent despite the extremely small initial size of the seedlings (average height of 30 cm) used in the experiment (Table 4). Preharvest disking improved first year survival of planted seedlings, 91 versus 79 percent, but did not affect height after

Table 3. Height, Diameter and Growth Response of 2,0 Planted Cherrybark Oak Seedlings to Herbicide Competition Control During and After Third Growing Season on a Red River Bottomland in South Carolina.[1/]

Treatment[2/]	Height[3/] (cm)	Height Growth (cm)	Diameter (mm)	Diameter Growth (mm)
Herbicide	157.0a	42.3	19.7a	7.7
Control	172.3b	58.5	17.7b	6.0

[1/]Means are of 48 seedlings per treatment.
[2/]Herbicide treatment was a glyphosate, direct foliar spray to wetting of 1 meter radius around each seedling.
[3/]Column values adjacent to same letter are not significantly different at the .05 level.

Table 4. Height and Survival of 1,0 Cherrybark Oak Seedlings After One and Four Growing Seasons on a Red River Bottomland in South Carolina.[1/]

Preplanting Treatment[2/]	Height (cm)[3/] 1 yr.	Height (cm)[3/] 4 yrs.	Survival (%) 1 yr.	Survival (%) 4 yrs.
SW	32.1a	94.2a	79.4a	50.2a
SD	34.6a	90.6a	91.2b	51.1a

[1/]Means are of 136 seedlings per treatment after 1 year and 45 seedlings after 4 years in field.
[2/]SW - shelterwood, SD - shelterwood with preharvest disking.
[3/]Column values adjacent to same letter are not significantly different at the .05 level.

one year nor height or survival after four years in the field, three years of which were under a fairly dense overstory (80-90 ft^2 BA). Seedling heights averaged 92 cm and survival averaged 50 percent after four growing seasons, but some seedlings are spindly and overtopped by grasses and vigorous sprouts and vines after three growing seasons under the dense overstory. Removal of the overstory resulted in some plots being totally destroyed as logging debris and equipment passage effectively obliterated seedlings on plots that were near loading decks. Remaining seedlings exhibit good crown development and healthy foliage and in many instances are not overtopped by competing vegetation. Deer browsing and mutilation of seedlings is a localized problem where main animal trails pass through plots. Vine growth and vigorous stump sprouts are quickly overtopping some seedlings, but other seedlings (about 50 percent) are vigorously growing and may achieve a dominant position in the main canopy of the new stand if they continue to grow at a reasonable rate (2-3 feet/year). Some of the 1,0 seedlings (about 20 percent) are now in excess of 183 cm (6 feet) tall and appear to have great potential for keeping up with the competing vegetation.

CONCLUSIONS

Preharvest disking greatly improved survival and growth of 2,0 cherrybark oak seedlings planted in areas clearcut and cut to a shelterwood overstory condition. McGarity (1980) cites a number of studies that have shown the benefits of disk cultivation in planting hardwoods, especially where plantation establishment is the objective. The current results are informative primarily because of the preharvest nature of the disking and may not be applicable in bottomland stands that differ appreciably from the study tract in understory and overstory density and composition. Herbicide competition control done 2 years after planting seemed to afford little advantage to 2,0 seedlings one growing season after application. Seedling height and survival were reduced by growing under a shelterwood for more than one year. Beck (1970) reported similar results for the growth of natural red oak seedlings which were subjected to six years of varying degrees of understory and overstory release in an upland hardwood stand at Bent Creek, North Carolina. Planted oak seedlings probably benefit from partial overstory control of competition while they establish adequate root systems, but height growth will undoubtedly be reduced if overstory removal is delayed longer than one or two years. The advantages of delayed competition must be weighed against the potential loss in height growth due to the residual overstory. Planted 2,0 seedlings exhibited a wide range of vigor. After three growing seasons, seedling heights averaged 165 cm (5.4 ft) but ranged from 36 cm (1.2 ft) to 370 cm (12.1 ft) in height. Further research into determining the reason for the excellent growth of the high vigor seedlings may increase the potential for success of enrichment plantings of high quality oak species like cherrybark oak.

Planting 1,0 cherrybark oak seedlings under a shelterwood overstory gave surprisingly good results as survival averaged 50 percent and heights averaged 92 cm (3 ft) after four growing seasons (three years under a shelterwood). Preharvest disking provided no advantage to 1,0 planted seedlings; but if survival and growth continues in the present manner, such enrichment plantings may provide a significant component of high quality oak stems (at least 15-20 stems/acre) in the mature stand. These are very early results and definitive conclusions must await a 10- or 15-year reassessment of the status of the enrichment planted seedlings relative to the rapidly developing natural regeneration in the stand. Krinard and Francis (1983) reported excellent results after 20 years where

cherrybark oak had been planted in old fields on brown loam bluffs with only preplanting disking as competition control. Codominant trees in that study averaged 55-65 feet tall and 300+ trees per acre. Many planted seedlings in the present study are now taller than six feet and, having survived five years in the field, should begin the rapid height growth (3-4 feet per year) that characterizes cherrybark oak on good bottomland sites.

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COPPICE REGENERATION OF UPLAND HARDWOODS FROM INTENSIVE WHOLE-TREE HARVESTING[1/]

James W. McMinn[2/]

Abstract.--Mixed hardwood-pine stands in the Upper Piedmont of Georgia were whole-tree harvested down to 1-inch or 4-inch diameter limits in both winter and summer. Coppice regrowth was assessed following the second and fourth growing seasons after harvesting. Early regrowth was significantly affected by both season and degree of biomass removal, with the greatest sprout coverage resulting from the highest degree of removal in winter and the least from the lowest degree of removal in summer. After four growing seasons sprout coverage was significantly affected by intensity, but not by season of harvest. Seasonal effects were confounded by pine natural regeneration. The results imply different strategies for conversion to conifers by natural regeneration, conversion by artificial regeneration, or for sustained hardwood biomass production.

INTRODUCTION

Harvesting is often the only manipulation applied to forest stands and whole-tree chipping is viewed as a potential means for accomplishing various silvicultural objectives (Butts and Preston 1979). Fuel chip production is attractive because it permits economic removal of more material than conventional harvesting. More stand treatment has been recognized as a widespread critical need on nonindustrial private forests (Society of American Foresters 1979). McGee (1980) found that on the Cumberland Plateau whole-tree harvesting of all material 4 inches and larger could be followed by successful pine planting or hardwood coppicing, although further site preparation or release might be necessary. Four inches is a generally accepted lower limit for fuelwood harvesting, but smaller limits might be feasible if silvicultural benefits were considered. In addition, Belanger (1979) reported that coppicing of sycamore (*Platanus occidentalis* L.) was significantly affected by season of harvest in the Georgia Piedmont. The objective of this work was to compare the effects of season and intensity of whole-tree harvesting on subsequent stand development in mixed hardwood-pine associations of the Upper Piedmont.

[1/] Paper presented at Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Athens, Georgia.

METHODS

The study was conducted in the Upper Piedmont of Georgia NNE of Atlanta on the Dawson Forest, which is managed by the Georgia Forestry Commission. Soils are Fannin fine sandy loam and Tallapoosa fine sandy loam. The site reverted to forest following agricultural abandonment early in the century. Timber stands on the site had been high-graded for both pine and hardwood prior to management by the Commission. The resulting poor-quality stands had insufficient merchantable volumes for profitable logging with conventional systems. The hardwood component was comprised primarily of scarlet oak (*Quercus coccinea* (Muenchh.), post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lam.), chestnut oak (*Q. prinus* L.), southern red oak (*Q. falcata* Michx.), hickory (*Carya* spp.), and blackjack oak (*Q. marilandica* Muenchh.). The pine component was primarily loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.). Basal area averaged about 90 square feet per acre, of which about 59 percent was hard hardwood, 2 percent soft hardwood, 28 percent yellow pine, and 11 percent miscellaneous species according to standard Forest Inventory and Analysis classifications (USDA Forest Service 1980). Of the 900 to 1,000 total stems per acre, nearly four-fifths were smaller than 4.5 inches d.b.h., but this component accounted for only a quarter of the total basal area per acre. One-acre treatment plots were harvested by Georgia Forestry Commission crews using a typical whole-tree system with a small feller-buncher, grapple-skidders, and an 18-inch disk-type chipper. Harvesting removed all material down to 4-inch or 1-inch d.b.h. limits in both winter and summer (January and June of 1980).

Each combination of season and intensity was replicated three times in a completely randomized design. Detailed observations and sampling were confined to the interior half-acre of each 1-acre plot. The most intensive harvest yielded from about 67 to 83 green tons per acre and the least intensive approximately 20 percent less.

Coppice regrowth was characterized from a 100-percent inventory of sprout clumps that were at least 4.5 feet tall in October of 1981 and 1983 (two and four growing seasons after harvest). At the second inventory virtually all clumps were measured. Height of the tallest sprout and average crown spread were recorded for each clump. Both mean sprout height per plot and sprout coverage per acre, based on vertical projections of crown area, were subjected to analysis of variance. In April of 1981 and 1984, milacre plots spaced at 10-foot intervals along line transects were examined for pine seedling stocking, density, and height.

RESULTS AND DISCUSSION

The statistical significance of coppicing associated with season and degree of biomass removal changed over time (table 1). After 2 years the approximately 9 percent advantage in height following winter versus summer harvesting (table 2) was statistically significant. There was no significant difference, however, in height by treatment after 4 years, when the overall mean sprout height was approximately 8.7 feet (table 3). Increased height variability for the 4-inch limit compared with the 1-inch limit harvest is probably due to the irregular spatial distribution of competition from residual stems.

The 2-year differences in sprout coverage were statistically significant both by season and intensity of biomass removal (table 4). There was 68 percent greater coverage from the winter harvesting than from the summer harvesting and 69 percent greater coverage as a result of the 1-inch limit compared with the 4-inch limit. The combined result was approximately three times as much sprout coverage from harvesting in the winter to a 1-inch limit as from harvesting in the summer to a 4-inch limit. The difference in sprouting by season is consistent with other coppicing work in the Piedmont (Belanger 1979) and is attributed to the probable existence of carbohydrate reserves in the winter that are depleted by spring and early summer growth. The difference in sprouting by degree of biomass removal is attributed to competition from the residuals in the 4-inch limit plots. Theoretically, the 1-inch limit stands would have a much larger number of sprouting stumps, but in reality a negligible proportion of the sprout coverage in those stands resulted from trees less than 4 inches d.b.h.

Table 1.--Summary of analysis of variance results for coppice stands from natural upland hardwoods

Source of variation	2-year		4-year	
	Coverage	Height	Coverage	Height
Season	*	*	NS	NS
Intensity	*	NS	**	NS
S x I	NS	NS	NS	NS

* Significant at the 0.05 level.
** Significant at the 0.01 level.
NS Not significant.

Table 2.--Mean height of the tallest sprout per clump (with standard deviation) after two growing seasons, by season and intensity of whole-tree harvesting

Diamter limit (inches)	Season		Mean
	Winter	Summer	
	- - - - - - -	Feet	- - - - - - - -
4	6.3 (0.2)	5.9 (0.3)	6.1
1	6.2 (0.3)	5.7 (0.3)	6.0
Mean	6.3	5.8	

Table 3.--Mean height of the tallest sprout per clump (with standard deviation) after four growing seasons, by season and intensity of whole-tree harvesting

Diameter limit (inches)	Season		Mean
	Winter	Summer	
	- - - - - - -	Feet	- - - - - - - -
4	9.6 (1.2)	8.8 (1.1)	9.2
1	8.3 (0.5)	8.0 (0.3)	8.2
Mean	8.9	8.4	

Table 4.--Sprout coverage per acre (with standard deviation) after two growing seasons, by season and intensity of whole-tree harvesting

Diameter limit (inches)	Season		Mean
	Winter	Summer	
	- - - - - - -	ft^2/acre	- - - - - - - -
4	3,985 (715)	2,046 (653)	3,016
1	6,175 (2,490)	3,996 (1,336)	5,086
Mean	5,080	3,021	

After four growing seasons the difference in sprout coverage by intensity was highly significant with overall coverage from the 1-inch limit more than twice as great as from the 4-inch limit (table 5). Difference in coverage by season of harvest was no longer significant, with the coverages approximately the same by season for the 4-inch limit and the winter mean less than the summer mean for the 1-inch limit. However, a confounding factor emerged for the 1-inch limit harvest. Harvesting to a 1-inch limit in winter resulted in substantial regeneration from the pine component in the original stand (McMinn 1983), and this result is probably not anomalous. The 1-inch limit winter harvest duplicated the "seeds-in-place" pine regeneration technique conceived by Lotti (1961) and evaluated by Langdon (1981) as an effective natural regeneration method for loblolly pine. At 2 years after harvest, the pine seedlings and hardwood sprouts offered little mutual competition, but after 4 years the sites were totally occupied by the combined pine and hardwood components. Mean pine seedling density was more than 7,000 stems per acre and mean stocking was 96.6 percent. Mean height of the tallest pine seedling on each stocked plot was 5.5 feet, or only 34 percent shorter than the mean hardwood sprout height for that treatment. Individual plot pine densities and their associated sprout coverages for the 1-inch winter treatment were as follows:

Plot number	Pine density	Hardwood sprout coverage
	(stems/acre)	ft²/acre
W1-1	5,538	12,800
W1-2	10,179	5,757
W1-3	7,308	10,889

A linear regression of hardwood sprout coverage on pine seedling density produced a near-deterministic negative relationship (coverage = 21,661 - 1.54349 density) with a coefficient of determination of 0.985. The winter 4-inch limit had a pine seedling density of 1,949 stems per acre, a mean stocking of 65 percent, and a mean tallest seedling height of 2.9 feet. Residuals in this treatment appeared to limit growth of both hardwood sprouts and pine seedlings more than the mutual competition of these two components.

Table 5.--Sprout coverage per acre (with standard deviation) after four growing seasons, by season and intensity of whole-tree harvesting

Diameter limit (inches)	Season: Winter	Season: Summer	Mean
	- - - - - - - ft²/acre	- - - - - - - -	
4	4,669 (752)	5,086 (527)	4,877
1	9,815 (3,642)	12,157 (3,852)	10,986
Mean	7,242	8,622	

The relative species composition of the initial stands and sprout stands are shown in table 6. The general categories follow standard groupings used in forest surveys conducted by the USDA Forest Service. White oak (*Q. alba* L.) was less prevalent than post oak in the first group. The red oaks in order of predominance were scarlet oak, black oak, and southern red oak. Other hard hardwoods in order of predominance were hickory, dogwood (*Cornus florida* L.), and persimmon (*Diospyros virginiana* L.) in the initial stand and dogwood, hickory, and persimmon in the sprout stand. The soft hardwoods were blackgum (*Nyssa sylvatica* Marsh.), yellow-poplar (*Liriodendron tulipifera* L.), and black cherry (*Prunus serotina* Ehrh.). Blackjack oak was the only species consistently represented in the other miscellaneous category. The species that increased most in proportion to initial representation were chestnut oak, sourwood (*Oxydendrum arboreum* (L.) DC.), and the soft hardwoods, represented primarily by blackgum. Those which decreased most were white oak-post oak and blackjack oak. There was only a change of about 11 percent in the red oak representation. Although the total coverages differed, treatment appeared to have no effect on the species composition of sprout stands.

Table 6.--Relative species composition in initial stands and 4-year sprout stands

Species or species group	Initial stand basal area	Sprout stand coverage
	- - - - - -Percent-	- - - -
Yellow Pine		
Yellow pine	28	0
Hard Hardwoods		
White oak-post oak	14	13
Chestnut oak	8	18
Red oaks	28	35
Other hard hardwoods	9	11
Soft Hardwoods		
Soft hardwoods	2	6
Miscellaneous Species		
Sourwood	5	13
Other miscellaneous	6	4

CONCLUSIONS

Although these data reflect coppice stands relatively early in their development, the study has demonstrated that pine-hardwood composition and hardwood coppice production are significantly affected by season and intensity of whole-tree harvesting. If the initial stands include chestnut oak or sourwood, those species may be expected to exist in the coppice stand in greater proportion than their initial representation. Although sourwood will eventually become a midstory or understory component, it may offer substantial competition to more desirable species in the early stages of stand development. Our data support the following treatments for the indicated silvicultural objectives:

Objective	Treatment
Pure hardwood	Summer, 1-inch
Maximum natural pine component	Winter, 1-inch
Artificial pine component	Summer, 1-inch
Maximum woody biomass	Winter, 1-inch

Although economics of logging may preclude removal of all woody biomass, there is no silvicultural objective for which a residual stand would be recommended. The small residuals compete with desirable coppice and pine seedlings, and earlier work has shown nutrient removal is not significantly affected by harvesting the 1- to 4-inch material (McMinn and Nutter 1983).

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THE ORIGIN, GROWTH AND DEVELOPMENT OF NATURAL, PURE, EVEN-AGED STANDS OF BOTTOMLAND OAK[1/]

W. Michael Aust, John D. Hodges, and Robert L. Johnson[2/]

Abstract.--Eighty natural, pure, even-aged stands of bottomland red oaks were studied to determine the conditions that result in pure red oak stands and to evaluate the patterns of growth and development. The histories of these stands reveal that fire, cattle grazing, mowing, or some combination tends to increase the red oak stocking. Fixed plot data indicate that these pure stands can produce acceptable qualities and quantities of sawtimber. Also, crown classes of the red oak can be used to predict stocking in the future.

INTRODUCTION

One of the more important problems facing managers of bottomland hardwood forests is the tendency of new stands to contain a smaller oak component than did the previous stands. This is a critical problem because oak is one of the major and more valued species groups of the hardwood products industry. Also, optimal conditions for the growth of the oak component are not fully understood. The purposes of this study are: (1) to identify the conditions that are conducive to red oak regeneration through an examination of the histories of natural, pure, even-aged stands of red oak, and (2) to determine the patterns of stand growth and development in these stands and the resulting effect on tree quality.

LITERATURE REVIEW

The literature reveals that most oak reproduction apparently goes through a stage of slow initial growth. If the regeneration survives for the first few years, the growth rate and competitiveness improve (Beck 1970; Johnson 1979; McKnight and Johnson 1980; Sander 1972). For oak regeneration to survive this period of slow growth, it is generally accepted that oak reproduction should be well-established before the overstory is removed. If oak regeneration is not present when the overstory is removed, new oak seedlings may be rapidly overtopped by established competitors (Arend and Scholz 1969; Carvell and Tryon 1961; Hilt 1977; Oliver and Stephens 1977; Sander 1971; Sander and Clark 1971; Sander et al. 1976).

Red oak stands originate from three forms of reproduction: (1) true seedlings produced from acorns before and after harvest, (2) seedling sprouts, and (3) stump sprouts. The number of true seedlings is often low due to erratic acorn production, acorn predators, damaging agents, or unsuitable site conditions. After germination, true seedlings are often killed by suppression or moisture stress (Arend and Scholz 1969; Carvell and Tryon 1961; Johnson 1974; Olson and Hooper 1968). Seedlings that die back and then resprout are referred to as seedling sprouts. Seedling sprouts may die and resprout several times, which allows them to develop a root system much larger than the stem size would indicate. This larger root system enables the seedling sprout to survive and compete more vigorously than true seedlings of the same size (Arend and Scholz 1969; Sander 1971; Sander et al. 1976). Stump sprouts are similar to seedling sprouts in that they have large root systems, but they originate from stumps of severed trees. Formerly, stump sprouts were scorned by some foresters due to their supposed tendency towards butt rots. However, modern harvesting practices leave a much lower stump and result in less butt rot. Stump sprouts are now considered a satisfactory source of regeneration. Some research has shown that stump sprouts are faster-growing than true seedlings and are quite capable of producing trees of acceptable quality (Johnson 1977; Roth

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[2/] Michael Aust is a graduate research assistant and Dr. John D. Hodges is Professor in the Department of Forestry, Mississippi State University. Dr. Robert L. Johnson is Project Leader, Silvicultural Research, USDA Forest Service, Stoneville, Mississippi.

and Hepting 1969; Sander 1971; Sander et al. 1976; Wendel 1975; Zahner and Meyers 1984).

The factors that contribute to the survival of red oaks are varied. Carvell and Tryon (1961) suggested that the amount of oak regeneration present was closely related to the stands' past history of disturbance. They concluded that past logging, grazing, and burning all tended to increase oak regeneration by increasing the amount of direct sunlight available.

McGee (1979) postulated that fire may have played a larger role in establishing the oak component of previous stands than it does in current stands, although fire is generally considered harmful to hardwood management (McKnight and Johnson 1980; Putnam et al. 1960). Grazing by cattle, less prevalent now than in the past, may explain a portion of the oak component of established stands. Cattle seem to prefer species other than oak, which apparently has a low palatability. Cattle may aid oak regeneration by consuming competitors (Carvell and Tryon 1961; McKnight and Johnson 1980).

Site quality is another factor which may influence oak regeneration. Quality hardwoods are usually produced only on the better sites. However, oak regeneration and composition are generally better on the poorer sites. When an opening is created in a stand on a poor site, the oak seedlings receive more sunlight because competition is less vigorous. This results in the maintenance of a high oak component in the new stand (Carvell and Tryon 1961; Johnson 1979; Johnson and Biesterfeldt 1970; Putnam et al. 1960; Sander and Clark 1971; Trimble and Hart 1961).

There are differences of opinion over what constitutes adequate oak regeneration. For the North Central Region, the U.S. Forest Service recommended that at least 400 well-established seedlings or sprouts per acre, which are over one foot tall, be present before the overstory is removed (Arend and Scholz 1969). Oliver (1975) contended that only 45 well-placed red oak seedlings or seedling sprouts are needed per acre for adequate stocking of oak in mixed stands in the southern part of New England. Clatterbuck[3/] suggested similar stocking for cherrybark oak (Quercus falcata var. pagodaefolia Ell.) in mixed oak-sweetgum (Liquidambar styraciflua L.) stands in Mississippi minor stream bottoms. Both Oliver and Clatterbuck assert that wider spacing of the oaks in mixed stands will generate good diameter growth of the red oaks, while the other species tend to prune the oaks.

[3/] Clatterbuck, W. K. 1984. Unpublished data. Mississippi State University, Forestry Department.

METHODS AND PROCEDURES

Eighty stands were located for the study. Of these stands, ten were located within each of eight age classes. The youngest age class was 1- to 10-years old and the age classes ranged upward in 10-year intervals to a 70- to 80-year age class. Each stand had to have a minimum site index for cherrybark oak at 50 years of 85 feet (Baker and Broadfoot 1979). The red oak component had to comprise at least 70 percent of the total stand basal area. Pure stands of willow oak (Quercus phellos L.) or water oak (Quercus nigra L.) on flats were not acceptable. Thinned stands were also rejected. For a stand to be classified as even-aged, the range of ages within the stand's canopy could be no greater than 20 percent of the stand's age.

The majority of the stands were located in minor stream bottoms in east-central Mississippi, although 23 upland stands having acceptable site indices were sampled. Eight stands along the Saline River in Arkansas were also examined. Average stand size was between five and ten acres although a few larger stands were included.

The stands' histories were reconstructed through a combination of interviews, aerial photographs, and stand inspection. These subjective methods of determining stand history were not entirely satisfactory. Interviews provided useful information in some cases and none in others. Photographs could not provide all of the necessary information, nor could personal inspection. As might be expected, the amount and accuracy of information tended to decrease as the stand age increased. Events such as grazing and burning, and stand conditions during establishment, were recorded only when known with a high degree of certainty. In the older stands, grazing and/or burning were often suspected, but could not be verified. Therefore, it was decided to analyze only those stands under 50 years of age for stand origin.

Within each of these eighty stands, fixed radius plots were established to create a chronosequence of stand growth and development. The plot size varied with stand age and stocking, and various measurements concerning the trees size, merchantability, location, species, and condition were obtained.

Also, on each plot a dominant or codominant tree, and all of its immediate competitors (usually all red oaks) were cored at breast height and the increment cores were graphed. A core taken at one foot on the largest, smallest, and an average diameter red oak was used to determine stand age.

Other information recorded included mortality measurements, and general comments concerning the stand's understory, topography, etc.

RESULTS AND DISCUSSION

At least 90 percent of the stands had annual flooding or residual red oaks to serve as a possible seed source (Table 1). This observation, however, does not mean that most of those stands were regenerated directly from acorns. Indeed, 94 percent of the stands were formed to a large degree by sprouts. The seed sources merely explain a basis for those sprouts, especially in old-field or old-pasture situations.

The history of fire in these stands was difficult to determine. In only 2 percent of the stands was it possible to find conclusive evidence of burning during initial stand establishment. Periodic burning later in the stands' development was slightly more evident (14 percent). Both values are suspected to be lower than actual (Table 1).

Cattle grazing was evident in several stands; 48 percent had definitely been grazed during stand establishment, while 66 percent had been grazed periodically or continuously during the life of the stand. Possibly both of those figures are low, but they are consistent with the ownership pattern as 49 percent of the landowners had owned or do own cattle.

Stand origin was extremely variable. Clearcuts accounted for 36 percent of the total. Old-field and old-pasture conditions occurred in 52 and 12 percent of the stands, respectively. It should be noted that some of the sites on which stands originated from clearcuts had previously been agricultural lands. One particular stand had been subjected to agriculture, cattle, stand development, clearcutting, fire, and then stand re-establishment, in that order, within 40 years.

The estimated site index for cherrybark oak at 50 years was fairly consistent within and between age classes. The highest site index was 109 feet, while the lowest was 85 feet. Mean site index for all plots was 95 feet (Table 1).

The stands in the bottomlands were found principally on high flats between the sweetgum-oak stands typically found on the higher sites, and the willow oak-water oak-overcup oak (Quercus lyrata Walt.) stands of the low flats. The stands on the uplands were located on upland flats and were very similar in species composition and general appearance to the bottomland flats.

Table 1.--Conditions found in fifty natural, pure, even-aged red oak stands that could have contributed to high oak composition.

Age Class YEARS	Flooded Annually PERCENT	Red Oak Residuals Present PERCENT	Burned Initially PERCENT	Burned Periodically PERCENT	Grazed Initially PERCENT	Grazed Periodically PERCENT	Clearcut Origin PERCENT	Old Field Origin PERCENT	Old Pasture Origin PERCENT	Primarily Sprouts PERCENT	Combined Disturbance PERCENT	Mean SI FEET
1-10	50	20	10	10	40	40	50	50	0	100	60	94
11-20	80	40	0	0	30	40	50	40	10	100	50	100
21-30	40	80	0	10	60	100	20	60	20	90	100	91
31-40	40	80	0	50	70	70	30	50	20	90	90	93
41-50	60	70	0	0	40	80	30	60	10	90	90	95
Mean	54	58	2	14	48	66	36	52	12	94	78	95

No one past activity or conditin explained the high percentage of red oak composition, although a general trend emerged. Site index was commercially acceptable but was not exceptional. This slightly "low" site index may partially explain the low species diversity. Also, the high percentage of the stands that were primarily of sprout origin indicated a relatively fast initial height growth for the red oaks. This could have enabled a high percentage of the red oaks to survive and "out compete" other species. Burning seemed relatively unimportant in accounting for the development of these stands, although it may have been more important than was apparent. The most prevalent disturbance in these stands was grazing by cattle. Grazing may remove seedlings of competing species, or the cattle may simply clip oak seedlings repeatedly over the years to create a vigorous seedling sprout. In addition to these disturbances, 52 percent of the areas had been subjected to agricultural practices prior to stand establishment and another 12 percent had been pasture, subject to mowing.

No single factor alone could explain the high percentage of red oak composition. However, at least 78 percent of all stands investigated had been subjected to fire, cattle, or mowing, either immediately prior to or during stand establishment. This indicates that single or combined disturbances during stand establishment may enhance the red oak component.

The fixed plot data for the eight age classes formed a chronosequence of the patterns of stand growth and development. Stocking was adequate in all age classes. Overstocking was apparent in some of the younger ages. The youngest age class (1- to 10-years) had an average of 3735 upper story trees per acre, of which 3125 (84 percent) were red oak species, primarily cherrybark oak. The percentage of red oak basically remained the same over the years, although the total number of upper story trees decreases drastically. In the oldest age class (71- to 80-years) the total number of upper story trees had decreased to 74 per acre, of which 59 (79 percent) were red oaks (Figure 1).

Total basal area of the plots increased most rapidly in the younger age classes, and then leveled off in the older age classes. Red oak basal area followed this pattern. The red oaks formed over 80 percent of the total basal area in all age classes (Figure 2).

The relative quality of red oak growing stock can be evaluated from "tree classes," which rate an individual tree's potential on the basis of its crown, site suitability, potential or actual bole quality, and vigor. Preferred growing stock refers to the "best" trees and reserve growing stock refers to "good" and/or "fair" trees. Three other tree classes include those trees which are potential mortality or

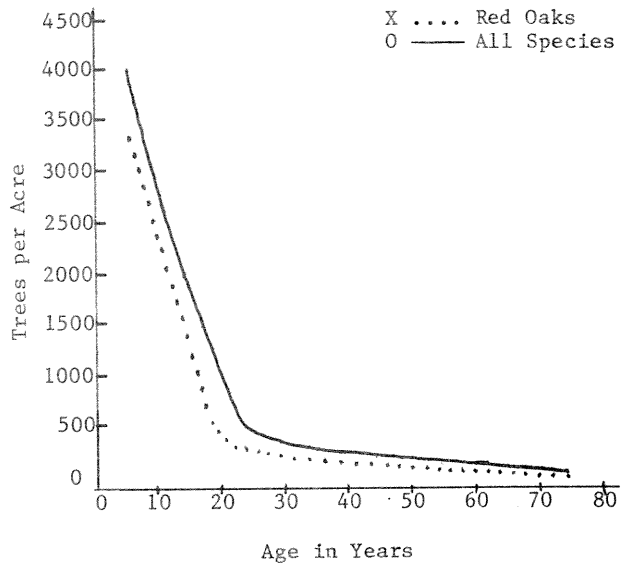

Figure 1.--Average age, total number of trees per acre, and number of red oaks per acre in eight age classes of natural, pure, even-aged red oak stands.

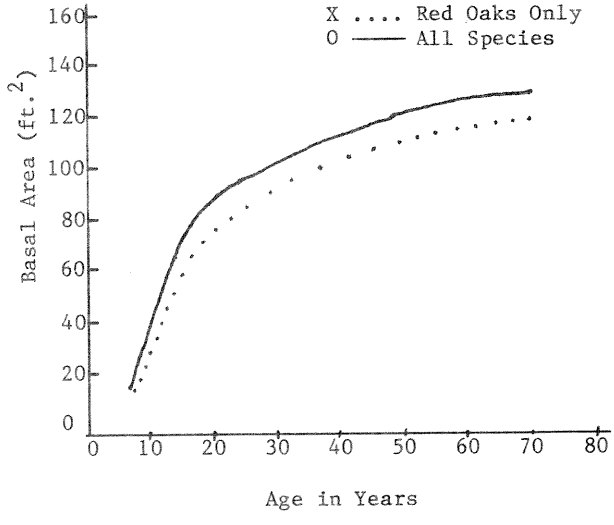

Figure 2.--Mean age, total basal area, and red oak basal area for eight age classes of natural, pure, even-aged red oak stands.

those having little commercial value. All age classes had at least 80 percent of the upper story red oaks classed as preferred or reserve growing stock, so these stands have the potential to produce quality sawtimber (Table 2).

Table 2.--The numbers of trees per acre and percent of total of upper story and red oaks by age and tree classes for eighty natural, pure even-aged stands.

Age Class Years	Preferred No./Acre	Preferred Percent	Reserve No./Acre	Reserve Percent	Cutting Stock No./Acre	Cutting Stock Percent	Sound Cull No./Acre	Sound Cull Percent	Unsound Cull No./Acre	Unsound Cull Percent
1-10	1149	36.8	1941	62.1	0	0	0	0	35	1.1
11-20	429	61.4	248	35.5	0	0	14	2.0	8	1.1
21-30	155	48.9	126	39.7	6	1.9	23	7.3	7	2.2
31-40	83	41.1	94	46.5	5	2.5	20	9.9	0	0
41-50	71	47.7	56	37.6	6	4.0	16	10.7	0	0
51-60	59	54.1	38	34.9	3	2.8	8	7.3	1	0.9
61-70	55	63.2	21	24.2	7	8.0	4	4.6	0	0
71-80	28	47.4	20	33.9	7	11.9	3	5.1	1	1.7

Hardwood crown classes are an indication of a tree's relative height and vigor, therefore crown classes may be used to evaluate a tree's ability to grow. In these pure oak stands, the codominant crown class contained the most trees per acre in all age classes (Table 3), while the dominant and intermediate crown classes contained fewer trees per acre, and were approximately equal. This suggests that most of the stems in these stands are growing at less than optimal conditions. Apparently crown classes can be used to estimate a stand's stocking in the next ten year period (Figure 3). The total number of dominant red oaks per acre in the 1- to 10-year age class approximated the total number of red oaks per acre in the 11- to 20-year age class. All of the dominants and one-half of the codominants of the 11- to 20-year age class survive to form red oaks of the 21- to 30-year age class. In all other age classes all dominants and all codominants survive to form all crown classes of the next age class. Using this relationship, estimates of future stocking in pure oak stands may be possible. Increment cores verify that the dominant trees of all age classes exhibit little growth slowdown, while the other crown classes did show signs of growth slowdown, usually within a 10- or 20-year period prior to the stands immediate age. The change of a dominant or codominant crown to intermediate or suppressed within a 20-year period may be due to the nature of the crown competition in these pure stands. Once an oak gains a better position than the neighboring ones, the crown starts to enlarge. Since growth patterns between the competitors are similar, the lower crown classes have little chance of ever re-attaining their former position, as is sometimes possible in mixed stands.

Age Class (years)	Surviving Trees as Age Increases
1-10	All Crown Classes of which Dominants
11-20	All Crown Classes of which Dominants, ½ Codominants
21-30	All Crown Classes of which Dominants, Codominants
31-40	All Crown Classes of which Dominants, Codominants
41-50	All Crown Classes of which Dominants, Codominants
51-60	All Crown Classes of which Dominants, Codominants
61-70	All Crown Classes of which Dominants, Codominants
71-80	All Crown Classes

Figure 3.--Red oak crown classes and the next ten year survival.

Table 3.--Numbers per acre and percentage of total by age class and crown class for the upper story red oaks of eighty natural, pure, even-aged stands.

Age Class (years)	Dominant No./Acre	Dominant Percent	Codominant No./Acre	Codominant Percent	Intermediate No./Acre	Intermediate Percent	Overtopped No./Acre	Overtopped Percent
1-10	715	23	1338	43	666	21	406	13
11-20	131	19	340	48	89	13	139	20
21-30	41	14	162	55	45	15	48	16
31-40	32	16	112	55	37	18	23	11
41-50	15	10	91	61	27	18	16	11
51-60	9	8	74	68	22	20	15	14
61-70	6	7	54	62	16	18	11	13
71-80	10	17	26	44	12	20	10	17

The crown classes were also found to be related to bole quality. Epicormic branches, a symptom of environmental stress, were more common on those red oaks having intermediate or overtopped crown classes. Epicormic branches lessen the commercial value of the bole.

Some patterns of growth which directly affect the commercial aspects of these red oak stands were evaluated. There were three factors which determined the merchantable height of the trees in these stands. They were, in order of importance, the diameter, the crown height, and the defects. Diameter was primarily determined by the spacing and crown classes of the trees (Table 4). Closer spaced trees had slightly shorter merchantability and smaller diameters than did wider spaced trees. Crown height was independent of spacing in these stands and was related to age and crown class. Dominant and codominant trees had larger diameters than did intermediate or overtopped trees (Figure 4). Although the average diameter of oaks in pure stands is less than that of oaks in mixed stands of similar age, the diameter difference is much less when comparisons are made within crown class.

The board foot volume (International ¼ inch rule) produced by these pure red oak stands is considered acceptable. By age 50 the stands average production is approximately 12,000 board feet (International ¼ inch rule) per acre. By age 70 the production is nearly 24,000 board feet per acre (Figure 5). Clearly, these "unmanaged" pure red oak stands are capable of producing acceptable quantities and qualities of red oak.

SUMMARY

Regeneration of natural stands of red oak is highly desirable, but it is not unusual for stands containing a high percentage of red oaks to regenerate less successfully after harvest. Past studies indicate that stand disturbances seem to increase the composition of red oak and this study substantiated that observation. While no single factor totally explained the high red oak component, it is important to note that 78 percent of all stands were either burned, mowed, or grazed during stand establishment. These results may prove useful in modifying and improving current silvicultural practices.

An examination of the data collected from the fixed plots revealed that these stands initially started with tremendously high numbers of red oak, but stocking declined rapidly. Apparently the dominant crown classes survive from the youngest age class to form the red oaks of the next age. In subsequent age classes the dominants and codominants survive to form all crown classes of the next age class.

Evaluations of the tree classes and the crown classes point out that these pure red oak stands are capable of producing quality sawtimber in acceptable volumes.

Table 4.--The average dbh of upper story red oaks by age and crown class for eighty natural, pure, even-aged stands.

Age Class (years)	Crown Classes			
	Dominant DBH (in)	Codominant DBH (in)	Intermediate DBH (in)	Overtopped DBH (in)
1-10	1.3	0.9	0.7	0.7
11-20	5.1	4.7	3.0	2.6
21-30	10.0	7.4	5.7	4.6
31-40	12.6	10.0	7.0	6.1
41-50	15.1	11.6	9.0	6.7
51-60	19.8	16.0	12.5	10.0
61-70	21.7	16.9	13.1	10.2
71-80	26.0	19.8	14.3	11.0

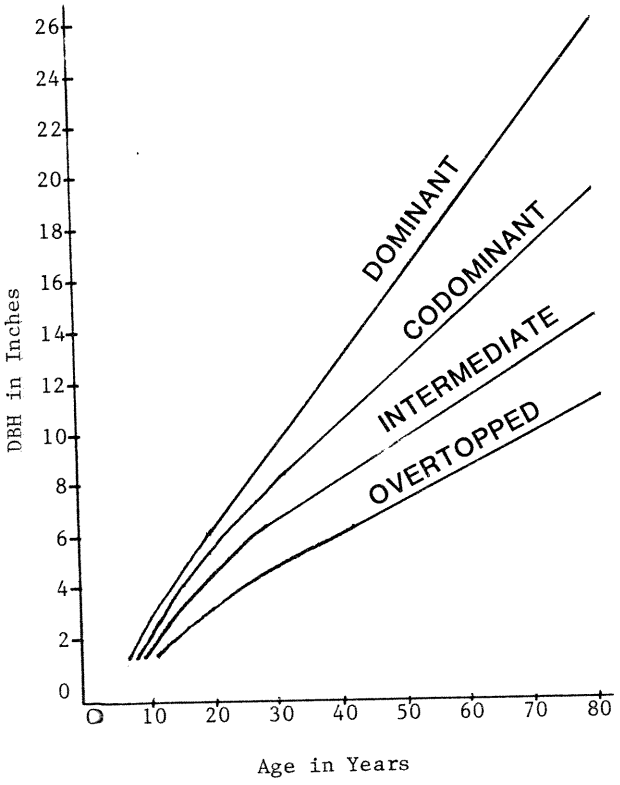

Figure 4.--Mean DBH of four crown classes of red oak by age for natural, pure, even-aged stands.

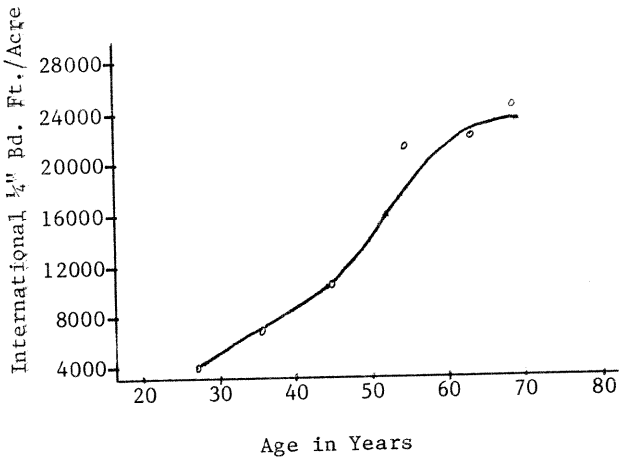

Figure 5.--Mean age and board foot volume per acre (International ¼" rule) of red oak for eight age classes of natural, pure, even-aged red oak stands.

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DEVELOPMENT OF OAK, ASH AND CHERRY REPRODUCTION FOLLOWING THINNING AND FERTILIZATION OF UPLAND HARDWOOD STANDS IN THE BOSTON MOUNTAINS OF ARKANSAS[1/]

David L. Graney and Thomas L. Rogerson[2/]

Abstract.--A study of reproduction growth following thinning and fertilization in mixed upland hardwood stands was initiated in the Boston Mountains of Arkansas in the spring of 1976. Sixty-four plots were thinned to residual overstory stocking densities of 40 percent to more than 100 percent; and 32 of the plots received a fertilizer application of 300 lb N per acre one year after thinning. Growth of established oak (Quercus alba L., Q. velutina Lam., and Q. rubra L.), white ash (Fraxinus americana L.), and black cherry (Prunus serotina Ehrh.) advance reproduction was monitored for 5 years following thinning. In nonthinned stands, total oak, ash, and cherry reproduction averaged more than 4,000 stems per acre; but fewer than 400 per acre were taller than 1 foot and only 4 stems exceeded a height of 4.5 feet. After 5 years, numbers of reproduction stems taller than 4.5 feet ranged from 100 per acre in nonfertilized stands receiving a light overstory thinning to 300 per acre in fertilized stands receiving medium to heavy thinning treatments. Black cherry and ash accounted for more than two-thirds of the stems taller than 4.5 feet and were the only species to exceed 10 feet in height growth during the 5-year period. Fertilization had no effect on height growth of established oak reproduction, but increased 5-year heights of ash and cherry reproduction by 1 to 2 feet.

INTRODUCTION

Mixed oak types comprise most of the commercial forest land area in northern Arkansas and oaks are the dominant timber species throughout the area. Valuable, fast-growing intolerant species such as yellow-poplar (Liriodendron tulipifera L.) do not occur in the upland mixed oak areas and other desirable species such as black walnut (Juglans nigra L.), black cherry, and white ash occur only sporadically and only on the better sites. Therefore, it is imperative that present stands are regenerated to predominately oak stands following harvest.

Research has shown that the oak component of young hardwood stands following complete overstory removal will be proportional to the numbers and size of oak advance reproduction present at the time of overstory removal (Sander 1971, 1972). Size of oak reproduction at the time of final harvest is critical for successfully regenerating the stand. Newly-established oak seedlings and small advance reproduction grow much too slowly to compete successfully following harvest (Sander and Clark 1971; McQuilkin 1975). However, large stems of oak advance reproduction grow rapidly after harvest and have a high probablilty of becoming dominant in the new stands (Carvell 1979; Sander 1971, 1972).

Upland hardwood stands in the Boston Mountains of northern Arkansas may have several thousand reproduction stems of oak and other desirable species per acre that are less than 1 foot tall, but large reproduction is sparse or completely

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2/ Principal Silviculturist and Hydrologist at the Silviculture and Hydrology Laboratory, maintained at Fayetteville, AR, by the Southern Forest Experiment Station, USDA, Forest Service, in cooperation with the University of Arkansas.

absent. Many of these stands are within 30 years of rotation age, are fully stocked, and have well-developed understories consisting primarily of tolerant noncommercial species. Given the present size and status of existing reproduction, the new reproduction stand following final overstory removal will contain a mixture of species but will almost certainly contain a low proportion of oak. To enhance development of established oak advance reproduction in such stands, a modified shelterwood system (Sander 1979, 1983; Loftis 1983a, 1983b; Gottschalk 1983) involving light to medium overstory removals, coupled with partial to complete understory control, is being evaluated for upland oak stands in several areas.

This report reviews the 5-year height growth response of oaks (northern red, black, and white), white ash, and black cherry advance reproduction to overstory release and fertilization. The study sites are oak stands with understories partially controlled by cutting.

METHODS

A series of 64 fertilized-nonfertilzed paired plots, installed on Ozark National Forest lands as part of an oak growth and yield study (Graney 1980), provided an opportunity to study effects of stand density and fertilization on establishment and growth of oak, ash, and cherry reproduction.

Each plot was approximately one acre in size (0.4 or 0.5 acre measurement plot plus a 33-foot buffer strip treated the same as the plot). The 64 plots represented a range in stand age of 40 to 75 years and in site index (base age 50 years for northern red or black oak) of 48 to 84 feet, and included four overstory density treatments: 40 percent, 60 percent and 80 percent relative stocking density (Gingrich 1967) plus a nonthinned control. Pretreatment stocking densities for all plots averaged about 106 percent for trees 2.6 inches d.b.h. and greater and initial basal areas averaged about 113 sq. ft. per acre (Table 1). The understory subcanopy was well developed on all study plots. Small trees (0.6 to 2.5 inches d.b.h.) averaged more than 600 stems per acre and contributed and additional 6 sq. ft. of basal area and 13 percent stocking on study plots.

Table 1. -- Stand characteristics per acre before and after treatment for trees 2.6 in. d.b.h. and greater.

Stocking Treatment	Original Stand: Number of Trees	Original Stand: Basal Area	Original Stand: Stocking	Residual Stand: Number of Trees	Residual Stand: Basal Area	Residual Stand: Stocking
		Ft.^{2}	Percent		Ft.^{2}	Percent
Nonthinned	431	111	107	431	111	107
80 Percent	331	115	106	212	87	78
60 Percent	382	114	106	156	66	58
40 Percent	415	111	104	124	42	41

Individuals of each plot-pair were usually contiguous (or located in the same stand) and received the same residual stocking treatment. One plot in each pair received a single fertilizer application of 300 lb N per acre applied as ammonium nitrate (34-0-0) 1 year after the thinning treatment.

Overstory density treatments in these intermediate-aged stands were accomplished by thinning mostly from below. Culls and poor quality trees were removed first, then intermediate and suppressed trees of low quality and vigor. Residual stands generally contained the better dominants and codominants as uniformly distributed as possible, although it was necessary to leave some midstory stems on plots receiving the 80 percent stocking treatment. Overstories on all plots were predominately oak. Northern red, black, and white oaks accounted for more than 90 percent of the overstory basal area before treatment and more than 95 percent after thinning. Although often a major component of the advance regeneration in most stands, ash and cherry represented less than 1 percent of the overstory stocking on all plots.

Understories on study plots were well developed and consisted of tolerant brushy or less desirable species such as red maple (Acer rubrum L.), serviceberry (Amelanchier arborea (Michx. f.) Fern.), redbud (Cercis canadensis L.), and blackgum (Nyssa sylvatica Marsh.) on poor to medium sites, while dogwood (Cornus florida L.), hophornbeam (Ostrya virginiana (Mill.) K. Koch), pawpaw (Asimina triloba (L.) Dunal), and sugar maple (Acer saccharum Marsh.) were common on good sites. Numbers of small trees were highly variable and ranged from fewer than 400 per acre on some site index 50 plots to more than 1,000 per acre on site index 70 and 80 plots. To make the contribution of small trees initially as uniform as possible across all treated plots, numbers of trees in the 0.6- to 2.5-inch d.b.h. classes were reduced to about 200 per acre (approximately 4 percent stocking). Throughout the period of plot establishment and treatment, the Ozark National Forest was restricted from use of all herbicides. Therefore, numbers of small trees were reduced by manually cutting individual stems.

Reproduction was measured on a series of 14 to 16 2-milacre circular subplots systematically distributed across each plot. On each subplot, all regeneration up to 2.5 inches d.b.h. was tallied by species, origin (true seedling, seedling sprout, or sprout from a cut stem) and total height to the nearest 1-foot class. For all oak, ash, and cherry reproduction, total height and height growth during the 5 years since treatment was measured to the nearest 0.1 foot.

The study design was a split-plot with overstory stocking levels representing the whole plots and fertilizer treatment the subplots with 8 replications. Data were analyzed using analyses of variance to test for differences in main effects. Duncan's multiple range tests were used to compare individual treatment means.

RESULTS

Advance Reproduction in Nonthinned Stands

The height distribution of oak, ash, and cherry reproduction on the 8 nonthinned and nonfertilized plots is fairly typical of reproduction under nonthinned intermediate-aged upland oak stands in the Boston Mountains (Table 2). Although the amount of oak reproduction would be more than adequate to replace existing stands, tall advance reproduction (taller than 4.5 feet) is often sparse or (as in this case) absent. Most of the oak reproduction is under 1 foot tall and relatively few stems are taller than 2 feet. Ash and cherry reproduction is highly variable throughout the Boston Mountains but is usually most abundant on medium to good sites. Although ash and cherry will collectively contribute less than 1 percent of the overstory in most stands, they will represent the majority of the desirable species advance reproduction taller than 2 feet and nearly all of the reproduction over 4.5 feet in height (Table 2).

Table 2.--Mean height distribution of oak, ash, and cherry reproduction stems per acre present in the 8 nonthinned-nonfertilized oak stands.

Species	Height Class (Feet)				
	<1.1	1.1-2.0	2.1-3.0	3.1-4.5	>4.5
	Number of Stems				
Oaks 1/	2130	40	31	7	0
Ash + cherry	2278	145	78	34	4

1/ White, black, and northern red oaks.

Reproduction After Treatment

Effects of Thinning

Residual overstory density had no effect on numbers of small stems less than 1 foot in height, but numbers of stems in the 1.1 to 4.5 and greater than 4.5 height classes were significantly greater on thinned plots (Table 3). Numbers of oaks taller than 1 foot were greater in stands thinned to 40 or 60 percent stocking. Ash and cherry reproduction followed the same general trend as the oaks although greatest numbers of ash and cherry stems were associated with the 60 percent overstory density treatment.

While numbers of oak, ash, and cherry reproduction in the thinned stands increased significantly over numbers in the nonthinned situation, the actual numbers of stems are small when compared to the increase in competing stems of other species. Stems of other species increased from more than 4,000 per acre in nonthinned stands to 7,000 to 10,000 in thinned stands. Of the 2,000 to 4,000 stems greater than 4.5 feet in height, nearly 1,000 per acre (primarily red maple sprouts) averaged 10 to 20 feet after 5 years (Table 3).

Effects of Fertilization

Numbers of oak, ash, and cherry stems less than 1 foot were significantly lower on fertilized plots across all levels of stocking but were greatly reduced in the nonthinned stands (Table 3). On the other hand, numbers of ash and cherry stems taller than 4.5 feet increased significantly on thinned and fertilized plots. Competing stems of other species in all height classes were not affected by the fertilizer treatment (Table 3).

Height Growth After Treatment

Effects of Thinning and Fertilization

Oak, ash, and cherry seedlings established following the overstory treatments produced little or no additional growth after the first year and generally averaged 0.5 foot or less (Table 4). Ash and cherry seedlings on thinned and fertilized plots indicated some response to the fertilizer treatments, but total heights averaged only about 0.8 feet for 3- and 4-year seedlings.

Table 4.--Total average height in feet of oak, ash, and cherry seedling reproduction established following treatment

Treatment	Residual Stocking Percent			
	Nonthinned	80	60	40
Oaks 1/				
Nonfertilized	0.4	0.4	0.5	0.5
Fertilized	0.4	0.4	0.5	0.5
Ash + cherry				
Nonfertilized	0.4	0.5	0.6	0.5
Fertilized	0.4	0.5	0.8	0.8

1/ White, black, and northern red oak

Growth of older oak seedlings was also relatively slow during the 5-year period since treatment but was significantly greater under thinned stands. Heights of oak seedlings in thinned stands increased 0.6 to 0.7 foot while seedlings in nonthinned stands grew 0.3 foot over the 5-year period (Table 5). Ash and cherry seedling reproduction responded significantly to thinning and fertilization with each treatment contributing about 1 foot of additional height growth (Table 5).

Sprout reproduction, under stands thinned to 40 or 60 percent stocking, produced the greatest height growth during the 5 years since treatment. Oak sprouts increased in height by an average of about 2 feet, but did not show an additional response to fertilizer. Heights of ash and cherry sprouts increased by 2 to 3 feet on thinned and nonfertilized plots and by 3 to 5 feet on thinned and fertilized plots (Table 5).

Table 3.--Reproduction per acre 5 years after thinning and 4 years after fertilization of intermediate-aged upland oak stands

Species	Residual Stocking Percent: Nonfertilized: Nonthinned	80	60	40	Fertilized: Nonthinned	80	60	40
	Number of stems							
Oaks[1/]								
<1.1 ft.	2130a[2/]	1643a	1530a	1380a	398a[2/]	895a	714a	500a*[3/]
1.1-4.5 ft.	78a	162b	360c	440c	69a	295b	370c	402c
>4.5 ft.	0a	50b	88b	104b	0a	25b	50b	98c
Ash + cherry								
<1.1 ft.	2278a	926a	1750a	976a	220a	310a	310a	413a*
1.1-4.5 ft.	257a	660b	848c	476b	197a	692b	1058c	806b
>4.5 ft.	4a	50b	94c	64b	0a	138b	230c	206c*
Other species								
<1.1 ft.	2645a	3080a	2372a	1595a	2010a	2248a	1734a	2317a
1.1-4.5 ft.	3163a	6458b	5775b	5784b	2850a	5633a	5193b	6105b
>4.5 ft.	1113a	2940b	3966b	3506b	1625a	1945a	3265b	3962b

1/ White, black, and northern red oaks
2/ Stocking treatment means in rows within each fertilizer treatment followed by the same letter are not significantly different at the 0.5 level
3/ Fertilizer treatment statistically significant; * = P < .05

Table 5.--Average 5-year height growth (in feet) of oak, ash, and cherry reproduction established prior to the time of treatment

Treatment	Residual Stocking Percent: Nonthinned	80	60	40
	Seedling Reproduction			
Oaks[1/]				
Nonfertilized	0.3a[2/]	0.6b	0.7b	0.6b
Fertilized	0.3a	0.6b	0.7b	0.6b
Ash + Cherry				
Nonfertilized	0.5a	1.4b	1.7b	1.6b
Fertilized	0.7a	2.1b	3.0c	2.6c*[3/]
	Sprout Reproduction			
Oaks[1/]				
Nonfertilized	0.5a	1.2b	1.8c	2.2c
Fertilized	0.5a	1.4b	2.1c	2.3c
Ash + cherry				
Nonfertilized	0.8a	2.2b	3.3c	3.1c
Fertilized	1.2a	3.3b	4.9c	5.1c*

1/ White, black, and northern red oaks.
2/ Stocking treatment means in rows followed by the same letter are not significantly different at the 0.5 level.
3/ Fertilizer treatment statistically significant; * = P<.05.

DISCUSSION

A primary objective in using the shelterwood system in upland oak stands is to enhance development of small established oak reproduction to a size sufficient to be competitive in the new stand after final harvest. Under the overstory and partial understory control treatments implemented in this study, all stocking levels resulted in an increase in average size of oak, ash, and cherry reproduction over that existing in nonthinned stands. Numbers of oaks taller than 1 foot increased from less than 100 per acre in nonthinned stands to more than 500 per acre in the medium and heavily thinned stands. Numbers of ash and cherry stems taller than 1 foot in thinned stands ranged from 300 to 1,000 per acre more than observed for nonthinned stands. Most of the increase resulted from smaller stems growing into the 1.1- to 3.0-foot classes (Table 6). Over all stocking treatments, most of the oak reproduction taller than 4.5 feet developed from stump sprouts and primarily in the 40- to 60-year old stands. No oak stump sprouts were recorded for 70-year old stands in study plots on sites 70 and 80. Based on prethinning diameter distributions for oak growth and yield plots representing 70- to 80-year old stands on site indexes 70 and 80, estimated stump sprouting (Johnson 1977; Sander et al 1976) for black, northern red, and white oaks would average only approximately 40 stems per acre. Therefore, continued development of small oak reproduction into the larger size classes is imperative for regenerating existing stands to predominately upland oak.

Table 6.--Mean height distribution of oak, ash, and cherry reproduction stems per acre present in nonfertilized stands for nonthinned and 60 percent stocking treatments

Treatment	Height Class (Feet)				
	<1.1	1.1-2.0	2.1-3.0	3.1-4.5	>4.5
	Number of Stems				
Oaks[1/]					
Nonthinned	2130	40	31	7	0
60 Percent	1530	183	94	83	88
Ash + Cherry					
Nonthinned	2278	145	78	34	4
60 Percent	1750	477	216	153	94

[1/] White, black, and northern red oaks

Ash and cherry reproduction taller than 4.5 feet developed primarily from extended growth and sprouts from established seedlings. Although representing fewer than 10 stems per acre, ash and, particularly, cherry sprouts originating from cut stems attained average heights of 10 feet on nonfertilized plots and more than 15 feet on fertilized plots, the maximums observed over the 5-year period.

While overstory and understory treatments imposed in this study resulted in significant increases in the numbers of oak, ash, and cherry stems taller than 1 foot, the average 5-year increase in height for established reproduction, particularly oaks, was relatively small. Older oak seedling reproduction averaged about 0.1 foot height growth per year, while sprouts averaged 0.2 to 0.4 feet, depending on overstory density. Nearly all of the oak seedling and seedling sprout reproduction present at the time of treatment was less than 1 foot tall (averaging 0.3 to 0.5 foot). Although the data are based on relatively few stems, response of established reproduction taller than 1 foot at the time of treatment indicated somewhat greater increases in height (Table 7). Five-year height increases for medium- to heavily-thinned stands averaged about 3 feet for taller oak seedlings while increases for ash and cherry averaged about 4 and 5 feet for nonfertilized and fertilized treatments, respectively. Height growth of oak sprouts originating from either cut stems or existing stems taller than 1 foot averaged about 4.5 feet. Ash and cherry sprouts averaged about 5-foot increases on nonfertilized stands thinned to 60 and 40 percent overstory stocking, while heights of sprouts in fertilized stands averaged about 6 to 7.5 feet for the same stocking treatments.

The stands fertilized in this study produced significant increases in gross basal area and cubic foot volume growth of the overstory (Graney 1983) and woody browse production in the understory (Snyder et al 1982). These same fertilized stands also experienced heavy overstory mortality during the severe drought of 1980 that negated much of the growth response to fertilization (Graney 1983).

Table 7.--Average 5-year height growth (in feet) of oak, ash, and cherry reproduction taller than 1.0 foot at the time of treatment or sprouting from cut or established stems taller than 1.0 foot

Treatment	Residual Stocking Percent			
	Nonthinned	80	60	40
	Seedlings			
Oaks[1/]				
Nonfertilized	0.5	1.6	3.3	3.0
Fertilized	0.5	1.6	3.4	2.9
Ash + cherry				
Nonfertilized	1.0	2.0	4.2	4.0
Fertilized	1.3	3.2	5.2	5.2
	Sprouts			
Oaks[1/]				
Nonfertilized	-	3.0	4.4	4.6
Fertilized	-	2.9	4.3	4.5
Ash + cherry				
Nonfertilized	-	2.8	4.8	5.3
Fertilized	-	3.4	5.9	7.5

1/ White, black, and northern red oaks

Apparently, the combination of nitrogen fertilization and drought has also resulted in significant mortality of small oak, ash, and cherry reproduction. On fertilized plots, seedling mortality occurred primarily in the smaller stems, less than 1 foot tall, and was most severe in the nonthinned plots. While seedling mortality on thinned plots occurred primarily in younger seedlings established since thinning, losses on nonthinned plots included most of the older seedlings and sprouts as well. Although the 1980 drought caused some seedling mortality on nonfertilized plots, in most cases seedlings suffered top kill and subsequently resprouted. Nonfertilized plots generally had a higher proportion of small seedling sprouts in the 1- to 3-year age classes.

Fertilization produced no significant effect on numbers of stems of other species, although numbers of stems less than 4.5 feet tall were somewhat lower for the fertilized 60 percent, 80 percent, and nonthinned treatments than on the nonfertilized plots.

While 5-year height growth of established oak reproduction was not affected by nitrogen fertilization, ash and cherry produced a significant height growth response on all thinned plots. Fertilizer application increased 5-year heights by about 1 foot for older ash and cherry seedlings and 2 feet for sprouts. Greatest response was generally associated with the 40 and 60 percent stocking levels. The additional 1- to 2-foot increase in ash and cherry height growth is much lower than the 1.8m (5.9 feet) 5-year increases observed for N- and

P-fertilized cherry seedlings in Pennsylvania (Auchmoody 1982). However, the Pennyslvania results were based on clearcut stands with initially taller reproduction (taller than 5 feet) and included an additional response to P fertilizer. In the Boston Mountains, only fertilized cherry stump sprouts approached the height growth responses indicated for the Pennsylvania cherry.

The partial understory control treatment applied in this study (reducing the numbers of stems in the 0.6- to 2.5-inch d.b.h. classes to 200 per acre by cutting) was probably the least desirable method of control but represented the only feasible option due to the ban on herbicide usage. While possibly a desirable multiple use type of treatment, it significantly increases the number of competing stems from sprouts and will require at least one additional control treatment before an adequate number of desirable stems reach the minimum size to be competitive at final harvest. After 5 years, numbers of competing stems on thinned plots more than doubled, and stems taller than 4.5 feet were three times greater than on nonthinned plots. Before treatment, heights of subcanopy stems in the 0.6- to 2.5-inch d.b.h. classes averaged more than 25 feet, and on most plots represented a secondary closed canopy of shade above the small oak, ash, and cherry reproduction. In such stands, overstory thinning alone will often have no appreciable effect on the amount of light reaching the small reproduction. The understory treatment significantly increased light penetration to the small reproduction layer for a period of at least 3 years and resulted in some improvement through the 5-year period. However, as sprouts from cut understory stems continue to increase in height and smaller reproduction continues to develop, most of the small oak reproduction will become overtopped by less desirable species during the next 5 years.

CONCLUSIONS

While based only upon the initial 5-year growth response after treatments, the following general observations are made:

1. The shelterwood system, combined with partial understory control, appears to be an effective system to enhance development of established desirable reproduction in upland oak stands in the Boston Mountains. After 5 years, numbers of oak, ash, and cherry stems taller than 1 foot were significantly greater in treated stands than observed for the nonthinned controls. Ash and cherry generally produced a greater height growth response to the overstory treatments than did the oak. The partial understory control by cutting treatment imposed on thinned plots decreased the level of subcanopy shade and possibly was of some temporary benefit to small reproduction. However, rapid development of the nontreated understory and growth of sprouts from cut stems have, after 5 years, more than doubled the number of competing stems per acre and have mostly overtopped the small oak, ash, and cherry reproduction. To maintain development of desirable reproduction, an additional understory control treatment will be required.

2. A residual overstory stocking density of 60 percent seems adequate to achieve development of established oak, ash, and cherry reproduction. Leaving a residual overstory density of 80 percent generally reduced height growth of oak, ash, and cherry seedlings and sprouts and did not obviously reduce numbers of competing stems. Mean height growth for oak, ash, and cherry reproduction on plots thinned to 40 percent stocking was essentially the same as that on 60 percent stocking plots. Therefore, there appears to be no advantage to leaving an understocked situation over the 10-or-more-year period required for development of large advance reproduction.

3. Application of nitrogen fertilizer to stimulate growth of oak advance reproduction cannot be justified and could prove to be a liability under certain circumstances. On fertilized plots, at least half of the new seedlings established during the study, and many older seedlings less than 1 foot tall were lost to mortality during the severe drought of 1980. Mortality of advance reproduction taller than 1 foot and large seedling and stump sprouts was generally low.

4. Older ash and cherry reproduction responds to nitrogen fertilization and numbers of stems taller than 4.5 feet increased from fewer than 10 to more than 200 per acre, which was more than double the numbers on nonfertilized plots. However, on nonfertilized plots, ash and cherry are present in adequate numbers and are still outgrowing the oaks. These species will most likely become a significant component in the thinned stands on good sites without nitrogen fertilization

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NATURAL HARDWOOD REGENERATION IN THE SOUTHERN APPALACHIANS[1/]

Mark Petruncio and Russ Lea[2/]

Abstract. Numerous unmerchantable trees frequently remain standing following commercial clearcutting of hardwoods. These undesirable stems compete with regeneration for light, moisture and nutrients. This study was designed to compare alternative methods for controlling residuals to promote quality hardwood regeneration. Three treatments--chainsaw-felling all residual stems (≥ 1" DBH), injecting all residual stems (≥ 1" DBH) with Tordon(R) 3/ 101R, and a control in which all residuals were left standing--were evaluated on an Appalachian hardwood site in western North Carolina. The number of free-to-grow naturally regenerated stems of desirable species, including oaks, is significantly increased by chainsaw-felling and decreased by injecting in comparison to the control. Stand productivity can be upgraded by appropriately controlling residuals following commercial harvest.

INTRODUCTION

Results from a number of related hardwood regeneration studies in the Southern Appalachians (McGee, 1967; McGee and Hooper, 1970; McGee and Hooper, 1975; McGee, 1975) indicate that almost any intensity of cutting is followed by abundant reproduction. Early height growth of seedlings and sprouts, however, is superior following clearcutting as opposed to partial cutting.

Clearcutting alone cannot solve all of the problems of establishing a desirable stand. Following a commercial clearcut of merchantable timber, there are often numerous desirable species below merchantable size, cull trees and undesirable species which remain standing. The amount of residuals left is dependent upon the amount of unmerchantable stems in the original stand and the degree of utilization. Residuals are potential wolf trees, with the inherent capacity of impeding the growth and development of the ensuing regeneration by competing for light, moisture and nutrients.

Suggested methods for controlling residual trees include shearing, chopping, girdling, chainsaw-felling or herbicide injection. The complete clearcut where residual trees are controlled, as opposed to a commercial clearcut where no residual control is practiced, is suspected to be the most desirable method for ensuring maximum regeneration productivity in the Southern Appalachians. This study is designed to compare alternative methods for controlling residuals to promote quality hardwood regeneration. Three treatments--chainsaw-felling all residual stems with a diameter at breast height (DBH) of one inch or greater, injecting all residual stems (≥ 1" DBH) with Tordon(R) 101R, and a control in which all residuals are left standing--are examined as to their effects on natural regeneration on an Appalachian hardwood site in western North Carolina. The research results are a portion of a larger, long-term project, "Natural Hardwood Regeneration in the Southern Appalachians," organized by the North Carolina State University-Industry Cooperative Hardwood Research Program.

SITE CHARACTERISTICS

The location of the study site is within the South Mountains near Dysartsville, McDowell County, N. C. The experimental unit is on the Robertson Tract owned by Champion International Corporation. Elevations on the unit range from 1400 to 1700 feet with 40 to 70% slopes and a north-northwest aspect. Mean annual precipitation is approximately 55 inches, and the site index is 70 feet on a 50-year red oak base. The stand had 76 ft^2/ac. basal area of merchantable

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ The authors are, respectively, Research Assistant and Associate Director, North Carolina State University Hardwood Research Program, Raleigh, North Carolina.

3/ The use of trade names in this paper is for the convenience of the reader and does not constitute an official endorsement or censure.

timber that consisted of a mixture of red and white oaks, hickories and red maple. (Scientific names of the species are given in the Appendix.) Ages of the trees ranged from 75 to 150 years. The tract has always been forested but has probably been high-graded in the past because it did not have a lot of quality for its age. The high-graded condition is typical of most southern hardwood stands which have been subjected to repeated, incomplete harvests.

The soils comprise a three-series complex, the Evard, Cowee and Saluda series, which are Typic Hapludults. They are well-drained, moderately permeable, loamy-textured soils that formed in residuum from granite, gneiss or schist. These soils are medium in natural fertility and well-suited for commercial production of hardwoods but have severe equipment limitations due to steepness of slope.

PROCEDURES

In July 1978, installation procedures for the study were carried out as directed in the "Generalized Working Plan for Development of Southern Hardwood Stands from Natural Regeneration."[4/] Prior to harvesting, boundaries for a randomized complete-block design were established on 15 acres. Twelve plots, each 1.25 acres, were permanently marked to permit four replications of three treatments. In addition, four permanent four-milacre subplots were established within each plot for regeneration sampling. The merchantable stand was inventoried by a 20% cruise of each plot, and advance reproduction was tallied on all of the four-milacre subplots.

The 15-acre experimental unit is within a 138-acre tract which was commercially clearcut by an independent contractor in 1978 and 1979. All merchantable timber with a DBH of 6 inches or greater was harvested. The experimental residual control treatments were imposed after harvest. One treatment involved clearfelling all residual stems ($\geq$ 1"DBH) by chainsaw. In the second treatment, all residual stems ($\geq$ 1" DBH) were injected with Tordon (R) 101R, using Hypo-Hatchets (R). The third treatment, a control in which all residuals were left standing, represents the typical condition following a commercial clearcut.

The regeneration was measured on the permanent subplots in June 1983, during the fifth growing season following harvest. In addition to diameter and height tallies, the seedlings and sprouts were rated as either free-to-grow or overtopped by other trees or shrubs, for sprouts only one stem per sprout clump was measured and rated.

RESULTS AND DISCUSSION

The original stand's 76 ft²/ac. basal area of merchantable timber consisted of white oaks (49%), red oaks (23%), hickories (14%), red maple (6%), and the remainder (8%) of scattered yellow-poplar, black gum, shortleaf and Virginia pine (Table 1).

Table 1.--Tally of merchantable stems prior to harvest (July 1978) on the Robertson natural regeneration study site, McDowell County, NC

Species	Trees/Acre	Basal Area (ft²/ac.)
White Oaks	55	37
Red Oaks	27	18
Hickories	14	11
Red Maple	10	4
Other Species[1/]	8	6
Total	114	76

1/ Other species tallied included yellow-poplar, black gum, shortleaf and Virginia pine.

The advance reproduction less than 4.5 feet tall averaged 1026 stems per acre of desirable species and 1042 stems per acre of undesirable species (Table 2). The desirable advance reproduction consisted of white oaks (35%), red oaks (14%), red maple (37%), and the remainder (14%) of yellow-poplar, cucumber magnolia, hickories, black gum and yellow buckeye. Dogwood and sassafras accounted for 83% of the undesirable species. Also present were silverbell, sourwood, persimmon and black locust. In addition, there was an average of 958 stems per acre of desirable and undesirable species greater than 4.5 feet tall but below the 6-inch merchantable diameter.

Five years following harvest, there were significant differences between the treatments. The control plots had an average residual basal area of approximately 30 ft²/ac. The malformed crowns of the residuals had closed, shading out the regeneration. On the chainsaw plots there was no overstory competition. In the absence of competition, the ensuing regeneration was unencumbered and developed rapidly. A different situation was observed on the inject plots, the area was much more open, and a predominance of early successional weed species were present. This was attributed to the flashback phenomenon. Tordon (R) 101R, a highly

4/ Kellison, R. C. and W. E. Gardner. 1977. Generalized Working Plan for Development of Southern Hardwood Stands from Natural Regeneration. IN Work Plans, Hardwood Research Cooperative, N. C. State Univ., Raleigh, N. C. (Unpublished)

Table 2.--Advance reproduction (≥ 4.5 feet) tallied prior to harvest (July 1978) on the Robertson natural regeneration study site, McDowell County, N. C.

Desirable Species	Stems/ Acre	Undesirable Species	Stems/ Acre
White Oak	31	Dogwood	583
Chestnut Oak	323	Sassafras	276
Northern Red Oak	73	Silverbell	99
Scarlet Oak	42	Sourwood	68
Black Oak	31	Persimmon	10
Red Maple	380	Black Locust	5
Other Species[1/]	146		
Total	1026	Total	1041

[1/] Other species present included yellow-poplar, cucumber magnolia, hickories, black gum and yellow buckeye.

active systemic herbicide, is water soluble, can move with surface runoff water, and can remain phytotoxic for a year or longer when it enters the soil (Dow Chemical, 1979). Tordon (R) 101R not only eliminated the residuals but other seedlings and sprouts by translocation through root grafting. Additionally, untreated trees were affected by root uptake of herbicide leached into the soil or excreted by the roots of nearby treated trees.

The results of each of the two alternatives are compared and the number of stems is expressed as a percent difference from the control situation (Table 3). In doing so, we are evaluating for biological differences and economic justification for imposing each of the two treatments which have associated costs, compared to what would ensue with no treatment at no additional cost. Overall, chainsaw-felling the residuals increased the number of stems in all categories except total stems of desirable species, while injecting the residuals decreased the number of stems in all categories except large regeneration of desirable and undesirable species collectively.

The total number of stems of all species was significantly increased by chainsawing and decreased by injecting. When the total regeneration was analyzed by species, there was an increase in the number of desirable stems on the chainsaw plots and a significant decrease on the inject plots. The injected residual stems included both desirable and undesirable species. Injecting eliminated the stems of desirable species below merchantable size, whereas chainsawing induced vigorous resprouting. The opposing responses to these treatments accounts for the differences in the number of stems of desirable species.

Table 3.--Fifth-year (June 1983) comparative analysis of regeneration developing after a commercial clearcut. Two treatments--chainsaw-felling residuals and injecting residuals with Tordon (R) 101R--are compared to a control (residuals left untreated) on the Robertson natural regeneration study site, McDowell County, N. C.

	Treatments		
	Control	Chainsaw	Inject
	Stems/ Acre	Percent Difference From Control	
Total Regeneration[1/]			
All Species[2/]			
Total Stems[3/]	18,719	+40*	- 9
Seedlings	9,219	+20	-15
Sprouts[4/]	2,969	+43*	- 2
Desirable Species[5/]			
Total Stems[3/]	13,953	+ 6	-27*
Seedlings	8,203	+10	-26
Sprouts[4/]	1,750	+ 5	-24
Large Regeneration[6/]			
All Species[2/]			
Total Stems[3/]	5,125	+101*	+ 3
Seedlings	438	+121	+18
Sprouts[4/]	984	+ 87*	+ 6
Desirable Species[5/]			
Total Stems[3/]	3,875	- 7	-28
Seedlings	391	+ 28	-20
Sprouts[4/]	625	+ 5	- 8
Free-to-Grow Desirable Species[5/]	2,625	+ 52*	- 8
Total Oak Regeneration			
Total Stems[3/]	3,500	+ 17	-37*
Seedlings	797	+ 61	-28
Sprouts[4/]	766	+ 6	-37*

[1/] Total regeneration includes regeneration of all sizes.

[2/] All species includes desirable and undesirable species.

[3/] Total stems includes all stems per sprout clump plus seedlings.

[4/] Sprouts includes only one dominant stem per sprout clump.

[5/] Desirable species are listed in the Appendix.

[6/] Large regeneration is greater than 4.5 ft. tall.

* Significant at 0.10 level of significance

Chainsawing significantly increased the total number of stems greater than 4.5 feet, while there was almost no difference between injecting and the control. The large regeneration of desirable species will likely have the best chance of surviving and becoming future crop trees, compared to the regeneration less than 4.5 feet at 5 years. Tallies of the numerous stems would not have been as informative without a measure of competition such as the free-to-grow category. Although no significant differences were found in the number of large stems of desirable species between the treatments, there was a significant increase in the number of free-to-grow stems of desirable species on the chainsaw plots.

Timber managers in the Southern Appalachians are concerned with the proportion of oaks in the ensuing regeneration because of their commercial value. On the control plots, oak regeneration made up 25% of the desirable species. The number of oaks was increased by chainsawing the residuals and significantly decreased by injecting. The more valued species, oaks, appear to be very susceptible to flashback by Tordon(R) 101R.

CONCLUSION

We are beginning to manage the total forest resource, including hardwood sites. Tremendous opportunities exist for improving the quality of the resource. Objectives of judicious hardwood management are to perpetuate and upgrade stand productivity. Early results indicate that these objectives can be achieved by clearcutting and appropritately controlling residuals to favor natural regeneration, a method that mimics Nature better than any other harvesting system.

Treatment by chainsaw is faster, less expensive (Cathey, 1983) and a more effective means of controlling residuals than the Hypo-Hatchet(R). The appearance of the cutting unit is tremendously improved by clearfelling the residuals. This is an important issue for an aesthetically minded public.

Chainsaw-felling is currently being adopted by land managers as a preferred residual control treatment on Appalachian hardwood sites as a result of this study and other operational experience (Cathey, 1983). The number of free-to-grow stems of desirable species, including oaks, is significantly increased by chainsaw-felling the residuals and decreased by injecting with Tordon(R) 101R in comparison to the control. Analysis of fifth-year regeneration measurements indicates that the use of chainsaws to control residuals can be an effective and desirable method for improving natural hardwood regeneration in the Southern Appalachians.

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APPENDIX

Scientific and common names of tree species referred to in this study:

Scientific Name	Common Name
+ *Acer rubrum* L.	Red Maple
+ *Aesculus octandra* Marsh.	Yellow Buckeye
* *Amelanchier arborea* (Michaux F.) Fernald	Serviceberry
+ *Carya* spp. Nuttall	Hickory
* *Castanea dentata* (Marshall) Borkh.	American Chestnut
* *Castanea pumila* (L.) Miller	Chinquapin
* *Cornus florida* L.	Dogwood
* *Crataegus* spp. L.	Hawthorn
* *Diospyros virginiana* L.	Persimmon
+ *Fagus grandifolia* Ehrh.	Beech
* *Halesia carolina* L.	Silverbell
* *Ilex opaca* Aiton	Holly
+ *Liriodendron tulipifera* L.	Yellow-Poplar
+ *Magnolia acuminata* L.	Cucumber Magnolia
+ *Nyssa sylvatica* Marsh.	Black Gum
* *Oxydendrum arboreum* (L.) DC.	Sourwood
+ *Pinus echinata* Miller	Shortleaf Pine
+ *Pinus virginiana* Miller	Virginia Pine
+ *Prunus serotina* Ehrh.	Black Cherry
+ *Quercus alba* L.	White Oak
+ *Quercus coccinea* Muenchh.	Scarlet Oak
+ *Quercus prinus* L.	Chestnut Oak
+ *Quercus rubra* L.	Northern Red Oak
+ *Quercus velutina* Lam.	Black Oak
* *Robinia pseudoaccia* L.	Black Locust
* *Sassafras albidum* (Nuttall) Nees.	Sassafras

+ Desirable Species
* Undesirable Species

PRELIMINARY RESULTS OF EXPERIMENTAL PRESCRIBED BURNING TO FAVOR OAK REGENERATION ON THE NORTH CAROLINA PIEDMONT[1/]

William C. Davis and Stephen J. Begin[2/]

Abstract.--A study was begun on Duke Forest in 1980 to assess the effects of prescribed burning on the establishment of oak regeneration beneath mixed hardwoods stands. Five stands were first burned in the fall of 1980 and reburned during the late winter of 1984. Understory vegetation was tallied annually in four height classes: 0-2 ft, 2-5 ft, 5-12 ft, and greater than 12 ft but less than 2 inches dbh. The larger size classes were essentially eliminated by the first burn. The number of stems in the smaller size classes increased after the fire, and species densities changed substantially. Yellow-poplar produced an average of 64,000 germinants in 1982, which had decreased to 19,000 by 1983. The number of oak seedlings remained constant although their relative position declined due to the yellow-poplar germinants and abundant sprouting of large top-killed hardwoods. The burning regime and annual monitoring will continue.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Assistant Professor of Silviculture and Research Assistant, respectively, Duke University, Durham, NC.

FEDERAL INCOME TAX TREATMENT OF SILVICULTURAL COSTS ASSOCIATED WITH YOUNG PINE STANDS1/

William C. Siegel2/

Abstracts.--The Revenue Code provides five methods for recovering silvicultural costs. The correct or optimal procedure is often difficult to determine. This paper reviews and analyzes the present law in terms of various silvicultural and protection practices associated with young pine stands.

INTRODUCTION

Many silvicultural and related protection practices are employed by foresters in the establishment and early management of young pine stands. The Internal Revenue Code permits recovery of part of the costs of these activities, if reported on the federal income tax return. This process, however, is not always an easy one. The law reflects the wide variability among practices by providing five separate methods of recovering expenses.3/ The extent of savings depends on which is used. The correct or optimal procedure, and whether mandatory or optional, in turn depends on: (1) what the practice is, (2) its purpose, and (3) the taxpayer's tax status and cash-flow position. Being able to treat a particular silvicultural expenditure in a certain way for federal income tax purposes, as opposed to another way, may mean the difference between the practice being cost-effective or not.

The major problem is determining whether a silvicultural activity is legally part of the stand establishment process, a protection measure, or associated with maintaining and improving an established stand. Sometimes a single practice may fall into two or more of these categories at the same time. In many instances the distinction is not clear, but depends on a number of different factors -- all of which must be considered. Recent tax law changes in this area have further added to the confusion. What was formerly correct may not necessarily be so today.

This paper will review and analyze the present law regarding the federal income tax treatment of silvicultural and related protection costs associated with the establishment and management of young pine stands. Such activities as prescribed burning, use of chemicals, mechanical brush and weed control, rodent control, insect and disease control, fertilization, weeding, cleaning, precommercial thinning, wildfire prevention and control, and various timber stand improvement (TSI) practices will be addressed. Guidelines will be presented to assist managers in making the proper federal income tax determinations.

COST RECOVERY PROCEDURES

In order to partially recover silvicultural costs, they must either be deducted as operating expenses (often called expensing) or capitalized. Sometimes a tax credit may also be taken. Capitalization is generally less advantageous than expensing.

Capitalization

Section 263 of the Internal Revenue Code provides that amounts expended for real estate or equipment used for business or investment purposes, or to make improvements that increase the value of such property, are non-deductible capital investments.4/ The rule of thumb is that the benefits of capital expenditures are either permanent, or that they will last for a determinable period of more than one year. Such costs must be capitalized -- that is, they must be segregated

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Chief Economist and Project Leader, USDA, Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana.

3/ These methods include three types of capitalization -- deduction of capitalized expenditures from sale proceeds, capital cost recovery (depreciation) and amortization -- as well as expensing (deduction of expenditures in year incurred) and investment tax credits.

4/ The term "non-deductible" as used here does not mean that such costs are not deductible per se, but rather that they cannot be taken as a current deduction in the year they are incurred.

into a capital account. They are generally not recoverable immediately, but rather are deducted from income over a period of time as the capital asset or improvement with which they are associated is sold, used up, or worn out. The precise procedures employed to recover capital costs vary, depending on the nature and useful life of the asset acquired or the practice undertaken.

Deduction from Sale Proceeds

Deduction of a capitalized expenditure from sale proceeds is usually the least desirable recovery method from the taxpayer's standpoint. However, this procedure must be followed for items with a permanent or indeterminable life, or for practices with a permanent benefit. Not only is the deduction deferred until the asset is sold (sometimes a period of many years), but it usually offsets a long-term capital gain that is taxed at a much lower rate than is ordinary income.

Capital Cost Recovery

Capitalized expenditures for machinery and equipment having a useful life of more than one year are generally recovered by a process called capital cost recovery (formerly termed depreciation).5/ Annual deductions, which in the aggregate total the cost of the item being depreciated, are taken on the tax return over the useful life of the item. Useful lives (recovery periods) are determined in accordance with guidelines issued by the Internal Revenue Service. Capital cost recovery deductions may offset ordinary income from any source, which makes them considerably more advantageous than a deduction from a long-term capital gain.

Amortization

The third method of recovering a capitalized cost is by amortization. Capital expenditures not associated with machinery or equipment, or not otherwise depreciable, but which add value to a capital asset by providing a non-permanent benefit of more than a year's duration, may be deducted in annual installments over the life of the benefit or, in some instances, over another specified period of time. These deductions may also be offset against ordinary income from any source and thus have an advantage similar to that of depreciation.

Expensing

Expenditures categorized as operating costs may be deducted in full from ordinary income from any source (expensed) in the year they are incurred.6/ These expenses -- sometimes referred to as "ordinary and necessary" costs -- are those generally related to the income potential of the property (Briggs and Condrell, 1980; U.S. Department of Agriculture 1982). It is not necessary that the property be currently producing income, but the owner must have a profit motive. The term "profit" can be limited to appreciation in value. Expensing is, of course, more advantageous than capitalization since the entire deduction is taken in the year that the cost is incurred and may always be offset against ordinary income. A dollar saved today is more valuable than one saved later.

Tax Credit

A tax credit, rather than being a deduction from taxable income -- as are the other methods of recovery -- is a direct deduction from taxes owed. For example, a person in the 40 percent tax bracket with a $500 cost taken as a deduction against ordinary income would save $200 in taxes. If the $500 were allowed as a tax credit, however, the savings would be $500 -- not $200.

TAX TREATMENT OF SPECIFIC SILVICULTURAL PRACTICES

How should the costs of specific silvicultural and related protection practices be treated on the federal income tax return? Costs directly associated with establishment are capital expenditures and must be capitalized.7/ On the other hand, most of those incurred for stand maintenance or protection are usually considered to be current operating costs and thus expensable. There are some exceptions to this general rule, however. For example, even though particular machinery or equipment expenditures may be incurred for stand maintenance or protection, they are nevertheless considered to be capital items and must be capitalized. If a practice involves both stand establishment and stand maintenance, the cost may be proportionately allocated between each.

Recovery of Stand Establishment Costs

Prior to 1980, stand establishment costs could only be recovered as a depletion deduction when the timber was cut, or as a deduction from sale proceeds when the timber was sold. The gain in such situations, against which the deduction is taken, is usually a long-term capital gain -- taxable generally at a much lower rate than

5/ Internal Revenue Code, Sections 167-168.

6/ Sections 161-162 of the Internal Revenue Code allow corporate and individual businesses to deduct all "ordinary and necessary expenses." Similar language is found in Section 212 relating to expenses of producing income from, or in managing and conserving nonbusiness investment type property held by individuals.

7/ Treasury Regulation 1.611-3(a)

ordinary income.8/ This type of recovery is not nearly as advantageous as a more timely deduction from ordinary income.

Since 1980, however, the first $10,000 of stand establishment costs each year, even though capitalized, have been recoverable by amortization before the trees are cut or sold. A fiction in the law was created, setting the useful life of the trees at seven years. Two options are available. The first consists of amortizing the total allowable annual cost ($10,000 maximum) over 8 tax years, beginning with the year the expenditure was made. One-fourteenth of the cost is amortized that year, one-seventh during each of the next six years, and the remaining one-fourteenth the eighth year. The deductions may be taken whether or not the taxpayer itemizes deductions on his tax return. In addition, an eight percent tax credit is also allowed (eight percent of a maximum of $10,000).

The second option is to amortize 95 percent of the total allowable annual cost ($9,500 maximum) over eight tax years as described above. In this case, a ten percent tax credit is allowed (ten percent of a maximum of $10,000). This latter election is usually more advantageous for most taxpayers.

The amortization and credit provisions are separate elections. Either or both can be selected or rejected. If the taxpayer chooses not to amortize qualifying expenditures, they may be capitalized in the traditional way -- as an offset when the timber is cut or sold. In any event, all establishment costs in excess of $10,000 per year must also be recovered by that method.

Recovery of Stand Maintenance and Protection Costs.

All stand maintenance and protection expenses that fall within the category of current operating costs (ordinary and necessary expenses) may be deducted (expensed) against ordinary income from any source in the year they are incurred (U.S. Dept. Agriculture 1982, Cox 1984)9/. To utilize this procedure, however, the taxpayer must itemize deductions on his return. As an alternative, most current operating costs may be capitalized as "carrying charges" rather than expensed.10/ This would normally occur only in those years in which the taxpayer does not itemize deductions. In those instances, if not capitalized, they would be permanently lost for tax purposes. Capitalized carrying charges are deducted from sale proceeds when the timber to which they apply is cut or sold.

As has been pointed out, certain costs associated with stand maintenance and protection may not be current operating costs. Such expenses must be capitalized. Specific recovery procedures will be discussed later.

Stand Establishment Versus Stand Maintenance.

Some silvicultural situations obviously fall into the establishment category and some into the maintenance and/or protection category. For example, the law is clear that direct costs incurred in connection with reforestation by planting, direct seeding or natural seeding are part of the stand establishment process and must be capitalized.11/ The Internal Revenue Service (IRS) has ruled12/ that such costs include those for:

(a) Preparation of the site, including any girdling, herbicide applications, baiting of rodents or brush removal work to afford good growing conditions;

(b) acquisition of seedlings and seed; and

(c) labor and tools, including depreciation of equipment such as tractors, trucks, tree planters and similar machines used in planting or seeding.

The IRS has further ruled13/ that:

(a) The cost of seedlings includes the amount expended for those purchased, and those planted and raised by the taxpayer; and that

8/ For non-corporate taxpayers, the long-term capital gain tax rate is only 40 percent of the tax rate applied to ordinary income. For corporate taxpayers, the ordinary rate is less than the long-term gain rate on the first $50,000. On that portion of a corporate taxable gain exceeding $50,000, however, the reverse is true. In such situations, the differential between the two rates can be as much as 18 percent--a 28 percent long-term capital gain rate versus a 46 percent ordinary rate.

9/ Also see footnote 4, supra.

10/Internal Revenue Code Sections 265-266; Treasury Regulation 1.266-1.

11/ Treasury Regulation 1.611-3(a); Chapman and Dewey Lumber Co. v. United States, 238 F. Supp. 869 (W.D. Tenn. 1965, rev'd on other grounds, 359 F.2d 495 (6th Cir. 1966); Belcher v. Patterson, 60-2 U.S. Tax Cas. 9733 (N.D. ALA. 1960), rev'd on other grounds, 302 F.2d 289 (5th Cir. 1962).

12/Revenue Ruling 75-467, 1975-2 C.B. 93, superceding Revenue Ruling 55-252, 1955-1 C.B. 319.

13/Revenue Ruling 66-18, 1966-1 C.B. 59. Although this ruling deals with a Christmas tree operation, it is applicable to other timber operations as well. See Barham v. United States, 301 F. Supp. 43 (D. GA. 1969), affirmed 429 F.2d 40 (5th Cir. 1970).

(b) Labor and tool expense includes all costs involved in planting the seedlings, including all amounts expended for transportation, supervision and labor, equipment rental and depreciation of owned equipment and tools used in connection with the planting. The portion of the depreciated cost of equipment thus added to the basis of the seedlings should be proportionate to the use of the equipment or tools in planting as compared with the use of such equipment or tools in other activities of the taxpayer.14/

Thus there is no question that silvicultural costs directly concerned with site preparation, natural regeneration, seeding and planting are a part of stand establishment and must be capitalized. The law is less clear, however, regarding silvicultural operations performed after regeneration has been accomplished, or in stands that contain a mixture of both older trees and young reproduction. When are such activities part of the establishment process and when are they associated with stand maintenance? Some of these issues have been addressed by the IRS, both informally and in the form of revenue rulings. Still others have received the attention of the courts.

Brush Control

The IRS has discussed brush removal in young pine stands by stating in Revenue Ruling 66-18 15/ that "brush removal work performed a year or two after planting is considered to be proximately related to the establishment of the seedlings. Such work is essentially a part of the planting operation, and its cost should be capitalized." A key distinction raised by this ruling is the difference between brush removal and silvicultural practices. The ruling goes on to state that costs for brush removal incurred after trees have become established are in the nature of maintenance charges for a silvicultural practice and thus are deductible as an ordinary and necessary trade or business expense. Therefore, whether brush control expenditures must be capitalized -- or may be deducted -- depends on the timing of the practice. The critical factor is whether the seedlings have become established or not. It is immaterial whether chemicals, fire or mechanical control means are used. Seedlings would not be considered to be established if brush control was crucial to their continued survival. This could still be the situation several years after planting or seeding. On the other hand, the IRS here recognized that seedlings could become established in as little as one year -- that is, brush removal would enhance their growth and vigor, but not be essential for survival. The practice may also serve a dual purpose in uneven-age stands. It may be a site preparation measure (prior to either interspersed planting or natural regeneration), but at the same time increase the growth and vigor of established seedlings. In such a situation, allocation of cost can be made between capital and expense, proportional to the extent of each of the two benefits.

Since Revenue Ruling 66-18 deals with a Christmas tree operation, some IRS officials have attempted to limit its applicability with respect to brush control to just Christmas trees and not to commercial timber operations.16/ They have argued that brush control in established commercial stands improves the timber by promoting its long-term growth and enhancement (a benefit lasting more than one year) and thus is a capital improvement the cost of which must be capitalized. The weight of authority, however, is against this position. Revenue Ruling 66-18 contains expression of opinion by the IRS regarding issues of capitalization versus business expense which are relevant as well to standard timber operations (Briggs and Condrell, 1978 at page 86). These were pointed out in Barham v. United States 17/ where a federal district court held that the brush control portion of Revenue Ruling 66-18 applies to commercial timber stands as well as to Christmas tree operations. The District Court, which was upheld by the Fifth Circuit Court of Appeals, ruled that just because commercial southern pine timber may be harvested many years into the future (as opposed to only a few years for Christmas trees) is no basis for not applying the ruling to brush control expenditures in such stands. The Court, citing several additional authorities, further pointed out that brush control in established stands -- even though having certain capital characteristics -- is nevertheless a cultural practice, and thus its cost is an ordinary and necessary trade or business expense which is currently deductible under Section 162(a) of the Internal Revenue Code. Briggs and Condrell (1980) have also stated that the cost of brush removal, if done as a cultural operation after planting has been accomplished (the stand established), may be expensed.

The correct tax determination will obviously vary among individual brush control situations. If it becomes an issue, independent professional forestry judgment and opinion should suffice to settle the question. For example, in the Barham Case, the plaintiffs relied on the testimony of a

14/ Thus that portion of the machinery and equipment depreciation allowance attributable to stand establishment must be capitalized as a stand establishment cost. It may not be taken as a normal depreciation deduction.

15/ Footnote 11 supra.

16/ The forestry staff of the IRS district office in Atlanta evidently still holds to this position, as indicated by informal communications between members of that staff and several of the author's colleagues.

17/ Footnote 11, supra.

consulting forester that the young pine trees in question were established and growing.

Fire Protection and Control

Although the issue has not been addressed by either the IRS or the courts, there may be a way that a portion -- or even all -- of brush removal costs in unestablished pine stands can be expensed rather than capitalized. Fire protection and control expenditures are always currently deductible as operating costs, whether incurred in an established or unestablished stand (Briggs and Condrell, 1978; U.S. Department of Agriculture 1982; Briggs and Condrell, 1980; Cox 1984).18/ Thus, to the extent that brush removal can be shown to be a fire protection measure by reducing the fuel hazard, the cost should be a deductible rather than a capital one. In other words, the expenditure should be deductible to the extent that it relates to fire protection versus the extent to which it is necessary for stand establishment. If brush removal is essential for stand survival, and can also be shown to serve as a fire protection and control measure (a dual purpose), then it would seem to be reasonable to capitalize half the cost and deduct the other half. If the issue is raised, expert opinion or testimony may be necessary to establish the probability of fire in a particular area and the necessity of control by removing brush. Foresters can also render expert opinion about the liklihood of stand establishment in the absence of control. Soil moisture conditions, seedling vigor, time of planting or seeding, and other successful reforestation efforts nearby that did not rely on the practice would all be relevant to proving that stand establishment is not a primary motive and function of brush removal.

Weeding, Cleaning, Improvement Cutting and Precommercial Thinning

The IRS also stated in Revenue Ruling 66-18 19/ that silvicultural practices such as weeding, cleaning and noncommercial thinning -- and, by implication, improvement cutting -- "incurred after the trees have become established" are in the nature of maintenance activities and thus the costs are deductible as ordinary business expenses. Situations in which this distinction becomes an issue will also very likely be decided on the basis of the timing of the work, just as with brush control. The Barham decision20/ also addressed the applicability of this portion of the ruling to commercial timber operations. The court held that expenditures for these practices in association with young but well established pine trees being grown for commercial timber purposes were deductible business expenses in keeping with the IRS position in Revenue Ruling 66-18. The plaintiffs here relied on the expert testimony of their consulting forester that the costs in question were common and economically beneficial ones associated with established stands in the tree farming business.

Weeding and cleaning expenditures have not been addressed by other authority except to the extent that such activities would be included under brush control. Numerous other authorities substantiate the expensing of precommercial thinning costs, however (Cox 1984; Briggs and Condrell, 1980; U.S. Department of Agriculture, 1982; Research Institute of America, 1984).21/ Pitsenbarger (1982) has written that although a few IRS agents have proposed that precommercial thinning is sometimes a part of stand establishment, that none to his knowledge have forced the issue. Improvement cuttings are discussed by Briggs and Condrell (1980) as follows: "if ordinary and necessary business expenses fall within the category of ... carrying charges, they can be expensed .... While carrying charges are not specifically defined in the regulations, they generally include ... such expenses as ... improvement cutting." Briggs and Condrell go on to say "Suppose he makes expenditures for ... and improvement cutting in immature stands not as incidental to any planting operations. These expenses are deductible."

Weeding, cleaning, improvement cutting -- and possibly pre-commercial thinning -- may also serve a multiple purpose in mixed-age stands. These practices can increase the growth and vigor of established trees and at the same time insure survival of young seedlings. In such situations it should be possible to allocate expenditures between capital and expense based on professional expertise and judgment.

Timber Stand Improvement (TSI)

The costs of destroying unwanted mature hardwoods have also been the subject of a recent IRS ruling.22/ The facts stated in that ruling that the taxpayer owned extensive loblolly-shortleaf

18/ Also see Treasury Regulation 1.162-1; Revenue Ruling 66-18, supra; Warner Mountains Lumber Co. v. Commissioner, 9 T.C. 1171 (1947), Acq. 1948-2 C.B. 4.

19/ Footnote 11, supra.

20/ Footnote 11, supra.

21/ For example, see U.S. Department of Agriculture 1982, Guide to Federal Income Tax for Timber Owners. This publication was reviewed and approved by the IRS prior to publication. On page 9, the following statement is made: "Noncommercial thinnings of immature stands and timber stand improvement (TSI) work are not, strictly speaking, activities involving carrying charges. If such work is done after the stand is established, you can deduct the cost as an operating expense."

22/ Revenue Ruling 76-290, 1976-2 C.B. 188.

pine acreage that also contained numerous hardwoods. For restocking after harvesting, the owner relied primarily on natural regeneration by utilizing seed trees, eradicating the hardwoods when the seedlings were from 3 to 7 years old. However, if adequate natural stocking was not achieved after 3 to 5 years, he resorted to planting. The hardwoods were then eliminated as part of the site preparation process. Both mechanical and chemical control methods were used. The hardwood eradication, whether associated with planting or seeding, was a one-time endeavor -- not a recurring practice. The IRS ruled that it constituted site preparation in both situations, was therefore a part of stand establishment, and thus a capital cost. An important issue associated with this ruling concerns identification of that point in time when naturally regenerated loblolly and shortleaf seedlings under a hardwood canopy become established. The IRS held here, under the facts presented by the taxpayer, that establishment does not occur until at least 7 years. However, the time period could differ from one situation to another. Pitsenbarger (1982) reports that a common agreement with IRS agents with respect to hardwood deadening has been 5 years, and that the time period is negotiable depending on the particular agent involved. It is also possible that hardwood eradication as described in this ruling could serve a dual purpose -- therefore justifying an allocation of costs between capital and expense.

Numerous other authorities also support the deductibility of TSI expenditures in established stands as current operating costs (Cox 1984; U.S. Department of Agriculture 1982; Briggs and Condrell, 1980).23/

Rodent, Animal, Disease and Insect Control

The costs of rodent, animal, disease and insect control in established stands are clearly deductible expenses even if non-control would result in death of the trees (U.S. Department of Agriculture 1982; Briggs and Condrell, 1980). In stands that have not yet become established, however, the tax status of such expenditures would seem to hinge on whether control is essential for initial seedling survival and growth or whether it serves only to enhance vigor and existing growth. In the former instance, the cost is part of the stand establishment expense and thus a capital expenditure.24/ In the latter situation, it is clearly a maintenance expense and thus currently deductible. Again, in stands of mixed age, multiple purposes could be involved, pointing to allocation of cost between capital and expense. If the issue arises, professional expertise and judgment should be utilized to make the proper determination.

Fertilization

The IRS has issued no formal rulings on the treatment of fertilization expenditures, nor has the issue been a part of any court decision. Fertilization that is clearly part of site preparation is obviously associated with stand establishment and its cost should be capitalized as such. Fertilizer expenditures that occur after planting or seeding, however, are treated as amortizable expenses by the IRS (Pitsenbarger 1982). This is because seedling survival does not depend on the practice being conducted at that point in time. These costs are amortized by allocating the total amount among annual deductions over the beneficial life of the particular fertilizer being used. The deductions may be offset against ordinary income from any source. The beneficial life of most fertilizers is still in question and there is even considerable difference of opinion within the IRS on this point. Thus, amortization periods are usually negotiated on an individual basis between taxpayers and the IRS. Pitsenbarger (1980) reports that generally the costs are being amortized over 5 to 15 years depending on the particular fertilizer applied. They do not have to be amortized, however. They may be capitalized in the regular manner, and recovered when the trees are cut or sold, if the taxpayer wishes.

Machinery and Equipment

Those portions of depreciation deductions for machinery and equipment that are associated with stand establishment must be capitalized as such.25/ They may then be recovered as an offset against the gain realized when the timber is cut or sold, or under the reforestation amortization procedure. The reforestation tax credit is not available for such costs. Machinery and equipment expenditures not associated with stand establishment may be recovered by depreciation in the normal fashion -- that is, by taking deductions from ordinary income over the established life of the item. In both types of situations, an investment tax credit may also be taken. For machinery and equipment with a recovery life of three years, the credit is 6 percent -- for items whose costs are recovered over 5 years, the credit is ten percent. If the taxpayer's timber operation is clearly a business as opposed to only an investment, he has the option of expensing the first $5,000 of otherwise depreciable costs each year. If he elects to

23/ See Footnote 17, supra.

24/ The IRS has addressed rodent control in nonestablished stands in Revenue Ruling 75-467 (Footnote 10, supra), stating that the expense of such control is a capital cost if part of the site preparation process. Although animal, disease and insect control have not been formally discussed by the IRS in a similar context, the same rationale would seem to apply.

25/ See footnote 12 supra.

do so, however, the investment tax credit on that amount is lost.

CONCLUSION

The federal income tax status of some silvicultural and related protection expenditures associated with young pine stands is clear. The status of certain other costs is not. The correct and/or optimal way to handle each expenditure depends not only on the nature of the practice, its timing, and its purpose -- but also on the taxpayer's cash flow situation, his tax status and his available tax options. Continuing changes in the tax law tend to further complicate the decision-making process, as does the fact that the IRS has not formally ruled on many silvicultural issues. Thus each silvicultural situation must not only be related to the law and to possible tax choices, but also to current IRS practices.

By utilizing professional forestry judgment and expertise, many taxpayers should be able to expense certain costs that at first glance would appear to be capital expenditures. Even when all of a particular cost cannot be allocated to the expense category, it may be possible to expense a certain portion. In that type of situation, aggressive effort by the taxpayer -- coupled with the proper technical advice -- can often pay big dividends in the form of tax savings. Such initiative may well result in a particular silvicultural practice being cost effective whereas otherwise it would not be. The key is to know the technical facts of each silvicultural situation, be cognizant of the law, and meld the two together for maximum advantage.

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THE INVESTMENT POTENTIAL OF COTTONWOOD SAWTIMBER PLANTATIONS[1/]

Walter C. Anderson and Roger M. Krinard[2/]

Abstract.--Cottonwood sawtimber plantations provide an exceptionally rapid rate of value growth per acre over a relatively short investment period. But the costs of establishing and tending a stand the first year are high. The conditions and alternative management strategies yielding investment payoffs exceeding 8 percent annual rate of return were analyzed.

Cottonwood plantations could help to supply a market that is dependent on a declining resource.

The principal products made from cottonwood lumber and veneer are boxes, crates, baskets, and pallets (Forest Products Laboratory 1974). The furniture industry also uses cottonwood lumber and veneer because of their desirable characteristics. The wood glues easily and holds paint well. Because of its light color, faint grain, and the indistinct division between heartwood and sapwood, cottonwood can be grained to simulate any species.

Eastern cottonwood (Populus deltoides Bartr.), -- the fastest growing tree in North America -- reaches its optimum growth in the rich, moist, soils of southern bottomlands (McKnight 1971). Although cottonwood grows in every state east of the Rocky Mountains, most of the commercial timber is found in natural stands on alluvial soils in the Mississippi River Delta.

By controlling the flow of the River, the Corps of Engineers is hindering the formation of new land and thus is slowing the creation of new natural stands. At the same time, cottonwood acreage is being reduced by clearing land for field crops, such as soybeans, and the construction of impoundments.

More than a million acres in the lower Mississippi River Valley are suitable for cottonwood production. However, only 50,000 acres have been planted.

Expansion of cottonwood acreage in the Delta depends on the attractiveness of cottonwood plantations as an investment. No extensive economic analysis of cottonwood plantations was made before that by Dutrow and others (1970). They reported rates of return for combinations of site quality, establishment costs, and stumpage prices that could be used by cottonwood planters as guides in making investment decisions. Only fragmentary data on plantation yields existed at the time. Consequently, the investigators were unable to fully specify the conditions under which investments in cottonwood provide an adequate return on capital. An improved biological data base has become available since then, which allows a more extensive evaluation of cottonwood plantations as an investment alternative.

This paper examines and compares investments in cottonwood sawtimber plantations. The results indicate the conditions under which they may earn an adequate return.

DATA AND METHODS

Production Data

Yield data for single rotations of 30-year-old plantations were provided by the Southern Hardwood Laboratory at Stoneville, Mississippi (Table 1). They are based on records of experimental plantings, supplemented with measurements of other plantings, and the expert judgment of knowledgable individuals. These are the best currently available data.

Three site classes were recognized -- medium, good old field, and good forest. The site index for medium sites equals 100 feet at 30 years; that for good sites is 120 feet. Good sites are usually on loam soils, and medium sites are often on clay.

Five spacing intervals were used on medium sites and six on good sites, with the addition of 36- by 36-foot spacing. At the narrowest spacing

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2/ Walter C. Anderson is Principal Economist Forest Resource Law and Economics, Southern Forest Experiment Station, New Orleans, Louisiana and Roger M. Krinard is Principal Silviculturist, Southern Hardwoods Laboratory, Southern Forest Experiment Station, Stoneville, Mississippi.

Table 1.-Cubic and board-foot volume yields of cottonwood sawtimber plantations by site, spacing interval, and thinning regime

Spacing interval (feet)	Age	Remaining stand: Trees per acre	Remaining stand: Average d.b.h.	Volume cut per acre	
	years	number	inches	cu ft	bd ft
Medium Site					
12x12	7	128	6.1	645	--
	18	58	10.5	830	--
	30	0	14.1	(300)[1/]	3,330
16x18	12	64	9.1	910	--
	30	0	16.2	(630)	6,980
24x24	21	42	15.5	(120)	1,320
	30	0	18.8	(855)	9,480
24x24	21	47	15.5	(95)	1,060
	30	0	18.8	(940)	10,430
28x28	21	36	16.0	(95)	1,080
	30	0	19.3	(765)	8,530
28x28	30	0	18.8	(975)	10,860
32x32	30	0	19.4	(835)	9,290
Good Site					
12x12	5	120	6.1	630	--
	12	76	11.8	760	--
	20	50	16.5	(145)	1,620
	30	0	21.5	(1,610)	17,910
16x18	8	68	9.4	1,040	--
	18	45	16.8	(135)	1,530
	30	0	22.8	(1,725)	19,150
24x24	15	40	16.7	(205)	2,270
	30	0	23.8	(1,805)	20,060
28x28	15	38	17.6	(130)	1,450
	30	0	24.7	(1,885)	20,950
32x32	30	0	24.9	(1,920)	21,350
36x36	30	0	25.4	(1,580)	17,560

[1/] Figures in parentheses are topwood.

interval on medium sites, little sawtimber may be produced because the average d.b.h. at harvest is only 14.1 inches. Stands in which the largest trees are 15 inches d.b.h. or less cannot be sold as sawtimber.

All stands were thinned at least once except those with the two widest spacing intervals on each site -- 28 by 28 and 32 by 32 feet on medium sites, and 32 by 32 and 36 by 36 feet on good sites. The first thinnings in the stands spaced 12 by 12 and 16 x 18 feet were row thinnings in which every other row was removed. Stands at these close spacings on good sites were thinned more frequently than those on medium sites. On medium sites, stands spaced 24 by 24 feet were thinned at one of two intensities, and stands spaced 28 by 28 feet were either thinned or not thinned.

Board-foot volume yields were greatest for stands spaced 24 by 24 feet on both medium and good sites. On medium sites, the volume harvested was greater where thinning was lighter. On good sites, there was little difference in total yields between stands spaced 24 by 24 feet and those spaced 28 by 28 feet -- 22,330 vs. 22,400 board feet.

Costs

Establishing a plantation includes selecting and preparing the site and planting the stand and cultivating it during the first year. Procedures for establishing and tending plantations are those currently employed by growers in the Delta, and costs are those typically being paid in the region.

The highest site preparation costs are for forested sites that must be cleared of timber before they can be readied to plant (Table 2). Site preparation costs are lowest where clearing is not needed, such as old fields. In this study, all medium sites were treated like old fields, i.e., not requiring clearing. Old fields must be plowed, however, to break the sod and thus eliminate soil compaction and aerate the soil. On some old fields, subsoiling is necessary to breakup hardpans that have developed through years of cultivation.

Costs of planting and tending a stand during the first year are about the same for all sites. Included in this cost are planting stock, labor, and machine time. There also may be an additional cost of $5 to $10 per acre the first year for insect control. Plantations spaced 24 by 24 feet or wider must be mowed in years 2, 3, and 4 at a cost of $5 per acre each year. Ad valorem taxes are to $0.65 per acre per year. The yearly cost of fire protection, management, and other expenses amounts to $10 per acre.

There are pruning costs for trees in stands spaced 24 by 24 feet and wider. Without pruning, trees in widely spaced stands cannot be sold because the boles, due to persistent limbs, are of such low quality.

At spacings of 24 by 24 feet and wider, all trees are pruned to 16 feet in two steps at a cost of $0.75 per tree. Crop trees are pruned from 16 to 32 feet with a contract cherry picker at an additional cost of $2 per tree. Pruning is done during the dormant season.

Timing of pruning differed by site index. Pruning to the specified height occured after the specified growing season:

Height	SI 120	SI 100	Cost per tree
--ft--	--growing season--		------$------
0 to 7	2	3	$0.20
7 to 16	4	6	$0.55
16 to 32	7	11	$2.00

Periodic pruning costs per acre are shown in Table 3.

Price

Three price levels were used in this analysis. Medium stumpage prices were the average prices being paid in the Delta. The medium price for sawtimber was $100 per thousand board feet (Doyle). The low level was 50 percent below the medium price, and the high level was 50 percent above it. For pulpwood, the three stumpage price levels were $5, $10, and $15 per standard cord. The respective prices for pulpwood per 100 cubic feet, based on 90 cubic feet per cord, were $5.56, $11.11, and $16.67. These prices were applied to volumes of topwood recovered from sawtimber trees and to pulpwood-size trees removed in thinnings.

Internal Rate of Return

The 19 investment options (based on 7 spacing and thinning combinations for the medium site class and 6 for each of the 2 good site classes) were evaluated on the basis of costs and expected returns before income taxes. The profitability of each option was measured in terms of internal rate of return (ROR). This measure of capital efficiency is preferred for decision making because it permits comparisons of investments whose returns and costs come at different times during the rotation. ROR is the compound rate of interest that exactly equates the discounted value of future revenues with the sum of the initial capital outlays and the discounted value of all other costs incurred during the rotation.

RESULTS

Returns from Cottonwood Plantations

The highest RORs were obtained for plantations on good old field sites, followed by those on good forest sites (Table 4). The lowest RORs were for plantations on medium sites (Table 5).

At the medium stumpage price level, the best spacing on good old field sites was 12 by 12 feet and on good forest sites was 16 by 18 feet. The best spacing on medium sites was 24 by 24 feet. Stands at this spacing with the highest RORs were lightly thinned.

At the medium stumpage price level, the highest RORs for stands established at the least cost per acre, by site class, were 8.9 percent for good old field sites, 6.4 percent for good forest sites, and 3.4 percent for medium sites.

Increased cost per acre to establish a stand reduced the ROR. The amount of the reduction varied from 13 to 20 percent and averaged 16 percent for the lowest to the highest costs used in the study.

Stumpage price levels also had an effect on RORs. Moving from one price level to the next changed the ROR for a given spacing interval on a given site class by 2 or 3 percentage points, and even more in some instances.

Table 2.-Costs of growing cottonwood sawtimber plantations in the Mississippi River Delta

Item of expense	Cost	
	Low	High
	$/acre	
Preparation [1] of:		
Forested site	250.00	350.00
Old field site	50.00	60.00
Planting and first-year costs [2]	115.00	155.00
Insect control	5.00	10.00
Annual costs [3]	10.65	10.65
Mowing [4]	5.00	5.00

[1] Includes site selection, land clearing where needed, and readying site for planting.

[2] Includes planting stock, planting, and cultivation for 1 year.

[3] Includes taxes, fire protection, and management expenses.

[4] In years 2, 3, and 4 in plantations spaced 24 x 24 feet or wider.

Table 3.-Pruning costs per acre by year for two site classes and four spacing intervals

Spacing (feet)	Medium (SI 100)		Good (SI 120)	
	Year	Cost	Year	Cost
		$/acre		$/acre
24x24	4	14.00	3	14.00
	7	38.50	5	38.50
	12 [1]	84.00	8	80.00
	12 [2]	94.00		
28x28	4	10.00	3	10.00
	7	27.50	5	27.50
	12 [3]	72.00	8	76.00
	12 [4]	100.00		
32x32	4	8.00	3	8.00
	7	22.00	5	22.00
	12	80.00	8	80.00
36x36	4	--	3	6.00
	7	--	5	16.50
	12	--	8	60.00

[1] Heavily thinned plantation.

[2] Lightly thinned plantation.

[3] Thinned plantation.

[4] Unthinned plantation.

Table 4.-Rates of return for cottonwood sawtimber plantations by site spacing interval, establishment costs, and stumpage price level

Stumpage price level	Estabm't cost	Spacing interval (feet) 12x12	16x18	24x24	28x28	32x32	36x36
	$/acre	percent					
Good Old Field							
Low	165	4.85	4.95	3.43	3.49	3.11	2.43
	195	4.39	4.50	3.13	3.20	2.84	2.15
	225	3.99	4.10	2.86	2.93	2.59	1.90
Medium	165	8.88	8.81	6.95	6.87	6.23	5.58
	195	8.28	8.24	6.60	6.52	5.92	5.26
	225	7.77	7.75	6.27	6.20	5.64	4.97
High	165	11.54	11.28	9.06	8.85	8.01	7.37
	195	10.82	10.61	8.66	8.47	7.68	7.03
	225	10.20	10.05	8.31	8.13	7.38	6.72
Good Forest							
Low	365	3.20	3.31	2.43	2.49	2.23	1.66
	435	2.66	2.77	2.02	2.08	1.83	1.26
	515	2.13	2.25	1.60	1.66	1.44	0.86
Medium	365	6.32	6.36	5.36	5.32	4.87	4.25
	435	5.69	5.75	4.89	4.85	4.44	3.82
	515	5.08	5.15	4.42	4.39	4.01	3.39
High	365	8.37	8.34	7.19	7.05	6.45	5.82
	435	7.66	7.66	6.67	6.55	6.01	5.37
	515	6.98	7.00	6.17	6.06	5.56	4.92

Table 5.-Rates of return for cottonwood sawtimber plantations on medium sites by spacing interval, establishment cost, and stumpage price level

Stumpage price level	Estabm't cost	Spacing interval (feet) 12x12	16x18	24x24 Hvy. Thin	24x24 Lt. Thin	28x28 Thin	28x28 No Thin	32x32
	$/acre	percent						
Low	165	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	195	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	225	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medium	165	0.63	3.27	3.23	3.40	2.84	3.84	2.54
	195	0.20	2.85	2.94	3.12	2.55	2.80	2.26
	225	0.00	2.49	2.67	2.86	2.28	2.55	2.01
High	165	3.50	5.50	5.24	5.38	4.85	4.97	4.44
	195	2.95	5.03	4.92	5.07	4.52	4.67	4.24
	225	2.49	4.61	4.62	4.78	4.22	4.40	3.86

Techniques for Increasing Returns

Two ways RORs from investments in cottonwood plantations in the Delta can be increased are by reducing establishment costs and obtaining additional income from the land by utilizing revenue sources from other than cottonwood alone.

The high cost of clearing a good forest site could be lowered by growing an agricultural crop the first year after the site has been prepared for planting but before a plantation is established. In the Delta, soybeans could be used for this purpose. The cost per acre is about $100, and average yields are about 25 bushels per acre. Personal communications with a soybean farmer and an Agricultural Research Service economist indicate that there would be no reduction in yield from the crop grown on new ground the first year. At $6 per bushel, the income from an acre of soybeans is $150. Net receipts would offset clearing cost by $50 per acre. At the lowest level of investment on good forest sites, the establishment cost would be reduced from $365 to $315 per acre. At the medium price and for the best spacing interval -- 16 by 18 feet -- the ROR would be increased from 6.4 to 6.9 percent, or by one-half of 1 percent. However, defraying part of the cost of clearing in this way lengthens the investment period by a year.

Two additional sources of revenue from land planted to cottonwood are fees for hunting leases and receipts from soybeans interplanted between rows of trees. Fees for hunting leases are currently around $5 per acre per year, and involve no additional costs to the landowner.

Soybeans can be grown only for the first year among trees planted at spacings of 12 by 12 and 16 by 18 feet. Where trees are spaced 24 by 24 feet or wider, this field crop can be grown for the first 2 years. Forty percent of the area would be in soybeans in a plantation with 12- by 12-foot spacing, and 70 percent in plantations with wider spacings. Yields are proportionate to the percentage of the area in the crop. If costs are also proportionate to the area, intercropping would add $20 per acre to the income from a plantation with 12- by 12-foot spacing and $35 per acre to the income from a plantation with 16- by 18-foot spacing. Where stands are more widely spaced, $35 per acre would be received each of the first 2 years.

The effect of income from each of these additional sources of revenue and their combined effect on increasing RORs is shown in Table 6. In general, soybeans increased RORs more than did hunting leases. Seldom was the increase from either of these additional sources of revenue more than 2 percentage points, and sometimes it was less than 1 percent. The increase in the RORs from the combined incomes of these additional income sources varied from 1 percentage point to nearly 4 percentage points.

DISCUSSION

Although cottonwood has a very rapid growth rate, producing as much as 750 board feet per acre per year on good sites, this advantage is countered by high establishment costs. The initial investment in an average 200-acre plantation could be between $33,000 and $103,000. With so much capital being committed for a long period, investment decisions must be made carefully.

The available options from which an individual landowner can choose depend on that landowner's situation, expectations, and judgments. These include the site class of the land, establishment costs, anticipated future market prices, and length of planning horizon. A landowner with a short planning horizon would exclude growing cottonwood as a possible investment if the time were too short for trees to reach sawtimber size. The degree of profitability the landowner considers sufficient is another factor of choice.

From an economic perspective, an individual's decision whether to grow cottonwood depends on their minimum acceptable rate of return. The investor's acceptable rate is sometimes called the guiding rate of interest. Options expected to return less than the guiding rate are rejected. Among those that promise to exceed the guiding rate, the option with the highest return that can be obtained is the investor's choice.

If a landowner's guiding rate of interest is 8 percent, at medium prices it will pay to grow cottonwood only on good old field sites. At low price levels, it would not pay to grow cottonwood plantations on any sites. At high prices, in addition to good old field sites, it would also pay to grow cottonwood on good forest sites, provided establishment costs were kept to a minimum.

Even with the addition of supplemental income, it is not possible to raise RORs above 8 percent at low price levels. At high price levels, however, RORs above 8 percent are realized on medium sites when income from both hunting leases and soybeans are added and establishment costs are less than $200. On good forest sites and at the high price level, RORs above 8 percent are obtained when revenues from either a hunting lease or soybeans are added, except at the highest establishment cost.

On good old field sites, additional income from hunting lease fees or soybean returns are unnecessary to raise RORs above 8 percent at the medium or high stumpage price level. These subsidiary revenues can raise RORs to as high as 12 1/2 percent at the medium stumpage price level, or to 15 1/2 percent at the high level.

CONCLUSIONS

This paper examined RORs for cottonwood sawtimber plantations on three site classes at three

Table 6.-Rates of return for cottonwood sawtimber plantations when additional income from hunting lease fees or soybeans (or both) are included by site class, stumpage price level, and establishment cost

Stumpage price level	Establm't cost	Source of additional income: None	Hunting lease	Soybeans	Hunting lease and soybeans
	$/acre	percent			
Medium					
Low	165	0.00	1.16	1.39	3.25
	195	0.00	0.86	1.00	2.68
	225	0.00	0.59	0.66	2.20
Medium	165	3.40	4.41	5.31	6.92
	195	3.12	4.06	4.80	6.20
	225	2.86	3.75	4.37	5.62
High	165	5.38	6.28	7.52	9.23
	195	5.07	5.91	6.43	8.22
	225	4.78	5.57	6.44	7.58
Good Old Field					
Low	165	4.95	6.33	6.38	8.30
	195	4.50	5.75	5.72	7.35
	225	4.10	5.26	5.16	6.61
Medium	165	8.88	10.19	10.70	12.55
	195	8.28	9.44	9.80	11.32
	225	7.77	8.81	9.08	10.39
High	165	11.54	12.87	13.56	15.49
	195	10.82	11.97	12.46	14.00
	225	10.20	11.22	11.59	12.89
Good Forest					
Low	365	3.31	4.13	3.97	4.91
	435	2.77	3.52	3.33	4.16
	515	2.25	2.93	2.72	3.46
Medium	365	6.36	7.06	7.14	7.96
	435	5.75	6.37	6.39	7.09
	515	5.15	5.71	5.69	6.30
High	365	8.37	9.06	9.21	9.98
	435	7.66	8.26	8.37	9.02
	515	7.00	7.51	7.59	8.16

stumpage price levels, several spacing intervals, and various establishment costs.

RORs were found to be sensitive to site class. It does not pay to grow cottonwood sawtimber on medium sites because of their low productivity. Neither does it pay on good forest sites because of extremely high establishment costs, which cannot be substantially reduced. Only on good old field sites can RORs of 8 percent and higher be realized at the medium stumpage price level without adding income for hunting leases and soybeans.

At the high stumpage price level, RORs of 8 percent can also be realized on good forest sites. But high stumpage prices seem unlikely because there is no indication the demand for cottonwood sawtimber will rise substantially. Because of the current (1984) sluggish market, there is a greater possibility that the price will fall, although not by as much as 50 percent. If stumpage prices do fall by this much, it would not pay to grow cottonwood sawtimber, even on good old field sites.

In the near future, thousands of acres of marginal soybean land in the Delta may be retired as the result of a change in the international soybean market. Brazil's and Argentina's share of the market may expand if consuming nations switch to these two countries from the United States as sources of supply because of the strong dollar. This change would not provide an opportunity for extending the acreage in cottonwood plantations because most of these fields are on clay soils and have a site index of no more than 100. Only a change in Delta agriculture that would free more good old fields for cottonwood plantations or a fundamental change in the cottonwood lumber and veneer markets that would raise prices will bring about an expansion of cottonwood acreage.

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DYNAMICS AND DEVELOPMENT OF A ONCE-CUTOVER, UNMANAGED LOBLOLLY PINE STAND IN SOUTHEASTERN ARKANSAS[1/]

by James M. Guldin
and James B. Baker[2/]

Abstract.--Developmental dynamics of an unmanaged loblolly pine stand are presented. The stand was cut to a 12-inch d.b.h. limit in 1915; eight inventories were taken between 1937 and 1983. In 1983, 76% of the total merchantable cubic-foot volume and 83% of the sawlog cubic-foot volume was pine, but pines have virtually disappeared from the sub-sawtimber class. Oaks are the predominant hardwoods in the sawtimber class, and non-oak hardwoods are most common in the sub-sawtimber class. In the past two decades, periodic annual increment of the pines has dropped dramatically, and hardwood PAI has not concomitantly increased. These dynamics classically illustrate the transition of southern upland forests from pine to hardwood in the absence of disturbance.

INTRODUCTION

When a forester or non-industrial private landowner ponders a silvicultural intervention in a forest stand, among the first choices considered is the alternative of doing nothing. Silviculturists implicitly expect a prescribed treatment to enhance the growth and yield of a stand. However, many non-industrial private landowners are less likely to believe that silvicultural intervention is either necessary or even desirable.

As such, improving the silvicultural understanding of the long-term results of stand development in the absence of silvicultural intervention is an important goal of stand development research. A silviculturist can enhance his or her decision-making ability if the specific results of performing no treatment are understood. Such knowledge also can assist private landowners in comprehending the true silvicultural implications inherent in selecting the alternative of no treatment on their lands. This paper presents an interim summary of the development of a once-cutover, unmanaged pine-hardwood stand in the Mid-South Coastal Plain.

STUDY AREA

The study area is a pair of contiguous 40-acre tracts on the Crossett Experimental Forest, located seven miles south of Crossett, Arkansas. Soils on the study area are Providence and Bude silt loams (Typic and Glossaquic Fragiudalfs, respectively), having a loblolly pine site index of 85 to 90 feet at fifty years (U.S.D.A., 1979). The area was harvested to a 14-inch stump diameter limit (roughly analogous to a 12-inch d.b.h. limit) in 1915. In 1935, the two forties were set aside as a natural area; they were selected as being the most representative forties on the Experimental Forest. No management practices, with the exception of both fire protection and the occasional salvage of timber killed by the southern pine beetle, have been undertaken since

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[2/] Authors are, respectively, Assistant Professor, Department of Forest Resources, Agricultural Experiment Station, University of Arkansas at Monticello, AR; and Principal Silviculturist, Forestry Sciences Laboratory, USDA-Forest Service, Monticello, AR.

that date. The compartments were inventoried in 1937, 1942, 1946, 1952, 1957, 1963, 1973, and 1983. All trees 4.5 inches d.b.h. and larger were measured and tallied by 1-inch d.b.h. classes.

The tally was kept for three distinct species groups. The pines consist of loblolly pine (*Pinus taeda*) and shortleaf pine (*P. echinata*). The oaks consist of both the red oak group, including southern red oak (*Quercus falcata*), cherrybark oak (*Q. falcata var. pagodaefolia*), black oak (*Q. velutina*), Shumard oak (*Q. shumardii*), and water oak (*Q. nigra*), and the white oak group, including white oak (*Q. alba*) and post oak (*Q. stellata*). The third category, other hardwoods, includes sweetgum (*Liquidambar styraciflua*), black gum (*Nyssa sylvatica*), hickories (*Carya* spp.), ashes (*Fraxinus* spp.), black cherry (*Prunus serotina*), dogwood (*Cornus florida*), and red maple (*Acer rubrum*).

METHODS

Inventory records were summarized for each compartment by calculating total volumes and expressing the results on a per-acre basis. Volumes were calculated from the diameter distributions using Crossett Experimental Forest tree volume equations for loblolly and shortleaf pine (Farrar et al., 1984), and by deriving hardwood volume equations from local volume tables, as presented in Appendix 1. An approximation of the Doyle sawlog volumes was obtained by multiplying the cubic-foot sawtimber volumes by 5.8 for pines, and 5.0 for hardwoods.

RESULTS

Pine-hardwood dynamics

A summary of the development of the pine and hardwood (both oak and other hardwood) components is presented in Table 1. During the 46-year period, pine has diminished considerably from 105 stems per acre (72% of the stand) in 1937 to 45 stems per acre (36% of the stand) in 1983. However, pine volume has increased between 1937 and 1983, with total merchantable cubic-foot volume approximately doubling and sawlog cubic-foot volume roughly tripling. Thus, 68 years after cutting, stand volumes in 1983 continue to be disproportionally pine, with 76% of the total merchantable cubic-foot volume and 83% of the total sawlog cubic-foot volume in pine.

Conversely, the number of hardwood stems has doubled, from 40 stems per acre in 1937 to 80 stems per acre in 1983. Hardwood volume has also increased, though not at the same rate as the pine volume. Total merchantable cubic-foot volume for all hardwoods has increased by 62% between 1937 and 1983, and sawlog cubic-foot volume has increased by 59%.

TABLE 1. Number of trees per acre, standing volume per acre, and periodic annual increment per acre during the interval 1937-1983 for both the pine and hardwood components of the 80-acre Unmanaged Area at the Crossett Experimental Forest.

	NUMBER OF TREES per acre			STANDING VOLUME per acre			PERIODIC ANNUAL INCREMENT per acre		
Year	5"-11"	12"+	Total	Total Merch. cu.ft.	Sawlog, cu.ft.	Doyle, bd.ft.	Total Merch. cu.ft.	Sawlog, cu.ft.	Doyle, bd.ft.
PINES									
1937	81.3	23.9	105.2	1473	820	4755	56.2	37.9	219.8
1942	83.4	28.0	111.4	1754	1009	5854	39.5	49.8	288.6
1946	66.5	32.2	98.8	1912	1208	7009	52.0	58.6	340.1
1952	50.0	36.5	86.5	2224	1560	9049	37.2	45.7	265.2
1957	40.9	38.6	79.6	2410	1789	10375	53.5	62.5	362.3
1963	29.5	42.4	72.0	2731	2164	12549	18.5	31.0	179.7
1973	15.7	41.9	57.6	2916	2473	14346	4.6	17.0	98.9
1983	6.3	38.4	44.7	2962	2644	15335			
					PAI, 1937-1983		32.4	39.7	230.0
HARDWOODS (ALL)									
1937	26.2	14.3	40.5	579	350	1750	31.2	5.7	28.9
1942	47.5	16.4	63.9	735	379	1894	9.1	7.2	35.9
1946	48.4	17.4	65.8	771	408	2038	10.0	9.9	49.5
1952	48.0	19.0	67.0	831	467	2335	-13.5	-5.1	-25.8
1957	42.3	17.8	60.1	764	441	2206	3.3	5.4	26.6
1963	39.1	18.3	57.4	783	473	2365	6.6	4.4	22.0
1973	48.7	18.7	67.4	849	517	2585	8.6	4.0	20.0
1983	61.4	19.1	80.5	935	557	2784			
					PAI, 1937-1983		7.8	4.5	22.5

The periodic annual increment (PAI) of this stand reached a bimodal peak in the intervals from 1946 to 1952 and again from 1957 to 1963, at which time the highest PAI was attained. The drop in increment in the interval between 1952 and 1957 is explained by the prolonged drought of 1953-1955, during which time the pine volume increment was roughly 75% of the adjacent intervals, and the hardwood volume increment was actually negative (via a reduction in the number of stems in the sawtimber class, attributable to drought-related mortality in the mesic hardwood component).

However, the drop in PAI for the last two decades is quite dramatic. Total merchantable cubic-foot volume per acre per year for both pines and hardwoods has declined from a peak of 56.8 during the interval 1957-1963, to 25.1 during the interval 1963-1973, to 13.2 between 1973 and 1983. The drop in sawlog cubic-foot volume per acre per year has been equally precipitous, from a peak of 67.9 during 1957-1963, to 35.4 during 1963-1973, to 21.0 during 1973-1983.

Reasons for this can be inferred from the numbers of stems over time in the sub-sawtimber versus the sawtimber component of the pines and hardwoods. In the pines, ingrowth into the sawtimber component reached a peak in 1963, and has declined since. At the same time, pines have not been replacing themselves in the understory, as indicated by the reduction in the number of sub-sawtimber stems since 1942, though particularly in the past two decades.

Rather, it is the hardwoods which are occupying the sub-sawtimber class in increasing proportions. In 1963, hardwoods accounted for 57% of the stems in the 5"-11" class; this percentage increased to 76% in 1973, and 91% by 1983. With the relatively unchanging number of hardwood stems in the sawtimber component for the past three decades, the increases in the total number of hardwood stems per acre in the area have been almost entirely found in the sub-sawtimber component.

Hardwood dynamics

A summary of the development of the two species groups, the oaks and the other hardwoods, which comprise the hardwood component is presented in Table 2. During the forty-six year period, the number of oaks has increased slightly, from 23.1 merchantable (> 4.6" dbh) stems per acre to 31.7 stems per acre. When considering all hardwood stems, this represents a slight decline from 57% in 1938 to 39% in 1983. But when considering only sawtimber stems, the percentage of oaks has increased from 60% of all hardwood sawtimber trees in 1938 to 83% in 1983. Oaks have retained a relatively constant number of stems in the sub-sawtimber component.

TABLE 2. Number of trees per acre, standing volume per acre, and periodic annual increment per acre during the interval 1937-1983 for both the oak and non-oak hardwood component of the 80-acre Unmanaged Area at the Crossett Experimental Forest.

	NUMBER OF TREES per acre			STANDING VOLUME per acre			PERIODIC ANNUAL INCREMENT per acre		
Year	5"-11"	12"+	Total	Total Merch. cu.ft.	Sawlog, cu.ft.	Doyle, bd.ft.	Total Merch. cu.ft.	Sawlog, cu.ft.	Doyle, bd.ft.
OAKS									
1937	14.5	8.6	23.1	354	216	1077			
1942	15.1	8.2	23.3	337	193	966	-3.4	-4.5	-22.2
1946	12.6	8.6	21.2	332	203	1014	-1.2	2.4	11.9
1952	12.6	10.0	22.6	386	249	1246	9.1	7.7	38.7
1957	12.6	9.9	22.5	383	249	1245	-0.7	0.0	-0.2
1963	9.7	10.5	20.2	402	279	1397	3.2	5.1	25.3
1973	16.9	15.6	32.5	627	449	2243	22.5	16.9	84.6
1983	15.8	15.9	31.7	664	489	2442	3.7	4.0	20.0
					PAI, 1937-1983		6.8	5.9	29.7
NON-OAK HARDWOODS									
1937	11.7	5.7	17.4	225	134	672			
1942	32.4	8.2	40.6	398	186	928	34.6	10.2	51.1
1946	35.8	8.8	44.6	439	205	1024	10.3	4.8	24.0
1952	35.4	9.0	44.4	445	218	1088	0.9	2.2	10.8
1957	29.7	7.9	37.6	381	192	961	-12.8	-5.1	-25.6
1963	29.4	7.8	37.2	381	194	968	0.1	0.3	1.3
1973	31.8	3.1	34.9	222	68	342	-15.9	-12.5	-62.6
1983	45.6	3.2	48.8	271	68	342	4.9	0.0	0.0
					PAI, 1937-1983		1.0	-1.4	-7.2

Concomitantly, oak volume per acre has increased between 1937 and 1983, with total merchantable cubic-foot volume increasing by 127%. The standing hardwood volume in 1983 continues to be predominantly oak, with 71% of the total merchantable cubic-foot volume and 88% of the sawlog merchantable cubic-foot volume in the oak component.

The number of merchantable non-oak hardwoods has almost tripled, from 17 stems per acre in 1937 to 49 stems per acre in 1983. This increase has occurred even as the number of non-oak sawlog stems has decreased, from 5.7 stems per acre in 1937 to 3.2 stems per acre in 1983. Volumes of the non-oak hardwood component reflect this trend; between 1937 and 1983, total merchantable cubic-foot volume increased 17% but the sawlog cubic-foot volume dropped 49%. The most pronounced pattern in the non-oak hardwoods is the quadrupling of the number of stems per acre in the 5"-11" dbh classes. This pool of sub-sawtimber growing stock has yet to cross the threshold of ingrowth into the sawtimber class.

The periodic annual growth of the hardwood component (cf. Table 1) shows the same bimodal pattern as the pines, with a plateau in growth from 1942 to 1963 interrupted by the drought between 1952 and 1957. Both species groups of the hardwood component showed a depression in growth relative to their pre-drought rates. However, the oaks stabilized at a level where growth was only fractionally less than the loss to mortality; the non-oak hardwoods showed a marked loss of increment attributable to mortality. In the interval from 1957 to 1973, the oaks show a very strong recovery of periodic annual increment. During the same period, however, the PAI of non-oak hardwoods never recovers, and even shows a marked loss in the interval of 1963-1973.

DISCUSSION

Developmental patterns point to the advanced successional status of this pine-hardwood stand, locating the stand in the early transition phase (after Bormann and Likens, 1979) or the understory reinitiation stage (after Oliver, 1981) of stand development. The pines are overmature, growing slowly, undergoing mortality, and not replacing themselves in the understory. These dynamics epitomize the classic transition of southern upland forests from pines to hardwoods in the absence of disturbance.

The developmental pattern in the hardwood component of this stand is one dominated by oaks in the sawtimber category. The non-oak hardwood sawtimber component has demonstrated a net loss in increment during the 46 years of inventory records of this 80-acre compartment. Nor does the apparent domination of the sub-sawtimber component by non-oak hardwoods obscure the rather constant number of sub-sawtimber oak stems throughout the recorded inventories of this stand. The oaks appear to be in an extremely favorable competitive position (relative to the non-oak hardwoods) in the sawtimber component; and while it is too early to speculate on the relative dynamics of the two groups in the sub-sawtimber component, it is apparent that oak is not yet being outcompeted by non-oak hardwoods in the sub-sawtimber classes.

The total merchantable cubic-foot volume mean annual increment of this stand, over the 46 years of inventory activity, is 40.2 cubic feet per acre per year (of which 81% is pine M.A.I.). Sawtimber cubic-foot mean annual increment is 44.2 cubic feet per acre per year, which converts roughly to a mean annual increment in feet board measure (Doyle) of 252.5 (91% of which is pine M.A.I.). By way of comparison, Baker and Murphy (1982) reported total merchantable cubic-foot average annual production values of from 84 to 117, and Doyle board-foot average annual production values of 260 to 377, in managed stands on the Crossett Experimental Forest. In addition, the decreasing importance of the pine component, and the corresponding rise in the hardwood component, of this unmanaged area suggest that future growth will be even less than that observed to date.

The costs of choosing the alternative of no silvicultural treatment are largely economic opportunity costs. Growth and yield are at lower levels than are possible with the judicious application of silvicultural treatments; economic returns are certainly less than those which could be gained. But equally important is the opportunity cost in a silvicultural sense, represented by developmental dynamics which suggest incipient loss of the pine component and vigorous occupancy of the site by the hardwood component. Should the landowner decide in the future to integrate pine management with other goals of ownership, the silvicultural interventions required will be increasingly capital-intensive. The inability to satisfy a landowner's goals with silvicultural creativity rather than capital expenditure represents a foregone silvicultural alternative which foresters can increasingly ill afford to lose.

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APPENDIX 1.

Local Tree Volume Equations for Hardwoods, Crossett Experimental Forest.

1. $TMCV = -2.58607 + 0.20763\ (D^2) - 0.00833\ (D^3) + 0.00018\ (D^4)$;

   where TMCV = Total merchantable cubic-foot volume, i.b., above a varying stump height to a 3.5-inch top;

   D = tree d.b.h. in inches, $3.5 < d.b.h. < 32.5$,

   and R^2 (adj) = 1.000, $S(y \cdot x) = 0.4037$.

2. $SMCV = -142.20493 + 27.77802\ (D) - 1.86965\ (D^2) + 0.05935\ (D^3) - 0.00064\ (D^4)$

   where SMCV = Sawlog merchantable cubic-foot volume, i.b., above a varying stump height to a 7.5 inch (or merchantable) top;

   D = tree d.b.h., in inches, $9.5 < d.b.h. < 32.5$,

   and R^2 (adj) = 0.997, $S(y \cdot x) = 1.828$.

ADAPTATION OF THE FOREST NUTRIENT CYCLING TREND EVALUATOR (FORCYTE) FOR LOBLOLLY PINE PLANTATIONS[1/]

T. R. Fox, J. P. Kimmins, and H. L. Allen[2/]

Abstract.--An ecosystem modeling project has been established at North Carolina State University to adapt the FORest nutrient Cycling Trend Evaluator (FORCYTE) to loblolly pine. The purpose of the project is to integrate and synthesize existing knowledge on loblolly pine into a simulation model capable of describing the processes influencing site productivity. FORCYTE permits forest managers to examine the consequences of management activities in relation to stand and site productivity. The modeling effort also provides an opportunity to identify gaps in existing knowledge and, through sensitivity analysis, focus future research efforts.

INTRODUCTION

Forestry in the South is progressing from passive management of natural stands towards intensive plantation management. In some areas, the level of management is approaching that associated with the domesticated forest (Stone 1975). In these intensively managed plantations logging debris are often reduced by piling and/or burning to facilitate planting of genetically improved seedlings. Many sites are disced to reduce competition and improve soil physical conditions. Wet sites are routinely drained and bedded. Thinnings may be conducted to control the density of the growing stock, capture mortality and concentrate growth on the desired crop trees. Fertilizers may be applied to correct nutrient imbalances and accelerate growth. Finally, higher utilization standards are being employed during harvesting operations.

The productivity of many sites in the South is related to the supply of nitrogen and its rate of cycling through the ecosystem. Concern about maintaining long term site productivity has developed in the South, in part, because of the impact intensive forest management practices can have on nitrogen dynamics.

Much research in the area of nutrient cycling and site productivity has been conducted in recent years and has been summarized in numerous symposia (Tippen 1978, Leaf 1979, Ellwood and Ross 1983). Because of the complexity of the interactions among intensive forest management, nutrient cycling and site productivity, we believe a computer modeling approach is required to quantitatively describe a functioning ecosystem. The systematic development of a model will also identify gaps in our knowledge and help to focus future research efforts.

FORCYTE DESCRIPTION

In response to the need to integrate and synthesize information on the impacts of forest management on long term site productivity in the South, an ecosystem modeling project was initiated by the North Carolina State Forest Fertilization Cooperative. The goal of this effort has been to adapt an existing ecosystem model to loblolly pine (*Pinus taeda* L.) rather than develop a totally new model.

The FORest nutrient CYcling Trend Evaluator (FORCYTE) was selected because it possesses

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2/ The authors are respectively: Research Assistant, Department of Forestry, North Carolina State University, Raleigh, NC 27695; Professor of Forest Ecology, Faculty of Forestry, University of British Columbia, Vancouver, B.C. V6T1W5; and Assistant Professor, Department of Forestry, North Carolina State University, Raleigh, NC 27695.

several features that make it suitable for modeling loblolly pine plantation ecosystems:

1) It was developed for even aged, single species plantations that are clearcut prior to reaching maturity.

2) The model functions on a site specific basis.

3) Nutrient availability determines productivity in the model. A feedback between available nutrients and plant growth allows for both site improvement and site degradation.

4) The model runs on inventory type information. Growth and yield information is the primary driving function.

5) FORCYTE was developed as a management tool and is capable of examining many forest management practices.

FORCYTE is a stand level growth model of plant biomass production, accumulation, and nutrient cycling. Site improvement or degradation is possible depending on nitrogen availability. One limitation of the model is that it assumes that nutrient availability is the major factor limiting productivity. Where nutrient availability does not limit productivity, the model's predictions may be unreliable. To date the model has only been calibrated for nitrogen, however, other nutrients can be substituted if the required input data is available. The model does not deal directly with climatic variability or more specifically, moisture availability. These factors are handled implicitly through the use of site specific growth functions which integrate the effect of these factors on the stand.

Program Structure

FORCYTE-10 consists of two programs that run sequentially (fig. 1). The first program, FORCETUP, predicts biomass and nutrient content trends over time for trees, shrubs and herbs growing on a range of site qualities. For these predictions, an input file of empirical data from a range of sites is needed which describes 1) the accumulation of biomass in trees, shrubs and herbs over time; 2) maximum stocking density as a function of age; 3) nutrient concentrations in the various plant components; and 4) the number of age classes of these components. The second program FORCYCLE, uses the trends developed in FORCETUP, to project stand development over time according to a specific management scenario. FORCYCLE requires input data describing the management scenario, economic conditions of the run, energy costs, and biogeochemical (nutrient cycling) characteristics of the site. The state of the ecosystem at the start of the run must also be specified. FORCYTE produces a variety

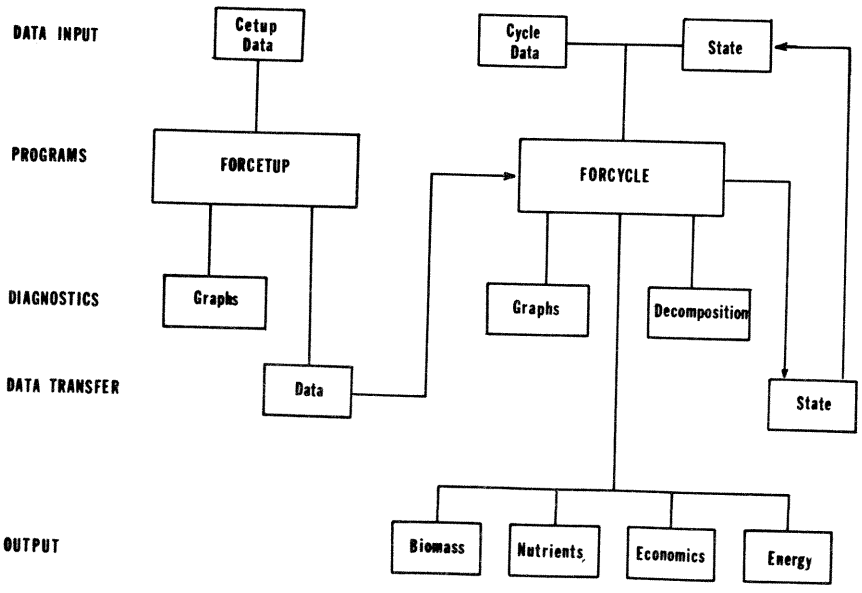

Figure 1.--FORCYTE program structure.

of output. Graphical representation of biomass and nutrient cycling trends over time and tabular information on decomposition and mineralization are output as diagnostic files so that the accuracy of the model's predictions may be judged. Four predictive tables summarize the biomass yield, nutrient cycling, economic performance and energy efficiency of the simulated management scenario. The state of the simulated ecosystem at the end of the run is also summarized.

Model Structure and Function

The biomass and nutrient compartments, transfer pathways, and regulating factors present in FORCYTE are illustrated in figure 2. FORCYTE simulates the state of three compartments: plant biomass and nutrient content; forest floor biomass and nutrient content; and available soil nutrients.

The main driving function in the model is a series of site specific growth curves for stemwood biomass accumulation of the Chapman-Richards form (Pienaar and Turnbull, 1973) (fig. 3). The biomass of foliage, branches, stembark and the total root system is obtained by applying age-specific ratios of the component biomass to stemwood biomass: i.e. foliage biomass/stemwood biomass or total root biomass/stemwood biomass (fig. 4). In applying these ratios, age is replaced by the ratio of stemwood biomass to maximum stemwood biomass. As this ratio increases from a small value toward 1, stand age increases. This surrogate for age was used to facilitate the use of data from a variety of sources. Total root biomass is allocated between large, medium, and fine roots in the same ratio as stemwood biomass to branch biomass to foliage biomass.

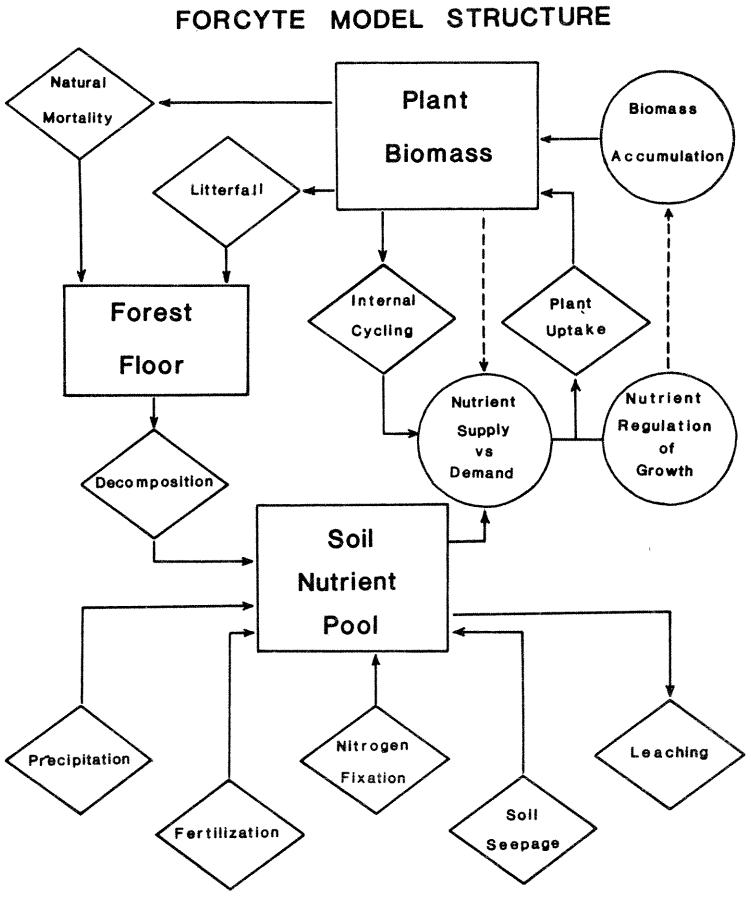

Figure 2.--Flow chart of biomass and nutrient compartments, biomass and nutrient transfers and regulating factors in FORCYTE.

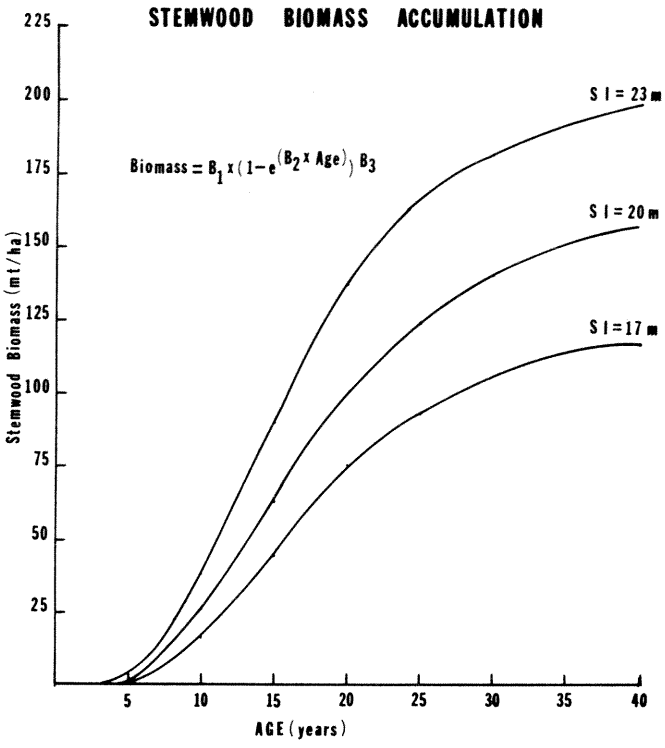

Figure 3.--Chapman-Richards growth equations for stemwood biomass on good, medium, and poor sites. (Data from Hafley et al. 1977)

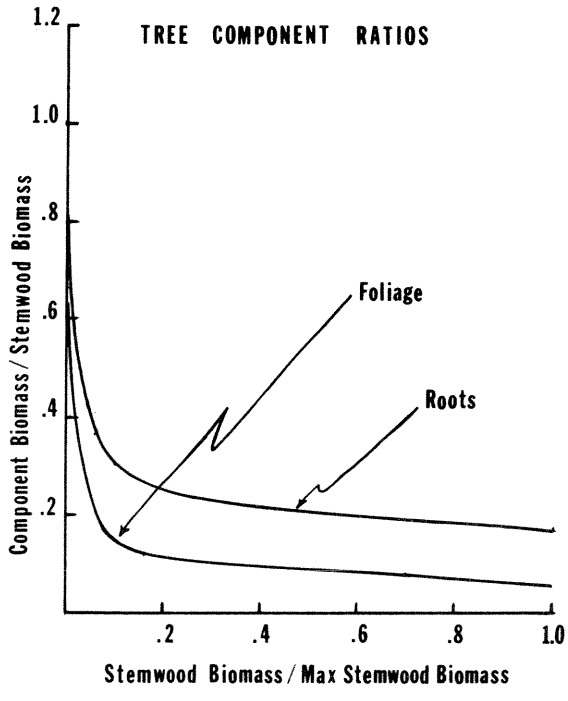

Figure 4.--Tree component ratios for foliage and roots in loblolly pine. (Data from Switzer et al. 1966, and Harris et al. 1977)

Growth of each component is allocated into three parts: replacement of ephimeral litter, replacement of natural mortality, and new growth needed to produce the predicted increase in net biomass. Plant nutrient content is determined using nutrient concentration data and predicted biomass for each component. The nutrient uptake requirement of vegetation is calculated by adding the quantity of the nutrient required to produce the predicted new growth and the quantity required to replace losses from plant leaching and litterfall, and subtracting from that sum the amount obtained from redistribution within the plant.

In order to simulate natural mortality of trees, FORCYTE requires data on stand density changes with age for each site (fig. 5). Mortality occurs whenever density in the simulated stand exceeds the maximum allowed for a given age. In FORCYTE-10, mortality removes average-sized, entire trees and transfers them to mortality related litterfall. When stand density is below the maximum allowed for a given age, as occurs after a thinning, stand development continues without mortality until stand density again reaches the allowed maximum (fig.5).

Litterfall production in FORCYTE is illustrated in figure 6. The model keeps track of each year's cohort of an individual plant component. When a cohart of the component reaches the age specified for litterfall, it is transferred to the forest floor as litter. Foliage is transferred directly to the forest floor. Live branches are converted to dead branches which remain on the tree for a fixed period before being transferred as litter. "Litterfall" from the fine root component is calculated by multiplying the ratio of foliage litterfall to total foliage biomass by the fine root biomass. The current year's stemwood increment is treated as sapwood until it is converted to heartwood after a specified period. Stemwood litterfall occurs only with tree mortality.

When each cohort of litterfall reaches the forest floor it undergoes changes in weight and nutrient concentration as it decomposes. The decomposition rate defines the shape of the weight loss vs time curve (fig. 7). The shape of the curve defining nutrient concentration changes during decomposition (linear, exponential, asymptotic) varies with the type of decomposing litter (fig. 8). The number of years required to decompose from fresh litter to humus is also dependent on the type of material.

The combination of weight loss and nutrient concentration change for each component of the forest floor determines the amount and rate of nutrient release to the soil nutrient pool (fig. 9). In the example illustrated, a period of net immobilization of available nitrogen out of the soil nutrient pool is followed by a period of net mineralization and release of nitrogen into the available nutrient pool.

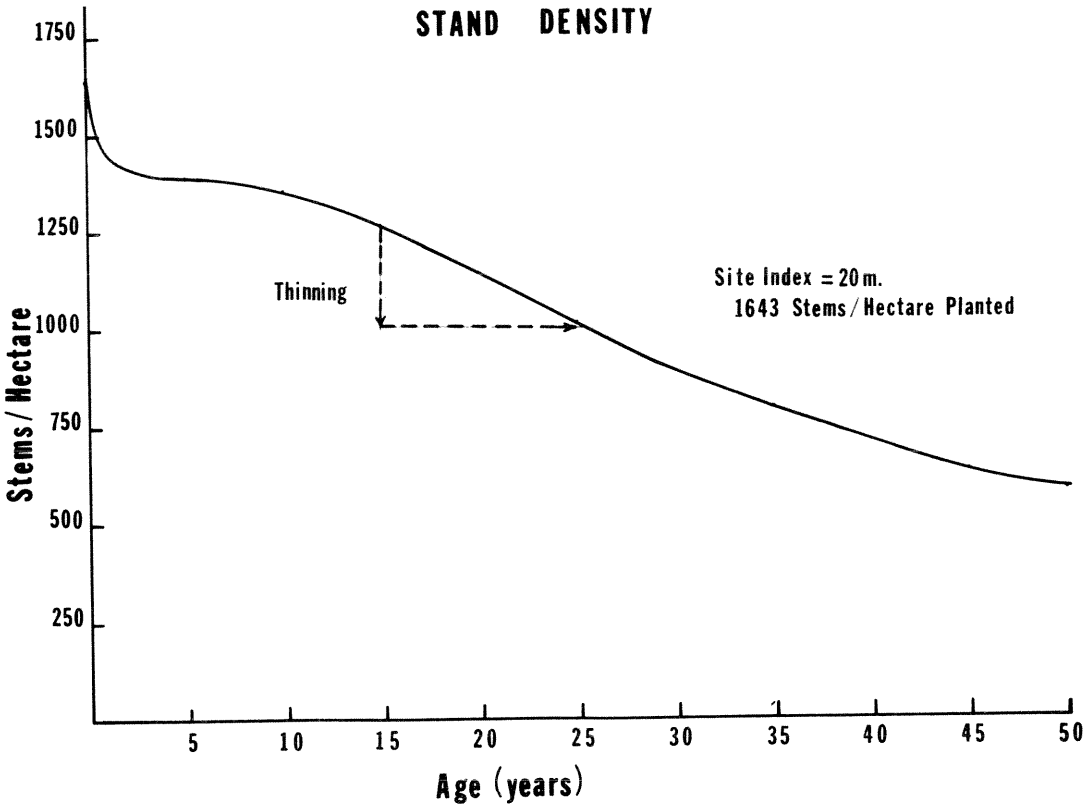

Figure 5.--Stand density development for a loblolly pine plantation on a medium site. (Data from Hafley et al. 1982)

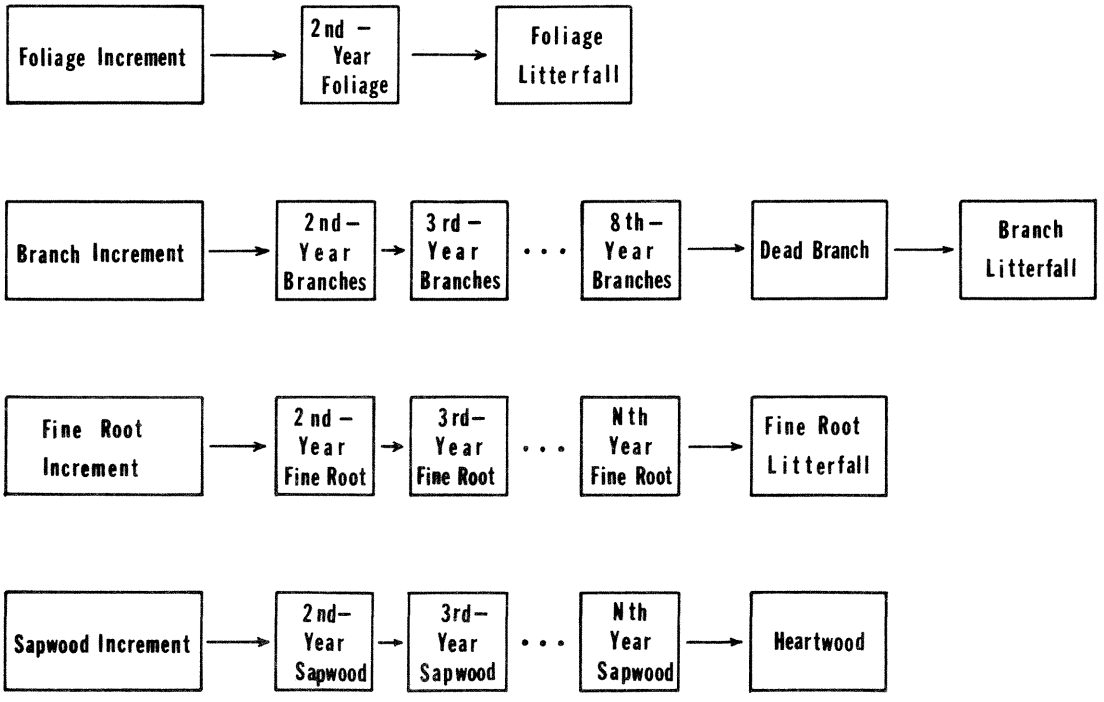

Figure 6.--Litterfall calculation in FORCYTE.

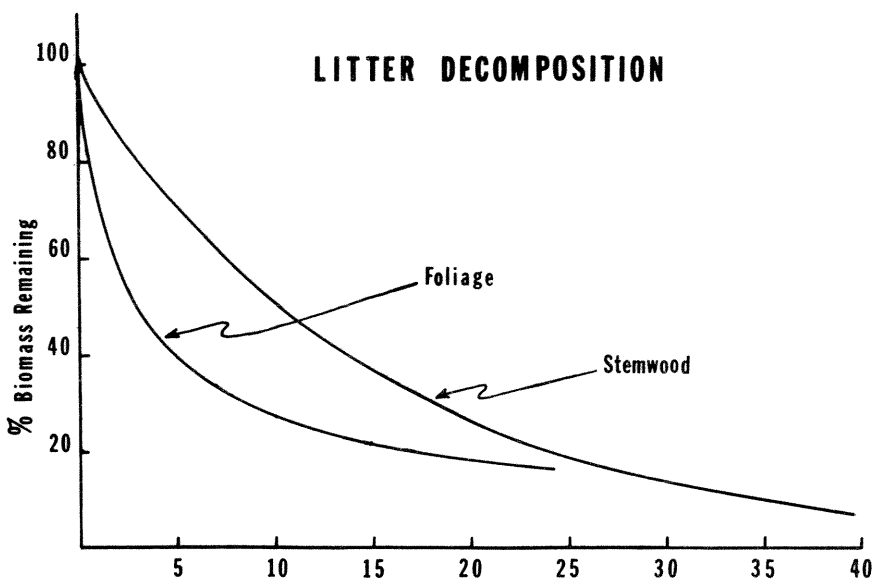

Figure 7.--Weight loss in decomposing forest floor components. (Data from Jorgensen et al. 1980, and Barber and vanLear 1984)

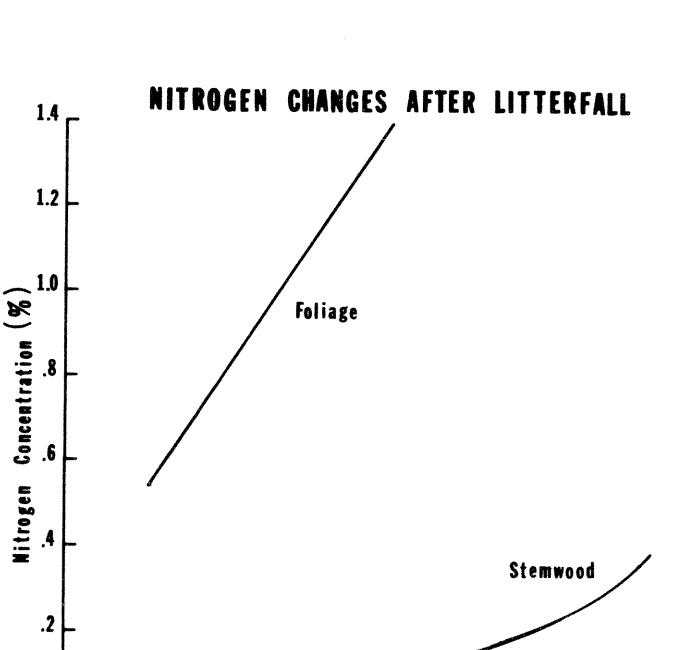

Figure 8.--Changes in nitrogen concentration during decomposition of loblolly pine foliage and stemwood. (Data from Jorgensen et al. 1980, and Barber and vanLear 1984)

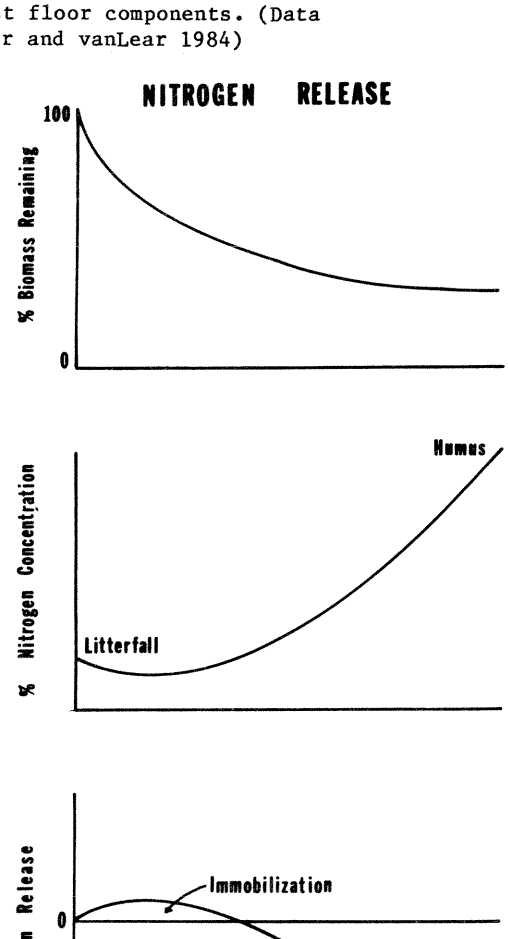

Figure 9.--Calculation of nitrogen release during decomposition in FORCYTE.

A unique feature of FORCYTE is how nitrogen availability influences plant growth and site quality (fig. 10). Plant nitrogen demand is calculated from predicted biomass increment and nutrient concentration data. The balance between nitrogen immobilization and mineralization, together with inputs from soil seepage, precipitation, fertilization and nitrogen fixation determines the size of the soil nutrient pool. The nitrogen supply available for plant growth is the sum of the soil nitrogen pool and nitrogen obtained by internal redistribution. When the available nitrogen supply is less than the nutrient demand required for plant growth, plant growth is reduced in proportion to the deficiency. If a deficiency continues for more than 3 consecutive years, FORCYTE reduces site quality. Conversely, when the nitrogen supply is greater than the nutrient demand required for growth, plant growth is increased in proportion to the excess. When the excess exists for more than 3 consecutive years, FORCYTE increases site quality. Changes in site quality, either up or down, alter a large number of parameters in the model including biomass accumulation, nutrient concentrations and decomposition parameters.

Preliminary Results With Loblolly Pine.

A calibration data set for loblolly pine has been constructed from the information available in the literature. Preliminary results indicate that the model performs realistically. Stemwood volume predictions generated by the FORCETUP program are presented for two sites in figure 11a. These values mimic the input data (Hafley et al. 1982) indicating that FORCYTE accurately predicts growth and yield in the absence of management manipulations. More interesting are the foliage biomass results presented in figure 11b. Foliage biomass increases more rapidly and to a greater value on a better site followed by a gradual decline in foliage biomass after a maximum value has been reached. This is the same pattern that has been shown to occur in loblolly pine (Switzer et al. 1968).

In order to test the model's predictions following management inputs, a series of fertilization and thinning scenarios were evaluated. A medium site (site index 20m; base age 25) planted with 1643 trees per hectare was thinned at age 20 removing 33% of the stems.

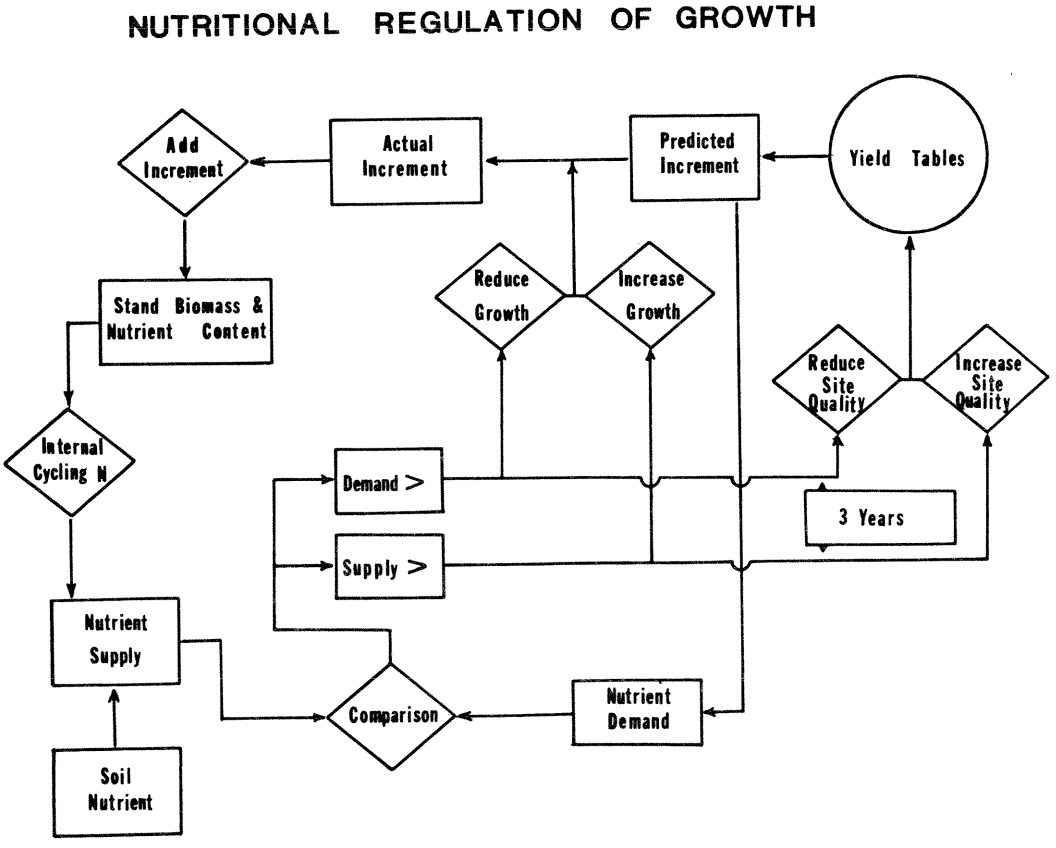

Figure 10.--Flow chart of feedback mechanism relating nutrient availability to biomass production and site quality.

Amendments of 0 to 200 kg/ha of nitrogen were added in 50 kg/ha increments. The volume response due to fertilization predicted by FORCYTE is presented in table 1. At 5 years, volume response ranged from 4.8 to 11.6 m^3/ha. This is at the lower end of the range of response that could be expected on a medium site.

FUTURE EFFORTS

FORCYTE has not yet been completely calibrated or tested for loblolly pine. Future efforts will center on improving the calibration data set and performing sensitivity analyses. This will allow us to focus future research efforts on important gaps in our knowledge. Two of the more important areas where research is needed included the development of site specific litter decomposition parameters and information concerning root production, turnover and decomposition. Although it is practically impossible to validate an entire ecosystem model such as FORCYTE, independent data sets exist that will allow validation of small segments of the model. This will build confidence in the predictions made with FORCYTE.

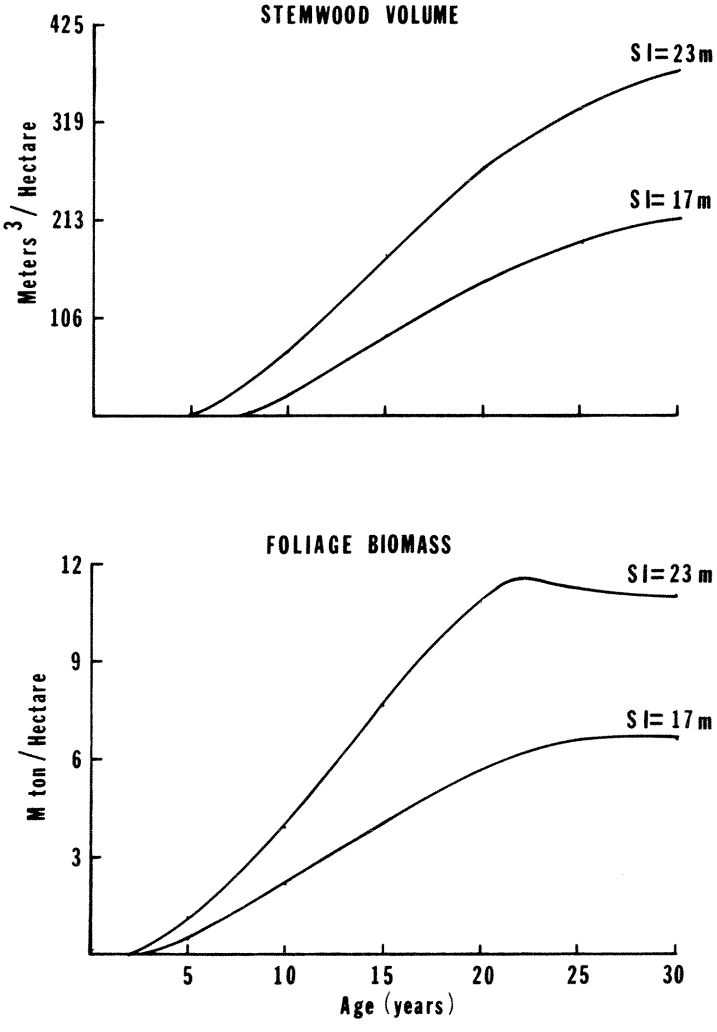

Figure 11.--Preliminary results from FORCYTE indicating stemwood (a) and foliage (b) accumulation on a good and a poor site.

Table 1. Predicted Response to thinning & fertilization with FORCYTE

Nitrogen added	Volume response
(kg/ha)	(m^3/ha)
200	11.6
150	10.9
100	7.8
50	4.8
0	-

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POTENTIAL FOR SECOND THINNINGS IN SOUTHERN PINE PLANTATIONS[1/]

W. Dale Greene
Bobby L. Lanford[2/]

Abstract -- In a recent survey, most forest products firms in the South indicated plans to thin their pine plantations two or more times during a rotation. Substantial thinning research has been conducted in recent years, but almost all of this has examined first thinnings. Additional research is necessary to improve methods for second and later thinnings.

INTRODUCTION

In recent years, much debate in forestry circles has centered on thinning of southern pine plantations. Opinions about thinning differ from region to region and company to company as well as within regions and companies. To date much of this debate, as well as substantial corporate, government, and university research, has been directed at the first thinning of plantations. First thinnings have dominated thinning research because they represent a current and often pressing problem for many landowners in the South. However, many industrial landowners in the South have planned rotations of 30 to 40 years in order to produce solid wood product material at final harvest. To get maximum value growth, these plantations will require more than one thinning during the rotation. In fact, many plantations which have been thinned once are now approaching the age for a second thinning.

First thinnings pose a challenging problem to a logger because small trees are expensive to harvest but have little market value, there is little room to maneuver equipment, and residual stand damage must be minimized. Efficient logging machinery and work methods as well as good business management are required to make a profit. At first glance, second thinnings would seem to offer more opportunity for the logger since tree sizes are larger and access into the stand was created in the first thinning. On the other hand, fewer trees are removed and the importance of protecting the residual stand is greater since each tree represents a larger investment. While it is possible for small sawlogs to be produced from trees removed in a second thinning, this raises additional merchandising questions. Clearly second thinnings represent a unique problem, which has yet to be studied in any detail.

The objectives of this research were --

1) to determine the importance of second thinning as a management practice for forest products firms in the South, and

2) to identify current methods and systems used for second thinnings and needs for future research.

METHODS

During the summer of 1984, 27 forest products firms operating from Texas to Virginia were contacted and questioned about their thinning practices. These firms represented the largest landowners and timber-using firms in the region. Twenty-one of these firms were ranked among the top 500 U.S. corporations (Anon. , 1984). The other six firms were substantial firms in their area but were not among the top 500. Some of the largest firms contained distinct regional operations, which were contacted separately in order to accurately determine the amount of land under different management regimes. Thirty middle- and upper-level managers, representing the 27 firms, were contacted during the study. Each of these contacts was treated as a sample observation.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Graduate Research Assistant and Associate Professor, respectively, in the School of Forestry, Alabama Agricultural Experiment Station, Auburn University, Alabama, 36849.

Each contact was questioned about the general plantation management regime and thinning treatments planned for their plantations. General questions were also included in the questionnaire to characterize the respondees. Five firms which were currently thinning his plantations for the second time were visited to obtain detailed information on factors affecting second thinning.

RESULTS

Loblolly pine was the principal species grown by 87 percent of the contacts while slash pine was the principal species of the remainder. Initial planting density of plantations ranged from 500 to over 1000 trees per acre with the average between 700 and 800 trees per acre. Forty-five percent of the firms used rotation ages of 31-35 years while 36 percent used rotation ages of 26-30 years. Fourteen percent reported rotations of 36-40 years with only five percent reporting rotations of less than 25 years. Most firms (87 percent) anticipated peeler logs or sawlogs as end products of their plantations while the remainder (13 percent) were expecting pulpwood only.

Twenty percent of those contacted indicated no plans to thin their plantations during the rotation (Table 1). Most of these firms were non-integrated paper producers with little market in their area for solid wood products. Other reasons given for not thinning included increased risk of ice damage in thinned stands, higher incidence of disease and insects, and concerns about reduced pulp yields with juvenile wood. Of this group, about half were located in coastal slash pine areas and the other half were found in the higher elevations of the range of loblolly pine.

The overwhelming majority of those contacted did plan to thin their plantations. Larger firms made thinning decisions on a stand by stand basis while smaller firms tended to use blanket rules which were applied throughout their holdings. These different approaches seem practical given the varied level of resources available to the decisions. The 80 percent majority planning to thin was comprised of 17 percent planning a single thinning, 30 percent planning up to two thinnings, and 33 percent planning up to three thinnings. These findings indicate the need for a closer look at possible problems associated with later thinnings.

First thinnings

Most firms (75 percent) planned to thin for the first time between the ages of 13 and 17 (Table 2). Four percent planned first thinnings for age 8 to 12 while 22 percent planned for age 18 to 22. All firms used site quality measures to determine thinning age for [illegible] stands.

Stand density before and after first thinning varied greatly. Most firms reported original stands of 400 to 600 trees per acre, which were reduced to 200 to 300 trees per acre after first thinning. Thirty percent of those contacted reported original stand density of over 600 trees per acre and residual stand density of over 300 trees per acre. This group roughly corresponded to the group planning three thinnings. Eighty percent of those questioned reduced basal area to 70 to 80 square feet -- a common rule of thumb in pine management.

Most firms (78 percent) reported six to eight cords of wood removed in first thinnings while another 12 percent removed 10 or more cords. Pulpwood was the only product reported for first thinnings with 65 percent removed as shortwood and 35 percent as longwood.

Felling methods in first thinning were about equally split between chainsaw and feller-buncher methods. About half the thinnings used Bobtail trucks to move wood from the stump. Skidding accounted for 35 percent of the thinned wood with forwarding (or prehauling) moving 17 percent of the thinned wood. Most firms reported using manual delimbing and bucking methods while 35 percent using some type of mechanical method to delimb and buck trees. The most popular

Table 1. Maximum number of thinnings considered by responding firms.

Thinning Treatment	Currently Practiced	1-5 years in future	5-10 years in future	Total Responding
	Percent of those contacted			
None	20	--	--	20
First thin	70	7	3	80
Second thin	40	17	7	64
Third thin	17	7	10	34

Table 2. Typical first and second thinning treatments reported by surveyed firms.

Stand Variable	First Thin	Second Thin
Age	13-17	23-27
Trees/Acre before thinning	400-600	200-400
Trees/Acre after thinnings	200-300	100-200
Cords removed	6-8	10-12
Method of thinning	row/selective	selective
Product obtained	pulpwood	pulpwood, small logs
Products form	shortwood	longwood

mechanical method was a delimbing gate. Almost all (96 percent) of first thinnings were performed on a row/selective basis. Only one firm stated that purely selective thinning could be performed in a first thinning. For most firms, the need to create access corridors for equipment mandated that a row/selective method be used for first thinning.

Second thinnings

Most plantations (78 percent) were thinned for the second time at age 23 to 27. Another 22 percent of those contacted planned second thinnings for age 18 to 22.

Original stand density in second thinnings was 200 to 400 trees per acre with a residual stand of 100 to 200 trees per acre. Basal area was seldom used in second thinning decisions.

Volume removed was higher for second thinnings with almost two-thirds of those questioned reporting 10-12 cords removed. A solid majority (78 percent) anticipated both pulpwood and small logs or peelers to be removed in the second thinning.

Longwood accounted for 89 percent of wood removed in second thinnings, reflecting the higher proportion of solid wood product material. Feller/bunchers performed 88 percent of the felling. Once access had been created in the first thinning, most firms felt that mechanical felling was preferred in the second thinning. Skidding moved 95 percent of second thinning wood to roadside with the remainder forwarded. Almost two-thirds of the delimbing/bucking duties were performed manually. Several firms commented on the poor quality of gate-delimbed wood for stud mills. Almost all second thinning was performed on a selective basis since access was created in the first thinning for most stands.

Thinning systems

For first thinning, six different general thinning systems were reported by the companies contacted (Table 3). The most often reported system was the venerable Bobtail system. While this system appears to be a permanent fixture of pulpwood logging in the South, its importance is beginning to diminish. Most firms were hoping to see more mechanized contractors replace their Bobtail contractors in the future. Presently 42 percent of first thinning was reported to be performed by Bobtail systems. A system using a small feller/buncher, grapple skidder, and gate delimber was performing another 34 percent of first thinning work with four other systems accounting for the remaining 24 percent.

Table 3. Systems reported for first thinnings.

Type of System	Description[1/]	Percent of Total
Shortwood	Saw-Saw-Bobtail	42
	Saw-Saw-Forwarder	8
	F/B-Saw-Forwarder	4
	F/B-Process-Forwarder	4
Longwood	Saw-Skidder-Saw	0
	F/B-Skidder-Saw	8
	F/B-Gate-Skidder	34

[1/] Felling-Delimbing/Bucking-Woods Transport components.

Almost all systems for second thinning produced longwood (Table 4). Systems using a feller/buncher, grapple skidder, and delimbing gate were reported by 42 percent of those contacted. Similar systems using chainsaw delimbing instead of a delimbing gate were reported by 32 percent of the firms while cable skidder systems were reported by 21 percent. Such systems are versatile and can often be used effectively for small clearcuts when second thinning opportunities are not available. As the number of stands requiring a second thinning increases, some firms may develop specialized second thinning systems.

Table 4. Systems reported for second thinnings.

Type of System	Description[1]	Percent of Total
Shortwood	Saw-Saw-Bobtail	0
	Saw-Saw-Forwarder	0
	F/B-Saw-Forwarder	5
	F/B-Process-Forwarder	0
Longwood	Saw-Skidder-Saw	21
	F/B-Skidder-Saw	32
	F/B-Gate-Skidder	42

[1] Felling-Delimbing/Bucking-Woods Transport components.

CONCLUSIONS

While first thinnings have been intensively researched, second and later thinnings have been ignored. Research needs in second thinnings include examination of spatial constraints with larger machines, merchandising rules for thinned wood, and appropriate logging systems. The effects of the type of first thinning conducted (row or row/selective) and tree size also need examination. If second thinnings are to be a common practice in pine management, they need to be studied and improved.

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INTERMEDIATE THINNINGS IN A MISSOURI SHORTLEAF PINE STAND: A 30-YEAR HISTORY[1/]

Robert Rogers[2/]
Ivan L Sander

Abstract.--Thirty years ago an experiment was begun in a 30-year-old natural stand of shortleaf pine (*Pinus echinata* Mill.) to investigate the effect density and hardwood control had on pine growth. Thirty 1/2-acre plots were thinned to leave six levels of basal area ranging from 50 to 138 square feet and to remove hardwoods. Plots were thinned every 10 years to the same density level. Results after 30 years show that stands repeatedly thinned to a constant basal area eventually become understocked and subsequently lose volume. Hardwoods reduce pine yield by eight to twelve percent.

INTRODUCTION

Of all the silvicultural activities available to the forester, thinning stands undoubtedly has the greatest impact on the production of sawtimber. Even at the turn of the century, early foresters intuitively recognized that growth and subsequent yield of forest stands were closely related to stand density. Perhaps they saw a likeness between growing forests and growing agricultural crops. But regardless of the reason, these early foresters began to study the effect stand density had on individual tree and stand growth.

Today, we still study stand density in relation to growth. Why has our progress been so slow? The answer is true now as it was 80 years ago. Trees simply mature slowly. The fact that the time from seed to harvest spans a half a century or more requires a commitment to long term research that few organizations or individuals are willing or able to undertake. Add to this, the many commercially valuable species and species associations that need to be studied and the reason for our slowness becomes painfully clear.

A technique that has been used to compress time involves substituting space for time. Here, individual tree and stand attributes are measured at a given point in time in stands of different ages growing on similar sites. Responses across time are obtained by linking observations together from different aged stands. This technique is useful, providing prior stand treatment does not influence stand responses to current treatments.

Alternatively, one can follow the same stand and its development through time. Studies of stands that span decades are especially valuable because often they provide insights into the dynamics of stand growth and development that are simply not attainable in any other way.

The study we report here documents the results of thinning shortleaf pine stands in Missouri over a 30-year period. The objectives of the study were to determine how stand growth is affected by changing stand density, by using different methods of thinning, and by reducing or eliminating hardwood competition.

DESCRIPTION OF THE STUDY AREA

The natural range of shortleaf pine extends northward into Missouri for about 100 miles. In fact, it is Missouri's only native pine. The present range of pine in Missouri extends over approximately seven million acres, and is located for the most part in the rougher south central section of the Ozark Mountains. Here it exists in pure stands or in admixture with hardwoods -- principally the oaks.

1/ Paper presented at Third Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Associate Professor of Forestry, College of Natural Resources, University of Wisconsin/Stevens Point, Stevens Point, Wisconsin and Principal Silviculturist, North Central Forest Experiment Station, USDA Forest Service, Columbia, Missouri, respectively.

Practically all the old growth pines had been cut shortly after the turn of the century, so current stands are mainly second growth. These new stands have grown and developed chiefly as a consequence of fire control programs that were instituted in the state during the early 1930's.

The area selected for study is on the Sinkin Experimental Forest which is maintained by the North Central Forest Experiment Station, USDA Forest Service. The Experimental Forest is located about 120 miles south of St. Louis in Dent County. Within this area thirty 1/2-acre plots were picked for study. They were located on the tops and sides of two main ridges found in the headwaters of the Red Hill Branch of Sinking Creek. The elevation at these plots varies from 1200 to 1350 feet above sea level. The soil is thin, contains chert and rocks, and is classified as a Clarksville stony loam soil. Annual precipitation averages about 44 inches, but distribution is highly variable especially during the growing season. Although about half the precipitation falls during the growing season, rainless periods during late summer lasting up to six weeks are common. Mean annual temperature is 21°C (29°C in July, 12°C in January).

EARLY HISTORY

At the time the study was started in 1950, the shortleaf pine stand was 30 years-old. It was established naturally soon after an oak-pine stand was harvested during the years between 1918 and 1920. For the next thirteen years wildfires periodically swept over the area. But since 1933, when the area became part of the Clark National Forest (currently the Mark Twain National Forest), no burning has occurred.

Information about initial establishment rates and composition were lacking. However, we do know that in 1934 when the stand was fourteen years old most of the overstory hardwood trees were cut or girdled. At the same time the pine was thinned, the number of trees were reduced almost in half from 1100 trees per acre to approximately 600 trees per acre. Unfortunately, no comprehensive records were kept so nothing is known about how much basal area was kept or what the diameter distribution of the residual stand looked like in 1934.

Nevertheless, at the time the study began in 1950, stands averaged 570 trees per acre, 6.6 inches dbh, 130 square feet of basal area, and were close to being 100 percent stocked according to the stocking chart developed by Rogers (1983). Average height of the codominant and dominant trees was about 50 feet at age 30 which gave a site index (index age = 50 years) of 70. The actual site index turned out to be slightly lower--65 feet. Few trees in the study were either less than 0.6 inches nor more than 12 inches dbh.

Most of the hardwood trees that were present were in the understory and probably were the result of sprouts that arose from the precommercial thinning conducted about 15 years earlier. Hardwoods less than 0.6 inches dbh averaged about 2800 stems per acre. However, 900 trees per acre were greater than 0.6 inches but only had an average basal area of 14 square feet per acre. Sassafras, flowering dogwood, white and black oaks were the predominate species in the stand. Other less abundant species included hickory, blackgum, and post, scarlet, northern red and blackjack oaks.

Four density levels were created by thinning--50, 70, 90, and 110 square feet of basal area per acre. In addition, an unthinned treatment was left as a check. Stocking percents (Rogers 1983) were 35, 50, 65, 77, and 105 percent, respectively.

In order to evaluate the effect hardwood competition had on the growth of pine, understory hardwoods were left on some plots thinned to 70 square feet of basal area and all hardwoods were left on some unthinned plots. Hardwoods were controlled with herbicides on all other plots.

The method used to select trees for thinning can best be described as a free thinning in which trees from all crown classes are free to be removed. During thinning the objective was to leave the best possible trees spaced as uniformly as possible over the area.

Since the experiment started thirty years ago the experimental plots have been thinned three times at ten year intervals. The first two thinnings reduced basal area to the same level fixed by initial treatments. However, basal area was allowed to increase on some of the plots at the third thinning.

RESULTS

Compared to other density levels, net annual periodic cubic foot volume growth was greatest at 70 square feet following the first thinning. Maximum growth occurred at the 110 level following the second and third thinnings (Table 1). Although growth following the first thinning peaked at a density of 70 square feet, growth at all levels was not significantly different ($p < 0.05$) from each other. However, growth varied

Table 1.--Net annual periodic cubic foot volume growth per acre of shortleaf pine stands thinned to various density levels.

THINNING PERIOD 10 years	DENSITY LEVEL BASAL AREA (square feet) 50	70	90	110	UNTHINNED
1ST	67	83	77	68	68
2ND	86	125	152	170	165
3RD	215	190	410	490	-211

Table 2.--Net periodic cubic foot yield of shortleaf pine thinned to various density levels

AGE	DENSITY LEVEL BASAL AREA (square feet) 50	70	90	110	UNTHINNED
30	2238	2278	2351	2129	2354
40	2907	3105	3120	2861	3038
51	3853	4480	4786	4738	4909
60	3700	4575	5100	5675	5100

significantly following subsequent thinnings and increased with increasing stand density up to 110 square feet and then declined. Similar trends were observed with basal area and board foot volume growth.

The cubic foot yield at the time of the first thinning was the result of natural stand development to age 30 except for the thinning that was made at age 15 (Table 2). Although yield at age 40 is highest at the 70 density level no clear trend develops until the older ages. Yield increases with increasing stand density and is highest in the unthinned stands at age 51. However, there is no significant ($p < 0.05$) difference between the yield of unthinned stands and that of stands thinned to basal areas of 90 and 110 square feet. Yield peaks at a stand density of 110 square feet in stands at age 60 and then declines. Board foot volume yields followed similar trends over this thirty year period.

Periodic annual net basal area growth of shortleaf pine following the first thinning was better on plots where hardwoods were controlled than on plots where they were not controlled. Although the differences in net growth were not large (0.6 and 0.5 square feet per acre per year for the 70 and unthinned stand density levels, repectively), they were significant. Net basal area growth since the second thinning appeared to be the same regardless of density level.

The study also showed that the presence of a hardwood component in a shortleaf pine stand has a negative affect on both annual merchantable volume growth and yield. However, the depression of growth was not observed until after the second thinning. Overall, the presence of hardwoods reduced overstory pine growth and yield by 8 to 12 percent.

DISCUSSION

The decreases in growth and yield currently observed in stands thinned heavily at the outset of the study illustrates what happens when stands are repeatedly thinned to the same residual basal area level. In the development of evenaged stands, basal area normally increases until an age is reached when mortality and growth are about equal. If basal area is not allowed to increase, an understocked stand is eventually created. Although it is too early to come to any definite conclusions, growth and yield of plots appear to

be greater in plots where residual basal area was increased following the third thinning. In general, the trends observed in this study indicate that understocking occurs after one thinning in stands repeatedly thinned to 50 square feet of basal area and after two thinnings in stands thinned to 70 square feet.

During this 30 year period of stand development, ingrowth was an important factor contributing to growth and yield, especially at the beginning of the study. Initially, plots at all density levels had many trees smaller than the threshold diameters used to determine cubic foot and board foot volumes. Therefore, the potential addition to volume by ingrowth was high. But after the second thinning, few trees smaller than the threshold diameter were left except those in unthinned plots. For this reason, volume gains were great in unthinned plots prior to the last thinning. Now, few ingrowth trees remain in the unthinned plots so dramatic increases in volume due to ingrowth are not likely. In fact, current net growth and yield are depressed in the unthinned stands because of the severe competition occurring within the stand.

The failure to observe a difference in growth response of overstory pines between plots where hardwoods were controlled and where they were not controlled after the second thinning can be attributed to the development of a pine understory in plots where hardwoods were controlled and where residual stand density was kept at 70 square feet of basal area. The pine understory appears to have the same affect on overstory pine growth in plots where hardwoods were controlled as in plots where the hardwood understory was not controlled (density held constant at 70 square feet). In unthinned plots competition is so severe it makes little difference to overstory pine growth whether a hardwood understory exists or not.

CONCLUSIONS

Thinning shortleaf pine stands is a beneficial silvicultural practice that results in increased product yields and shorter rotations. Thinnings should begin at age 10 to 15 and continue regularly at 10 to 15 year intervals. Residual basal area should be allowed to increase at each thinning to effectively use all available growing space. Basal areas corresponding to 60 percent stocking (Rogers 1983) can be used to guide thinning.

The results reported here apply specifically to similar natural shortleaf pine stands in Missouri but may be indicative of responses that can be expected to occur in stands throughout the range of shortleaf pine. However, they should be carefully checked before being applied.

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RESPONSE OF SUGARBERRY TO RELEASE TREATMENTS[1/]

J. S. Meadows, J. D. Hodges,

E. C. Burkhardt, and R. L. Johnson[2/]

Abstract.--The five-year response of 65-year-old sugarberry (Celtis laevigata Willd.) trees both to complete release and to two types of partial release treatments was evaluated. Complete release produced a very large increase in diameter growth rate for trees of all crown classes, but the largest increase was observed among previously overtopped trees. Partial release resulted in increased diameter growth rates that ranged from 63 to 83 percent of those obtained through complete release. Height growth and crown diameter growth were not affected by release, although bole taper was slightly increased.

INTRODUCTION

Sugarberry is increasingly becoming a major component of hardwood stands in the major bottomlands of the South. Nearly pure stands of sugarberry are relatively common, particularly on the moist sites of the batture lands between the rivers and the levees. Most of these stands are the result of past "high-grading" practices coupled with a lack of forest management. Because sugarberry is a shade-tolerant species, it will persist for many years in the lower and mid-canopies beneath larger trees of other, more intolerant species (Putnam et al. 1960). When the upper canopy is removed in some type of partial cutting, the residual sugarberry trees develop into a nearly pure stand.

Sugarberry is commonly considered to be a slow-growing species. Average diameter growth rates of dominant and codominant trees on good sites have been reported to range from 1.3 to 3.3 inches per decade (Briscoe 1955, Fowells 1965, Putnam et al. 1960). A maximum growth rate of 4 inches per decade on good sites was found by Bull (1945). However, recent data collected from CFI plots indicate that individual sugarberry trees are capable of growing at rates of nearly 6 inches per decade in some situations.[3/]

Stumpage values of sugarberry have increased in recent years, as markets for sugarberry as a furniture wood have become available, making management more economically attractive. However, little is known about the proper silvicultural techniques to use in management of these pure sugarberry stands.

For this reason, a study was begun in 1978 by Mississippi State University, in cooperation with the U. S. Forest Service and Anderson-Tully Company to determine the response of individual sugarberry trees to various release treatments. The study was designed to obtain information about an individual tree's ability to respond to different types of release, but not to test the effectiveness of various silvicultural techniques.

METHODS AND PROCEDURES

Description of Study Area

The study area is located in Issaquena County, Mississippi, in the Mississippi River floodplain, on land owned by Anderson-Tully

[1/] Paper presented at 3rd Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Graduate Research Assistant and Professor, Department of Forestry, Mississippi State University, Mississippi State, MS; Consulting Forester, Vicksburg, MS, and was Chief Forester, Anderson-Tully Co. at the time of study installation; and Project Leader, Southern Hardwoods Laboratory, USDA Forest Service, Southern Forest Experiment Station, Stoneville, MS, respectively. Contribution No. 5976 of the Mississippi Agricultural and Forestry Experiment Station.

[3/] Burkhardt, E. C. 1978. Unpubl. data. Anderson-Tully Co., Vicksburg, MS.

Company. The area is in the batture lands between the Mississippi River and the levee and is subject to flooding. Such areas are normally good sugarberry sites.

The stand selected for the study had received no cutting since the mid-1950's and was primarily composed of sugarberry. It had apparently originated beneath an old-growth stand of mixed hardwoods. Past cutting practices had produced a wide variety of tree size classes in the current 65-year-old sugarberry stand. Most of the trees in the stand exhibited poor bole form. Forked and crooked sugarberry trees apparently developed under a dense overstory, whereas those trees with long or potentially long merchantable lengths probably developed in "free-to-grow" conditions.

Two methods were used to determine the response of individual sugarberry trees to release. In the first method, response to complete release was evaluated. In the second method, the response to various partial release treatments was determined.

Paired-Tree Study

The first study method was designed to determine the response of individual sugarberry trees to complete release. A paired-tree technique was used, such that one tree of a pair was completely released and another tree of similar size and crown class served as a control. A total of 88 trees were used - 12 dominants, 12 codominants, 32 intermediates, and 32 overtopped trees.

Complete release was achieved by cutting all except study trees in four small areas, ranging in size from ½ acre to 4 acres. A fifth clearing was about 8-10 acres in size. Control trees were located in the adjacent uncut stand. To insure that each tree was indeed completely released, trees selected for release were located at least 200 feet from each other and from the edge of the uncut stand. All non-sample trees in the clearings were felled in the winter of 1978-79.

Diameter at breast height, total height, diameter-outside-bark (dob) at 17.3 feet, and crown diameter were measured on all paired trees at the time of study installation. Previous five- and ten-year diameter growth rates were measured from increment borings of each tree. Taper was calculated to be the reduction in dob along the bole between 4.5 feet and 17.3 feet. Some trees were forked or had branches at 17.3 feet. In these cases, upper-stem diameter was measured at the most appropriate point nearest to 17.3 feet. To standardize the data, bole taper was calculated according to the following formula, and expressed in terms of an 8-foot bole section:

$$\text{Taper} = \frac{DBH - DOB_u}{A - B} \times 8$$

where: DOB_u = upper-stem dob

A = height on bole where upper-stem dob was measured

B = height on bole where dbh was measured

Stand basal area before treatment was taken with a 10-factor prism from a point 6 feet south of each tree. Fifth-year remeasurements of all these traits were made in January 1984.

Treatment Plots

The second study method was designed to determine the effects of various partial release treatments on the growth of individual sugarberry trees. Three treatments were evaluated:

1. Release from Above - all dominant and codominant trees were cut, leaving all intermediate and overtopped trees;

2. Release from Below - all intermediate and overtopped trees were cut, leaving all dominant and codominant trees; and

3. Control - uncut plots.

Treatments were applied to rectangular plots measuring 4 x 8 chains (3.2 acres) each. Sampling of trees to determine growth response was performed on four 1/10-acre circular subplots systematically established on each plot. Treatments were replicated three times and were applied in the winter of 1978-79.

Measurements made at the time of study installation were the same as those performed in the paired-tree study, except that stand basal area was determined directly from sub-plot data. Fifth-year remeasurements were made in January 1984.

RESULTS AND DISCUSSION

Paired-Tree Study

Initial Conditions

A wide variety of size classes existed in the stand prior to treatment (Table 1). There was a fairly sharp distinction between the upper crown class trees and the lower crown class trees in all characteristics measured, but particularly in total height and crown diameter. Most of the dominants were large trees with deep, spreading crowns. Codominants were also large trees, but typically had narrower crowns with less dense foliage than the dominants.

Table 1.--Mean pre-treatment characteristics, by crown class, of sugarberry trees selected for the paired-tree release study.

Crown Class	DBH	Previous 10-yr Diameter Growth	Total Height	Crown Diameter
	-in-	-in-	-ft-	-ft-
Dominant	15.5	1.8	78	33
Codominant	12.1	1.7	72	27
Intermediate	6.4	1.1	56	16
Overtopped	4.7	0.6	41	15

Greater variation in both size and crown condition was found within the lower crown classes. As a group, the intermediate trees had larger diameters and were taller than overtopped trees, but most were characterized by short, narrow crowns. The majority of the overtopped trees had a flat-topped crown, sparse foliage, very poor bole form, and were leaning. However, a few of the overtopped trees had good bole form and dense foliage.

The average 10-year diameter growth rates of dominants and codominants, 1.7-1.8 inches/decade, were fairly typical for sugarberry grown in unmanaged stands. However, these rates were on the lower end of the range of 1.3-3.3 inches/decade mentioned above. The overtopped trees had a very slow average diameter growth rate of 0.6 inches/decade (Table 1).

Comparison of control and released trees revealed no significant differences between treatments, regardless of crown class, in any of the characteristics measured prior to treatment (Table 2). Mean stand basal area was relatively high and, when averaged across both treatments, was 114 ft^2/acre.

Five-year Response to Complete Release

Of the 88 trees originally included in the study, 34, or 39 percent, were eliminated for various reasons. Wind storms in February 1979 and April 1980 destroyed 9 of 44 control trees (20 percent) and 18 of 44 released trees (41 percent). Logging operations also destroyed 6 released trees (14 percent). Only one tree, an overtopped control, died of natural mortality during the study period. Total mortality was 10 control trees (23 percent) and 24 released trees (55 percent).

Fifth-year remeasurements are summarized in Table 3. Complete release produced a nearly three-fold increase in diameter growth, as compared to the controls - 1.4 inches versus 0.5 inches, averaged over all crown classes. However, no significant differences between treatments were found in height growth or crown diameter growth. Trees of both treatments averaged less than 2 feet of height growth in 5 years. Crown diameter growth for trees of both treatments was also negligible. However, trees that were completely released did show a slight increase in crown diameter, whereas control trees exhibited a slight reduction in crown diameter, probably due to crown die-back associated with their unreleased condition. Complete release also resulted in a significant increase in bole taper. However, the increase in taper of only 0.11 inches/8 feet was relatively unimportant in comparison with the large increase in diameter growth produced by complete release.

An interesting way of comparing the diameter growth rates produced by these two treatments is to use a diameter growth ratio: the diameter growth for the 5-year period after treatment divided by the diameter growth for the 5-year period immediately before treatment. This ratio is a measure of the increase in diameter growth rate relative to the growth rate existing prior to treatment. The diameter growth ratio of 2.98 exhibited by the completely released trees (Table 3) indicated that complete release produced a nearly three-fold increase in diameter growth rate, when averaged over all crown classes. On the other hand, control trees were not quite able to maintain their previous growth rates, as indicated by their average diameter growth ratio of 0.89. Basal area growth ratio was calculated in the same manner as diameter growth ratio - individual-tree basal area growth 5 years after treatment as compared to 5-year individual-tree basal area growth before treatment. The basal area growth ratios in Table 3 more strongly illustrate the significant growth response exhibited by the completely released trees.

These growth ratios were also analyzed by crown class within treatment (Table 4). The growth ratios exhibited by the control trees were indicative of the course of natural development of the stand. Dominant control trees, with a mean diameter growth ratio of 1.10, slightly improved their growth rates, and codominant control trees, with a mean diameter growth ratio of 0.96 and a mean basal area growth ratio of 1.05, barely maintained their previous growth rates. Lower crown class control trees were thus squeezed out even more, as reflected by growth ratios for both intermediate and overtopped control trees of less than 1.0.

The effect of complete release on diameter growth rates, as illustrated in the diameter

Table 2.--Mean pre-treatment characteristics, by treatment, of sugarberry trees selected for the paired-tree release study.

Treatment	DBH	Previous 10-yr Diameter Growth	Total Height	Crown Diameter	Bole Taper	Stand Basal Area
	-in-	-in-	-ft-	-ft-	-in/8 ft-	-ft^2/acre-
Control	8.4a[1/]	1.2a	60a	21a	1.11a	116a
Release	9.8a	1.3a	60a	23a	1.18a	112a

[1/] Treatment means not followed by the same letter are significantly different at the 0.05 level of probability.

Table 3.--Five-year response of sugarberry trees subjected to either complete or no release in the paired-tree release study.

Treatment	Diameter Growth	Height Growth	Crown Diameter Growth	Increase In Taper	Diameter Growth Ratio	Basal Area Growth Ratio
	-in-	-ft-	-ft-	-in/8 ft-		
Release	1.41a[1/]	1.2a	1.2a	0.11 b	2.98a	3.47a
Control	0.54 b	1.7a	-1.7a	0.02a	0.89 b	0.96 b

[1/] Treatment means not followed by the same letter are significantly different at the 0.05 level of probability.

Table 4.--Five-year growth ratios, by crown class within treatment, of sugarberry trees in the paired-tree release study.

Crown Class	Diameter Growth Ratio		Basal Area Growth Ratio	
	Control	Release	Control	Release
Dominant	1.10	1.61	1.17	1.79
Codominant	0.96	2.04	1.05	2.30
Intermediate	0.80	2.79	0.86	3.21
Overtopped	0.87	5.50	0.91	6.63

growth ratios of Table 4, was significant. The diameter growth ratio of 1.61 exhibited by dominant released trees was significantly greater than the ratio of 1.10 exhibited by the dominant control trees. Stated another way, there was a 10 percent increase in the diameter growth rate of dominant control trees, whereas complete release produced a 61 percent increase.

The explanation for this fairly large response to complete release by dominant trees is probably related to the shade-tolerance of sugarberry. Consequently, sugarberry trees are not good natural pruners (Fowells 1965). Lower limbs tend to be retained for a long time. Foliage on these lower limbs, even on dominant trees, probably receives just enough sunlight to remain alive, but not enough sunlight to enable it to effectively contribute to the growth of the tree. When the adjacent trees are removed, as in complete release, the amount of sunlight received by the upper crown is not increased. However, the amount of sunlight received by those previously unproductive lower limbs is greatly increased. As a result of complete release, then, the lower crown begins to become effective in contributing to the diameter growth

of the tree. In this way, even the dominants were able to show a significant response to complete release. The increased amounts of soil moisture and nutrients made available to completely released trees may have also contributed to their significant growth response.

This line of reasoning can be extended to trees of the other crown classes. The magnitude of the diameter growth ratio of released trees in this study was a reflection primarily of the amount of the tree's foliage that was converted from a level of low productivity to a level of high productivity by the increased sunlight afforded by complete release.

The most dramatic response to complete release was observed in previously overtopped trees, which showed a mean diameter growth ratio of 5.50 (Table 4). Overtopped trees were representative of the extreme situation, in which nearly all of the tree's foliage was operating at a level of low productivity before release, and all of it was converted to a level of high productivity by complete release. Marquis (1981) reported similar results, in that 67-year-old overtopped American beech (Fagus grandifolia Ehrh.) saplings and poles increased their diameter growth rates four-fold five years after nearly complete release, produced by clearcutting all merchantable timber from a site in the Allegheny National Forest.

Treatment Plots

Initial Conditions

Prior to treatment, the stand in which the release treatment plots were located had a mean stand basal area of 129 ft^2/acre for trees greater than 2.0 inches dbh, with 276 trees per acre and a mean stand diameter of 9.2 inches. Sugarberry comprised 58 percent of the total stand basal area (75 ft^2/acre) and 53 percent of the total number of trees (146 trees per acre). Mean diameter of the sugarberry component was 9.7 inches. The remainder of the stand was composed of scattered, large green ash (Fraxinus pennsylvanica Marsh.) and sweet pecan (Carya illinoensis (Wangenh.) K. Koch), some pole-sized boxelder (Acer negundo L.), and numerous small elms (Ulmus spp.).

Uncut control plots averaged 270 total trees per acre, 131 ft^2 of basal area per acre, and had a mean stand diameter of 9.4 inches (Table 5). Release from above resulted in a slight decrease in the number of trees to 204 per acre, but a 75 ft^2 reduction in stand basal area. Cutting the larger trees on these plots reduced mean stand diameter to 7.1 inches. Release from below had the opposite effect. There was a very large reduction in the number of trees to only 55 per acre and a 45 percent decrease in stand basal area to 72 ft^2/acre.

Table 5.--Residual stand characteristics immediately after partial release treatments were imposed on treatment plots.

Treatment	Trees	Stand Basal Area	Mean Stand Diameter
	-no/acre-	-ft^2/acre-	-in-
Control	270	131	9.4
Release - above	204	56	7.1
Release - below	55	72	15.5

Cutting the smaller trees on these plots increased mean stand diameter to 15.5 inches.

There were large initial differences among residual trees of the three treatments in size and previous diameter growth rates (Table 6). Trees remaining immediately after release from below were larger and had faster diameter growth rates than control trees. On the other hand, trees remaining immediately after release from above were smaller and had slower diameter growth rates than control trees.

Five-year Response to Various Release Treatments

Because of these significant differences in initial size and growth rates among residual trees, analysis of covariance was performed on the five-year results to adjust for these differences, and to allow direct comparison of the effects of these partial release treatments

Table 6.--Mean characteristics of residual sugarberry trees immediately after partial release treatments were imposed on treatment plots.

Treatment	DBH	Previous 10-yr. Diameter Growth	Total Height	Crown Diameter
	-in-	-in-	-ft-	-ft-
Release-below	14.5a[1/]	1.8a	80a	29a
Control	9.9 b	1.4 b	64 b	23 b
Release-above	7.1 c	0.9 c	52 c	18 c

[1/] Treatment means not followed by the same letter are significantly different at the 0.05 level of probability.

on growth response. Fifth-year adjusted treatment means reflect the response that would have been observed if all the trees were originally the same size.

Five-year response to these release treatments is summarized in Table 7. Both types of partial release (release from above and release from below) produced diameter growth significantly greater than the control, but did not differ from each other in their effect. Both height growth and crown diameter growth were slow and no significant differences among treatments were found in either parameter. However, trees released from below did show a significantly larger increase in bole taper than did trees in the control plots. Trees released from above showed no such adverse effect on taper.

Growth ratios calculated for these treatments indicated that both types of partial release produced significant increases in both diameter growth rate and individual-tree basal area growth rate (Table 7). Dominant and codominant trees released from below showed a mean diameter growth rate about 1.5 times greater than that exhibited before release, whereas intermediate and overtopped trees released from above showed a mean diameter growth rate about 2.7 times greater than that observed for the five-year period before release. Expressed on a percentage basis, release from above produced a 169 percent increase in the diameter growth rates of lower crown class trees, and release from below resulted in a 48 percent increase in diameter growth rates of upper crown class trees.

These results compared favorably with those obtained by other workers. Johnson (1950) found that heavy partial release produced a 26 percent increase in the 10-year diameter growth rates of mixed bottomland hardwood trees (principally oak (Quercus spp.) and sweetgum (Liquidambar styraciflua L.)) after an improvement cut in Mississippi. Beck (1981) reported that, five years after lower crown class trees were partially released by a diameter-limit cut on an upland site in North Carolina, diameter growth rates were improved by 200 percent for oak, 223 percent for yellow-poplar (Liriodendron tulipifera L.), 228 percent for hickory (Carya spp.), and 248 percent for red maple (Acer rubrum L.). Schlesinger (1978) conducted a study in southern Illinois in which white oaks (Quercus alba L.) of all crown classes except dominant received partial release. He found that partial release produced a 160 percent increase in diameter growth in lower crown class trees, and a 60 percent increase in codominant trees. Schlesinger's results were very similar to those found for sugarberry in this study.

The results obtained for partial release in the treatment plots also compared favorably with those obtained for complete release in the paired-tree study. Partial release (from below) resulted in a diameter growth ratio for dominant and codominant trees of 1.48 (Table 7), or 83 percent of the diameter growth ratio for dominants and codominants obtained through complete release. Intermediate and overtopped trees, when released from above, showed a diameter growth ratio of 2.69 (Table 7), or 63 percent of the diameter growth ratio of completely released intermediate and overtopped trees.

Table 7.--Five-year response of sugarberry trees subjected to partial release on the treatment plots.

Treatment	Diameter Growth		Height Growth		Crown Diameter Growth		Increase in Taper		Diameter Growth Ratio	Basal Area Growth Ratio
	Actual[1/]	Adj.[2/]	Actual	Adj.	Actual	Adj.	Actual	Adj.		
	--------in-------		------ft------		------ft------		----in/8 ft---			
Release - above	1.00	1.15a[3/]	2.7	2.4a	0.9	0.0a	0.12	0.09ab	2.69a	3.10a
Release - below	1.18	0.99a	2.8	3.2a	0.6	1.8a	0.18	0.18 b	1.48 b	1.61 b
Control	0.60	0.58 b	3.0	3.0a	-0.9	-0.7a	0.03	0.04a	0.91 c	0.98 c

[1/] Means based on actual measurements.

[2/] Means adjusted through analysis of covariance.

[3/] Means not followed by the same letter are significantly different at the 0.05 level of probability.

Response of sugarberry to either complete or partial release is apparently both large and rapid. Results from these studies indicate that satisfactory growth rates of sugarberry are possible. The development of silvicultural techniques designed to encourage growth rates similar to those obtained in these studies is needed. These techniques, coupled with a better understanding of how individual sugarberry trees develop long merchantable lengths, would enable the forest manager to produce sugarberry stands with satisfactory growth and quality. Management of existing large acreages of sugarberry would thus become both practical and profitable.

SUMMARY

1. Sugarberry trees of all crown classes showed a significant improvement in diameter growth rate when completely released. However, the greatest amount of increase in diameter growth rate was observed in previously overtopped trees.

2. Sugarberry trees, when released either from below or from above, also showed significant increases in diameter growth rate. Trees released from above exhibited a greater response in increased diameter growth rate than did trees released from below.

3. Partial release, either from above or from below, produced increases in diameter growth rates that were 63-83 percent of those obtained through complete release.

4. Neither complete nor partial release had a significant effect on height growth or crown diameter growth, but complete release and release from below did result in a significant increase in bole taper.

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THINNING FROM BELOW AFFECTS THE GIRARD FORM CLASS AND FINAL VOLUME OF LOBLOLLY PINE PLANTATIONS[1/]

A. T. Shearin, L. E. Nix, and R. T. Collins[2/]

ABSTRACT.--Investigation of a long-term thinning study of loblolly pine (Pinus taeda L.) plantations in the Piedmont of South Carolina indicated that at age 42 Girard form class was greater in thinned than in unthinned plots. Mean form class values for sawlog sized stems on plots which were heavily thinned were 2.7 percentage points higher than those on the unthinned control plots. Board-foot volume of thinned plots averaged 24 percent greater than that of unthinned plots at age 42, and thinning yield averaged 24 cords per acre from 4 low thinnings begun around age 14. At least 8 percent of the sawtimber volume difference was due to the increase in Girard form class of the thinned trees. The intermediate income from the thinnings and the increase in sawtimber volume at age 42 suggest that thinning is desirable if closely-spaced stands are to be carried past age 30.

INTRODUCTION

Plots for monitoring long-term response of loblolly pine (Pinus taeda L.) to thinning were installed in plantations established in the late nineteen thirties on old-field sites in upper South Carolina (Goebel et al. 1974). Although many of the plots have been lost to construction over the years, the remaining plots are being maintained on the Clemson University Experimental Forest, located in the Piedmont of South Carolina.

The original study was designed to evaluate the effect of various thinning regimes on the growth and yield of loblolly pine plantations. The remaining plots except for controls have all been thinned, primarily from below, 4 or 5 times according to the original study plans which specified a residual basal area (ft^2/acre) to be left on each plot. In the process of determining the board-foot volumes of the plots in recent measurements, Girard form class measurements were taken of a sample of trees in each diameter class on the plots. An apparent trend in the data associating higher Girard form class values with more intensive thinnings suggested the current report.

DESCRIPTION OF STUDY

To test the hypothesis that thinning affects tree taper as measured by Girard form class, measurements were taken of at least twenty percent of the trees in each one-inch diameter class on the plots remaining in the Clemson long-term study. Trees to be measured were climbed, and diameter inside bark at 17.3 feet was determined by subtracting double bark thickness, measured at two 90-degree adjacent points with a Swedish bark gauge, from the diameter outside the bark. The upper diameter was divided by diameter outside bark taken at breast height (dbh) to calculate the Girard form class value for the trees. Measurements were made of 210 trees located on 15 plots at 4 locations. Four unthinned control plots and 11 plots thinned to various levels of intensity were included. The form class data were analyzed using the General Linear Models procedure with plot residual basal area (BA) as treatment and diameter as a covariable to test the relationship of form class to diameter. Plot means were tested individually, combined into 4 levels of thinning or as thinned or unthinned treatments. The fifty-year base site indices of the 4 groups of study plots ranged from 76 to 96 feet indicating that the site quality of the study plots is average to slightly above average for loblolly pine in the Piedmont. The age of the trees when the last measurements were made was 42 years.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Assistant Professor, Associate Professor, and former Graduate Student, respectively, Department of Forestry, College of Forest and Recreation Resources, Clemson University, Clemson, South Carolina.

Plot volumes were determined by measuring the dbh of all trees and ocularly estimating merchantable heights of sawtimber trees (dbh > 9.5 inches) to the nearest 1/2 log using a 16 foot pole as reference. Sawtimber tree volumes were taken from the form class volume tables of Mesavage and Girard (1946) using the International 1/4" rule and basing tree form class on the average value determined for each diameter class on the plot. Pulpwood volumes (trees 4.6 to 9.5 inches dbh) were calculated using diameter and total height (determined from a height/diameter relationship curve) with the equation of Schumacher and Coile (1960). Per acre volumes were then expanded from the plot values. Board foot volumes are reported only for trees > 9.5 inches dbh.

RESULTS

The analyses showed that when all trees measured were included, form class was significantly related to basal area residual, but that diameter was a significant covariable. With the effect of diameter removed, form class differences were not significant at the 5% level. When the analysis was rerun using 136 trees > 9.5 inches dbh, diameter was not a significant covariable and form class was significantly different only between the best thinning treatment (110 ft^2 BA) and the poorest (the unthinned plots). When treatments were combined into levels of thinning, form class was significantly different only between thinned and unthinned plots (Table 1).

Table 1. Volumes and Girard Form Class Values of Loblolly Pine Influenced by Thinning Treatments.

Residual Basal Area (ft^2/ac)	Mean Girard Form Class[1/]	Mean Volume per Tree[2/] (BF-Int ¼")	Mean Volume per Acre[2/] (BF-Int ¼")	Thinning Yield per Acre[3/] (cords)
180-200	77.0a	86.0	10,710	0
75- 85	79.7b	122.5	14,288	24.4
90-100	79.2b	115.7	14,981	25.2
110-135	79.3b	96.0	10,480	21.5

[1/] Girard form class is a measure of taper of the butt log of the tree. Values with same letter adjacent are not different at the 5% level.

[2/] Volumes are for trees ≧ 9.6" dbh (sawtimber size) at age 42 years.

[3/] Unthinned plots averaged 27 cords per acre of residual pulpwood (trees > 4.5 inches dbh), thinned plots averaged 5.5 cords per acre.

At age 42 the plots which were thinned averaged 105 square feet of residual basal area per acre, 11.8 inches dbh, 114.5 board feet per tree, 13,800 board feet and 5.5 cords per acre and a Girard form class of 79.4 for trees > 9.5 inches dbh. The average thinning yield was 24.2 cords per acre from 4 low thinnings begun around age 14. The unthinned plots averaged 193 square feet of basal area, 11.0 inches dbh, 86.0 board feet per tree, 10,710 board feet and 27 cords per acre, and a Girard form class of 77.0 for trees > 9.5 inches dbh. At least 8 percent of the 24 percent sawtimber volume difference between thinned and unthinned plots is attributable to the improved form class of the trees on thinned plots.

DISCUSSION

The findings of this study agree with those of other researchers who have documented an increase in form class values as a result of thinning when the comparison is made between thinned and unthinned plots. There was no attempt to measure changes in form class over time, and no attempt was made to classify trees as to crown position, i.e., according to the classic positions of trees in evenaged stands as related to dominance.

Many studies have shown that heavy thinning results in increased taper of residual trees (Myers 1963, Morrow 1974, Barker 1980). It is important to distinguish between measures of tree taper. Husch (1963) and Larson (1963) discuss tree form and taper in detail. Tree taper as such cannot be equated with Girard form class because form class is a measure of the taper in only a portion of the stem, namely the first 16-foot log; nevertheless, form class measurements were originally devised to estimate taper in the most valuable portion of the tree and over the years have served well. Mesavage and Girard (1946) state that in using their volume tables "one percent in form class approximates 3 percent in tree volume." This relationship indicates the importance of monitoring form class changes in measuring growth and yield. For example, an increase in mean form class from 76 to 78 percent for a typical stand of loblolly pine would result in a 6-percent increase in tabular board foot volume.

When Girard form class is used as a measure of tree taper, tree form apparently improves with thinning. Brinkman et al. (1965) found that in heavily thinned plots in evenaged shortleaf pine (*Pinus echinata*, Mill.) the largest trees had the best form, the fastest diameter growth rates, and the greatest improvement in form over the years of the study. The improvement in form necessitated an adjustment in the volume tables used. Hilt and Dale (1979) in a thinning study of oak (*Quercus* spp.) showed that it was possible to find an increase in taper as measured by breast-height form factor and simultaneously to find a decrease in taper of the same tree as measured by Girard form class.

Andrulot et al. (1972) attributed finding form class differences between thinned and unthinned plots to comparing different populations. There were more trees of intermediate and suppressed crown positions on the control plots, thus, they concluded that these lower crown class trees had the effect of lowering the mean form class of the unthinned plots. Comparison of just the larger diameter trees from their thinned and unthinned plots showed no difference in form class. In the present study, there was significant difference in the form class means of thinned and unthinned plots but only if trees > 9.5 inches dbh were included in the analysis. When all trees were included, diameter was a significant covariable and, when its influence was removed, form class differences were not statistically significant.

Williston (1967), comparing dominant and codominant loblolly pine trees on thinned versus unthinned plots, found that form class increased, over a 10-year period, by 9 percentage points on the thinned plots while form class on the control plots increased by 7 percentage points. The results of the present study are in agreement with Williston (1967) in that the comparison between form class means of larger trees, i.e., over 9.5 inches in dbh, showed significant difference between thinned and unthinned plots.

In the present study, the plots, except for the control plots, were all thinned from below at approximately 5 to 8-year intervals. This resulted in the plots having been thinned 4 or 5 times, with primarily the trees of intermediate and codominant crown class being removed. Intermediate and codominant trees are generally considered to be more cylindrical in form than dominant trees, resulting in higher form class values (Larson 1963) and so the thinnings should have resulted in a reduction of mean form class for the thinned plots. Such was not the case and there was no significant relationship between form class and diameter among trees > 9.5 inches dbh.

It would be difficult to explain the higher form class values of the thinned plots on the basis that a biologically sound type of thinning, i.e., primarily from below and incidentally removing poorly formed or diseased trees from any crown class, automatically results in taking out trees with lower form class values, thus, improving the average form class of the thinned plots. Ocular estimation of form class is difficult to do except within very broad limits of accuracy, and even an experienced timber cruiser would have difficulty in selecting mostly trees of below average form class values for removal.

The present findings could be a quirk of thinning interacting with tree height, depth of crown at the time the thinnings began, or density of stands at or near the current age (42 years). Many observations of the diameter growth patterns of trees in the local area through stem analyses done by students and fellow researchers clearly show a variable pattern of vertical distribution of diameter growth such that there is a region of rapid diameter growth that seemingly follows the crown as it recedes upward with age and natural pruning. Thus, the influence of thinning in prolonging retention of lower branches could have provided for greater diameter growth in the proximity of the lower crown at the time thinnings were initiated. If the lower limit of the crown coincided with the general area where the upper diameter measurement is taken for Girard's form class when the plots were first thinned, then thinning could cause a higher form class value in this manner.

Based on the results and studies discussed here, there does not seem to be a clear response to thinning in regard to its effect on the taper of trees of different crown positions. However, if conclusions are limited to young evenaged stands of loblolly pine, thinned starting at an early age and primarily from below, this and other studies have shown an increased rate of volume accretion in the first 16-foot log where, for many products, the wood is most valuable. This is an effect of thinning that is seldom mentioned but that is adequately described by Girard Form Class measurements. Since the plots investigated in this study are close to rotation age for many management plans for loblolly pine, it would seem worthwhile to take a closer look at the possible value of increased merchantable volume resulting from form class improvement due to thinning, which has not received as much attention in the past as it might deserve.

The other benefits of thinning, such as intermediate income and, in this case, higher sawtimber volumes at rotation end, are accrued primarily when such stands are carried longer than 30 years. An earlier study of these same stands by Goebel et al. (1974) showed no economic advantage of thinning up to age 33 years. The primary advantage of thinning may be gained when sawtimber is the major objective of stand management and form class improvement is considered in volume determinations.

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EFFECTS OF FUSIFORM RUST ON GROWTH OF PLANTED SLASH PINES[1/]

P.Y. Burns and S.C. Hu[2/]

Abstract.--Living stems in an unthinned slash pine plantation were classified at age 11 into three severity-of-infection categories. Growth data to age 14 showed that mortality was largely rust-associated. Volume growth of survivors was slightly but significantly reduced by infection; the greater the degree of cankering the less the growth.

INTRODUCTION

Fusiform rust of southern pines is the most damaging disease of forest trees in the South. It is caused by the fungus Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme (Blakeslee 1983). The two most widely planted species in the South, loblolly pine (Pinus taeda L.) and slash pine (P. elliottii Engelm.), are susceptible. There has been a dramatic increase in the incidence and impact of this disease in the planted slash pine ecosystem since 1960 (Dinus and Schmidt 1977), and mortality caused by fusiform rust is serious in some areas of the South. Recommended rust-management strategies based on rust hazard have been developed for slash pine plantations (Schmidt and Klapproth 1982), and a yield model for unthinned slash pine plantations infected with fusiform rust is now available (Nance et al. 1983).

Although Powers et al. (1974) and Sluder (1977) found that stem growth of rust-infected trees was reduced, others reported that fusiform rust does not significantly affect growth of slash pine trees (Barber 1961, Dell and Driver 1963, Dinus and Schmidtling 1971, Jones 1972). Noting the conflicting results in the literature Holley and Veal (1977) suggested that these differing findings might at least be partially explained if investigators would rate severity of infection by measuring the percentage of the stem which is girdled. The objective of our current study was to test this suggestion by classifying trees into severity-of-infection classes and to measure their growth for the ensuing three years.

METHODS

In the spring of 1970 one-year-old slash pine seedlings were planted at LSU's Lee Memorial Forest in southeastern Louisiana. The seed source was fast-growing high-quality trees from the same general area. Spacing was 9 ft x 12 ft (403 trees/acre).

The plantation was located on a stream terrace site where a 40-year-old natural loblolly pine stand had been harvested and the site and been prepared. The soil type is Kalmia very fine sandy loam. Oaks which are highly susceptible to fusiform rust are abundant in the surrounding forest, and the area is in a region of high rust-infection hazard for slash pine plantations (Squillace 1976).

Four 0.74-acre plots were established, and each plot received one of four intensive culture treatments, including a control. Only the two most intensively treated plots (A and B) were utilized for this report. These two plots were plowed before planting, fertilized, mowed as needed for brush and weed control, and pruned at age 7 to a height of 6 ft. Plots A and B have been nearly identical in growth and rust infection; therefore they were combined for this investigation.

Tree d.b.h. and height were measured annually through 14 growing seasons on the interior 0.424 acre of each plot (total 0.848 acre for the combined plots). Fusiform cankering on each standing tree was tallied at ages 8½ and 10. The relationship between rust infection and intensive culture on these plots at age 10 was reported at the 1980 Southern Silvicultural Research Conference (Burns et al. 1981).

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Professor and Associate Professor, respectively, School of Forestry, Wildlife, and Fisheries, Louisiana Agricultural Experiment Station, LSU Agricultural Center, Baton Rouge, Louisiana 70803.

At age 11, each tree was classified into one of three severity-of-infection categories: (1) no stem canker, (2) canker with less than 50 percent of the stem circumference affected, and (3) canker with 50 percent or more of the stem circumference affected. In addition, the presence or absence of limb cankers was recorded for each tree. The age-11 tally thus resulted in six canker classes.

Student's t-test was used for statistical analysis of the effects of degree of cankering on stand parameters at age 11 and on growth from age 11 to age 14.

RESULTS

Stand Description at Age 11

At age 11, survival was 81 percent. Stand characteristics as shown in table 1 were: 327 trees/acre, average d.b.h. 6.6 inches, average height 41 ft, and average volume 3.6 ft^3. Basal area was 80 ft^2/acre and volume 1167 ft^3/acre. Cumulative mortality volume was 75 ft^3/acre, 85 percent of which was rust-associated. Rust-associated mortality at age 11 was 9 percent, based on the definition by Wells and Dinus (1978)-- the cumulative number of trees killed by rust divided by the number planted less those dead of causes other than rust. Site index (average height of the dominants and codominants at base age 25) was high--84 ft.

The percentage of living trees at age 11 in the six canker classes is presented below.

Stem canker class	Limb canker class: None	Canker	Total
	--Percent of trees--		
None	10	32	42
Under 50% circumference	6	39	45
50% or more circumference	1	11	13
Total	18	82	100

Stem Canker Effects

The geographic spread of stem infection and mortality was fairly uniform across the plot area. Bole cankers were tallied on 58 percent of the living trees at age 11.

As table 1 shows, at age 11 there were no statistically significant (0.05 level) differences in average d.b.h., height, and volume per tree between trees with no stem canker and those with stem cankers extending less than halfway around the bole. However, there were significant differences between trees with 50 percent or more of the trunk affected by rust and the average of the other two canker classes: average d.b.h. was 11 percent smaller, average height was 10 percent lower, and average volume was 26 percent less for the most severely cankered class.

Mortality during the three-year period from age 11 to age 14 (table 1) amounted to 5 percent of the trees, a volume loss of 2.7 percent of the age-11 stand volume. Of the trees which died, 86 percent had stem cankers at age 11, 7 percent apparently died of suppression, and 7 percent died of unknown causes. Although only 2 to 3 percent of the trees with either no stem canker or a canker extending less than halfway around the bole died, 23 percent of the trees in the most severely cankered class failed to survive.

No statistically significant differences were found among sizes of dead trees relating to stem-canker class. However, rust-associated mortality was related to tree size; cankered trees which died average only about half as large as those which survived.

Table 1.--Relationship of stem canker classes to age-11 stand characteristics and to mortality and survivor growth, ages 11 to 14.[1/]

Canker class	Trees per ac.	Ave. dbh[2/]	Ave. ht.	Ave. vol.[3/]
	No.	In.	Ft.	Ft.^{3}
	Age-11 characteristics			
None	139	6.65 a	41.4 a	3.65 a
Under 50%[4/]	147	6.76 a	41.1 a	3.71 a
50% plus[5/]	41	5.93 b	37.3 b	2.73 b
All trees	327	6.61	40.7	3.57
	Mortality, ages 11 to 14			
None	2	6.45 c	41.0 c	3.37 c
Under 50%	5	5.58 c	37.2 c	2.19 c
50% plus	9	4.71 c	33.4 c	1.45 c
All trees	16	5.21	35.6	1.94
	Survivor growth, ages 11 to 14			
None	137	0.80 d	9.1 d	2.06 d
Under 50%	142	0.69 e	8.5 e	1.86 d
50% plus	32	0.62 e	8.0 e	1.53 e
All trees	311	0.73	8.4	1.91

1/ Means in the same column followed by the same letter are not significantly different at the 5 percent level.
2/ Arithmetic average.
3/ Total stem inside bark.
4/ Less than 50% of the stem circumference affected.
5/ 50% or more of the stem circumference affected.

Growth of trees which survived between ages 11 and 14 was apparently reduced slightly but

significantly (0.05 level) by stem cankering (table 1). Compared to trees without a stem canker, trees having a canker extending less than 50 percent around the bole had average growth reductions of 5 percent per year in diameter and 2 percent per year in height; annual volume-growth reduction for this canker class was 3 percent, slightly less than the amount required for statistical significance. Trees with a canker extending at least halfway around the stem sustained average diameter-growth reduction of 8 percent per year, average height-growth reduction of 4 percent per year, and annual volume-growth reduction of 9 percent.

Limb Canker Effects

Limb cankers occurred on 82 percent of the trees at age 11. Only 10 percent of the trees were "clean;" that is, with neither a stem nor a limb canker.

Limb cankering was well distributed through the range of tree sizes, although within the no-stem-canker class the average limb-cankered tree was 4 percent shorter than the average tree without limb infection.

Small but statistically significant growth reductions were associated with limb cankers. Compared to trees with no limb canker, limb cankered trees had average annual growth reductions of 8 percent in diameter, 5 percent in height, and 8 percent in volume.

DISCUSSION

The findings in this study help explain the conflicting results in the literature concerning the effects of fusiform rust on slash pine growth. Although there is apparently a growth reduction in surviving trees due to the presence of bole cankers, the effect is slight for trees with a moderately severe infection. However, for severe cankering (50 percent or more of the stem circumference affected), the growth reduction is more pronounced, although still relatively small. Holley and Veal (1977) reported somewhat similar results.

Growth reduction associated with rust infection is by no means uniform. For example, some severely cankered trees (26 percent of the survivors) grew faster in our experiment than the average tree with no stem canker. Thus, in order for rust-associated growth reduction to be detected in a particular study, tree measurements need to be accurate and precise, and a large number of trees needs to be included in the sample so the growth estimates will be reliable.

Our finding that rust-associated mortality was heavier among the smaller trees is apparently in contradiction to the results of a study by Nance et al. (1981) in Louisiana and Mississippi slash pine plantations. They reported that at ages 10, 15, and 20, tall trees had a higher proportion with a stem gall than did short trees; however, among stem-infected trees survival was higher for large trees than for small ones, so that rust-associated mortality was approximately the same for all size classes.

That our data indicated a reduction of 8 percent per year in volume growth associated with limb cankering is somewhat surprising. Cause and effect are not clear here. It is of course possible that the infections caused lessened growth; however, it is also possible that slow-growing trees were more prone to branch infections.

The growth loss associated with fusiform rust in our study plots is quite small to-date compared to the growth gain due to intensive silvicultural practices. Through age 14, our intensive culture plots A and B have produced nearly three times as much wood per acre as our unthinned control plot, in which only 16 percent of the stems are infected. At the end of the rotation, whether or not the growth increase due to intensive silviculture will be negated by the attendant mortality and growth loss due to increased rust infection is still uncertain.

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THINNING LOBLOLLY PINE PLANTATIONS

Terry R. Clason and Quang V. Cao

Abstract.--Effects of thinning on a 29-year-old loblolly pine plantation are being studied. Research plots stocked at 100, 200, and 300 TPA since age 11 were thinned by reducing each stocking level to 75, 50, and 25 TPA. Merchantable wood yields at age 29 were 3080, 3400, and 3950 ft^3/acre for 100, 200, and 300 TPA, respectively. Prior to thinning, sawtimber accounted for 82, 65, and 47 percent of the standing volume, while post-thinning percentages were 82, 77, and 71. Mean annual sawtimber growth increment between age 11 and 29 was 138, 123, and 92 ft^3/acre. Five years after thinning the periodic annual sawtimber growth increment was 60, 80, and 65 ft^3/acre and sawtimber percentages were 89, 84, and 82 for 100, 200, and 300 TPA. Per acre values for the respective treatments increased by $267.66, $300.66, and $248.28.

INTRODUCTION

Landowner management objectives determine the intermediate harvesting practices utilized in loblolly pine plantations. Wahlenberg (1960) noted that yield increases subsequent to thinning resulted from increased net merchantable volume harvested during a rotation rather than increased total wood growth.

Research has indicated that thinning may not increase net merchantable yields in plantations with a rotation length of 25 years of less. Crow (1952) found no yield difference between a light thinning (88 ft^2/acre of residual basal area) and an unthinned control in 24-year old slash pine plantations in south Louisiana. Thinned natural loblolly pine stands in Louisiana produced yield increases by age 33 (Mann 1952). Thinning young loblolly pine stands in Illinois failed to increase yields at age 17 (Minckler and Dietschman, 1953). A spacing and thinning study in northwest Louisiana indicated that loblolly pine yields were maximized at denser stocking rates, while individual tree size was greater at lower rates (Sprinz et al., 1979).

Although maximum fiber production on a given site is the biological objective of short rotations, a satisfactory rate of return on invested capital may not be achieved without thinning. The need to apply both biological and economic principles to timber management was recognized by Bond (1952). He stated "Net returns are maximized when the growing stock is regulated and held to the smallest amount of timber capital that will produce maximum yield within the capacity of the site and species. With too much volume of growing stock the net return per acre may be high, but the rate of return on the large investment unsatisfactory. With too little growing stock the rate of return on the small investment is likely to be high but the net return per acre unsatisfactory." Thinning provides the land manager a tool that can be utilized to maintain timber capital at levels, which can maximize financial gains for either short or long rotations.

Loblolly, slash, and other pine plantations established at relatively wide spacings and grown under severe thinning schedules produced high yields during short rotations. In Australia, Jolly (1950) obtained the greatest volume yield and net return on investment during a short rotation by thinning Monterey pine to 300 trees per acre (TPA) at age 10. Kotze (1960) recommended that loblolly and slash pine in South Africa planted at a 7 ft x 7 ft spacing should be thinned to 500 TPA at age 11 and 300 TPA at age 16. Wood yields produced with this schedule were 10, and 15 cords/acre at age 11, and 16 with 60 cords/acre harvested at 25 years. Sprinz et al. (1979) found that total merchantable yields for loblolly pine thinned to 300 TPA at age 11 were comparable to an unthinned 10 ft x 10 ft treatment and greater than denser stocked unthinned treatments.

Where cultural practices are intense and site conditions favorable, thinned stands can produce higher yields than unthinned stands during a 30-year rotation. After age 30, thinning could

stimulate individual tree growth and produce higher value products. The purpose of this study is to determine the growth response of thinned 29-year-old loblolly pine stands stocked, since age 11, at 100, 200 and 300 TPA and how financial gains have been influenced since age 29.

METHODS

Since age 5, growth data has been collected from a loblolly pine plantation, which is currently 34 years old, located on the Hill Farm Research Station near Homer, Louisiana. The plantation was established on an abandoned cotton field with soil types mainly from the Shubuta, Luverne, and Bowie Series, all having a fine sandy loam texture. Site index averaged 68 feet at age 25 with site quality of individual plots ranging from 65 to 78 feet.

Bare-rooted seedlings, graded as 1 and 2 using guidelines similar to Wakeley's (1954) grading system, were planted on a 10-acre study area in February 1950. Seedlings were grown using seed collected from natural loblolly stands located in north Louisiana. Site preparation included removing existing pine and hardwood saplings, poisoning stumps and burning.

Each initial stocking rate, 4x4, 6x6, 6x8, 8x8, and 10x10-foot spacing, was established on a 1-acre block and replicated twice. First-year survival rates were high but interplanting was done where necessary. One 10x10-foot block was removed from the study due to hardwood competition and pine mortality.

In 1955 at age 6, each block was divided into 4 plots. Plot size ranged from 0.16 to 0.29 acres without buffer strips. Three cultural treatments were randomly assigned within each block:

1. Precommercially thin to 400 TPA;
2. Prune 400 crop TPA to 8 ft or 1/2 total height; and
3. Precommercially thin to 400 TPA and prune to 8 ft or 1/2 total height.

A fourth plot in each block was maintained as part of the original spacing study. Crop tree diameter and height were measured annually from 1955 to 1960.

Three commercial thinning treatments were applied at age 11 to the previously treated plots. Treatments included:

1. Thin to 100 TPA and prune to 17 ft;
2. Thin to 200 TPA and prune to 17 ft; and
3. Thin to 300 TPA and prune to 17 ft.

These treatments were replicated three times on each age 6 treatment and growth data were collected on a periodic basis from 1960 through 1978. Pulpwood volume removed during the age 11 thinning were 10.3, 6.7, and 5.1 cords per acre for 100, 200, and 300 TPA plots, respectively.

The plantation was thinned again at age 29. Stocking levels from the age 11 treatments were reduced to 25, 50, and 75 TPA. The nine treatment combinations that resulted were:

1. 100 TPA to 25 TPA;
2. 100 TPA to 50 TPA;
3. 100 TPA to 75 TPA;
4. 200 TPA to 25 TPA;
5. 200 TPA to 50 TPA;
6. 200 TPA to 75 TPA;
7. 300 TPA to 25 TPA;
8. 300 TPA to 50 TPA; and
9. 300 TPA to 75 TPA.

Each treatment combination was replicated three times and growth data were collected at age 32 and 34. Total inside bark volume was computed with the Smalley and Bower Equation (1968), and merchantable volume was determined with the Burkhart's (1977) volume ratio method using the following merchantability standards:

1. Sawtimber - from the tree butt to a 8 inch inside bark diameter (i.b.);
2. Chip-n-saw - from a 8 inch i.b. to a 3 inch i.b.; and
3. Pulpwood - from a 5 inch i.b. to a 3 inch i.b.

All data were analyzed with analysis of variance and individual means were compared orthogonally.

RESULTS AND DISCUSSION

Growth and Yield

Age 11 Treatments

The thinning treatments applied at age 29 to loblolly pine stocked at 100, 200 and 300 TPA had a nonsignificant effect at the 5% level on growth after 5 years. Although nonsignificant, the results of this study reflect on the interactive effect of past and present management practices on stand growth and value.

Table 1 presents stand attribute data for the age 11 thinning treatments through age 34. Individual tree growth was superior on the 100 TPA treatments, while yield was greatest at the 300 TPA stocking level. Following thinning at age 11, mean diameter and height were largest on the 100 TPA treatments (7 inches and 36.5 ft) and basal area and volume largest on the 300 TPA treatments (56.7 ft^2/acre and 580 ft^3/acre). Standing tree data at age 29 showed the effect of the various stocking levels on growth since age 11. Tree diameter growth on the 100 TPA treatments was 40 percent greater than the 300 TPA, averaging 7.7 inches (Table 1). Mean merchantable volume growth between age 11 and 29 was 2730, 3120, and 3370 ft^3/acre for the 100, 200 and 300 TPA,

Table 1. Stand attributes by Age 11 treatments

Treat-ment	Stock-ing	Dia-meter	Basal Area	Height	Volume
	TPA	In	Ft^2/ acre	Ft	Ft^3/ acre
	Age 11 Residual				
100	100	7.0	26.5	36.5	350
200	193	5.9	37.4	34.6	380
300	295	5.9	56.7	34.6	580
	Age 16				
100	100	10.3	57.2	49.0	1,040
200	189	8.4	72.0	48.2	1,320
300	294	7.8	98.3	48.8	1,800
	Age 21				
100	96	12.3	79.4	60.4	1,790
200	184	9.9	98.1	59.5	2,230
300	290	9.0	128.5	59.6	2,900
	Age 29				
100	94	14.7	112.4	74.6	3,080
200	172	11.9	133.0	74.4	3,400
300	275	10.9	162.0	73.1	3,950
	Age 29 Residual				
100	50	15.2	62.3	76.0	1,760
200	54	12.8	48.3	76.8	1,320
300	49	12.0	38.9	76.8	1,120
	Age 34				
100	49	15.7	65.8	79.7	2,060
200	54	13.7	55.3	81.7	1,720
300	49	13.3	47.3	80.9	1,450

Table 2. Cut volumes by Age 11 treatments

Treatment	Total Volume	Pulpwood Volume	Sawtimber Volume
	Ft^3/Acre		
	Age 11		
100	820	820	
200	540	540	
300	400	400	
	Age 29		
100	1,320	130	1,190
200	2,080	520	1,560
300	2,850	1,130	1,720

respectively. Total merchantable volume yields through age 29 were 3900, 3940, and 4350 ft^3/acre (Tables 1 and 2).

Although the 300 TPA treatments produced 500 ft^3/acre more volume than the 100 TPA, product distribution at age 29 differed greatly. Merchantable volume distribution within the 100 TPA was 87 percent sawtimber, 8.5 percent chip-n-saw, and 3.5 percent pulpwood. The 300 TPA breakdown was 56, 30, and 8 percent for sawtimber, chip-n-saw, and pulpwood, respectively.

At age 29, the initial thinning treatments were thinned so that stocking averaged 50, 54, and 49 TPA for the 100, 200, and 300 TPA. There were no detectable volume growth differences among age 11 treatments between age 29 and 34. Periodic annual increment averaged 60, 80, and 64 ft^3/acre for 100, 200 and 300 TPA for the growing period. Total merchantable volume yields through age 34 were 4,220, 4,340, and 4,700 ft^3/acre (Tables 1 and 2). The second thinning removed the smaller trees from the 200 and 300 TPA treatments; the product distribution for these treatments became predominantly sawtimber. Thus, sawtimber distribution averaged 89.5, 84.5 and 82.5 percent for the 100, 200, and 300 TPA treatments.

Age 29 Treatments

Table 3 depicts the characteristics for each thinning treatment applied at age 29. Treatment data prior to thinning reflect growth influences of the age 11 treatments. Residual stand attributes following thinning were inversely related to age 11 stocking levels. All attributes of the 100 TPA treatment thinned to 25, 50, or 75 TPA were greater than the corresponding age 29 stocking levels applied to the 200, and 300 TPA treatments (Table 3). Harvest volumes (Table 4) were directly related to the age 11 treatments for each age 29 stocking level. Harvest volumes ranged from 640 ft^3/acre for the 100 TPA thinned to 75 TPA (Treatment 3) to 3,760 ft^3/acre for 300 TPA thinned to 25 TPA (Treatment 7). Sawtimber distribution for the two volume extremes was 86 and 56 percent, respectively, but treatment 7 yielded 4 times more sawtimber than treatment 3 (Table 4).

Treatment diameter and height growth did not vary significantly at the 5% level during the five year growth period (Table 3). Diameter growth for all treatments averaged 0.9 inches and ranged between 0.5 inches for treatment 3 and 1.3 inches for treatment 4. Mean height growth was 3.8 ft ranging between 2.6 and 4.4 ft. The highest mortality rate was 5.4 percent and occurred on treatment 3.

There were no detectable volume growth differences among the age 29 thinning treatments. Individual mean comparisons within each age 11 x age 29 interaction group i.e., 100 TPA x 25, 50, and 75 (Treatments 1,2, and 3), 200 TPA x 25, 50,

Table 3. Stand attributes by Age 29 treatments

Treat-ment	Stock-ing	Dia-meter	Basal Area	Height	Volume
	TPA	In	Ft^2/ acre	Ft	Ft^3/ acre
			Age 29		
1	93	14.3	112.6	75.7	3,230
2	94	14.6	112.3	72.7	3,090
3	93	14.7	112.5	75.1	3,200
4	179	11.4	133.9	72.4	3,660
5	163	11.4	118.7	72.0	3,220
6	189	11.7	146.3	75.9	4,210
7	277	10.3	166.5	71.5	4,500
8	275	9.3	134.9	66.8	3,570
9	274	10.9	184.5	74.0	5,230
			Age 29 Residual		
1	30	15.6	39.9	78.7	1,190
2	46	15.1	57.6	73.9	1,610
3	73	14.8	89.5	75.6	2,560
4	27	13.1	26.2	76.1	750
5	55	12.6	48.2	75.3	1,360
6	80	12.6	70.4	79.1	2,100
7	29	12.6	25.7	77.3	740
8	47	11.8	31.1	74.2	1,020
9	71	12.3	60.1	79.7	1,800
			Age 34		
1	30	16.6	45.1	81.9	1,400
2	46	15.9	64.3	78.1	1,900
3	69	15.3	91.0	79.6	2,770
4	27	14.4	31.0	80.4	940
5	53	13.4	52.9	79.7	1,590
6	78	13.6	79.8	83.5	2,520
7	27	13.5	27.6	81.0	840
8	45	13.0	42.5	77.9	1,250
9	71	13.2	68.6	82.3	2,150

Table 4. Cut volumes by Age 29 treatments

Treatment	Total Volume	Pulpwood Volume	Sawtimber Volume
		Ft^3/Acre	
		Age 29	
1	2,040	280	1,760
2	1,470	220	1,250
3	640	90	550
4	2,910	880	2,030
5	1,800	640	1,210
6	2,100	650	1,450
7	3,760	1,670	2,090
8	2,550	1,540	1,010
9	3,420	1,310	2,110

and 75 (Treatments 4, 5, and 6), and 300 TPA x 25, 50, and 75 (Treatments 7, 8, and 9), were tested for growth differences at the 5% level. Growth within the 100 TPA group was nonsignificant averaging 210, 290, and 210 ft^3/acre for the 25, 50 and 75 TPA. Siginificant growth differences were detected among the age 29 treatments within the 200 and 300 TPA groups (Table 3). The 75 TPA treatments of both groups yielded significantly more volume than the 25 and 50 TPA treatments, 420 and 340 ft^3/acre for the 200 and 300 TPA, respectively. Failure of the age 29 residual stands to fully utilize available growing space decreased the periodic annual growth increment well below pre-thinning age 29 increment. Growth during the last five years was related inversely to the age 11 treatments and directly to the age 29 treatments. The exception was treatment 3, the least severely thinned stand. The 5-year merchantable volume yield for treatment 3 was 210 ft^3/acre, while the other 75 TPA stands, treatments 6 and 9, yielded 425 and 342 ft^3/acre, respectively (Table 3). In addition, the treatment 3 yield was the third lowest among all nine treatments.

Financial Aspects of Thinning

Biological conditions play a major role in determing the harvesting practices to be utilized in a loblolly pine plantation. The choice between an additional intermediate harvest and a final harvest should be attentuated by the financial requirements of the landowner. Income requirements, market conditions, taxes, and any number of intangible factors could influence harvesting methods. The stocking reduction applied at age 29 was designed to provide a range of timber capital values.

An attempt to assess the financial ramifications of intermediate harvests on 29-year-old loblolly pine plantations is at best an endless task. The purpose of the financial data presented is to show that pine plantations can be more than a source of fiber to service the needs of a mill. They are, to many nonindustrial landowners, an investment just as gold or silver. Pine plantations are unique because they can be nurtured to optimum financial maturity with judicious thinnings that produce intermediate income.

Tables 5 to 8 present standing and cut volumes and values for the age 11 and age 29 treatments. Product volumes at all age classes were computed from cubic-foot volumes in Tables 1 to 4 by using conversion factors published by Williams and Hopkins (1968). Product value determinations for northwest Louisiana were made as follows:

1. Pulpwood 1960: $4.50/cord
   Source: Actual stumpage paid during the age 11 thinning;

Table 5. Standing product volumes and values by Age 11 treatments

Treat-ment	Pulpwood Volume	Pulpwood Value	Sawtimber Volume	Sawtimber Value
	cords /acre	dollars /acre	Bd.Ft. /acre Doyle	dollars /acre
	Age 11			
100	3.5	15.75		
200	3.8	17.10		
300	5.8	26.10		
	Age 29			
100	1.8	14.58	6,570	1,103.76
200	2.2	17.82	3,890	653.52
300	2.2	17.82	3,130	525.84
	Age 34			
100	1.8	30.74	7,830	1,342.06
200	2.2	37.57	5,290	906.71
300	2.1	35.87	4,240	726.74

2. Pulpwood 1978: $8.10/cord and
   Sawtimber: $168.00/MBF Doyle
   Source: Louisiana Forest Products, Quarterly Market Report No. 3, Nov. 30, 1978;

3. Pulpwood 1983: $17.08/cord and
   Sawtimber: $171.40/MBF Doyle
   Source: Louisiana Forest Products, Quarterly Market Report 2nd Quarter, Aug. 1983.

Age 11 Treatments

Tables 5 and 6 depict the standing and cut product and value data related to the age 11 treatments. Standing product volumes and values differed by treatment (Table 5). Residual pulpwood volumes and were similar, while sawtimber data showed that the 100 TPA volume and value were twice the 200 and 300 TPA treatments. Thinning income from the 300 TPA at age 29 exceeded the 100 TPA by $172.00 and the 200 TPA by $110.00. Most of the value difference was due to the large pulpwood volume removed from the 300 TPA (Table 6). Stand value at age 29 totaled $1,928.15, $1,563,90, and $1,540.17/acre for 100, 200, and 300 TPA treatments, resulting in an average annual return of $67.86, $53.92, and $53.10, respectively.

There was no detectable product volume increase among treatments between age 29 and 34. Individual tree size had no apparent influence on per acre sawtimber growth. Table 5 shows that sawtimber growth averaged 1,200, 1,400 and 1,100

Table 6. Cut product volumes and values by Age 11 treatments.

Treat-ment	Pulpwood Volume	Pulpwood Value	Sawtimber Volume	Sawtimber Value
	cords /acre	dollars /acre	Bd.Ft. /acre Doyle	dollars /acre
	Age 11			
100	10.1	47.25		
200	6.7	30.15		
300	5.1	22.95		
	Age 29			
100	1.6	12.96	4,700	789.60
200	6.5	52.65	4,820	809.76
300	14.0	113.40	5,120	860.16

1,100 bd.ft./acre for 100, 200, and 300 TPA treatments. Value increases, which reflect growth and stumpage price, for the respective treatments were $276.66, $300.27, and $246.28. The average annual increase was $55.33, $60.05, and $49.26 per acre for 100, 200, and 300 TPA, while the annual rate of return on the residual timber capital was 4.9, 8.9, and 9.0 percent.

Age 29 Treatments

Standing product volumes and values prior to thinning for each age 29 treatments were related to age 11 treatments. Pulpwood volumes and values were related directly and sawtimber inversely. Through age 29 the average annual value increase ranged from $37.59 to $72.90 (Table 7 and 8). Although site quality had an effect on some individual treatment results, the residual stand volumes and values of the 100 TPA treatment plots thinned to 25, 50, or 75 TPA were greater than the similar stocking rates at 200 or 300 TPA (Table 7). Type and volume of product varied in relation to the age 11 treatment (Table 8). Except for the 75 TPA stocking level, values removed to obtain the prescribed age 29 stocking levels were comparable.

Stand data at age 34 (Table 7) show that highest volume and value yields occurred on treatments 2, 6, and 9. Value increase on these treatments totaled $288.87, $380.33, and $292.58 for 2, 6, and 9. The respective annual rates of return on the residual timber capital were 5.8, 7.3, and 6.7 percent. Treatments 4, 5, and 8, which had age 29 timber capital values of $375.84, $638.25, and $355.62, produced the optimum rates of return 9.8, 8.3, and 10.9 percent.

Table 7. Standing product volumes and values by Age 29 treatments.

Treat-ment	Pulpwood Volume	Pulpwood Value	Sawtimber Volume	Sawtimber Value
	cords /acre	dollars /acre	Bd.Ft. /acre Doyle	dollars /acre
	Age 29			
1	1.6	12.96	4,380	748.80
2	2.4	19.44	5,710	978.72
3	3.9	31.59	9,280	1,590.63
4	1.6	12.96	2,160	375.84
5	3.3	26.73	3,640	638.25
6	5.0	40.50	5,710	999.78
7	1.8	14.58	2,030	355.62
8	3.1	25.11	2,490	443.43
9	4.8	38.88	4,750	836.88
	Age 34			
1	1.6	27.33	5,550	978.60
2	1.5	25.62	7,210	1,261.41
3	3.1	52.09	10,470	1,794.56
4	1.6	27.33	3,060	551.51
5	3.3	56.36	4,830	884.23
6	5.0	85.40	7,790	1,335.21
7	1.7	29.04	2,540	464.39
8	2.7	46.12	3,650	671.73
9	4.7	80.29	6,350	1,088.05

CONCLUSIONS

Biological and economic criteria can be utilized to determine harvest methods for 29-year-old loblolly pine plantations growing at different stocking levels. In this study, optimum merchantable growth and net value were obtained where:

1. Residual stand average diameter exceeded 12.6 inches;
2. Residual stand basal area ranged between 60 and 70 ft^2/acre;
3. Residual stand merchantable volume ranged between 1,600 and 2,100 ft^3/acre; and
4. Residual stand value ranged between $875.00 and $1,040/acre.

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Table 8. Cut product volumes and values by Age 29 treatments.

Treat-ment	Pulpwood Volume	Pulpwood Value	Sawtimber Volume	Sawtimber Value
	cords /acre	dollars /acre	Bd.Ft. /acre Doyle	dollars /acre
	Age 29			
1	3.5	28.35	6,960	1,169.28
2	2.7	21.87	4,950	831.60
3	1.1	8.91	2,180	366.24
4	11.1	89.91	6,360	1,068.48
5	8.0	64.80	3,540	594.72
6	8.1	65.61	4,550	764.40
7	20.9	169.29	6,010	1,009.68
8	19.3	156.33	2,770	465.36
9	16.4	132.84	6,580	1,105.44

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EFFECTS OF DIFFERENT THINNING REGIMES ON GROWTH AND INVENTORY OF 50-YEAR-OLD LOBLOLLY-SHORTLEAF PINE STANDS[1]

Paul A. Murphy[2]
and
Robert M. Farrar, Jr.[2]

Abstract.--A study was begun in 1949 to determine the effect of different thinning regimes on the growth and development of natural, even-aged loblolly-shortleaf pine (*Pinus taeda* L.--*P. echinata* Mill.) stands in the West Gulf Coastal Plain. When these stands were 50 years old (in 1979), the growth from ages 45 to 50 and the standing inventories at age 50 were measured and analyzed. Greater basal area growth tended to be associated with higher initial densities, and volume growth was less for the more radical treatments--thinning from below to 70 square feet of less or basal area. Standing volumes at age 50 varied by treatment--but were less for thin-from-above plots when compared to thin-from-below plots of the treatment that allowed for an increase in residual basal area with each thinning.

INTRODUCTION

Beginning in the 1930's, the development of well-stocked, natural, second-growth pine stands in the West Gulf region was encouraged by organized fire protection, the adoption of cutting practices that provided for leaving a seed source, and improved low-grade hardwood control techniques. With an increasing interest in managing these young, well-stocked stands, a study was established during 1949 in south Arkansas and north Louisiana to investigate the effect of type and intensity of thinning on the growth and yield of young, even-aged loblolly-shortleaf pine (*Pinus taeda* L.--*P. echinata* Mill.) stands. This paper reports on that study, concentrating on the last remeasurement, when the stands were 50 years old.

STUDY DESCRIPTION

The purpose of the study was to determine how well-stocked, natural loblolly-shortleaf pine stands grow and develop when cut under different thinning regimes, some with changes at 5-year intervals. The treatments are based on the stand basal area of loblolly and shortleaf pines 3.6 inches d.b.h. and larger. The thinning treatments are described in table 1.

When the study was originally designed in 1949, nine treatents were to be established with three replications. Installation was to be on good sites, with a nominal site index range from 85 to 90 feet (loblolly pine, base age 50). A duplicate installation was to be done on medium sites, with a nominal site index range from 75 to 80 feet. No specific experimental design was mentioned in early study reports. It could be interpreted as a two-factor design, with site and thinning regime as the variables, or as two completely randomized designs to be analyzed separately. Three supplemental treatments were installed 5 years after the initial study was begun. These additional plots were set up on good sites and were also replicated three times. Table 1 lists all 12 thinning treatments. All the site index values are for loblolly pine at base age 50 (U.S. Department of Agriculture, Forest Service 1976).

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2] Principal Mensurationists, Forestry Sciences Laboratory, Monticello, AR, Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Department of Forest Resources and Arkansas Agricultural Experiment Station, University of Arkansas at Monticello.

Table 1.--Description of thinning treatments; all thinning done at 5-year intervals

Treatment	Age at initial thinning	Residual basal area	Type of thinning[1/]
	—years—	—ft^2/acre—	
55-B	25	55	B
70-A	20	70	A
70-B	20	70	B
85-A	20	85	A
85-B	20	85	B
100-A	20	100	A
100-B	20	100	B
115-B	25	115	B
130-B	25	130	B
INC-A	20	2/	A
INC-B	20	2/	B
J-J	20	3/	4/

1/ A = thinned from above
B = thinned from below

2/ The initial residual basal area at age 20 was 70 square feet per acre; it was increased 5 square feet per acre at each thinning until the residual basal area reached 105 square feet per acre.

3/ Thinning treatment determined every 5 years by collective judgment of field personnel.

4/ Mostly thinning from below with some thinning from above.

The good-site plots were located in Ashley County, Arkansas, the medium-sites plots, in Morehouse Parish, Louisiana. The Ashley County plots were located on nearly level uplands, where the site index averaged 90 feet. The Louisiana plots were on broad, low islandlike ridges in the Ouachita River floodplain, where the site index averaged 73 feet. Installation was done in the winter of 1949-50. The supplemental treatments were set up on plots in 25-year-old stands on good sites located in Ashley County, with a site index that averaged 93 feet. None were installed on medium sites.

The plots were circular, 0.1 acre in size, and surrounded by 33-foot isolation strips. All the Arkansas plots were installed in stands that had seeded-in after a 12-inch diameter-limit cut of the virgin timber conducted from 1927 to 1930. The Louisiana plots were in stands that originated from a 1929 seed crop; wildfires had ravaged the area for 10 years after the virgin timber had been cut to a 14-inch diameter limit in about 1918. Both areas were well stocked and had not been cut since the virgin timber harvests. Old residual pines and hardwoods were avoided when the plots were installed. Burton (1980) presents further details on the stands.

Thinning from below favored dominants while removing competing trees in the lower crown classes; occasionally, rough dominants were cut and codominants left instead. Thinning from above favored codominants and occasional intermediates by removing dominants. The judgment treatment (J-J, table 1) was mostly from below, but occasionally from above. Other things being equal, loblolly was favored by removing shortleaf pine. Fifteen crop trees were selected on each plot--these trees were chosen to become sawtimber and are cut in the latter stages of a rotation. On thin-from-below plots, dominants were selected for crop trees; on thin-from-above plots, codominants were usually chosen. Thinning was done to promote the growth of the crop trees while maintaining relatively uniform spacing.

All hardwoods 3.6 inches d.b.h. and larger were cut when the study was installed; smaller ones were killed with chemicals. In 1959, 10 years later, all hardwoods with a groundline diameter of 1.0 inches and larger were injected. Subsequent hardwood treatments consisted of cutting any hardwoods with a 1-inch groundline diameter or larger during each thinning.

A violent windstorm in 1970 destroyed one plot in the 85-B treatment on the good-site location.

ANALYSIS

A comprehensive analysis of the study through age 45 was done by Burton (1980). The present analysis concentrates on the periodic annual growth in basal area and volume from ages 45 to 50 and the standing inventory at age 50.

The same merchantability standards used by Burton (1980) are followed in this analysis. Basal area is in terms of square feet per acre for loblolly and shortleaf pines 3.6 inches d.b.h. and larger. Merchantable cubic-foot volume per acre is the solid wood content of loblolly and shortleaf pine trees 3.6 inches d.b.h. and larger from a 1-foot stump to a 3-inch merchantable top, inside bark. Sawtimber cubic-foot volume is the volume of loblolly and shortleaf pine trees 9.6 inches d.b.h. and larger from a 1-foot stump to an 8-inch top, outside bark, provided that the merchantable log length is at least 16 feet. Merchantable length is to the nearest 2 feet. Merchantability standards for board-foot volumes (Doyle, Scribner, and International 1/4-inch rules) are the same as for sawtimber cubic-foot volume.

The previous analysis (Burton 1980) calculated volumes from published tables (Mesavage and Girard 1946, Mesavage 1947). The present paper uses taper equations (Farrar and Murphy, in preparation) to calculate volumes. Therefore, the results are not comparable in the strictest sense. The stand variables studied were periodic annual growth or production, from ages 45 to 50, and standing inventories at age 50. Periodic annual growth or production is the difference

between the before-cut inventory at age 50 and the after-cut inventory at age 45, less any interim mortality, divided by 5 years. The standing inventory refers to the before-cut volume or basal area at age 50. Growth and standing inventory in terms of merchantable basal area, sawtimber basal area, merchantable cubic-foot volume, sawtimber cubic-foot volume, and board-foot volumes for the Doyle, Scribner, and International 1/4-inch log rules were all analyzed.

The data could have been analyzed in two different ways. One would have been to analyze the remaining 53 original plots and the 9 supplemental plots in three different analyses as done by Burton (1980), the other, to analyze the combined data as a completely randomized design in an analysis of covariance using site index as the covariate. Since analysis of the combined data was of paramount interest, analysis of covariance was used.

A direct estimate of site index was available for the plots once they attained 50 years, the standard index age for natural, even-aged southern pine stands. Using average height of the dominants and codominants at age 50 was complicated by some of the thinning treatments that involved thinning from above for the first two intermediate cuts. However, the thinnings from subsequent cuts were always from below, and the possible bias from these early thinnings may not be significant. To determine whether or not any bias was present, the site index determined at age 20 before treatment was subtracted from the average height of the dominants and codominants at age 50. If a bias is present, it should manifest itself in larger differences for the thin-from-above plots versus the thin-from-below plots. An analysis of variance was performed. Although a 2-foot difference occurred between the two types of thinning, it was not significant at the 5-percent level, and the heights at age 50 were used as the covariate.

More detailed multiple comparisons were made using Scheffe's procedure (Huitema 1980) when overall differences were detected at the 5-percent level of significance. A comparison of thinning from above versus thinning from below was made by contrasting treatments 70-A, 85-A, 100-A, and INC-A with treatments 70-B, 85-B, 100-B, and INC-B. Analysis of the thin-from-below and judgment treatments were made by comparing the 50-B, 70-B, 85-B, 100-B, 115-B, 130-B, INC-B, and J-J treatments. These comparisons were made only for the thin-from-below and judgment plots: thin-from-above is not the usual practice and was not compared. Comparisons were made using the adjusted or least-squares means, also at the 5-percent significance level.

RESULTS

Basal Area Growth

There were significant differences in treatments for merchantable basal area growth. The covariate site index was also significant with a negative coefficient, probably due to suppression mortality on high site index plots. No differences were detected when comparing thinning from above to thinning from below.

Growth from the thinning from below and judgment treatments ranged from 2.4 square feet per acre per year for the 70-B treatment to 3.5 square feet for the 130-B treatment (table 2). The comparisons for the thin-from-below and judgment plots are shown in table 2. The reader should remember that these comparisons in the table do not involve the thin-from-above treatments and that the growth figures are adjusted by the covariate. In general terms, merchantable basal area growth increases with increasing basal area with some exceptions. A significant difference was not detected for sawtimber basal area growth.

Cubic Volume Growth

Merchantable cubic-foot volume growth varied significantly among treatments. A comparison of thinning from above versus thinning from below for the 70, 85, 100, and increasing basal area treatments indicated a significant difference. Growth was less on the treatments thinned from below. This contrast was significant only for merchantable cubic-foot volume growth. Comparisons for merchantable cubic-foot volume growth for judgment and thin-from-below treatments are given in table 2 under the column labeled MCF. In general, the heavily thinned plots produced less growth for the period. No clear-cut trends B, 100-B, 115-B, 130-B, and INC-B treatments all have higher growth rates than the 55-B and 70-B ones (table 3).

Sawtimber cubic-foot volume growth differences were also significant. The contrast of thinning from above versus thinning from below revealed no significant differences. Comparisons of the thin-from-below and the judgment treatments are shown in table 3, column SCF. The most heavily thinned plots produced less growth than the more lightly thinned ones for these treatments.

Board-Foot Volume Growth

Board-foot volume growth measured by the Doyle rule did not vary significantly among the treatments. Doyle growth averaged 735 board feet per acre per year, based on adjusted means (table 3).

Table 2.--Adjusted means for periodic annual basal area growth per acre for loblolly-shortleaf pine plots, age 45 to 50, by treatment

Treatments	Merchantable basal area[1/]	Sawtimber basal area
	----------ft^2----------	
55-B	2.5ab	2.3
70-A	2.5	2.5
70-B	2.4a	2.4
85-A	3.2	3.0
85-B	3.1bcde	3.0
100-A	3.2	3.1
100-B	2.9abcd	2.9
115-B	3.1bcde	3.0
130-B	3.5e	3.2
INC-A	3.4	2.9
INC-B	3.1bcde	3.1
J-J	2.6abc	2.6

[1/] Adjusted treatment means followed by the same letter are not significantly different at the 5-percent level.

Board-foot growth as measured by the Scribner rule was significant for the period. Comparisons for the thin-from-below and judgment treatments are in table 3 under the column labeled BFS. Adjusted periodic growth ranged from 617 board feet for the 55-B treatment to 994 board feet for the INC-B treatment (table 3, column BFS) for these comparisons; board-foot growth was lowest for the heavily thinned plots. No significant difference was detected for the above versus below thinning contrast.

The results for the International 1/4-inch rule were somewhat similar to those for sawtimber cubic-foot and Scribner board-foot growth. There was an overall significance, and comparisons for the thinning-from-below and judgment treatments are given in table 3 under the column labeled BFI. Growth ranged from 673 to 1,102 board feet on an adjusted basis for the lowest and highest treatments (table 3). No differences were detected for thin-from-above versus thin-from-below.

Standing Inventory

An analysis of covariance was also performed for the standing inventories. However, the within-group regression slopes were not homogeneous, indicating a treatment-slope interaction. The analysis of covariance was abandoned in favor of a two-factor analysis of variance

Table 3.--Adjusted means for periodic annual volume growth per acre for loblolly-shortleaf pine plots, age 45 to 50, by treatment.

Treatment	Variable[1,2/]				
	MCF	SCF	BFD	BFS	BFI
	-----ft^3------		----------fbm----------		
55-B	101a	102a	536	617a	673a
70-A	124	131	682	809	888
70-B	112a	116ab	616	722ab	783ab
85-A	165	165	819	1,014	1,114
85-B	152bc	163c	782	980c	1,088c
100-A	173	180	842	1,081	1,206
100-B	150bc	164c	735	966c	1,089c
115-B	146bc	150bc	723	903bc	997bc
130-B	162c	163c	752	960bc	1,077c
INC-A	169	160	767	972	1,074
INC-B	154bc	165bc	788	994c	1,102c
J-J	130ab	136abc	693	841abc	921abc

[1/] MCF = merchantable cubic feet
SCF = sawtimber cubic feet
BFD = board feet, Doyle rule
BFS = board feet, Scribner rule
BFI = Board feet, International 1/4-inch rule

[2/] Adjusted treatment means followed by the same letter are not significantly different at the 5-percent level.

with thinning regime and site as the variables. The supplemental plots were excluded because they were found only on the good-site area. Separate analyses of merchantable and sawtimber basal areas, merchantable and sawtimber cubic-foot volumes, and board-foot volumes for the Doyle, Scribner, and International 1/4-inch rules at age 50 were done. Both site and treatment were significant at the 5-percent level, but the site-treatment interaction was not.

Pairwise contrasts were also made of above versus below thinning for the 70, 85, 100, and INC treatments. No comparisons were made for different basal area levels, because basal areas and volumes at age 50 are functionally related to residual basal area at age 45. No significant differences in contrasts were found for merchantable basal area and merchantable cubic-foot volumes. But the contrasts between INC-A and INC-B were significant for sawtimber basal area and sawtimber cubic- and board-foot volumes. The average basal area in sawtimber for the INC-A treatment was 92.3 square feet versus 110.7 square feet for INC-B (table 4). It is not suprising that the sawtimber volume contrasts are also significant. For example, the sawtimber inventory as measured by the Doyle rule was 10,123 board feet for the INC-A treatment versus 13,846 for the INC-B treatment (table 5). A possible reason for the difference in sawtimber basal area and volumes is that the first two thinnings in the INC-A treatment reduced the ratio of sawtimber to merchantable basal area. Increasing the ratio by later thinning was constrained by a combination of increases in residual basal area dictated by the treatment and a decline in basal area growth with age.

Table 4.--Treatment means for merchantable and sawtimber basal areas per acre for loblolly-shortleaf pine plots, age 50.

Treatment	Variable: Merchantable basal area	Sawtimber basal area
	ft^2	
INC-A	110.6	92.3
INC-B	110.7	110.7
J-J	86.6	86.6
100-A	112.1	106.2
100-B	107.1	107.1
70-A	84.3	82.5
70-B	83.5	82.6
85-A	100.0	91.7
85-B	101.1	98.8

CONCLUSION

This analysis was limited to basal area and volume growth for ages 45 to 50 and the standing inventories at age 50. Extension of these results to other ages should be done with caution. It appears that heavy thinning that leaves 55 or 70 square feet adversely affects both periodic basal area and volume growth at ages 45 to 50. However, few differences were apparent in the lighter thinning treatments. Thinning from above versus thinning from below affected only merchantable cubic-foot growth. There were overall differences for all variables except sawtimber basal area growth and board-foot growth using the Doyle rule.

There were overall differences in the standing inventories at age 50. The sawtimber inventory for both basal area and volume was significantly less for the INC-A versus the INC-B treatment.

Table 5.--Treatment means for cubic- and board-foot standing volumes per acre for loblolly-shortleaf pine plots, age 50.

Treatment	Variable: Merchantable volume	Sawtimber volume	Doyle rule	Scribner rule	Int. 1/4-inch rule
	ft^3		fbm		
INC-A	3,736	2,855	10,123	15,135	17,627
INC-B	4,001	3,669	13,846	19,885	22,945
J-J	3,144	2,938	11,754	16,237	18,529
100-A	3,975	3,415	12,451	18,303	21,244
100-B	3,784	3,348	11,671	17,648	20,661
70-A	2,935	2,655	10,832	14,682	16,705
70-B	2,933	2,716	11,007	15,026	17,090
85-A	3,484	2,993	11,432	16,262	18,691
85-B	3,625	3,269	12,684	17,864	20,508

Selection of a thinning regime should take into account growth throughout a whole rotation and not just one growth period or the final standing volume. This point is especially important for board-foot volume growth, since many thinning techniques tend to accelerate sawtimber production rather than raise the total production during the rotation. Future analyses will consider these aspects of growth and yield.

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CLONAL RESISTANCE TO AND INCIDENCE OF THE POPLAR BORER IN SOUTHERN COTTONWOOD PLANTATIONS 1/

T. E. Nebeker,2/ J. J. Schmitt,2/ J. D. Solomon,3/ and C. R. Honea2/

Abstract. Considerable experimentation has been undertaken to understand how the genetic superiority of fast growing clones of Populus deltoides Bartr. can be exploited through breeding and selection. As the selection process continues for clones with desirable characteristics, such as growth and survival, the impact from insects must be considered as well. Of 4,388 trees examined in ten clonal plantations, 19.5% were observed to have been attacked by the poplar borer. Higher infestation rates were observed in older cottonwood settings. Interestingly, the genetic material from Issaquena County, Mississippi had the lowest infestation rate in comparison to other geographic sources. This suggests the possibility of a geographic difference which may be taken into consideration when selecting clonal material for propagation.

INTRODUCTION

Eastern cottonwood (Populus deltoides Bartr.) has received considerable attention in the recent past as a commercial species. Rapid growth rate, ease of vegetative propagation, dioecism, and early attainment of sexual maturity are properties that have lent this species to several breeding programs for developing genetically superior clones. In conjunction with these programs is the concern of mortality and degrade due to insects and diseases. Of 10 major pests of cottonwood described by Morris et al. (1975), the poplar borer, Saperda calcarata Say (Coleoptera: Cerambycidae) is one of the more abundant species attacking the trunks of cottonwood in the lower Mississippi Valley. In Canada and the Great Lakes states, its hosts also include quaking aspen (P. tremuloides Michx.), bigtooth aspen (P. grandidentata Michx.) (Peterson 1947, Graham and Harrison 1954, and Ewan 1960) and balsam poplar (P. balsamifera L.) (Drouin and Wong 1975).

Adults of the poplar borer emerge in early summer and begin feeding on young twigs, petioles and foliage of various poplars and willows. After mating, eggs are laid in niches constructed by the female on the main stem. Usually there are 2 eggs per niche with the possibility of several niches being joined. After 2-3 weeks, eggs hatch and the larvae begin feeding on the sapwood. Active borer attacks are characteristically marked by a wet ooze and fine, fibrous frass that is extracted by the larvae as they feed. Maturing larvae begin to tunnel directly into the heartwood and upon reaching the main axis turn vertically upward in the stem. The poplar borer passes through 5 instars and pupates near the end of the tunnel or gallery. The life cycle duration is 2-4 years in the Lake States region, but is probably shorter in the South.

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2/ Professor and Research Associates, respectively, Department of Entomology, Drawer EM, Mississippi State University , Mississippi State, MS 39762

3/ Principal Entomologist, Southern Hardwoods Laboratory, U. S. Forest Service, Stoneville, MS 38776

The poplar borer usually attacks cottonwood 3 years and older (Abrahamson and Newsome 1972). The rough, thickened bark of large quaking aspen tends to be less suitable (Ewan 1960) for oviposition. The larvae, when boring, provide infection courts for Hypoxylon pruinatum (Klotsche) Cke., a highly parasitic fungus (Graham and Harrison 1954). Clusters of larvae tunneling close together may riddle portions of the trunk. These heavy infestations, which may also be accompanied by woodpecker attack and/or fungal decomposition, structurally weaken the trees, making them more susceptible to wind breakage.

Most of the research regarding the poplar borer has been conducted in Canada and the Great Lakes states. Our objectives were to evaluate older cottonwood plantations for impact and potential clonal resistance to the poplar borer.

METHODS AND MATERIALS

Evaluation of cottonwood clones for the presence of the poplar borer took place in ten experimental areas (ranging in age from 6-16 years and maintained by U.S. Forest Service personnel and by cooperating forest industries) (Fig. 1). Five studies identified by the U.S. Forest Service as the 80 Clone, Storage, Advanced Cottonwood Clonal, Provenance, and Full Sib-Genetics, located near Stoneville, Mississippi, were surveyed in the winter of 1981-82. Three areas identified as New Clearing, Old Site I and Old Site II located near Krotz Springs, Louisiana plus 2 studies, Hooker's Ridge and Fox Creek near Vicksburg, Mississippi, were surveyed in the winter of 1982-83. All study areas had been thinned manually and all residual trees (dead or alive) were observed to determine poplar borer infestation levels. Data collected included tree number, clone number, diameter of infested trees, borer activity (active or inactive), height of activity, and cardinal direction of activity (0-360°).

RESULTS AND DISCUSSION

In total 19.5% of the trees surveyed were under attack or had been attacked (Table 1). The lowest infestation rates occurred in the 6-7 year old studies (2-6%), with higher infestation rates being observed in the older studies. Fox Creek, an excellent site for cottonwood (Cooper, personal communication) had only a 3.9% infestation rate. The infestation rates observed in the various studies were much higher than expected (i.e. 45% in a 13 year old plantation) and suggests that management of cottonwood plantations should consider possible control tactics to reduce the impact of the poplar borer in these settings.

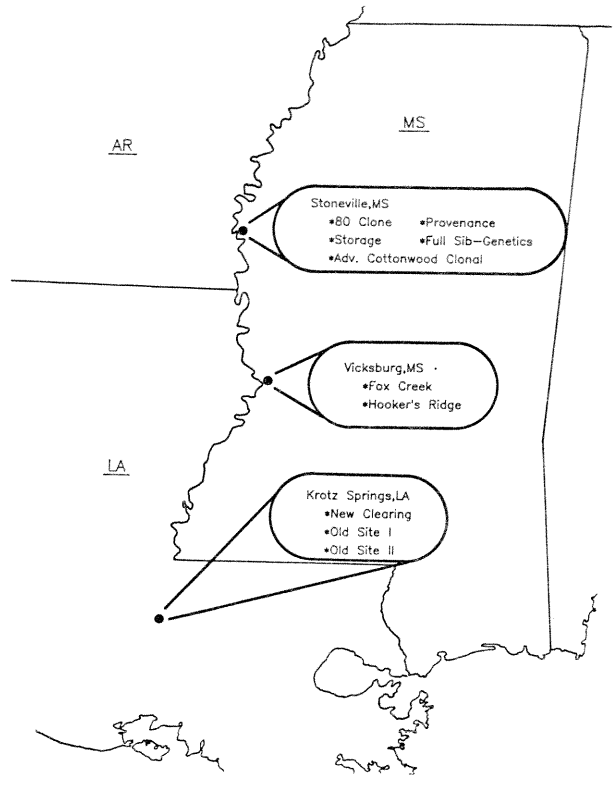

Figure 1. Locations of cottonwood plantations and related studies.

Of the 858 infested trees surveyed, 310 (36%) were dead. One hundred ninety-eight trees (23%) possessed multiple attacks (more than 1 group of several larval attacks-"brood trees") of which 61 were dead. In other words only 20% of the dead, infested trees possessed multiple attacks and these attacks although probably contributing to the mortality were not necessarily the terminal factor. Brood trees are characterized by a heavy reinfestation. Peterson (1947) and Drouin and Wong (1975) reasoned that this was due to high numbers of emerging females that were unable to fly due to malformed wings. The cause of this malformation was unknown. No observations regarding adult conditions were made during this study. In looking at the frequency of trees with one or more attacks the tendency was for solitary attacks. An attack is defined as 1 or several larvae boring at the same location and assumed it was the result of a single, females ovipositional activity. We observed 657 trees with a single attack, 144 with 2, 37 with 3, 14 with 4, 6 with 5 or more with more than 5 attacks per tree.

Table 1. Incidence of poplar borer, Saperda calcarata Say, in ten clonal cottonwood plantations.

Study	Infested Trees				Total Unifested	Total Trees	% Infestation
	Active	Non-Active	Active and Non-Active	Total			
80 Clone (16 yr. old)	23	30	5	58	212	270	21.5
Storage (16 yr. old)	3	10	3	16	67	83	19.3
Advanced Cotton-wood Clonal (6 yr. old)	28	10	3	41	674	715	5.7
Provenance (14 yr. old)	58	100	12	170	333	503	33.8
Full Sib-Genetics (10 yr. old)	97	168	10	275	717	992	27.7
New Clearing (13 yr. old)	12	42	2	56	252	308	18.2
Old Site I (13 yr. old)	14	133	8	155	189	344	45.1
Old Site II (13 yr. old)	15	46	6	67	206	273	24.5
Hooker's Ridge (7 yr. old)	5	8	-	13	708	721	1.8
Fox Creek (11 yr. old)	-	7	-	7	172	179	3.9
TOTAL	255	554	49	858	3,530	4,388	19.5

The mean height and cardinal direction of attack was 2.3 ± 0.05m and 189.6°, respectively. Overall, a skewed distribution to the lower portion of the bole was observed. In younger plantations the mean height was lower than in older plantations. Utilizing the mean infestation height and age of the study, a positive linear relationship was observed. A slight preference exists for the south and west aspects. Peterson (1947) suggested a potential preference to more heat intensive portions of quaking aspen in Canada, but this may not be as critical in the South. Since cardinal direction was recorded from 0-360° in a normal distribution a random attack pattern would result in a mean of 180°.

Infestation rates of clonal material propagated commercially and present in these experimental areas are presented in Tables 2 and 3. The 0% infestation rates (Table 2) may be misleading since overall infestation rates were lowest in the younger material and does not necessarily suggest resistance to the poplar borer. Of all Stoneville clones in the older plantations, St 240 had the highest infestation rate while St 244 had the lowest of the release clonal material present.

Table 2. Incidence of the poplar borer, Saperda calcarata Say, in released clones in 6-7 year old plantations.

Clone	Infested Trees				Total Uninfested	Total Trees	% Infestation
	Active	Non-Active	Active and Non-Active	Total			
St 66	-	-	-	-	20	20	0.0
67	-	-	-	-	18	18	0.0
74	-	-	-	-	18	18	0.0
92	1	1	-	2	17	19	10.5
109	-	-	-	-	19	19	0.0
148	-	-	-	-	18	18	0.0
163	-	-	-	-	16	16	0.0
240	1	1	-	2	18	20	10.0
244	2	-	-	2	17	19	10.5
259	-	-	-	-	21	21	0.0
261	-	-	-	-	20	20	0.0
TOTAL	4	2	0	6	202	208	2.9

Table 3. Incidence of the poplar borer, Saperda calcarata Say, in released clones in 10-16 year old plantations.

Clone	Infested Trees				Total Unifested	Total Trees	% Infestation
	Active	Non-Active	Active and Non-Active	Total			
St 66	4	8	1	13	39	52	25.0
67	3	11	-	14	25	39	36.9
74	1	9	-	10	33	43	23.2
92	1	13	1	15	22	37	40.5
109	1	10	1	12	16	28	42.9
240	6	11	2	19	18	37	51.3
244	1	2	-	3	35	28	10.7
TOTAL	17	64	5	86	188	264	28.8

Trees that are attacked by the poplar borer, especially those that have multiple attacks, i.e. brood trees, are more subject to damage (breakage) during high winds than non-infested material. We observed this in numerous plantations and especially in those plantations that had been thinned. Therefore, as part of the thinning guidelines we would suggest the removal of infested trees, especially those with multiple attacks, to decrease future poplar borer populations and wind damage.

Genetic material from Issaquena County, Mississippi had the lowest infestation rate (6.8%) in comparison to the other geographic sources available in the selected study areas which ranged from a low of 20% to a high of 40.8%. Issaquena County is the southern-most county that was represented in the study. This geographic pattern, i.e. lower infection and/or infestation rate for trees from the South was reported for cottonwood leaf beetle (Chrysomela scripta F.) (Oliveria and Cooper 1977) and melampsora rust (Melampsora medusae Thum.)(Cooper and Filer 1977) in cottonwood. Oliveria and Cooper (1977) suggested that the probable explanation for this apparent resistance is the extended growing season and somewhat more vigorous overall growth of more southerly sources.

ACKNOWLEDGEMENT

Dr. Tom Cooper provided us with a considerable amount of information concerning specific clonal identification including study area location. Lonnie Newsom and Thurman Hicks provided plot maintenance.

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THE NET RETRIEVAL SEED COLLECTION SYSTEM IN SOUTHERN REGION SEED ORCHARDS AN ECONOMIC STUDY 1/

James L. McConnell 2/
Jerry L. Edwards 2/

Abstract.--In 1983 and 1984, the Forest Service, Southern Region, collected seed in loblolly seed orchards using the net retrieval system. Collection costs vary, and the size of the crop to be collected is important economically. An analysis and comparison of costs are presented.

INTRODUCTION

Seed orchard managers have found the traditional loblolly pine cone collection method to be an overwhelming job. Orchard ramets have grown taller, intensified orchard management has increased cone production, and new generation orchards have been planted and are approaching on-line status quickly. All of these factors have made the need to improve methods of collecting seed for regeneration a high priority program.

The seed collection system described here is an extension of the original work of the Georgia Forestry Commission. The USDA Forst Service developed a system to retrieve netting placed in the orchard floor to collect seeds. Netting deployed over the entire orchard floor is retrieved after the cones have ripened and the seeds have fallen onto the net. One end of the net is attached to an aluminum core on the net retrieval machine. The machine then rolls the net onto the core. Seeds as well as straw and other debris are transferred from the net to the retrieval equipment, and from there to the seed separator (modified peanut combine) which separates the seed from the most of the unwanted material.

Use of the system extends the collection period, allows a small crew to do the entire job and eliminates tree-climbing or working out of bucket trucks or man-lifts. Because it eliminates the need for tree-climbing, use of the system creates a safer, more productive, and less labor-intensive method of cone and seed collection. Using the net retrieval seed collection system, a five-person crew can collect seeds from 40 to 60 acres of loblolly pine during an extended season.

1/ Paper presented at the Third Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8-, 1984.

2/ James L. McConnell, Regional Geneticist, Jerry L. Edwards, Mechanical Engineer, USDA Forest Service, Southern Region, 1720 Peachtree Rd., NW, Atlanta, Georgia 30367.

GENERAL

Description and Cost of Equipment

Net.--Polypropylene plastic, 16.5 feet wide, length variable, (average is 600 feet), weave count 6X8 per square inch. Cost: $316,214 (1982 price) for three orchards (350 acres). Expected life is 10 years.

Core.--Aluminum alloy 6063-T6, size 4.0 inches outside diameter. Length 17 feet 3 inches. Cost: $14,040 (1982 price). Expected life is 20 years.

Net Retrieval Equipment.--Net retrieval seed collection machine, netting transport trailer with crane, and tractor-mounted tree shaker. Cost: $144,408 (1982 price) for three orchards. Expected life is 20 years.

1983 COLLECTION

Net Collection

In 1983, 1,649 pounds of loblolly pine seeds were collected from 141 acres at three Southern Region seed orchards. Overall, 1983 was not a good seed collecton year; total production and yield were down. The seeds were collected at the following orchards: Francis Marion, South Carolina; Erambert, Mississippi; and Stuart, Louisiana.

Variable costs.--Labor, general-type equipment (vehicles, wheel tractors, etc.) $29,920.

Fixed annual costs.--

Item	Total Cost	Expected Life	Annual Amortization
Netting	$316,214	10 Years	$31,621
Cores	14,040	20 Years	702
Retrieval Equipment	144,480	20 Years	7,224
		Total	$39,547

Cost of Net Collection 1983

Category	Total Cost	$/Acre
Variable cost	$29,920	$212*
Fixed cost	39,547	280
Total	$69,467	$492

*No. of acres = 141

CONE COLLECTION

Loblolly cones collected in 1983 from the same orchards yielded 1.14 pounds of seeds per bushel of cones. The seeds collected from the netting system weighed 1,649 pounds. The equivalent number of bushels of cones required to yield the seeds obtained from the netting is 1,446 (1,649 pounds divided by 1.14 pounds per bushel = 1,446 bushels of cones). The collection of 1,446 bushels of cones obtained by contract or force account (using Forest Service workers) would have been $33 per bushel:

Collection	$30
Drying and extraction	2
Transportation to extractory	1
	$33

Cost of cone collection FY 1983 (hypothetical)

$47,718 (1,446 bushels X $33/bushel)

Comparison of Costs (cone collection versus Netting System).

$69,467 Cost of net collection
-47,718 Cost of cone collection
$21,749 Cone collection would have been more economical.

FISCAL YEAR 1984 COLLECTION

Net Collection

In Fiscal Year 1984, 4,529 pounds of loblolly pine seeds were collected from 216 acres with the netting systems from the three Forest Service seed orchards mentioned earlier. Seed production was spotty, east coast collections were light, but gulf coastal collections were good to heavy.

Variable costs.--Labor, general-type equipment (vehicles, wheel tractors, etc.)

Fixed Annual Costs.--Net retrieval equipment and materials (netting, cones, etc.) $39,547.*See Chart of FY 1983 Fixed Annual Costs.

Cost of Net Collection 1984

Category	Total Cost	$/Acre
Variable Cost	$48,575	$225*
Fixed Costs	39,547	183
Total	$88,122	408

*No. of acres = 216

CONE COLLECTION

Loblolly yield in 1984 was 1.43 pounds of seeds per bushel of cones. The netting system collected 4,529 pounds of seeds. The equivalent number of bushels of cones required for this seed yield is 3,167. This total is derived as follows:
4,529 pounds of seed divided by 1.43 bushels/pound = 3,167 bushels.

The collection of 3,167 bushels of cones obtained by contract or force account (using Forest Service workers) would have been $33/bushel or $104,511.

Collection	$30
Drying and extraction	2
Transportation to Extractory	1
Total	$33

Cost of cone collection versus netting system:

$104,511 cost of cone collection
- 88,122 cost of net collection
$ 16,389 Net collection would have been more economical.

A benefit of the net retrieval system not included in the study is the vast amount of clean pine straw that is available as a by-product. The pine straw can be used as mulch for nursery beds or sold to others for landscaping. Either use provides a sizeable benefit for the system. The orchard pine straw is of prime quality and does not contain the weed seeds and other debris normally found in pine straw bales. For this reason, our orchard managers have no problem disposing of the straw.

RESULTS AND DISCUSSION

In 1983 the per pound cost of seed collection on the net was $42.12, while cone collection was $28.93. The netting system cost $17.73 per pound more than the cost of seed obtained by collecting the cones. In 1984, the net collection cost $19.45 per pound and seed collected in cones would have cost $23.07 per pound. This produced a savings of $3.62 per pound in favor of the net seed-collection system.

The cost of the net seed-collection system is greatly affected by the volume of seed available. The larger the volume of seed on the net, the lower the cost per pound of the seed. Retrieval and quality of separation of the seed is virtually unaffected by the volume of seed. On the other hand, the volume of debris (pine straw, twigs, etc.) on the net has a measurable effect on the rate of separation.

In general, the smaller the seed and cone crop, the more the advantages are in favor of cone collections. When the crop is small, the cones can be selectively collected; however, it is nearly impossible to selectively deploy netting and still catch the seed fall.

The equipment now used for the net retrieval system is considered a first generation production prototype. Many improvements will be made to produce a more efficient and compact system. The cost of equipment may continue to rise, but probably not as fast as the cost of labor, especially the trained labor force that is required in cone collection.

The initial costs of the net retrieval system are high. Therefore this system would not be economical in young orchards or an orchard with a low production capacity. Use the following factors to decide whether to use the net system or harvest cones in a particular year.

Net Seed-Collection System

1. Number of acres of orchard under consideration.
2. Calculated production capacity of the orchard (number of bushels of cones or pounds of seeds on the acres of orchard under consideration; end product will be pounds of collectable seeds.
3. Cost of deploying and recovering the net seed collection system on the following basis: a five-person crew operates at the rate of .25 acres per crew per day. This work includes the total job of deploying the net, shaking the trees (twice) retrieving the net, processing the seed and returning the rolls of net to storage. The time sequence becomes relatively unimportant, because much of the job takes place before and after the cone ripening period. With this information, the orchard manager can calculate the price of seeds per pound.

Cone Collection System

1. Price per bushel to collect cones, transport, extract the process.
2. Can the cone crop be picked before they mature to the point of opening?
3. Is an adequate supply of collection equipment available?
4. Is there an adequate pool of people to do the work safely?

If the price per bushel for the netting system is higher than that for harvesting cones, the orchard manager would then decide that, in all probability, cone picking will be the most economical method.

Every orchard and organization will generate different numbers, but we feel the net retrieval seed collection system is a viable alternative to a difficult job.

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THE CASE FOR PLANTING LONGLEAF PINE

Eugene Shoulders[1/]

Abstract.--Twenty-year results from 35 comparisons of the four major southern pines in Louisiana and Mississippi indicate that longleaf (*Pinus palustris* Mill.) is potentially as productive as loblolly (*P. taeda* L.), slash (*P. elliottii Engelm. var. elliottii*), and shortleaf (*P. echinata* Mill.) pines under a wide variety of site conditions if the problems of poor planting survival and brownspot needle blight can be overcome. Late (after age 4) initiation of vigorous height growth was indicated to be a less important cause of longleaf's poorer performance than was low density resulting from poor planting survival and brownspot needle disease.

INTRODUCTION

Faced with the prospect that fusiform rust (caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiform*) may substantially reduce yields of loblolly and slash pine plantations, foresters across the South are reevaluating longleaf pine for planting in high rust hazard areas. Proponents of the species (Farrar and White 1983, Kais, et al. 1981) contend that longleaf pine will survive satisfactorily and initiate vigorous height growth in 3 or 4 years if vigorous seedlings are planted with care on well prepared sites and remain free of brownspot needle blight (caused by *Scirrhia acicola* (Dearn) Siggers) until they emerge from the grass stage.

These developments caused me to reexamine results of 35 site-species trials in Louisiana and Mississippi, where longleaf survival at 10 years exceeded 20 percent, to learn if early emergence of well stocked longleaf plantations from the grass stage would make them competitive in yields on a given site with the other major southern pines. In this paper, I compare actual yields of longleaf pine at 20 years in with those of loblolly, slash, and shortleaf pine. Also, I examine the individual and combined effects on relative performance of longleaf pine of (1) adjusting longleaf yields to reflect initiation of vigorous height growth in the fourth year after planting and (2) adjusting yields of all species to compensate for differences between them in basal area at 20 years.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Principal Silviculturist, USDA--Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

THE STUDY

In the years 1954 through 1958, the Southern Forest Experiment Station, with the help of both public and private forestry organizations, established pine species comparisons on 113 uniform sites in Louisiana and southern Mississippi. Every installation included loblolly, slash and longleaf pine. About half the installations also included shortleaf pine. Seedlings for the study were grown in State, Federal, and private nurseries in Louisiana and Mississippi and planted as 1-0 stock. Loblolly pine seedlings planted east of the Mississippi River were from seedlots collected in Mississippi, and those planted west of the River were from Louisiana seedlots. Slash pine seedlings for more than 80 percent of the plots were produced from seeds collected in southern Mississippi or the Florida parishes of Louisiana; seeds for the remaining stock were obtained from a Georgia dealer. Shortleaf seedlings from a Louisiana seed source were used in seven Mississippi installations. Otherwise, longleaf and shortleaf seedlings planted east of the Mississippi River were from seedlots collected in Mississippi, and those planted west of the River were from seedlots collected in Louisiana. No genetically improved seeds were used. The stock was graded by Wakeley's (1954) rules, and healthy, uninjured Morphological Grade 1 and 2 seedlings were accepted for planting.

Three plots of each of the three or four species were established at each location. Louisiana plots contained 49 measurement trees and Mississippi plots, 64. Planting interval in both States was 6 feet between and within rows (1,210 trees per acre). By age 20 years, poor survival of longleaf and disasters of one sort or another had reduced to 35 the number of installations where statistically valid comparisons could be made between longleaf yields and those of one or

more of the other species. The 35 included 33 installations where differences between longleaf and loblolly yields could be evaluated, 34 where differences between longleaf and slash yields could be evaluated, and 16 where differences between longleaf and shortleaf could be evaluated.

Thirteen of the 35 installations are east of the Mississippi River in southern Mississippi and the Florida Parishes of Louisiana; twenty-two are west of the River in Louisiana (fig. 1).

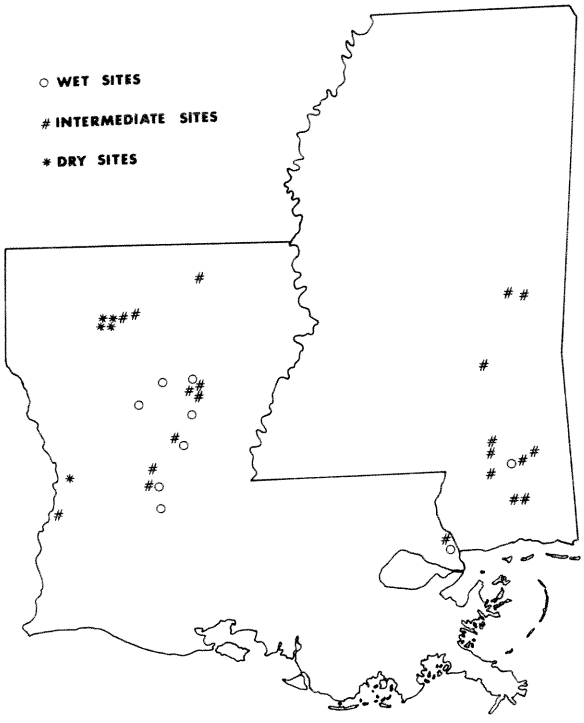

Figure 1.--Locations of 35 site-species trials in Louisiana and Mississippi

A few installations were established on old fields, but most were on open, cutover sites that had never been tilled.

Nine installations are on soils that lack prominent, abrupt changes in color or texture from the surface down to 3 or 4 feet (wet sites). These soils remain submerged or saturated with water during wet periods, especially in winter. They range in internal drainage from very poor to moderately good.

Twenty-one installations are on soils that have well defined horizons, which differ from each other in both color and texture (intermediate sites). These soils are moderately well to well drained.

Nine installations are on soils that have a thick surface layer of coarse sand or sandy loam material, which may or may not grade into somewhat finer material below a depth of 3 feet (dry sites). These soils have good to excessive internal drainage and a limited capacity to store readily available moisture.

To compensate for the effects of slow emergence of longleaf pine from the grass stage on yields at 20 years, it was necessary to establish the age at which dominant and codominant longleaf trees attained a height of 4 feet, and to project age-20 yields forward to compensate for the years greater than 4 that the trees required to initiate vigorous height growth. The procedure used to make these projections was as follows.

Height data from inventories at 3, 5, and 10 years were used to develop height (H) - age (A) relationships for each plot using the formula

$$\log_{10} H = a + \frac{b}{A} \quad .$$

(The a and b values are regression coefficients developed individually for each plot.)

The equations were then solved in reverse to determine the age at which trees attained a height of 4 feet. Values were rounded off to the next full year (e.g., 5.4 was rounded to 6 years), and 4 years was subtracted from them. Actual ages of longleaf plantations were reduced by this amount.

The next step was to grow the longleaf plantation to an adjusted age of 20 years. In this study, individual plot volume was reckoned as the product of plot basal area, based on the d.b.h. of all trees, and a volume-basal area ratio derived from sample tree measurements (see Shoulders 1976). So, estimates were needed of plot basal areas and volume-basal area ratios at actual ages corresponding to 20 years plus the number of years greater than 4 that trees remained in the grass stage. These values were obtained by linear interpolation using basal areas and volume-basal area ratios from inventories of individual plots that were made when actual age of the plantations was 20 and 25 years.

The assumptions underlying these adjustments to compensate for slow emergence of longleaf pine from the grass stage were (1) that once longleaf pine initiates vigorous height growth, its subsequent rate of growth is independent of the time seedlings spent in the grass stage and (2) that short term changes in individual plot basal areas and volume basal area ratios tend to be linear over time.

Because of the procedures described above for computing individual plot volumes, it was necessary to compensate for differences among species in density (survival) by adjusting plot basal areas and volume-basal area ratios. The assumption was made that plots of all species having the same number of surviving trees at 20 years would have approximately the same basal

area, but that their volume-basal area ratios would reflect differences among species in total height of the dominant and codominant trees. Because volume-basal area ratios are also sensitive to stand density, individual species regression was computed, which related actual volume-basal ratios to basal area and height of dominant and codominant trees. An adjusted volume-basal area ratio for each plot was obtained by solving these regressions for the average basal area of the installation and the actual height of dominant and codominant trees on the plot. The adjusted plot ratios were then multiplied by the average basal area of the installation to compute adjusted plot volumes. Both actual yields and expected yields, if longleaf had initiated vigorous height growth in the fourth year, were adjusted by this procedure to approximate, respectively, yields with comparable density between species and yields with comparable density if longleaf had commenced height growth at age 4.

Only total cubic-foot yields are reported. They include volume of wood and bark in the entire stem, from stump to tip, of trees 0.6 inch d.b.h. and larger. They exceed by about 20 percent corresponding yields from trees 5 inches d.b.h. and larger to a 4-inch top.

Actual and adjusted data for individual installations were evaluated by analyses of variance. Differences among species were isolated with Duncan's new multiple range test. Individual species were considered to be unequal in performance if differences among them were significant at the 0.05 level and equal in performance if differences were not.

RESULTS

Actual yields

At 20 years, actual yields per acre in the 35 installations were longleaf, 521 to 4,874 ft^3 (o.b.); loblolly, 654 to 5,644 ft^3; slash, 2,359 to 5,959 ft^3; and shortleaf, 1,065 to 5,313 ft^3 (fig. 2).

In only two installations were longleaf yields significantly greater than yields of another species (table 1). Longleaf yields exceeded slash pine yields on one well drained old-field site where longleaf survived exceptionally well (82 percent at 20 years) and emerged from the grass stage at an early age. Slash pine in this installation was heavily infected with fusiform rust and sustained 30 percent rust associated mortality by age 20. Longleaf growth averaged 237 ft^3 (o.b.) per acre per year in this installation, and slash averaged 175 ft^3. Longleaf outyielded shortleaf pine on a poorly drained open cutover site where neither species grew very well and yields of both were well below those of loblolly and slash pine. Shortleaf in this installation grew at an annual rate of only 53 ft^3 per acre and longleaf at an annual rate of 93 ft^3.

Longleaf yields equalled (i.e., were not significantly different from) those of loblolly in 33 percent of the installations, slash in 26 percent of the installations, and shortleaf in 63 percent of the installations where comparisons between individual species were possible.

Table 1.--Differences between longleaf and other southern pines in actual and adjusted total yields at 20 years

Item	Actual yields	Yields adjusted for - Prolonged grass stage	Stand density	Prolonged grass stage and stand density
	Number (percent) of installations			
Longleaf vs loblolly				
Longleaf sig. greater	0 (0)	0 (0)	0 (0)	7 (21)
No sig. difference	11 (33)	15 (45)	27 (82)	25 (76)
Loblolly sig. greater	22 (67)	18 (55)	6 (18)	1 (3)
Longleaf vs. slash				
Longleaf sig. greater	1 (3)	1 (3)	0 (0)	0 (0)
No sig. difference	9 (26)	12 (35)	18 (53)	29 (85)
Slash sig. greater	24 (71)	21 (62)	16 (47)	5 (15)
Longleaf vs. shortleaf				
Longleaf sig. greater	1 (6)	1 (6)	2 (12)	4 (25)
No sig. difference	10 (63)	11 (69)	14 (88)	12 (75)
Shortleaf sig. greater	5 (31)	4 (25)	0 (0)	0 (0)

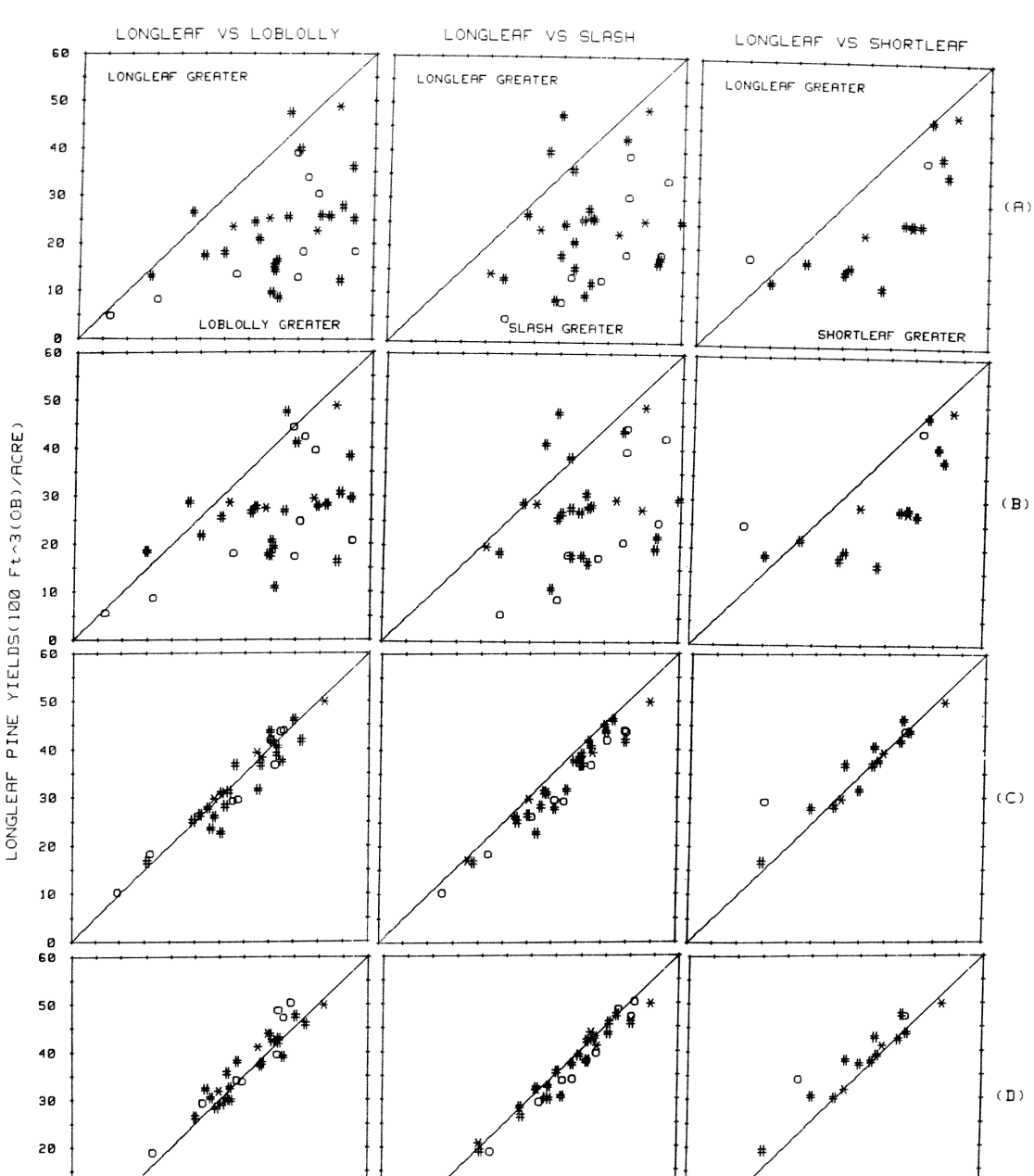

Figure 2.--Comparisons between longleaf pine and other southern pines in (A) actual total yields at 20 years, (B) total yields adjusted for late emergence of longleaf from the grass stage, (C) differences in stocking between species, and (D) both of the above conditions, by site condition (0 = wet, # = intermediate, * = dry). Diagonal lines represent equal performance of the two species in the comparison.

The proportions of installations where actual longleaf yields equalled or exceeded those of loblolly and slash increased as sites became drier, whereas the proportions of installations where longleaf yields equalled or exceeded shortleaf yields decreased.

Expected yields with rapid height growth

The adjustment to compensate for slow emergence of longleaf pine from the grass stage increased longleaf's competitive position only slightly. After this adjustment, longleaf yields equalled or exceeded those of loblolly in 45 percent of the installations, slash in 38 percent of the installations, and shortleaf in 75 percent of the installations. The adjustments ranged from zero for two installations, where longleaf commenced vigorous height growth in the fourth year, to 908 ft^3 (o.b.) per acre for an installation where a well stocked stand emerged from the grass in the seventh year.

Expected yields with equal density

The adjustment to compensate for differences in survival among species affected volumes of all species. After the adjustment, the range in expected yields per acre were longleaf, 1,072 to 4,991 ft^3 (o.b.); loblolly, 95.9 to 5,109 ft^3; slash, 1,290 to 5,432 ft^3; and shortleaf, 1,511 to 5,167 ft^3.

Analyses of these adjusted values showed that, with comparable basal areas at 20 years, longleaf was potentially as productive as loblolly in 82 percent and slash in 53 percent of the installations. With equal levels of stocking, longleaf yields equalled those of shortleaf in 88 percent of the installations and exceeded them in 12 percent of the installations where performance of these two species could be compared.

Expected yields with equal density and early emergence of longleaf from the grass stage

Removal of the effects of both slow emergence of longleaf from the grass stage and unequal density among species further altered expected yields and relative performance of the four species. Longleaf yields after the dual adjustment ranged from 1,135 to 4,991 ft^3 (o.b.) per acre, loblolly yields from 974 to 5,109 ft^3, slash yields from 1,311 to 5,433 ft^3, and shortleaf yields from 1,542 to 5,167 ft^3 per acre.

Given the advantage of emergence of a comparably stocked stand from the grass stage in the fourth year, longleaf should have performed as well as or better than loblolly on 97 percent of the sites and as well as slash on 85 percent. Longleaf yields should have equalled or exceeded those of shortleaf on all sites where both species were planted and survived. Moreover, there were no large differences between wet, intermediate, and dry sites in the proportion of installations where potential longleaf yields equalled or exceeded those of the other species.

DISCUSSION AND CONCLUSIONS

These exercises demonstrate that longleaf is potentially as productive as the other major southern pines under a wide variety of site conditions. They further emphasize that late emergence from the grass stage was a less important cause than low density for longleaf's poorer actual relative performance. Poor planting survival, brownspot needle blight, and competition from herbaceous vegetation all contributed to low density on longleaf plots. Together these factors eliminated longleaf completely from more than one-third of the installations where yields of two or more of the major southern pines could be compared and made it less productive than the best of the other three species in 86 percent of the remaining installations.

Research since this study was started has provided solutions to these problems. The problem of poor planting survival can be solved by adopting techniques for growing, handling, and planting bare-rooted nursery stock that are tailored to the unique requirements of longleaf pine (Farrar and White 1983, Kais et al 1981). Another alternative is to plant vigorous container-grown seedlings on well prepared sites (personal communications, A. G. Kais). Thorough site preparation may also alleviate the problem of brownspot needle blight by promoting early rapid height growth and removing the source of brownspot infection (Farrar and White 1983). Other, perhaps surer, methods of overcoming brownspot are planting brownspot resistant seedlings (Derr 1971, Derr and Melder 1970, Snyder and Derr 1972) or seedlings whose roots have been treated with the systemic fungicide benomyl (Kais et al. 1981).

The discussion must not end here: the issue of potential bias in the procedures used to adjust volumes should be addressed.

Since successful planting of longleaf depends in part on destruction of all competing woody and herbaceous vegetation (Farrar and White 1983), it could be argued that the procedure used to compensate for late emergence of longleaf from the grass stage was biased in favor of longleaf. Other species should also benefit from such thorough site preparation. The installation cited earlier in the paper, where longleaf outyielded slash pine at 20 years, provides some insight into the seriousness of this apparent bias. The site was a recently abandoned field with ground cover similar to that of a thoroughly prepared planting site. At 20 years, average height of dominant and codominant trees of the

four species ranged only from 50.9 ft for longleaf to 53.2 ft for slash pine, and differences between them were not significant. Dominant and codominant longleaf had averaged only 4.0 ft shorter than the tallest of the other three species at 5 years, 4.2 ft shorter at 10 years, and 2.6 ft shorter at 15 years.

It might also be argued that adjusting volumes to the average basal area of the installation to compensate for differences in density gave longleaf an undue advantage. Actually, the opposite is true. This adjustment eliminated any advantage longleaf may have had over loblolly and slash pine because of its greater resistance to fusiform rust. Also, longleaf is capable of producing stands just as dense as the other southern pines if survival is high. In the installation cited above, longleaf stand basal area equalled or exceeded that of the other species from age 15 onward. The adjustment, moreover, rendered nonsignificant a previously significant 1,258 ft^3 per acre difference in actual yields in favor of longleaf.

Because compensation for stand density had greater impact on yields than adjustments for longleaf's late initiation of height growth, the potential for longleaf to compete favorably with other southern pines for planting on a particular site may be even greater than the doubly adjusted values indicate. Therefore, a conservative rationale for planting longleaf pine rather than loblolly or slash pine might be to opt for longleaf whenever anticipated losses in discounted value of plantations of the other species from mortality associated with fusiform rust exceed the higher costs associated with producing and planting longleaf seedlings. Longleaf pine might also be chosen over shortleaf pine in such situations because despite shortleaf's resistance to fusiform rust, actual 20-year yields of shortleaf pine were never significantly greater in this study than actual yields of loblolly and slash pines (Shoulders 1983).

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PLANTING LOBLOLLY PINE NORTH AND WEST OF ITS NATURAL RANGE[1/]

O. O. Wells and George Rink[2/]

Abstract.--The fast initial growth rate of loblolly pine (Pinus taeda L.) has resulted in widespread use of this species north of its natural range throughout Tennessee, western Kentucky, and southern Illinois. Large amounts of Atlantic Coast loblolly are being planted in and near the Ouachita Mountains, also to maximize growth rate. These extensions of the natural range are taking the species to the limits of its cold and drought tolerance, and a considerable research effort is being made to identify the most cold hardy geographic seed sources and individual families. This report presents the 35-year results of a study that was begun in 1950 to identify the geographic sources of loblolly pine most suitable for Illinois. In addition to obvious injury, such as needle burn, damaged limbs or tops, or outright mortality at an early age, it appears from this and other studies that, when loblolly is subjected to excessive cold- or drought-induced stress, mortality of dominant and codominant trees can occur after 15 years or more of vigorous growth.

INTRODUCTION

Seed orchards are now the major suppliers of loblolly seed (Pinus taeda L.) for planting in the South. The trees in most seed orchards are of local origin, and the seedlings derived therefrom are intended to be planted in a relatively small geographic area that generally corresponds closely to the area where the orchard trees were selected. This is the dominant pattern of tree improvement in the South, and only in compelling circumstances would a forest industry or agency deliberately choose a non-local seed source instead of seed from their painstakingly developed and expensive orchards.

One instance in which some industries and agencies have made just such a decision has been in the high-rust-hazard areas of Mississippi, Alabama, Georgia, and South Carolina, where large areas have been planted to Livingston Parish Loblolly. The only other large areas where non-local loblolly seed sources are being used in substantial quantities are in and near the Ouachita Mountains of Arkansas and Oklahoma, throughout Tennessee, western Kentucky, and southern Illinois. The "compelling circumstances" in the Ouachitas has been the opportunity to substantially better the growth rate of trees from local seed sources. Growth gains of about 8 feet in site index or 20 percent in volume have been revealed by 25-year-old provenance tests near that area (Wells and Lambeth 1983). In Tennessee, Kentucky, and Illinois, the lack of a local seed source has forced the search for the optimum non-local one.

The recommended northern limit for loblolly in Illinois, which was determined by experimentation and experience (Gilmore 1980), follows the 180-day contour of a frost-free season very closely (Fig. 1). It is apparently a very critical limit. As noted by Gilmore, 30-year-old loblolly pine of Maryland origin suffered almost complete mortality only 60 miles north of the recommended limit when it was subjected to a record-breaking freeze in 1977.

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[2/] Principal Plant Geneticists, Southern Forest Experiment Station, Gulfport, MS, and North Central Forest Experiment Station, Carbondale, IL, respectively. The authors gratefully acknowledge the help of Henry Barbour, WESTVACO; and John Brissette, Ross Melick, and Glendon Smalley, USDA-Forest Service, in mapping the areas where loblolly is planted north of its natural range. We are also appreciative of the help of David Scanlon and the Tennessee Valley Authority (TVA) for access to the files of the 1950 TVA seed source study.

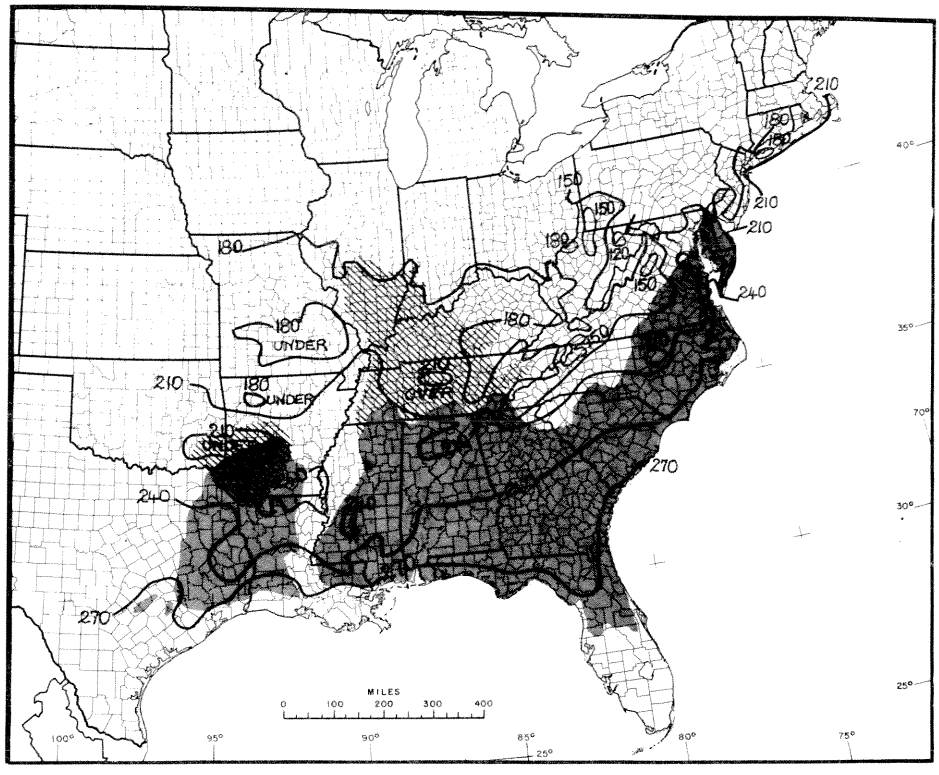

Figure 1.--Frost-free period (days) over the natural range of loblolly pine (shaded) and the principal areas where the range has been extended by planting (hatched).

Whenever non-local sources are used near or beyond the northern limit of the natural range, small differences in cold tolerance become critical, and "fine tuning" of individual families and geographic seed sources to sites become necessary. The goal is to find the source of seed having the optimum combination of maximum growth rate and minimum susceptibility to cold. In southern Illinois and Kentucky, which are at the limit of loblolly's cold tolerance, the primary consideration is to find the seed source having the most cold resistance. In somewhat milder areas, such as the Ouachitas, cold resistance is given slightly less weight, and seed from sources south of the extremity of the natural range, such as the Coastal Plain of North Carolina, are being used. Record cold in the Ouachitas in December 1983 demonstrated that North Carolina Coastal Plain loblolly was slightly less cold resistant than local Arkansas stock. Damage was mostly in the form of needle "burn" and was not considered heavy enough to discontinue use of loblolly from the North Carolina Coastal Plain in the Ouachitas (C. C. Lambeth personal communication).

There is still some question of which source has the most cold-tolerance. The coldest parts of the loblolly range, in terms of frost-free season, are in northern Delaware, Maryland, and the Piedmont of Virginia, and also in a very small portion of the southern Appalachians at the congruence of Georgia, North Carolina, and Tennessee (herein called the central-interior). The 180-day contour of frost-free days touches the natural range at these points. The portion of the natural loblolly range in central Arkansas is slightly warmer than the above areas, since it averages slightly under 210 frost-free days a year. But it too is among the most hardy loblolly seed sources.

Long-term tests are the only way to effectively determine the most suitable seed sources; and fortunately, our predecessors had the foresight to establish a network of provenance tests throughout Tennessee and the Ohio River Valley. Tests were established on seven sites in southern Illinois in 1948, and they have been followed closely to the present (Gilmore and Funk

1977, Gilmore 1980). On the basis of 27-year performance, Gilmore (1980) recommends southeastern Arkansas seed for southern Illinois, with Maryland seed a second choice. However, Barbour (1980), on the basis of much younger tests, recommends the central-interior part of the range for a seed source for western Kentucky, with Maryland or Arkansas a second choice. More recently, Barbour (personal communication) has come to favor Maryland and northeastern Virginia loblolly for western Kentucky. Apparently, differences in cold resistance among trees from all of these sources are not great.

Another substantial seed source study was undertaken by the Tennessee Valley Authority (TVA) in 1950 with the establishment of eight plantings of seedlings from nine seed sources throughout the Tennessee Valley and northern Arkansas. A report was published by Zarger (1961) on the basis of 10-year results, at which time trees from the central-interior part of the range, (nearest the Tennessee Valley) were excelling. A report on the northern Arkansas planting of the TVA study, issued after 15 years (Maple 1966), stated that trees from the southern Appalachians (analogous to the central-interior area) and Maryland were excelling. The northernmost of the TVA plantings was established on the Kaskaskia Experimental Forest in Hardin County, southern Illinois. It has been well-monumented and preserved by the North Central Forest Experiment Station, and 35-year results from this study are presented here.

METHODS AND MATERIALS

Seedlings from a variety of geographic seed sources were being grown in TVA nurseries in 1950, and seedlings from nine of these were used to establish the test (Zarger 1961). Commercial collections of seed collected between 1946 and 1948 were used, and most collections involved seed from more than one county. Seedlings were grown in two TVA nurseries in northeastern Tennessee and northern Alabama.

The planting in Hardin County, Illinois, was established in April 1950. Spacing was 7 by 7 feet. A randomized complete block design with 4 blocks of 25-tree plots was used, and a single border row was planted around each block. Observations and measurements were made after 5 years (Wiesehuegel 1955), 10 years (Zarger 1961), 15 years (TVA unpublished data), and 35 years, the subject of this report.

Units of analysis were plot means that were subjected to analysis of variance and Duncan's new multiple range test.

RESULTS

Trees from the mildest climates (southern Alabama, east-central Mississippi, and the South Carolina Coastal Plain), and also those from northern Mississippi, began to die in increasing numbers after the 10th year until, after 35 years, none of the relatively mild-climate trees had better than 20 percent survival (Fig. 2, Table 1). Trees of Tennessee, northern Alabama, and northern Georgia origin had the best survival (42 to 33 percent) after 35 years, and trees from Maryland and Virginia were intermediate, having about 28-percent survival. Survival near 40 percent at 35 years would be about average for loblolly pine plantations in the western Gulf Coastal Plain (Feduccia and others 1979), so trees from the three best seed sources have not suffered undue mortality above that caused by normal suppression.

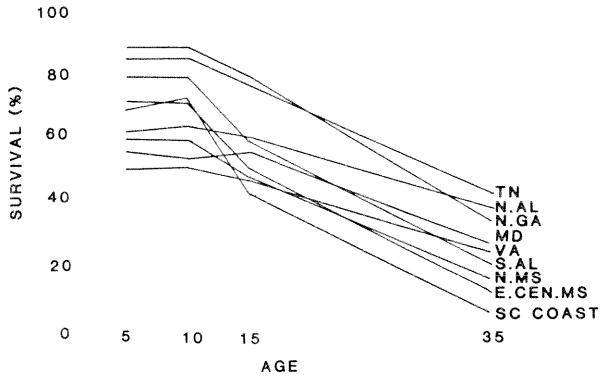

Figure 2.--Survival over years for loblolly pines from nine seed sources planted in Hardin County, (southern) Illinois.

Trees of Maryland and Virginia origin had below average survival the first year after planting but did not have a precipitous decline in survival after 10 years, as did the above-mentioned trees from Mississippi, Alabama, and South Carolina.

Differences in height or diameter were small and statistically non-significant at 35 years (Table 1).

DISCUSSION

The critical trait for discriminating among loblolly seed sources in the southern Illinois test is mortality over time. Growth rate differences have been suppressed in what are extreme climatic conditions for loblolly.

Table 1.--Survival, height, and d.b.h. of loblolly pines from nine seed sources grown in Hardin County, Illinois, for 35 years[1/]

Seed source	Survival (percent)	Height (feet)	D.B.H. (inches)
Southern TN	42 a	74.6 a	10.8 a
Northern AL	37 ba	72.6 a	10.9 a
Northern GA	33 cba	72.4 a	10.9 a
Maryland	24 dcb	73.2 a	11.1 a
Southeastern VA	22 dc	72.2 a	12.0 a
Southern AL	19 dc	71.9 a	11.1 a
Northeastern MS	14 ed	74.2 a	11.8 a
Eastern MS	10 ed	74.0 a	11.8 a
SC Coastal Plain	03 e	73.2 a	14.2 a

[1/]Means opposite the same letter do not differ significantly at the 0.05 percent level.

The results provide evidence that the effects of cold may not manifest themselves only in a straightforward, obvious fashion like needle burn, damaged limbs or tops, or outright mortality at an early age. The long-term mortality rate may be crucial to choice of seed source. More evidence of the same effect comes from long-term provenance tests that include Livingston Parish, Louisiana, loblolly and other seed sources originating near the Gulf Coast. When seedlings from these mild-climate sources were planted in southern Arkansas and the Piedmont of Georgia and Alabama, they developed satisfactorily at first, but after about 20 years in some plantings, and fewer in others, mortality of dominant-codominant trees began to occur at an excessive rate (Wells and Lambeth 1983, Wells in press). Cause of the mortality was not outright cold damage, but it was certainly related to the move into a colder climate, since more local stock was unaffected. Perhaps environmental stress weakens the warm-climate trees to the point where they become susceptible to common pests like bark beetles or root rots. A few trees may die each year, as in the southern Illinois test, or many may die in a short period of time, as in the southern Arkansas test. Overstocking may exacerbate the stress. This phenomenon is probably similar to that reported in provenance tests in east Texas (Long 1980). There, loblolly originating east of the Mississippi River experienced mortality of dominants and codominants similar to the type of mortality reported here. In the Texas tests, some aspect of drought, not cold, was assumed to be responsible, but perhaps the key is stress, whatever the cause.

Short-term laboratory tests to speed up the selection of cold resistant families of loblolly pine are being developed (Kolb 1984) and should be very useful, but at least some tests near the absolute limits of loblolly's range should be long term like the present one. The climatic event that may provide the ultimate test of adaptability may not occur for a long time. If one considers it necessary that the trees under test withstand a 100-year freeze, then the waiting period becomes very long indeed. Most land owners or foresters, however, would accept greater risk or adopt more limited objectives. A realistic objective in southern Illinois or western Kentucky would be to produce pulpwood on a 20- to 30-year rotation and accept minor damage, such as some broken tops or limbs, during that period. Obviously, there is a better chance of growing a satisfactory crop over a short period than a long one, and quality defects are of less concern in pulpwood than in sawlogs. Trees from the best loblolly seed sources seem capable of persisting in satisfactory fashion for at least 20 to 30 years in southern Illinois and western Kentucky. If sawtimber rotations are the goal, as would be the case for most non-industrial landowners, loblolly may not be the species of choice. In southern Illinois, shortleaf pine has slower initial growth rate than loblolly, but its survival over the long term is better (Gilmore and Funk 1977).

Sawlog rotations for loblolly of optimum seed source may well be feasible in the Ouachitas, where the climate is slightly warmer than in southern Illinois and Kentucky. In 25-year-old provenance tests about 50 miles south of the Ouachitas, the only loblolly populations that have performed poorly are those from near the Gulf Coast (Wells and Lambeth 1983). Trees from the Atlantic Coast sources, which are being used there the most, are performing particularly well.

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CHEMICAL WEED CONTROL TO ESTABLISH NATURAL AND ARTIFICIAL OAK REGENERATION IN A MECHANICALLY THINNED UPLAND HARDWOOD STAND.[1/]

G. M. Wright, P. E. Pope, B. C. Fischer, H. A. Holt, and W. R. Byrnes.[2/]

Abstract.--A combination of silvicultural treatments were evaluated in an attempt to establish adequate oak advanced regeneration prior to final harvest in an upland oak-hickory stand in southern Indiana. Thinning-from-below to 60% stocking, coppicing of small diameter oak stems, control of understory vegetation using mist-blown herbicides, and interplanting of 6 types of northern red oak (Quercus rubra L.) stock was performed on the 8 acre study site. Overall, thinning and total vegetation control was successful in improving establishment of natural and artificial advanced oak regeneration, with a release harvest probable after 5 years.

Advanced oak regeneration is rarely present in adequate numbers to replace a stand with an oak component equal to or greater than existed in the pre-harvest stand. This "oak regeneration problem" persists throughout the upland oak region. Failure to find solutions to this problem may cause significant changes in future availability of oak species to the forest product industry.

If oak regeneration is not well established at harvest, it is unlikely that oak will be a significant component of the future stand (Sander, 1979; Loftis, 1979). To be considered established, oak regeneration must be 4.5 feet tall. For a future stocking goal of 221 dominant and codominant oaks for an average stand diameter of 3 inches dbh, there must be 443 well distributed stems of advanced regeneration per acre (Sander et al., 1976). Advanced oak regeneration, however, chronically fails to meet these stocking levels, making up only 2 - 10% of new stands regardless of the silvicultural system (Watt, 1979; Sander, 1979; Fischer and Holt, 1981; Loftis, 1983).

Partial cutting to reduce overstory density may be combined with planting to improve advanced regeneration (Johnson, 1976; Wendel, 1980). Initial survival of planted seedlings is usually adequate, but they fail to compete with other types of woody vegetation and herbaceous invaders. This is especially true on good sites. Oak stump sprouts on the other hand, will compete and frequently have at least one dominant or codominant stem by age 15, and will produce a good potential sawlog tree (Lamson, 1976; Johnson, 1977; Johnson and Rogers, 1980).

Combining thinning, weed control, and sprout management with interplanting of selected oak species may be necessary to achieve an adequate oak component in the future stand (Holt et al., 1981). Removing all competing vegetation using a mist-blown herbicide site preparation treatment will enable planted oak seedlings to become established and compete (Horsley, 1982; Wendel and Kochenderfer, 1982). To prevent destruction of oak and other desirable reproduction, stems < 3 in. stump diameter should be coppiced at least one week prior to herbicide application. The 3 in. limit is chosen because Johnson (1977) reported that white and black oak sprouting probabilities peak at 3 in. stump diameter and decrease rapidly for stump diameters greater than 6 inches. In addition, the crown of trees > 3 in. stump diameter are usually above the effective 3 meter spray ceiling of the mist blower.

Unfortunately, past oak plantings have demonstrated discouragingly slow early growth and a high frequency of dieback (Sander et al., 1976). This is attributed to a root-shoot imbalance which upsets the relative ratio of transpiration to

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2/ Extension Forester, Associate Professors and Professors, Department of Forestry and Natural Resources, Purdue University, W. Lafayette, IN 47907.

absorption (Garrett et al., 1979). A number of cultural methods have been used to tailor the oak seedling to improve this balance in favor of the roots. Inoculation with selected ectomycorrhizal fungi, coupled with foliar fertilization in the nursery improved black oak root biomass, diameter, and leaf area (Wright, 1979) but failed to provide a significant competitive edge when outplanted (Dixon, et al., 1981). Containerization, top-pruning, mulching and fertilization have provided limited success in improving oak establishment (Wendel, 1980; Pope, 1981; Johnson, 1984).

A combination of cultural treatments will be necessary to successfully establish adequate oak regeneration. How much can a land manager afford to spend to increase the oak component of a stand? Based on the demand for high quality oak in the marketplace, can he afford not to spend what is necessary? This study examines a combination of intensive cultural treatments designed to insure adequate advanced oak regeneration at final harvest time.

The objectives of the study were to evaluate coppicing, total vegetation control with mist-blown herbicides, and six types of planting stock in establishing advanced oak regeneration in mechanically thinned and unthinned stands.

MATERIALS AND METHODS

The Study Area

The study is being conducted at the Southern Indiana Purdue Agriculture Center on unglaciated sand stone-shale derived soils. These soils are representative of about a million acres of upland forestland in Indiana. The predominate soil type was a Gilpin silt-loam (Ultic Hapludalf) with 6 - 20% slopes and a southerly aspect. This soil occurs on upland sites and is commonly forested due to slope steepness. It is well drained and moderately permeable, with a 42 in. depth to siltstone bedrock.

White oak (Quercus alba L.) was the dominant species in the uneven-sized oak-hickory stand and combined with northern red (Quercus rubra L.), black (Quercus velutina L.), and scarlet (Quercus coccinea Muenchh.) comprised 75% of the sawtimber sized (> 12 in. dbh) stocking. Hickories (Carya spp.), white ash (Fraxinus americana L.), and sugar maple (Acer saccharum Marsh.) were a minor component of the stand. The average age of the dominant trees was 80 years. White oak site index is 70 feet (Carmean, 1971).

Experimental Design

The experimental design for the study was a split-split plot with whole units arranged in a randomized complete block design. There were four blocks, two plots (unthinned, thinned), two cultural treatments (control, total vegetation control with mist-blown herbicides), and six sub-sub plots (six types of planting stock). The total study area was 8 acres.

Thinning

The thinning phase of the study was completed in 1981 using a feller-buncher to remove whole trees 4 - 12 in. dbh. This "thinning-from-below" simulated normal timber stand improvement (TSI) operations in which trees are chemically deadened. Unlike normal TSI, the inferior stems were skidded to a landing and chipped for pulp or energy chips.

The basal area was reduced from 105 ft/acre (> 2 in. dbh) to 65 ft/acre by the thinning operation (Gibson et al., 1982). The unthinned plots were adjacent to the thinned area and averaged 77 ft/acre basal area.

Coppicing of Oak Stems

All oak advanced regeneration greater than 4.5 ft. tall and < 3 inches stump diameter was coppiced using a chainsaw or hand pruners in August 1982. The coppicing was completed two weeks prior to the mist-blowing treatment to prevent herbicide uptake by the coppiced oak stems. All coppiced stems were tagged so sprout development could be monitored. Only sprouts in the total vegetation control treatments were coppiced.

Herbicide Application

On September 1, 1982 a 3 gallon Solo (Model 423) back-pack mist-blower was used to apply a broadcast application of glyphosate (1.5 lb ae/acre) plus triclopyr (1.5 lb ae/acre) in 25 gallons water per acre as the total vegetation control (TVC) treatment. All understory vegetation ≤ 3 meters in height was treated with the fine droplet spray in both the unthinned and thinned plots. Species in the understory included: Quercus spp., Carya spp., Acer spp., Fraxinus americana L., Fagus grandifolia Ehrh., Liriodendron tulipfera L., Crataegus spp., Viburnum spp., Sassafras albidum, Vitis spp., Rhus spp., Smilax spp., Carpinus caroliniana Walt., Ostrya virginiana (Mill) K. Koch., Diospyros virginiana L., and Amelanchier arborea (Michx. f.) fern.

To assess weed control success and determine the degree of woody competition for the oak regeneration, 1 m x 46 m permanent vegetation transects were established prior to the herbicide application (5% sample). Species, total height, stump diameter and origin (stump sprout or seedling) was recorded for all woody stems > 15 cm tall. In addition, each stem was assigned coordinates to facilitate remeasurement. The transects were remeasured in September, 1983, to assess weed control.

Planting Stock

Six types of planting stock were underplanted on a 3 m x 3 m spacing in all understory treatments. Sixteen seedlings of each stock type were planted in each 1/2 acre treatment sub-plot for a total of 1536 seedlings

on the study area. The stock types were: 1) containerized northern red oak (NRO) (Quercus rubra L.) inoculated with Pisolithus tinctorius (Pt), a known mycorrhizae-former with oak, 2) non-inoculated containerized NRO, 3) bare-root 1-0 NRO inoculated with Pt 4) non-inoculated bare-root 1-0 NRO, 5) bare-root 1-0 NRO grown in experimental subirrigated beds, and 6) bare-root 2-0 NRO grown in subirrigated beds.

The containerized seedlings were grown in a shadehouse for one growing season in 160 cm (4 cm x 4 cm x 10 cm) volume containers filled with a peat-vermiculite-soil potting mixture. The Pt mychorrizal inoculum was a peat-vermiculite media which was incorporated into the sterilized potting soil of the inoculation treatments at a rate of 200 ml/ft of surface area. The bare-root 1-0 seedlings were grown in conventional nursery beds at the Jasper-Pulaski State Nursery. The Pt inoculum was incorporated at a rate of 200 ml/ft into the inoculation treatment seedbeds by hand-tilling to a depth of 6 inches between the rows. The bare-root 1-0 and 2-0 subirrigated NRO seedlings were grown in experimental containerized seedbeds at the Vallonia State Nursery. The silica-sand rooting media was subirrigated to maintain a constant water table under the beds and a free water supply. The water table restricted tap root length to approximately 18 cm (1-0) and 25 cm (2-0). The subirrigation is designed to eliminate wounding from severe root pruning and stimulate lateral root formation. All planting stock was graded prior to planting to insure uniformity within stock types (Table 1).

Table 1.--Initial size of northern red oak planting stock.

Type of stock	Diameter mean (mm) [1/]	Height mean (cm)	Mycorrhizal infection (%)
CONT-I [2/]	5.1	29	42 [3/]
CONT-NI	4.7	29	17 [4/]
BR-I	7.1	42	48
BR-NI	6.6	45	24
BR-S 1-0	3.5	23	-
BR-S 2-0	5.1	31	-

1/ Measured 2 cm above root collar.

2/ CONT-I = containerized - inoculated with Pt
CONT-NI = containerized - non-inoculated
BR-I = bare-root 1-0 - inoculated
BR-NI = bare-root 1-0 - non-inoculated
BR-S 1-0 = bare-root 1-0 - subirrigated
BR-S 2-0 = bare-root 2-0 - subirrigated

3/ 76% of total infection was Pt.

4/ Infection due to natural forms of mycorrhizae, 49% of which was Thelephora terrestris.

RESULTS

Weed Control

One-year after the herbicide treatment, 88% of the understory vegetation 15 cm-3 m tall was controlled in the unthinned total vegetation control (TVC) treatments and 73% in the thinned treatment areas. An additional 7 and 10% of the vegetation respectively, was > 25% topkilled by the herbicides. Virtually all of the herbaceous vegetation was controlled by the non-selective herbicide treatment. Natural mortality in the unthinned and thinned control, 26 and 14% respectively, was enchanced by severe drought in the summer of 1983. The 15% difference in weed control between the unthinned and thinned TVC treatments was due to the large number of sprout clumps resulting from the 1981 thinning. The small amount of foliage surface area of the sprout clumps did not translocate a lethal dosage of herbicide to the large, established root system. The carry-over of weed control into the 1984 growing season was good despite the fact that glyphosate has no residual activity and triclopyr has little. Therefore, no additional weed control was necessary during the 1984 growing season.

Seedling Survival

After two years, seedling survival (Table 2a) was significantly greater ($p < 0.05$), 75%, for seedlings grown in thinned-TVC treatments compared to unthinned-controls, 64%. These trends are consistent across all seedling types with the exception of the bare-root 1-0 and 2-0 subirrigated seedlings, which displayed no trends between treatments. Containerized seedlings displayed the largest response to both thinning and TVC while bare-root stock responded significantly to either TVC (81-83%) or thinning alone (72-84%), when compared to unthinned controls (62-66%).

Inoculation had no significant effect on survival (Table 2b) for either the containerized or bare-root stock, with the exception of the thinned-control treatment. Overall, bare-root stock survival averaged 10% better than container stock (78% versus 68%). Bare-root 1-0 subirrigated seedling survival was significantly greater than bare-root 2-0 seedlings, averaging 20% better across all treatments (72% versus 52%).

Seedling Total Height

Total height (Table 2a) after two years was significantly greater ($p < 0.05$) for all seedlings receiving thinning or TVC, and was improved further for the containerized seedlings by the combination of thinning and TVC. Containerized seedlings averaged almost double (57 cm vs. 28 cm) the total height of the unthinned-control treatments. The bare-root 1-0 seedlings receiving some cultural treatment were 41% taller on the average than unthinned controls. The bare-root 1-0 and 2-0 subirrigated seedlings which had shown no significant trends in survival reflected improved total height by the addition of at least one type of cultural treatment.

Inoculation with Pt had no significant effect on total height (Table 2b) of the containerized or bare-root 1-0 seedlings. Bare-root 2-0 subirrigated stock was significantly taller in all treatments than the bare-root subirrigated 1-0 stock, averaging 7 cm (34 cm vs. 27 cm) across all treatments. This is probably due to the larger initial size of the bare-root 2-0 subirrigated seedlings.

Net Height Growth

Second-year height growth (Table 2a) was significantly ($p < 0.05$) greater for the unthinned-control in all cases. This is contrary to expectations. However, it can be explained by the large amounts of animal damage to the unthinned-control treatments. Seventy-five percent of the seedlings in the unthinned-control were browsed, primarily by deer, compared to only 13% of the seedlings in the thinned TVC. This resulted in vigorous lateral or basal sprouts. Browsing may partially account for the survival decrease for this treatment.

Again, inoculation did not significantly improve net height growth (Table 2b) with the exception of the containerized seedlings in the unthinned-control. Net height growth of the containerized seedlings was better than the bare-root 1-0 seedlings, though the differences, while statistically significant, were small (8.5 cm vs. 6 cm). There were no significant differences in net height growth between the bare-root 1-0 subirrigated and 2-0 seedlings.

Coppice Total Height and Number of Live Sprouts

Oak stems coppiced in the thinned area prior to the herbicide treatment were significantly ($p < 0.05$) taller than those in the unthinned area (79 cm and 60 cm respectively). Vigor of the stump sprouting was indicated by the larger number of live sprouts per stump in the thinned area (5.4 sprouts/stump vs. 4.1 sprouts/stump) and multiple flushes of growth.

DISCUSSION

The "thinning-from-below" accomplished the 60% overstory stocking prescribed by Sander (1979) (based on stocking guides developed by Gingrich (1967) for upland hardwoods) to regenerate oak successfully. The main difference is the size and quality of residual trees left in this stand. This study removed smaller diameter trees while normal shelterwood cuts remove only some of the dominants and codominates. The next phase of this study, whether another thinning or final harvest, will yield a very high value product. Over the 5-10 year interval between initial thinning and the next harvest or release, growth will be concentrated on higher value crop trees as they benefit from the decrease in moisture and nutrient competition.

Table 2a.--Growth parameters for seedlings after two years by stock type, thinned or unthinned, and understory treatment.

Stock/ Thinning	Treatment	Second/ Year Survival (%)	Total Height Year 2 (cm)	Net Height Growth Year 2 (cm)
CONT-I				
Unthinned	control	64a [1/]	31a	12a
	TVC [2/]	62a	49b	9b
Thinned	control	62a	47b	8b
	TVC	78b	57c	7b
CONT-NI				
Unthinned	control	69a	26a	9a
	TVC	69a	46b	9a
Thinned	control	62a	47b	7b
	TVC	80b	56c	7b
IBR-I				
Unthinned	control	66a	33a	9a
	TVC	83b	50b	6b
Thinned	control	84b	46b	5c
	TVC	87b	47b	4c
BR-NI				
Unthinned	control	62a	35a	9a
	TVC	81c	50b	6b
Thinned	control	72b	47b	5b
	TVC	87c	49b	4b
BR-S 1-0				
Unthinned	control	67a	21a	8a
	TVC	87b	29b	6b
Thinned	control	59c	28b	5b
	TVC	77d	29b	5b
BR-S 2-0				
Unthinned	control	59a	30a	6a
	TVC	75b	35b	4b
Thinned	control	33c	33b	4b
	TVC	41cd	37b	3c

1/ Numbers followed by the same letter within cultural treatments are not significantly different ($p < 0.05$) based on Duncan's multiple range test.

2/ TVC = total vegetation control

Table 2b.--Growth parameters for seedlings after two years by thinned and unthinned understory treatments and stock type.

Treatments	Stock	Second-Year Survival (%)	Total Height Year 2 (cm)	Net Height Growth Year 2 (cm)
Unthinned				
- Controls	CONT-I	64ab [1/]	31cd	12c
	CONT-NI	69b	26b	9b
	BR-I	66ab	33cd	9b
	BR-NI	62b	35de	9b
	BR-S 1-0	67b	21a	8ab
	BR-S 2-0	59a	30c	6a
- TVC	CONT-I	62a	49cd	9b
	CONT-NI	69ab	46c	9b
	BR-I	83d	50d	6a
	BR-NI	81cd	50d	6a
	BR-S 1-0	87d	29a	6a
	BR-S 2-0	75bc	35b	4a
Thinned				
- Controls	CONT-I	62b	47c	8b
	CONT-NI	62b	47c	7b
	BR-I	84d	46c	5a
	BR-NI	72c	47c	5a
	BR-S 1-0	59b	28a	5a
	BR-S 2-0	33a	33b	4a
- TVC	CONT-I	78b	57d	7b
	CONT-NI	80bc	56d	7b
	BR-I	87c	47c	4a
	BR-NI	87c	49c	4a
	BR-S 1-0	77b	29a	5a
	BR-S 2-0	41a	37b	3a

[1/] Numbers followed by the same letter within stock types are not signficantly different ($p < 0.05$) based on Duncan's multiple range.

Frequently, overtopped or intermediate oaks in a stand are as old as their dominant or codominant neighbors. McGee (1981) found that overtopped white oaks 6-12 inches dbh with good stem form and adequate crown would respond to release. Low vigor, smaller diameter trees with poor form or crowns should be coppiced since the sprouting probability is high (Johnson, 1977) and a more vigorous higher quality tree will probably develop. Generally, the large number of sprouts that form initially will naturally thin to 2 or 3 by year 15, with occasional stumps needing thinning to get a single, good quality stem. Coppicing of oak has proven successful in this study with multiple flushes resulting in 30-40 cm/year height growth of the dominant sprout. Only 17% of the coppiced stumps failed to sprout and a large number of the coppiced seedlings <4.5 feet tall have also produced vigorous sprouts. Completing the coppicing at a time when root-stored carbohydrates are at a peak, such as late summer, will also improve sprouting success.

Broadcast back-pack herbicide applications to large acreages are costly ($65.00 per acre total cost in this study) and labor intensive. However, in cases where group selection or patch clearcuts have been made or where a dense understory weed problem exists, the mist-blower treatment may be useful. The rate and combination of chemicals used provided good translocation and control. Higher rates would be an unnecessary expense and the risk of "quick kill" (burning of the foliage) may reduce translocation and decrease control. Glyphosate alone at 1.5 lb ae/acre has provided satisfactory understory control at another southern Indiana site, but without the carry-over effect seen in this study (John Seifert, personal communication).

Fall planting is not usually a recommended practice for bare-root hardwood stock in southern Indiana, due to the threat of frost heaving and animal damage. In contrast the early establishment of container stock (frost heaving is not a problem with containerized stock) should be beneficial to survival and first year growth, since root growth may begin shortly after planting. The mild winter after planting and lack of deep freezing prevented frost heaving of the bare-root seedlings in this study. However, first-year growth of these fall planted seedlings (12-16 cm) still was not adequate to keep up with natural sprouts. The question comes to mind--why interplant a stand that has oak coppice, with seedlings that at best may grow at a rate of only 25% that of sprouts.

The slow growth rates for the first two growing seasons (12-16 cm and 3-12 cm) may be partly attributed to the severe drought in summer of 1983 and prolonged dry spells in the summer of 1984. However, the seedlings infected with mycorrhizae should have been better drought avoiders and should have recovered better after these dry conditions ended (Dixon et al., 1980). This was not the case. Inoculation apparently provided no significant benefits to seedling survival or height growth. The mycorrhizal condition has been reported to reverse itself after outplanting (Shemakhanova, 1962). This may have been the case here, however no seedlings were reassessed to verify if this occurred. The reversal is due to unfavorable edaphic conditions such as soil moisture level, fertility, texture, temperature, pH, or presence of antagonistic forms of natural fungi (Wright, 1979). Also, colonization of the non-inoculated seedlings by natural forms in the nursery (17-24% infection) or after outplanting may have masked the benefits of the inoculation with Pt (42-48% infection).

The additional expense of growing, transporting and planting the containerized seedlings does not seem justified after two growing seasons, when compared to bare-root 1-0 nursery stock. It is believed that the planting of a containerized seedling with an undisturbed root system, a high root:shoot ratio, ideally hardened off and ready to plant, would result in less planting shock, better survival, and earlier growth (Tinus, 1979). However, the smaller

diameter seedlings were easy prey for rodents, and sometimes selectively browsed by deer due to their succulent nature and high salt concentrations. Second year growth was slightly improved for the container seedlings, so benefits may still be seen in later years.

The seedlings grown in subirrigated beds exhibited the slowest growth rates and poorest survival of the six stock types. This may be due in part to the smaller diameter and height of this stock, but a conspicuous lack of any mycorrhizal development of the root systems may have contributed to the poor performance, since fungal hyphae are the primary organ of absorption of mycorrhial plants (Harley, 1969).

CONCLUSIONS

The addition of at least one cultural treatment was beneficial to the survival and establishment of the oak coppice and planted seedling in all cases. When both thinning and total understory vegetation control were combined, survival and growth of containerized seedlings increased even more. The increase in available light, nutrients, and moisture from thinning and TVC have aided in establishment of this advanced oak regeneration. If the growth rate of the planted oak seedlings improves in year 3 or 4 then the site preparation treatment was probably successful in giving the seedlings the head start needed to compete with invading vegetation. However, it is doubtful that the planted seedlings will keep up with the coppice regeneration. Release of the advanced regeneration will take place in 5-10 years at a time before growth of advanced regeneration begins to slow.

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INFLUENCE OF MIDSTORY AND UNDERSTORY VEGETATION REMOVAL ON THE ESTABLISHMENT AND DEVELOPMENT OF OAK REGENERATION[1/]

G. C. Janzen and J. D. Hodges[2/]

Abstract.--Three years after treatment, the number of oak seedlings older than one year was increased either by injection or injection and spraying of the midstory and understory vegetation. Presence of herbaceous vegetation was found to be beneficial in the establishment of oak seedlings. Although new oak seedlings were not large enough to be depended on as advanced regeneration, they were more vigorous where the midstory and understory vegetation was eliminated.

INTRODUCTION

In many southern bottomland hardwood stands undesirable species tend to dominate the understory to the exclusion of the more desirable species (Johnson and Biesterfeldt 1970). This is a result of mismanagement or management of hardwoods through single-tree selection which favors the shade-tolerant species (Johnson 1975). Therefore, when these stands are regenerated, they consist of a lower proportion of oaks than the stands which preceeded them (Johnson 1979).

The major difficulty hardwood managers face is when advanced oak regeneration is not present. Clearcutting will not produce the desired oak stand if there is not adequate advanced oak regeneration (Marquis 1982). Before a hardwood stand is harvested, consideration should be given to the presence or absence of desirable advanced regeneration. Johnson (1980) has developed a system for evaluating regeneration in southern hardwood stands immediately preceeding final harvest. This system, as well as other systems developed for eastern U.S. hardwoods, is based on the size and number of desirable stems present before the stand is cut (Sander et al. 1976, Marquis and Bjorkhom 1982). Values are assigned according to the ability of seedlings or stumps to respond or sprout. Sizes which are given the highest value for oaks, according to Johnson's evaluation, are seedlings which are greater than one foot in height or stems less than ten inches diameter at breast height (dbh).

Newly germinated oak seedlings or very small oak seedlings present before the final harvest are not able to compete with larger sprout-origin stems when the stand is regenerated (Sander 1972, Loftis 1982). Thus, if oaks are the species to be managed in the next stand, treatments designed to establish advanced regeneration of adequate size should be undertaken. Reduction of overstory basal area is the technique most often recommended to establish oaks in the understory. If the overstory is such that sufficient sunlight passes through, reduction of overstory basal area does little to enhance establishment of desirable regeneration. Many stands contain high densities of shade-tolerant species in the lower canopies that exclude sunlight from shade-intolerant species (Johnson and Krinard 1976, McKnight and Johnson 1980, Kellison et al. 1981). Reduction of basal area in the upper canopy (or areas where the upper canopy is open enough to allow sufficient direct sunlight) must coincide with removal of midstory and understory vegetation in order to allow sufficient sunlight to reach the forest floor where seedlings are developing (Johnson and Jacobs 1981, Loftis 1982).

Also, vines and other herbaceous weeds can pose a serious problem to seedling development. If the amount of cover by vines is large, many more seedlings are needed in order to push their way above this mat of vegetation. If herbaceous weeds grow to heights of six feet or taller, they may shade out any seedlings developing underneath this herbaceous layer (Johnson and Biesterfeldt 1970). On the other hand, if herbaceous vegetation competition is not too

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[2/] The authors are research technician and professor, Department of Forestry, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University. Contribution No. 5966 of the Mississippi Agricultural and Forestry Experiment Station.

severe for seedling development, it can be beneficial to seedling establishment. Herbaceous weeds can serve to protect seedlings from browsing by deer. Also, they can protect the soil from baking or puddling, which in turn protects seedlings from too little or too much moisture (Putnam et al. 1960).

Another problem in establishing oak regeneration is the highly variable production of viable acorns. Also, loss of good acorns to animal depradation and weather can be substantial. If acorns remain to germinate, they must have adequate surface soil moisture to allow roots to grow into the mineral soil (Arend and Scholz 1969). Once a seedling is established, environmental conditions determine whether that seedling will be able to survive in the understory (Carvell and Tryon 1961).

In most bottomland hardwood stands lacking adequate advanced reproduction, light to the forest floor is probably the major factor that limits the development of desirable species. The objective of this study was to determine if removal of this unwanted vegetation in the midstory and understory was sufficient to allow oak and other desirable regeneration to become established before the final harvest.

METHODS

An area that did not contain adequate advanced oak regeneration was selected. This area is located on the John W. Starr (MSU) Memorial Forest in Oktibbeha County, Mississippi and is within the floodplain of the Noxubee River. The overstory is biologically mature as indicated by stem size, thin crowns, bark characteristics, and slow growth of the overstory trees. The overstory consisted primarily of cherrybark oak (Quercus falcata var. pagodaefolia Ell.) and swamp chestnut oak (Quercus michauxii Nuttl.); with the lower stories essentially hickory (Carya spp.), blue beech (Carpinus caroliniana Walt.), pawpaw (Asimina triloba (L.) Dunal), and green ash (Fraxinus pennsylvanica Marsh.). The small amount of ground flora present is composed mainly of shade-tolerant species. The overstory is 60 years old. Site index (base age 50 years) for cherrybark oak on this site is 100 feet (Baker and Broadfoot 1979).

There was very little difference in the number of stems per acre, basal area (square feet per acre), or mean dbh (inches) for those trees larger than 4.0 inches dbh present at the time treatments were installed (Table 1). The midstory was composed of mainly low value shade-tolerant species while the overstory consisted primarily of oaks. Due to the presence of a dense midstory, desirable species do not develop to a size such that they can be depended on as advanced regeneration.

Fifteen plots, 100 feet by 100 feet, were established. Within each plot, five permanent subplots of ten feet by ten feet were installed. These subplots were used initially to subsample seedlings (0 to 3 feet in height), small saplings (3 to 10 feet in height), and large saplings (10 feet in height to 4.0 inches dbh) of all species present before treatments were installed. All trees within each plot which were larger than 4.0 inches dbh were tallied according to species, dbh, and canopy position (upper- or mid-canopy).

The following treatments were randomly assigned according to the desired vegetation control sought.

(1) Inject only. Inject plots represent those plots in which all trees greater than 1.0 inch dbh which were not considered final crop trees were injected with Round-up[3/], regardless of strata position. Crop trees were chosen on the basis of their ability to produce at least one number three factory grade sawlog (USDA Forest Service 1981). Rot and other defects were only considered if there was a chance of mortality or loss of grade to the point where the tree would not meet the requirements for a number three sawlog.

(2) Inject/spray. Inject/spray plots combined injection as above and foliar spraying with Round-up of the remaining stems and vegetation which could be reached with a backpack sprayer (height of approximately 10 feet).

(3) Control. Control plots received no herbicide treatment; midstory and understory remained intact.

Measurements to assess treatment effects were made in the permanent subplots as needed to determine germination and establishment of new seedlings. Each stem found within the subplots was tallied according to species and size class. Size classes were assigned as follows: #1, 0 to 20 centimeters (cm) in height (newly germinated seedling); #2, 0 to 20 cm in height (seedling older than 1 year); #3, 21 to 50 cm in height; #4, 51 to 100 cm in height; #5, 101 to 150 cm in height; #6, 151 cm in height to 1 cm dbh; #7, 1 cm dbh plus. Also, a subsample within each size class for each species was marked in the initial measurement for future remeasurement. A subsample of oaks that germinated in the second year following treatment was also marked. Height (and dbh were applicable) was measured for each marked tree for an evaluation of growth and development.

[3/] Use of trade, firm, or corporation names is for the reader's information and convenience. Such use does not constitute official endorsement or approval by Mississippi Agricultural and Forestry Experiment Stattion.

Table 1.--Number of stems per acre, basal area (ft^2 per acre) and mean dbh (in) of trees greater than 4.0 inches dbh present before treatments (midstory and overstory trees).

	Number of Stems per Acre			BA (ft^2/acre)			$\bar{x}$ DBH (in)		
	Inject	Inject/ Spray	Control	Inject	Inject/ Spray	Control	Inject	Inject/ Spray	Control
Red Oaks[1/]	29	21	15	52.6	48.6	39.3	16.5	18.5	20.8
White Oaks[2/]	18	20	24	20.7	22.9	24.4	12.9	12.9	12.5
Other Desirables[3/]	27	21	34	8.6	10.0	13.1	7.1	8.5	7.3
Less Desirables[4/]	55	58	55	19.4	18.0	22.0	7.4	6.9	7.9
TOTAL	129	120	128	101.3	99.5	98.8	10.1	10.2	10.2

[1/]Red oaks: cherrybark, Shumard, water, and willow oak

[2/]White oaks: overcup and swamp chestnut oak

[3/]Other desirables: green ash and sweetgum

[4/]Less desirables: American beech, American holly, black cherry, blackgum, eastern hophornbeam, elm, hickory, ironwood, persimmon, red maple, and sugarberry

RESULTS AND DISCUSSION

Regeneration Present Before Treatment

The pretreatment survey showed no significant difference between the number of oaks present on the different plots (Table 2). Many of these oaks were seedlings which had germinated the same year as the plots were installed. Very few of these seedlings survived until the following year or the poor vigor made it doubtful that these seedlings would live very long. There were significantly more seedlings of desirable species in the inject/spray and control plots than in the inject plots. Other desirable species for the purpose of this study are green ash, sweetgum (*Liquidambar styraciflua* L.), and yellow-poplar (*Liriodendron tulipifera* L.). All other species were considered as less desirable due to their low commercial value or because they were off-site. Of the desirable species, green ash comprised a large percentage of the advanced stems. Green ash is the only desirable species found in this study area that is shade-tolerant. There was also a significant difference in the number of less desirable species present before treatments with the inject plots having the highest number and the inject/spray the lowest number. However, the high number of less desirable shade-tolerant species present in all plots reflects a situation which would lead to unsatisfactory regeneration if the stand were clearcut.

Table 2.--Regeneration present before treatments were installed.

Treatment	Number of Oaks/Acre[1/]	Number of Other Desirables[2/]	Number of Less Desirables[3/]
Inject	610 a[4/]	523 b	5,645 a
Inject/ Spray	714 a	1,080 a	3,101 b
Control	732 a	1,115 a	4,356 ab

[1/]Oaks: cherrybark, swamp chestnut, water, and willow oak

[2/]Other desirables: green ash and sweetgum

[3/]Less desirables: American beech, American holly, black cherry, blackgum, deciduous holly, dogwood, elderberry, elm, hickory, ironwood, pawpaw, persimmon, red maple, red mulberry, and sugarberry

[4/]Values that are followed by the same letter indicate no statistical difference at the .05 level.

Effects of Treatments on the Stand

Injection of the undesirable stems removed very little of the total basal area (Table 3). Because of the fairly open nature of the overstory, removal of midstory and understory stems usually created openings large enough for direct sunlight to reach the forest floor.

Effect of Treatments on Establishment and Development of Seedlings

The number of oak seedlings and saplings per acre greater than one year old present in the third year after treatment was significantly increased in the treatment plots (Table 4). Also, the condition of many of the oaks greater than one year old in the control plots is such that it is questionable whether they will be able to survive until the next growing season. Seedlings of other desirable species present three years after treatment were increased on the inject plots while the number of other desirable stems decreased on the inject/spray plots. This difference occurred because all stems were treated with chemicals on the inject/spray plots. Spray application was done in such a manner that both desirable and less desirable stems were treated with chemicals. Virtually all of the stems present on the inject/spray plots were killed whereas stems too small to be injected were not killed in the inject plots. There was a slight drop in the number of other desirable stems in the control plots. Yellow-poplar was practically

Table 4.--Regeneration greater than 1 year old present 3 years after treatments were installed.

Treatment	Number of Oaks/Acre[1/]	Number of Other Desirables[2/]	Number of Less Desirables[3/]
Inject	1,760 a[4/]	1,690 a	4,826 a
Inject/ Spray	1,359 ab	767 b	1,167 b
Control	505 b	923 ab	4,129 a

[1/]Oaks: cherrybark, swamp chestnut, water, and willow oak

[2/]Other desirables: green ash and sweetgum

[3/]Less desirables: American beech, American holly, beauty berry, black cherry, blackgum, deciduous holly, dogwood, elderberry, elm, hawthorn, hickory, ironwood, pawpaw, persimmon, red maple, red mulberry, and sugarberry

[4/]Values that are followed by the same letter indicate no statistical difference at the .05 level.

Table 3.--Number of stems per acre, basal area (ft^2 per acre), and mean dbh (in) of trees greater than 4.0 inches dbh present after treatments were installed (midstory and overstory trees).

	Number of Stems per Acre			BA (ft^2/acre)			$\bar{x}$ DBH (in)		
	Inject	Inject/ Spray	Control	Inject	Inject/ Spray	Control	Inject	Inject/ Spray	Control
Red Oaks[1/]	19	18	15	49.4	47.1	39.3	21.0	22.3	20.8
White Oaks[2/]	8	11	24	17.6	17.0	24.4	19.6	16.9	12.5
Other Desirables[3/]	5	6	34	3.7	5.1	13.1	12.4	13.1	7.3
Less Desirables[4/]	5	3	55	5.6	4.4	22.0	15.0	17.4	7.9
TOTAL	37	38	128	76.4	73.7	98.8	18.9	18.9	10.2

[1/]Red oaks: cherrybark, Shumard, water, and willow oak

[2/]White oaks: overcup and swamp chestnut oak

[3/]Other desirables: green ash and sweetgum

[4/]Less desirables: American beech, American holly, black cherry, blackgum, eastern hophornbeam, elm, hickory, ironwood, persimmon, red maple, and sugarberry

non-existent in the control plots and the few sweetgum that are present are dying back. Also, some of the green ash are showing signs of dieback. The number of less desirable stems remained practically the same in the control plots whereas they increased in number in the inject plots. The less desirable stems in the inject plots came from trees too small to be injected or new seedlings established after the treatments were installed. There was a sharp decrease in the number of less desirable species in the inject/spray plots due to the injection and spraying of all stems. Undesirable stems present three years after treatment of the plots came predominantly from seedlings established after the treatments were installed.

Effect of Treatments on Establishment and Development of New Oak Seedlings

Inject plots had significantly more new oak seedlings which germinated during the three years since treatment than did inject/spray and control plots (Table 5). Part of this increase can be explained by the fact that more herbaceous vegetation is present on the inject plots. Acorn germination was very poor the first year after treatments were installed; thus, very few new oak seedlings were found in any plot. During the winter before the second growing season after treatments were installed, the entire area was subjected to several floods in which the water moved very swiftly across the plots. Many of the new oak seedlings were found in areas where herbaceous vegetation or debris trapped acorns being washed across the plots. Herbaceous weeds and debris also played an important role in the survival of oak seedlings. Very few seedlings of any species were found in areas which were completely devoid of any vegetation or debris. This is probably due to protection of the soil from drying. During the three years since treatment there have been several droughts in which large cracks in the soil were observed. Areas that had herbaceous vegetation or debris covering the soil had few or no cracks in the soil. In all plots, cherrybark oak was the most prevalent of the oak species which germinated.

Table 5.--Number of oaks per acre that germinated after treatments were installed and the number of these new oaks that were greater than 1 year old 3 years after treatments were installed.

Treatment	Number of New Oaks/Acre	Number of New Oaks > 1 yr. old/Acre
Inject	6,081 a[1/]	1,620 a
Inject/Spray	2,997 b	1,254 ab
Control	2,439 b	418 b

[1/]Values that are followed by the same letter indicate no statistical difference at the .05 level.

Even though seedlings in none of the treatments showed outstanding growth, heights of new cherrybark oak seedlings on the inject and inject/spray plots are significantly taller than new cherrybark oak seedlings on the control plots (Table 6). Heights were taken on marked trees at the end of the third growing season after treatments were installed. Also, the vigor of new cherrybark oak seedlings appears to be better in the inject and inject/spray plots than in the control plots. There is not a statistical difference between the heights of other new oak seedlings for the three different treatments. But, there is such a small number of new oak seedlings other than cherrybark oak still alive in the control plots that any statistical analysis does not reflect the differences between plots.

Table 6.--Mean height (cm) for cherrybark oak seedlings which germinated after treatments were installed; measurements taken 3 years after treatment.

Treatment	$\bar{x}$ CBO Height (cm)
Inject	15.41 a[1/]
Inject/Spray	16.95 a
Control	9.60 b

[1/]Values that are followed by the same letter indicate no statistical difference at the .05 level.

CONCLUSION

Control or elimination of vegetation in the lower stories greatly enhances the environment for the development of desirable species and thus increases the possibility of obtaining adequate regeneration before the stand is harvested. One or two year old oak seedlings are not of a size that are most desirable for advanced regeneration, but they have survived better and appear most vigorous in areas where the midstory and understory vegetation was removed. This better performance in treated plots appears to be primarily the result of greater light exposure at the forest floor.

Germination of desirable species other than oak has been low on all plots, but establishment has been higher in the treatment plots than in the controls, and vigor of all seedlings appears much better in the treated plots. Development of less desirable species in the treatment plots has not adversely affected the development of desirable regeneration.

Some areas, where floodwaters flow rapidly across the surface, may be almost devoid of regeneration of any kind. On such areas, it appears that debris and herbaceous vegetation, if not too thick, can be beneficial to the establishment of oak seedlings by trapping the acorns and providing a favorable environment for germination and early growth.

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COMPETING VEGETATION ASSESSMENT SYSTEMS

IN YOUNG SOUTHERN PINE PLANTATIONS[1]

Bruce R. Zutter, Glenn R. Glover, and Dale F. Dickens[2]

Abstract -- Considerations and approaches in the design of a competing vegetation assessment system (CVAS) for use in evaluating southern pine plantations for release are outlined. The Virginia Division of Forestry Free-to-Grow (FTG) classification, a CVAS presently seeing limited use, is presented as an example of a system. Using data from three pine release research studies, the FTG classification is shown to adequately characterize the competitive status of pines prior to release, reflect effectiveness of vegetation control treatments, and relate to post-treatment growth of pines.

INTRODUCTION

Foresters are becoming more aware of the effects of competing vegetation on the growth and yield of southern pines. This increased awareness is largely due to research published within the last ten to fifteen years. The benefits from controlling herbaceous vegetation during the first few years of a stand, either by cultivation or herbicides, have been demonstrated for loblolly (Smith and Schmidtling 1970, Nelson et al 1981, Knowe et al 1985), slash (Baker 1973, Tiarks and Haywood 1981), and longleaf pines (Pessin 1944, Nelson et al 1982). The control of competing hardwood vegetation in young stands of loblolly (Cain and Mann 1980, Clason 1978, Shipman 1954, Minogue et al 1984), slash (Pienaar et al 1983), and longleaf (Michael 1980, Walker 1954) pines had a positive effect on pine growth. Although most of the above mentioned studies give only short term results for young stands, it is reasonable that effects of vegetation control would continue at least until intraspecific competition became a more dominant factor than interspecific competition.

Reduction of hardwoods at an early age in a plantation is extremely important given that in older, established stands there appears to be a disproportionate inverse relationship between pine volume and the percentage of hardwood basal area in the stand. This is illustrated in Figure 1 using data from competition control studies discussed by Langdon and Trousdell (1974) and Haines (1981). The Langdon and Trousdell study examined the effects of three levels of competition control in regenerating a natural loblolly pine stand in the North Carolina Coastal Plain, while the data from Haines is from a prescribed burn - site preparation study in slash pine in the Upper Coastal Plain of Southwest Georgia.

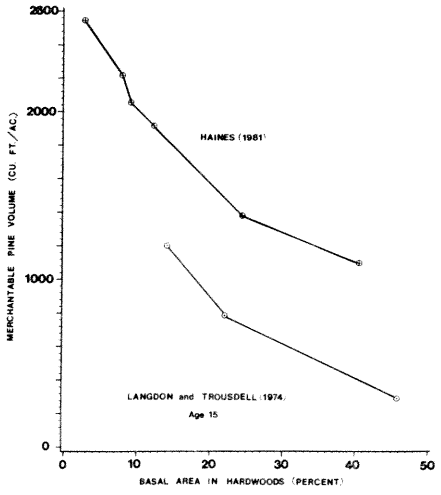

Figure 1.--Relationship between merchantable pine volume and percent of stand basal area in hardwoods for data from two studies examining hardwood competition control.

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[1] Paper presented at the Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2] Research Associate, Assistant Professor, and Graduate Research Assistant, Alabama Agricultural Experiment Station, Auburn University, Auburn University, Alabama 36849.

Recently Burkhart and Sprinz (1984) developed a model for assessing effects of hardwood competition on yields of loblolly pine plantations. Their model exhibits behavior similar to that noted in Figure 1.

With the knowledge that competing vegetation has a negative impact on pine growth, millions of dollars are being spent to treat weed problems in the Southeast. However, this is often done with minimal evaluation or survey of the problems. As a result, foresters have little reliable information on the need for treatment and the effectiveness of their treatments. It is the purpose of this paper to outline considerations in the design of a competing vegetation assessment system (CVAS), and examine the characteristics of a system seeing limited use.

CONSIDERATIONS IN THE DESIGN OF A COMPETING VEGETATION ASSESSMENT SYSTEM

Discussion concerning system design will center on evaluation of competing vegetation for release, the selective control of forest weeds in a stand of crop trees. Similar systems could also be developed for prescription of site preparation and post-planting herbaceous weed control treatments.

Purpose of a System

Development of a CVAS is largely the development of a data collection scheme which may be translated into some meaningful measure of assessment that may be used by management in making decisions.

The objective of a CVAS for pine release is to provide appropriate information such that foresters may:

1. Identify stands that will respond to release (increased survival, growth, etc.)
2. Rank stands based on need for release (probability of stand failure, expected growth loss, stand location, return on investment, etc.)
3. Determine appropriate treatment (method, chemicals, etc.)
4. Monitor short- and long-term effectiveness of treatments.

Desirable Attributes

Ideally, a CVAS must accurately measure the relative position of pines to competing vegetation. This may be done by measuring the relative size and abundance of competitors. However, the CVAS must be practical. Desirable attributes of a system are as follows (Adapted from Wagner (1982) :

1. quick
2. simple to understand
3. require little or no special training
4. some degree of objectivity
5. require no elaborate equipment
6. conducted by one or two people
7. compatible with other operations (i.e. stocking surveys)
8. applicable to different sizes and types of vegetation

A number of approaches may be undertaken which would assess the size and abundance of competing vegetation and yet have most, if not all, of the above desirable attributes.

One approach would be to simply adapt some traditional cruising procedure, such as systematic fixed-radius plot sampling, horizontal or vertical line or point sampling, strip sampling, etc. One would record the species and some measure of size, such as height or crown volume, for each rootstock tallied (hardwood or pine). Decisions concerning release might then be made based on relative size of pines and competing hardwoods, hardwood density, and species composition.

Another approach would involve examining competition around selected trees in a plantation. This tree-centered approach has been used in vegetation management research where detailed measurements of competing hardwood rootstocks are collected within a 6-foot or 2-meter radius circular plot centered on the pine. To be practical for field use a simple tally of crown volumes, rootstock heights or percent ground cover by species within a fixed-area plot might suffice. Wagner (1982) proposed a CVAS similar to this for application in the Pacific Northwest. In testing his system he found an inverse relationship between his measure of competing vegetation, total competitive influence index (TCI), and Douglas-fir tree size (Wagner 1984). He was also able to rank plantations based on their competitive status and determine the percentage contribution by individual species. He did not test his system to determine the efficacy of specific release treatments.

In the Southeast, Dierauf and Garner developed a tree-centered assessment system that has been used since 1971 in the State of Virginia to assess the need for release and evaluate subsequent treatments (Appendix). Since 1980 their system, known as the Virginia Division of Forestry (VDF) Free-to-Grow Classification, has been applied in cooperative pine release herbicide research studies between Auburn University and forest industry. It will be used as an example of a CVAS which may be used in making decisions concerning pine release.

- AN EXAMPLE -
VDF FREE-TO-GROW (FTG) CLASSIFICATION

Classification Description

In the VDF FTG classification, a pine seedling is placed into one of four classes based on a somewhat subjective determination of its potential for: (1) capturing a place in the crown canopy, and (2) diameter growth up to the time of crown closure. Classes are determined by the size and vigor of pine seedlings relative to the size, vigor and species of nearby hardwoods (and pines). These classes may be briefly defined as follows:

- Class 1 - Free-to-grow without significant hardwood competition. No shading from hardwoods above midpoint of pine stem.
- Class 2 - Judged to be free-to-grow, <u>but</u> experiences side shading from hardwood competition above the midpoint of the total height of the tree.
- Class 3 - Questionable tree. Without release, 10 to 90 percent of these pines will not capture a place in the crown canopy.
- Class 4 - Not free-to-grow. Under a 10 percent chance of gaining crown canopy position (i.e. suppressed).

A more detailed description of the classification is given in the Appendix. The classification involves a certain amount of subjectively, yet it has most of the desirable attributes previously mentioned.

Data

Data used to illustrate the FTG classification were taken from three pine release studies established in the fall of 1980 and the spring of 1981. Study site descriptions, etc. are given in Table 1. Detailed pine and hardwood measurements, including FTG, were made just prior to herbicide application, and one and two growing seasons after application. Post-treatment evaluations were made in late summer or early fall.

Study Results

At all three locations a decrease in pre-treatment pine height was observed as FTG class, and hardwood competition increased (Figure 2). This relationship should be characteristic of a good CVAS. This negative relationship between tree size and hardwood competition is not surprising as there is a positive relationship between present levels of competition and the amount of competition a pine has experienced in the past.

An additional characteristic of a good CVAS is the ability to detect treatment effects. A greater positive change in the percentage of free-to-grow pines (class 1) at the end of the first and second growing seasons following treatment was observed across all locations for pines receiving herbicide treatments (Table 2). Examination of detailed hardwood density data indicated that there was an inverse relationship between the change in the proportion of pines moving into class 1 and the change in hardwood density. Changes in hardwood density on herbicide treated areas relative to check areas were much less at location B than at the other locations, which is reflected in the smaller change in class 1 pines.

Provided there is no significant herbicide damage to the pines, changes in FTG for a given pine should, over a period of time, result in greater growth had that tree maintained or decreased its competitive position. This was examined for the three locations by computing the mean height growth during the two growing seasons following herbicide application for pre-treatment and one growing season post-treatment FTG values on plots receiving herbicide treatment. Results were largely as expected, with growth of pines being related to pre-treatment and post-treatment values of FTG (Figure 3; height growth values given are for FTG combinations where 20 or more pines were observed).

For trees maintaining the same competitive status or FTG class (dark hatched bars), growth increased as pines were more free to grow. Pines experiencing a positive change in FTG exhibited greater growth than trees remaining in the same class, while a negative change in FTG resulted in less growth. For example, at location B for pines prior to treatment falling in FTG class 2, those which moved up to class 1 grew 6.0 feet, those remaining class 2, 5.6 feet, and those which moved down to class 3, 5.2 feet.

In general, growth of pines having the same FTG class one growing season after treatment was inversely related to the FTG class prior to treatment. For example, at location B height growth of trees in FTG class 2 one year after treatment was 6.5, 5.6, 5.2 and 5.0 for pre-treatment classes 1 through 4, respectively.

Provided the species of major competitors of each evaluated pine are recorded, the FTG classification can provide the forester with adequate data on which decisions concerning pine release can be made. One possible drawback of the system is its subjectivity, particularly if several different individuals are making assessments. There is no published work that has shown this to be a problem.

Table 1.--Study site descriptions for pine release studies from which VDF Free-to-Grow data were taken.

	Location		
	A	B	C
Cooperator	Scott	Tennessee River	Westvaco
Location	Pine Level, AL	Houston, MS	Buckingham Co., VA
Study Type	Velpar rate and formulation	Velpar rate and formulation	Roundup rate
Treatment Date	April 8, May 11, 1981	March 27, 1981	August 29, 1980
Mean pine height at treatment (ft.)	4.9	8.1	3.2
Mean hardwood height at treatment (ft.)	4.8	5.9	4.3
Pine age at treatment	4	5	3

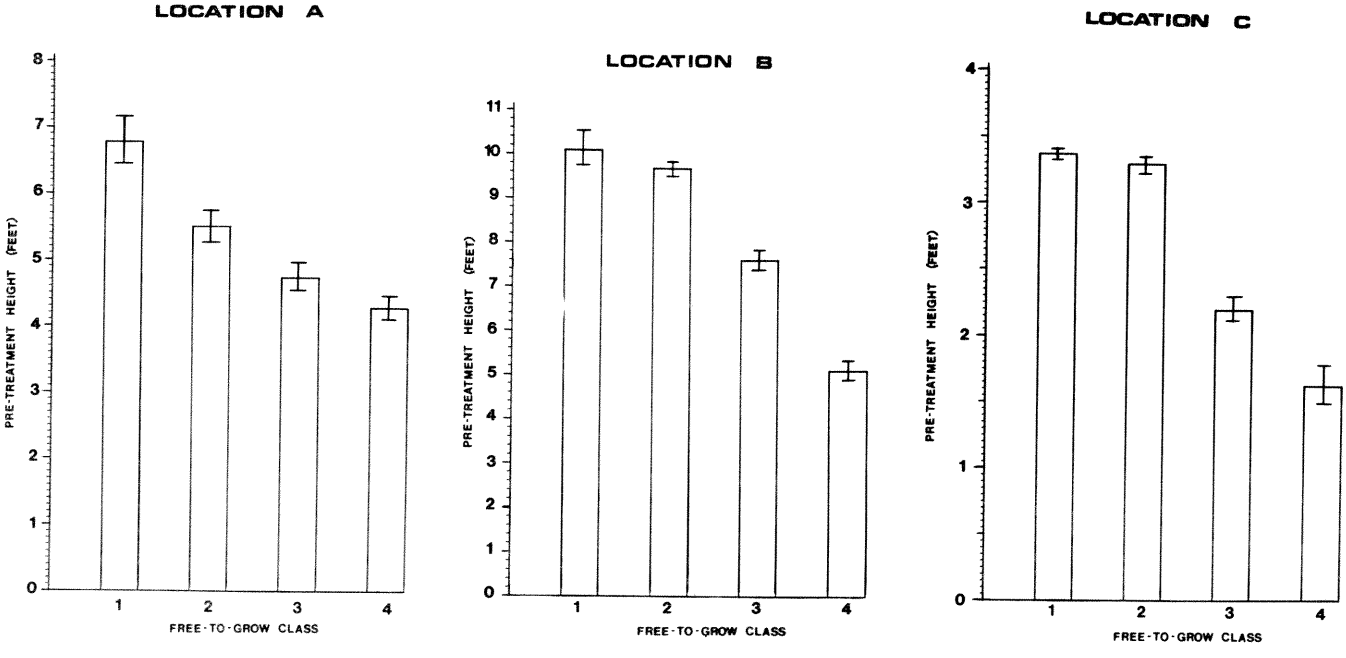

Figure 2.--Mean height (feet) by pre-treatment free-to-grow classes for each location (brackets give plus or minus twice the standard error).

Table 2.--Initial distribution of Free-to-grow classes and change in distribution one and two growing seasons following herbicide application date for check and herbicide treated areas.

Location	FTG Class	Pre-treatment Distribution Check (percent)	Pre-treatment Distribution Treated (percent)	Distribution Change by Growing Seasons after Treatment[1/] 1 Check (percentage points)	1 Treated (percentage points)	2 Check (percentage points)	2 Treated (percentage points)
A	1	13	14	+11	+39	+15	+43
	2	15	24	+ 3	-11	+ 5	0
	3	22	22	+ 1	0	+ 2	- 9
	4	49	40	-14	-28	-21	-34
B	1	8	8	+12	+19	FTG not collected	
	2	48	43	- 1	0		
	3	26	26	- 5	- 9		
	4	18	23	- 6	-10		
C	1	35	32	-21	+25	-28	- 2
	2	60	61	+18	-21	+20	+ 3
	3	4	6	+ 2	- 4	+ 5	- 1
	4	1	1	+ 1	- 1	+ 4	+ 1

1/ Values given represent differences in the percentages of pines falling within a given class prior to treatment and 1 or 2 growing seasons after treatment. (i.e. class 1 pre-treatment percentage of 10 and 1 year post-treatment percentage of 50 represents a (50-10) or a +40 percentage point change.)

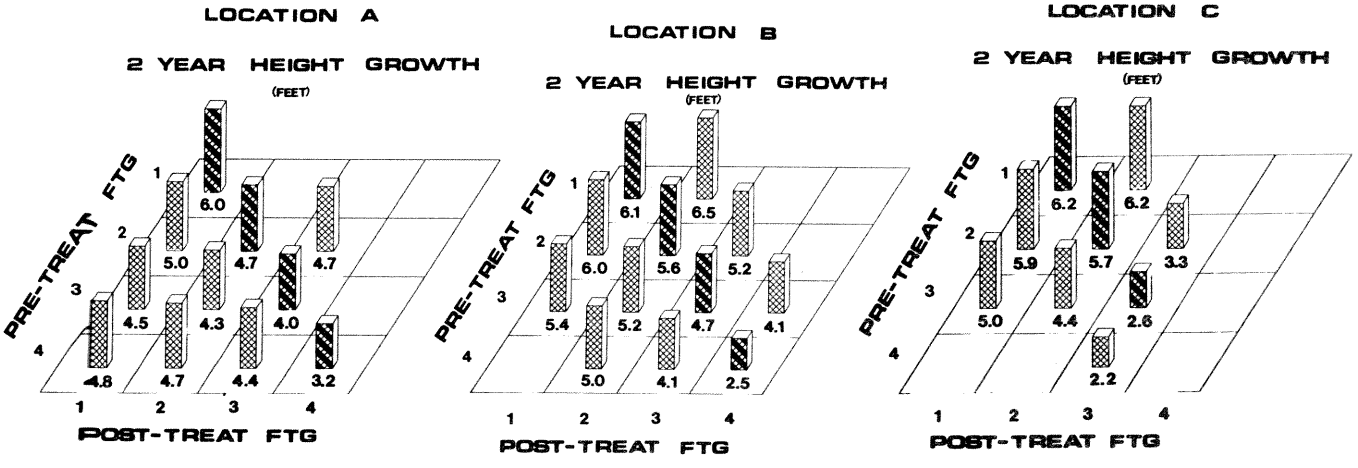

Figure 3.--Height growth (feet) during two growing seasons following herbicide treatment by pre-treatment and one growing season post-treatment free-to-grow (FTG) values.

Within organizations currently using this system, only a few individuals conduct evaluations which reduces potential problems due to subjectively.

Based upon data from a 24 year-old site preparation study near Fayette, Alabama (Whipple and White 1965), it appears that differences in pine size and growth for various FTG classes noted at the time of release or one or two years following release may continue throughout a rotation. At the end of six growing seasons each tree in the study was assigned to a vigor class, a classification scheme very similar to the VDF FTG. Each tree was located in a manner so that its identity could be maintained. After the twenty-fourth growing season the pines were remeasured.

A summary of selected treatments is given in Table 3. Trees at age six assigned to the excellent vigor class, similar to FTG class 1, had greater 24-year diameters than those in other classes, while those in the poor class had the smallest 24-year diameters.

Table 3.--Mean tree DBH in 1982 for 24-year-old planted loblolly pine by vigor class at age six and treatment, Fayette site preparation study, Fayette, Alabama.[1]

Treatment	Vigor class at age six: Excellent	Good	Fair	Poor
	DBH in inches			
Cut and Girdle	8.2	7.1	8.0	4.6
Injection	8.5	6.0	6.7	5.4
Frill and Poison	8.1	7.2	7.6	5.5
Bulldozed	8.1	5.8	8.0	6.0

[1] See Whipple and White (1965) for descriptions of treatments and vigor classes.

SUMMARY AND CONCLUSIONS

In order to more adequately determine whether to release a stand of young southern pines a forester needs a competing vegetation assessment system to provide information in order to determine the need for release, prioritize stands for release, determine appropriate treatment, and monitor short- and long-term effectiveness of treatments. Such a system needs to be simple, quick in application, require no special training, no elaborate equipment, be conducted by one or two people, compatible with other operations, applicable to various vegetation types, and has some degree of objectivity. The Virginia Division of Forestry Free-to-Grow (FTG) Classification is one system which meets many of these criteria. Although the FTG Classification is subjective, in research studies it has been shown to adequately characterize the competitive status of pines prior to release, reflect effectiveness of vegetation control treatments, and relate to subsequent growth of pines.

Additional work is being done at Auburn to evaluate somewhat less subjective approaches to competing vegetation assessment. Current research is evaluating modifications of the tree-centered approach upon which the VDF FTG Classification is based.

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APPENDIX

Free-To-Grow Classification

T. A. Dierauf and J. W. Garner,
Virginia Division of Forestry

We are using four classifications to describe a pine seedling's potential for: (1) capturing a place in the crown canopy, and (2) diameter growth up to the time of full crown closure. These classes are determined by the size and vigor of the pine seedlings compared to the size, vigor, and species of nearby hardwoods (and pines). This system can be used for pine reproduction of any age prior to full crown closure. Larger residual hardwoods are not considered; they should be eliminated during site preparation. Also, root competition from hardwoods is not considered.

Class 1.

Free-to-grow without significant hardwood competition. Class 1 trees are judged to have better than a 90 percent chance of capturing a place in the crown canopy. Release will not benefit these trees.

Class 2.

Also free-to-grow, but with more hardwood competition than class 1 seedlings. Most of the hardwood competition is side shading. Like class 1 trees class 2 trees are judged to have better than 90 percent chance of capturing a place in the crown canopy. The separation into class 1 or class 2 is arbitrarily based on whether nearby hardwoods can throw shade above the midpoint of the pine seedling. The method for determining height of shading is to measure the total height of the hardwood, then rotate a straight line of that length from the base of the hardwood to the point where it touches the pine stem (in practice, the hardwood is usually bent over). If this point is below one half the total height of the pine, the pine is class 1. If above one-half the total height of the pine, the pine is class 2. Release will benefit class 2 pines primarily by increasing diameter growth.

Class 3.

Questionable trees, judged to have between a 10 percent and 90 percent chance of capturing a place in the crown canopy. Even for pine which eventually make it into the crown canopy, competition will greatly reduce diameter growth. It is assumed that without release, half of these pines will not capture a place in the crown canopy.

Class 4.

Not free-to-grow. Judged to have less than a 10 percent chance of capturing a place in the crown canopy because of suppression by overtopping hardwoods (or pines). Release will benefit class 4 trees only at very young ages (see notes below).

Notes:

1. In deciding whether a seedling is class 1 or 2, side shading by nearby pines is not considered (release from hardwoods would have no effect on such competition).

2. Overtopping or potential overtopping by nearby pines however, must be considered if it will prevent a seedling from capturing a place in the canopy. In other words, a seedling can be class 3 or 4 because of competition from nearby pine.

3. In deciding whether a seedling is class 2 or 3, or class 3 or 4, the vigor of the seedling is often as important as the amount of hardwood competition. The previous year's leader growth and the length and density of the needles are indicators of vigor.

4. Class 4 seedlings cannot be released successfully after age 2 or 3, in most cases, because nearby class 1 and 2 seedlings will usually be so much taller that they will often suppress them. For the same reason, class 3 seedlings can not be released successfully after age 3 or 4, in most cases.

LOBLOLLY AND SHORTLEAF PINE DIFFER IN THEIR RESPONSE WHEN RELEASED USING HERBICIDE SPRAYS[1]

Richard W. Guldin[2]

Abstract.--A 60-acre uneven-aged natural stand of mixed loblolly and shortleaf pine (Pinus taeda L. and P. echinata Mill.) was operationally sprayed with 2 pounds active ingredient per acre of 2,4,5-T in 1955 to release understory pine seedlings from competing hardwoods. Surviving trees were sampled in 1982 to reconstruct diameter and volume growth and to develop an individual-tree growth response model. Young loblolly pine trees had grown an extra 1.42 inches in dbh by 1965 than if they had not been released, and taper decreased sufficiently to increase volume an additional 6 to 8 percent, depending on the log rule used. Shortleaf pine had responded with smaller diameter increments. Shortleaf pine also decreased in taper, but the volume changes induced were insignificant. Diameter response differed significantly by diameter class for both species.

INTRODUCTION

The loblolly pine-shortleaf pine (Pinus taeda L. and P. echinata Mill.) cover type is the most widespread of all the southern forest types (Mann 1980). Both pines are shade intolerant species whose growth is adversely affected by competition provided by their common hardwood associates--oaks (Quercus spp.), gums (Nyssa spp. and Liquidamber styraciflua L.), and hickories (Carya spp.) (Baker and Balmer 1983, Lawson and Kitchens 1983). For example, Grano (1979) reported that small hardwoods in the understory of a 47-year-old loblolly pine-shortleaf pine stand reduced cubic-foot volume growth by 43 percent and board foot volume growth by 59 percent.

Until the 1950's, hardwood control programs in established pine stands were very labor-intensive and time-consuming, because each tree had to be individually treated. Cut-stem treatments were applied using a variety of tools and techniques. Chemicals, such as ammonium sulfamate, were occasionally sprayed on the cuts or injected into frills hacked in the bole of each tree. When 2,4,5-T [2,4,5-(trichlorophenoxy) acetic acid] and Silvex [2-(2,4,5-trichlorophenoxy)propionic acid] became available to release pines from broadleaf competition, treatment costs declined. These chemicals could be broadcast inexpensively, eliminating the need to treat individual trees. Chemical application rates could be adjusted so that broadleaf vegetation was killed or severely stunted while the pines were undamaged or only mildly stunted.

Today, chemicals for pine release are no longer inexpensive, and costs for broadcast application by helicopter are rising. Forest managers must take into account possible differences in the response to release among tree species and sizes when evaluating potential release investments. The purpose of this paper is to report the response of an uneven-aged stand of loblolly and shortleaf pine to a broadcast chemical application. Forest managers can use the response data presented to help evaluate whether releasing their particular stands will be profitable.

DATA AND ANALYSIS

A 60-acre mixed loblolly and shortleaf pine stand located in north-central Louisiana had been released in 1955. The stand was on a north-facing slope that had seeded naturally to pine around the turn of the century after cotton farming was abandoned. Irregular harvests led to the establishment of several different pine age classes. By 1950, pines comprised the dominant and codominant crown classes with oaks, hickories, gums, elms (Ulmus spp.), ash (Fraxinus spp.) and red maple (Acer rubrum L.) joining pines in the intermediate canopy and understory. Shortleaf pine was the principal pine species at the top of the slope, growing on a Shubuta fine sandy loam. Shortleaf pine merged into loblolly pine at midslope as the soil changed to a wetter Kirvin gravelly fine sandy loam, which continued into a stream bottom

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2/ Principal Economist, USDA, Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana.

at the foot of the slope. The site is typical of many upland, rolling sites found in the Upper Coastal Plain throughout the South.

A wildfire in 1950 had consumed most of the understory of pine and hardwood seedlings, saplings, and small poles. Although new pine seedlings germinated prolifically on the exposed mineral soil, hardwood rootstocks resprouted vigorously and gained a dominant position. In 1955, the land manager decided to release the pine seedlings by applying 2 pounds active ingredient per acre of 2,4,5-T using a tractor-mounted mist-blower; this gave excellent control of hardwoods less than 35 feet tall.3/ No fires have burned on the site since 1955. The only other silvicultural treatment was a thinning in 1974 that removed a portion of the pine sawtimber.

When measured in August 1982, the stand contained an average per acre volume of 4,400 board feet Doyle with a basal area per acre of 68.5 square feet (table 1). Site index, base age 25, was 58 feet for loblolly and 47 feet for shortleaf. Heights and diameters were measured and increment cores were taken from 143 loblolly and 176 shortleaf pines. Twenty representative pines (based on the dbh distribution of all pines) were felled and sectioned to estimate height growth and change in bole taper.

Based on limited information from prior studies, research foresters studying herbicide effects have hypothesized that southern pines respond to release by increasing diameter growth for approximately 5 years. After this response period, and in the absence of other silvicultural treatments, rate of growth falls back to pre-spraying levels.4/ Consequently, periodic increments were measured for 5-year periods and data analyses constructed to test whether or not a response existed the first 5 years after spraying, 1955-59, and whether or not the response, if one existed, had ended by 1959 or continued into the second 5-year period after release, 1960-64.

Data analysis proceeded in the following steps:

1). Calculation of diameter growth rate for each tree. Periodic diameter increments were determined from increment cores by measuring the widths of annual rings for 5-year periods (1950-54, 1955-59, 1960-64, 1965-69, 1970-74, and 1975-79) to the nearest 0.025 inch.

2). Establishment of a diameter growth trend for "no-treatment" time periods. Based on the hypothesis of a 5-year response period, diameter growth was summarized by diameter class for the periods when no response was expected (1950-54, 1965-69, 1970-74, and 1975-79). This trend was used to project diameter growth backwards assuming an absence of treatment for the 1960-64 period, when continued response to release was questionable, and the 1955-59 period, when a response was expected. The no-treatment diameter growth trend was tested for sensitivity to variation in rainfall by time period and dbh size (also a surrogate for age).

3). Calculation of the diameter response to spraying for an individual tree. This was the difference between projected no-treatment diameter increment and actual diameter increment for 1955-64. Responses were calculated by diameter class.

4). Evaluation of possible height and form class differences for treated stands.

5). Estimation of volume differences. The diameter, height, and form class differences were combined to estimate volume response to spraying.

Detailed methodology for analyzing the data, appropriate statistical tests and investment analyses employing the results are available from the author.

Table 1.-- Average stand basal area and volume per acre in 1982 1/

	Basal area	Volume2/	
		International	Doyle
	-square ft -	------board feet------	
Loblolly Pine	13.0	2,538	1,172
Shortleaf Pine	16.0	4,298	2,159
Mixed Oaks	28.4	1,592	898
Other Hardwoods	11.1	286	145
	68.5	8,714	4,374

1/ Based on 110 plots established on a 2- by 2-chain spacing.
2/ International 1/4-Inch Rule calculates volume in trees 6 inches dbh and larger to a 4 inch top. Doyle Rule calculates volume in trees 10 inches dbh and larger to a 4-inch top.

RESULTS

Diameter Growth

For both species, average periodic diameter increment, calculated from increment cores, was significantly greater the first 5 years after spraying (1955-59) than any other 5-year period (table 2). The 1960-64 average periodic increment was also significantly greater than increments for all subsequent periods for both species. Consequently, most of the diameter growth response occurs the first 5 years after treatment, but some response was still seen the second 5 years. This finding conflicts with the hypothesis, based on

3/ William Henderson, T.L. James Co., Ruston, La., personal communication. Henderson was the forester in charge of the release operation.

4/ J.D. Haywood, T.E. Campbell, and J.L. Michael, Southern Forest Experiment Station, New Orleans, La.; R.H. Neill, Velsicol Chemical Company, Marietta, Ga.; and T.R. Clason, Louisiana Agricultural Experiment Station, Homer, La.

Table 2.-- Average periodic diameter increments

Period	Diameter Increment	
	Loblolly	Shortleaf
	---------inches---------	
1950-54	1.55 c1/	1.37 b
1955-59	2.29 a	1.65 a
1960-64	1.78 b	1.25 b
1965-69	1.56 c	1.06 c
1970-74	1.50 c	1.02 c
1975-79	1.26 d	0.89 c

1/Increments followed by the same letter are not significantly different at the 0.01 level.

limited information from prior studies, that response lasts approximately 5 years. Ongoing studies should be monitored for at least 10 years after release to measure the full diameter growth response to release in both loblolly and shortleaf pine. Economic decisions based on increased growth for only 3 to 5 years after release are based on only a part of the total dollar benefits.

Because the area was operationally treated, as opposed to a planned study with controls, an unsprayed "check" area was not available. To estimate pine growth in the absence of release, data pairs [dbh at the start of the period, diameter increment during the period] for the 5-year periods with no apparent response to herbicide release (1950-54, 1965-69, 1970-74 and 1975-79) were pooled into separate data sets for loblolly and shortleaf pine. There were 452 data pairs for loblolly and 513 pairs for shortleaf pine. There was no significant difference (0.05 level) in rainfall quantity among periods, so the data were unaffected by possible variations in soil moisture. Each data set was then divided into diameter classes (less than 6 inches, 8 inch, 12 inch, 16 inch, and 18 inches or greater), and average periodic diameter increments were calculated for each diameter class. Then these average "no-treatment" increments were compared class by class to the average increments for the 1955-59 and 1960-64 periods. Duncan's New Multiple Range Test (Duncan 1955, Kramer 1956) was used to evaluate whether differences in average diameter increment among dbh classes were significant. Test results showed significant differences not only among the 1955-59, 1960-64, and no-treatment periods for each dbh class, but also response differences among dbh classes within each time period. Consequently, the trees were grouped into three diameter categories: less than 10 inches dbh, 10 to 14 inches dbh, and greater than 14 inches dbh (table 3). The mean diameter growth response to release for each category was calculated as the sum of the 1955-59 and 1960-64 increments minus twice the no-treatment increment (table 4).

Table 3.--Average diameter increments by diameter class and period

DBH class	Loblolly 1955-1959	Loblolly 1960-1964	Loblolly No-trtmt1/	Shortleaf 1955-1959	Shortleaf 1960-1964	Shortleaf No-trtmt
	----------inches----------					
< 10	2.43a2/	2.05b	1.53d	1.91a	1.36c	1.27c
10-14	2.12a	1.72b	1.53bd	1.70b	1.30c	1.18c
> 14	2.16a	1.56c	1.35e	1.67b	1.25c	1.04e

1/The average diameter increment for the no-treatment time periods for each dbh class.
2/Within each species, increments followed by the same letter across rows or within columns are not significantly different at the 0.05 level.

Table 4.--Average diameter growth response to release

DBH class	Loblolly pine	Shortleaf pine	Difference between species
	----------inches----------		
< 10	1.42	0.73	0.69
10-14	.78	.64	.14
> 14	1.02	.84	.18

Volume Growth

The data from the felled trees were analyzed to determine whether a height response to spraying also occurred, but none was found for either pine species. Taper changes were estimated by comparing diameter increments at the base of the 1982 live crown with the diameter increments at breast height. For loblolly pine, diameter growth, inside bark, at the base of the live crown averaged 0.71 inches greater than projected from diameter response at breast height. The average increase was 4.7 percent of the average inside bark diameter at the base of the live crown. This decline in bole taper results in volume increases of 6.4 percent International 1/4-Inch Rule or 8 percent Doyle Rule. These volume increases are equivalent to an increase of two form class units (Mesavage and Girard 1946). For shortleaf pine, the small taper change present induced an insignificant (0.05 level) volume difference, and was therefore ignored. Increased diameter growth is totally responsible for the shortleaf volume increment due to release.

DISCUSSION

Pine dbh at time of spraying varied from 1 to 22 inches. Analysis of increment cores demonstrated that the pines from 1 to 10 inches (40 percent

of the total number) were younger, having been established after the 1950 wildfire. Pines between 10 and 14 inches (40 percent of the total number) were in the intermediate crown class at time of spraying, hence were older than the trees less than 10 inches dbh. Pines greater than 14 inches dbh (20 percent of the total) were the oldest, with the dominant and co-dominant trees being essentially even-aged. Consequently, the three diameter class categories used to group mean diameter response also represent a stratification by age.

Loblolly pines less than 10 inches responded the best of all diameter classes, adding nearly twice the diameter increment of shortleaf pine the same size. Pines in the 10 to 14 inch and greater than 14 inch categories showed little difference in diameter increment between species. Williston (1978) noted that loblolly pine can be expected to increase its proportionate share of a mixed loblolly-shortleaf pine stand when it is placed under management. The difference in diameter increment added to small (young) pines after release bears out Williston's contention. The results also suggest that if a manager has several young stands in need of release and a limited release budget, the stands with the highest proportion of loblolly pine should be released first. Because loblolly and shortleaf pine logs are direct substitutes in stumpage markets, treating the stands with the most loblolly pine first will maximize harvest returns.

The low response by pines of both species in the 10 to 14 inches dbh class is not surprising, given that the stand had essentially three stories to the canopy at time of spraying, and the treatment proved most effective in killing hardwoods less than 35 feet tall. The 10 to 14 inch diameter class represents pines that were competing with hardwoods in the intermediate crown class at time of spraying. The spray did not rise high enough to significantly affect 40- to 60-foot hardwoods in the intermediate canopy. Consequently, the pines in that stratum still faced considerable competition for light, even though root competition from understory hardwoods was diminished.

Pines greater than 14 inches dbh at the time of spraying, occupying dominant and co-dominant crown positions in the overstory, were apparently relieved of enough root competition from hardwood saplings and small poles in their immediate proximity to respond 25 percent better than pines in the intermediate canopy. Because of their crown position, competition for light was never a problem. Shortleaf pine response was best in this diameter class.

The size of the response for pines greater than 14 inches suggests that investments in releasing older shortleaf or loblolly pine stands may provide better financial returns than previously suspected. Treatments applied 8 to 10 years prior to harvest would not only provide additional pine stumpage volume, the return on the release investment would be realized much sooner than an investment in the release of a young stand that would not be harvested for at least 15 years. If older mixed pine-hardwood stands are treated prior to harvest, many of the expensive competition control measures normally employed after harvest to prepare the site for regeneration may not be necessary. When both an existing stand and a future stand benefit from the same silvicultural treatment, this has some federal income tax implications. For tax accounting purposes, the cost of the release treatment must be split between the stands in proportion to the benefit each obtains. The costs attributable to release can be deducted from current ordinary income, which is typically taxed at a much higher rate than long-term capital gains. The remaining portion of the release cost attributable to site preparation must be capitalized and offset against long-term capital gains at the time when the future stand is harvested. Long-term capital gains--for individual taxpayers --are effectively taxed at only 40 percent of the ordinary income tax rate. The single exception to this statement is for the first $10,000 of reforestation expenses, which can be amortized over 8 tax years. Because larger shortleaf pine responded better than expected, more of the release costs can be attributed legitimately to release than previously thought possible. These tax implications make releasing older stands, especially shortleaf pine, even more economical.

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COMPARISON OF LIQUID AND SOLID HEXAZINONE FORMULATIONS FOR PINE RELEASE[1/]

P. J. Minogue, B. R. Zutter, and D. H. Gjerstad[2/3/]

Abstract -- Velpar L and 1/2 cc Velpar Brush Killer pellets were tested at 4 rates at each of 5 study locations for release of loblolly pine (Pinus taeda L.). Efficacy of the two formulations was greatly influenced by soil texture. Where percent sand was more than 60 percent hardwood density reduction was greater for the pellet, while the liquid formulation was most efficaceous for more finely textured soils. Pine tolerance to herbicide treatments was influenced by soil texture, herbicide rate and plantation age. Pine height growth 3 to 15 months after treatment was greater for the liquid formulation.

INTRODUCTION

With the suspension of 2,4,5-T in 1979 there was an immediate need to develop new pine release herbicides. Foliar sprays of hexazinone had demonstrated good tolerance to newly planted pines and broad spectrum herbaceous weed control (O'Loughlin et al. 1976). Rangeland trials established in 1975 and 1976 showed herbicide tolerance for shortleaf pine at rates of hexazinone which provided good levels of hardwood kill (Nickels and Stritzke 1977). Early forestry trials with hexazinone in 1976 involved the use of pellets (Gonzalez 1980) and liquids (Newbold 1978) applied in a grid pattern to the soil surface. This grid concept had evolved from findings of studies dating back to the 1950's involving substituted urea herbicides (Meadors et al. 1956, Darrow 1960, Miller et al. 1967, and Peevy 1971). Forestry tests in the early 1960's with the substituted urea Dybar demonstrated more effective hardwood control when applied in concentrated spots in a grid pattern than for equal rates in broadcast applications (Gonzalez 1980). The triazine herbicide hexazinone, like the substituted urea herbicides, is a photosynthetic inhibitor with soil activity. It was believed that concentrating hexazinone in a grid pattern would be most efficaceous and the 2 cc Velpar Gridball was developed for this use.

Two problems commonly encountered with applications of the 2 cc Velpar Gridball for pine release were pine mortality when pellets were placed adjacent to pines and poor control of small hardwoods with limited root systems. Several solid hexazinone formulations have been tested since 1979 (Gonzalez 1983). The 1/2 cc 10% active ingredient pellet has been the most effective pelleted formulation with respect to hardwood control and pine tolerance (Michael 1981, Webb et al. 1981, Minogue et al. 1982, Gonzalez 1983). In the spring of 1982 a commercial 1/2 cc 10% hexazinone product became available but the manufacturer withdrew this formulation due to economic constraints in the summer of 1983. A granular hexazinone formulation, Pronone 10G, became available for commercial use in five Southern states under state Special Local Need (24-C) labels in the spring of 1983, and received Environmental Protection Agency registration in the late summer of 1983. When properly applied, the granular formulation evenly distributes the herbicide on the soil surface which provides better pine tolerance and effective hardwood control - particularly for small hardwoods with limited root systems (Lowery 1984).

Recent research has investigated the use of broadcast foliar sprays of Velpar L, a liquid formulation (Campbell 1982, Minogue et al. 1983, Griswold et al. 1984). The liquid formulation provides both foliar and soil activity when applied as a broadcast spray. Mixed results have been reported for broadcast foliar sprays of hexazinone. Campbell (1982) reported poor hardwood control for broadcast sprays at rates as high as 2.5 lb ai/A on a site with loamy fine sand to silt loam soils. Results on sandy clay loam soils were more promising (Griswold et al. 1984).

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[2/]Research Associate, Research Associate, and Associate Professor, Alabama Agricultural Experiment Station, School of Forestry, Auburn University, Alabama 36849.

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This paper presents results of hardwood control and pine tolerance obtained with broadcast sprays of liquid hexazinone and soil applications of 1/2 cc 10% hexazinone pellets at various rates over a range of soil textures. Although the 1/2 cc 10% hexazinone pellet is no longer available, results of this study provide a valuable comparison of the liquid formulation, a product having both foliar and soil activity, and a solid formulation which is active only through root absorption.

METHODS

Velpar L and 1/2 cc Velpar Brush Killer pellets were tested at 4 rates at each of 5 study locations for release of loblolly pine (Pinus taeda L.) (Table 1). A prescription rate (x) was assigned to each study location based on the results of soil textural analyses and plantation age. The liquid and pelleted formulations were tested at the x, 0.6x, 1.4x and 2.0x rates. Velpar L was applied as a broadcast foliar spray using a CO_2 pressurized backpack sprayer which gave a 30 ft swath width. Pellets were applied by hand in a square grid pattern. Pellet spacing was adjusted to obtain the various herbicide rates. Treatments were assigned in a randomized complete block design and replicated four times at each location. An untreated check was included in each replication except for the North Carolina site.

Treatment plots were 30 x 150 ft with a minimum 10 ft buffer between plots. Pine and hardwood evaluations were conducted in August following spring herbicide applications and in August the following year. All pines within a 10 x 130 ft pine measurement plot centered in the treatment plot were tagged and measured for total height, diameter at 6 inches above ground line, herbicide damage code and the Virginia Division of Forestry Free to Grow Classification developed by T. A. Dierauf and J. W. Garner (unpublished). Hardwoods were evaluated in six 6.5 ft radius circular hardwood measurement plots centered on randomly selected pines within the pine measurement plot. Hardwoods were evaluated for species, life form, height class, herbicide symptom code and percent defoliation.

Pine height growth data were analyzed through analysis of covariance. Pine mortality data were analyzed through analysis of variance. Duncan's New Multiple Range Test was used to compare individual treatment means at a significance level of 5 percent (alpha = 0.05).

RESULTS AND DISCUSSION

Hardwood Control

Percent change in hardwood density and percent pine mortality obtained with liquid and pelleted hexazinone formulations at the five study locations are presented in Figure 1. For a given soil texture hardwood control increased with increasing herbicide rate, either in a linear fashion or at a decreasing rate. Soil texture influenced hardwood control obtained with the liquid formulation relative to the pelleted formulation. The liquid formulation provided greater hardwood control than equal rates of the pellet for the site with clay texture. Conversely, for the two sites with loamy sand texture the pelleted formulation resulted in greater hardwood control than equal rates of the liquid. For the sites with soil texture intermediate to clay and loamy sand equal rates of liquid and pelleted hexazinone produced similar results in hardwood control.

Hexazinone is adsorbed by clay and organic colloids and chemical hydrolysis is an active mechanism of triazine degradation in acid conditions (Armstrong et al. 1967). For the clay soil the broadcast spray of the liquid formulation may have been more efficaceous than application of the pellets to the soil because the liquid formulation has both foliar and soil activity while the pelleted formulation is absorbed only through root uptake. Adsorption by clay colloids and chemical degradation is likely to render much of the herbicide applied to a clay soil unavailable for uptake by the roots of undesirable hardwoods. Leaching of the herbicide is expected to greatly influence hardwood control on sandy soils. Better hardwood control obtained with the solid formulation on loamy sand soils is likely a result of slow release characteristics.

Table 1.--Location, soil series, soil texture, plantation age and herbicide rates for five study locations.

Location	Soil Series	Soil Texture	Plantation Age (Yrs.)	Herbicide Rates 0.6x	x	1.4x	2.0x
				- - - - -(lb. ai/A)[1]- - - -			
Bellamy, AL	Lufkin	Clay	2-3	1.1	1.9	2.5	3.8
South Hill, VA	Cecil-Appling	Sandy Clay Loam	2	0.9	1.5	2.0	3.0
Rockingham, NC	Lockhart	Sandy Loam	4	0.8	1.3	1.7	2.6
Cuthbert, GA	Lucy	Loamy Sand	4	0.6	1.1	1.6	2.2
Prattville, AL	Rustin	Loamy Sand	3	0.6	1.1	1.6	2.2

[1] Herbicide rates are expressed in pounds active ingredient per acre.

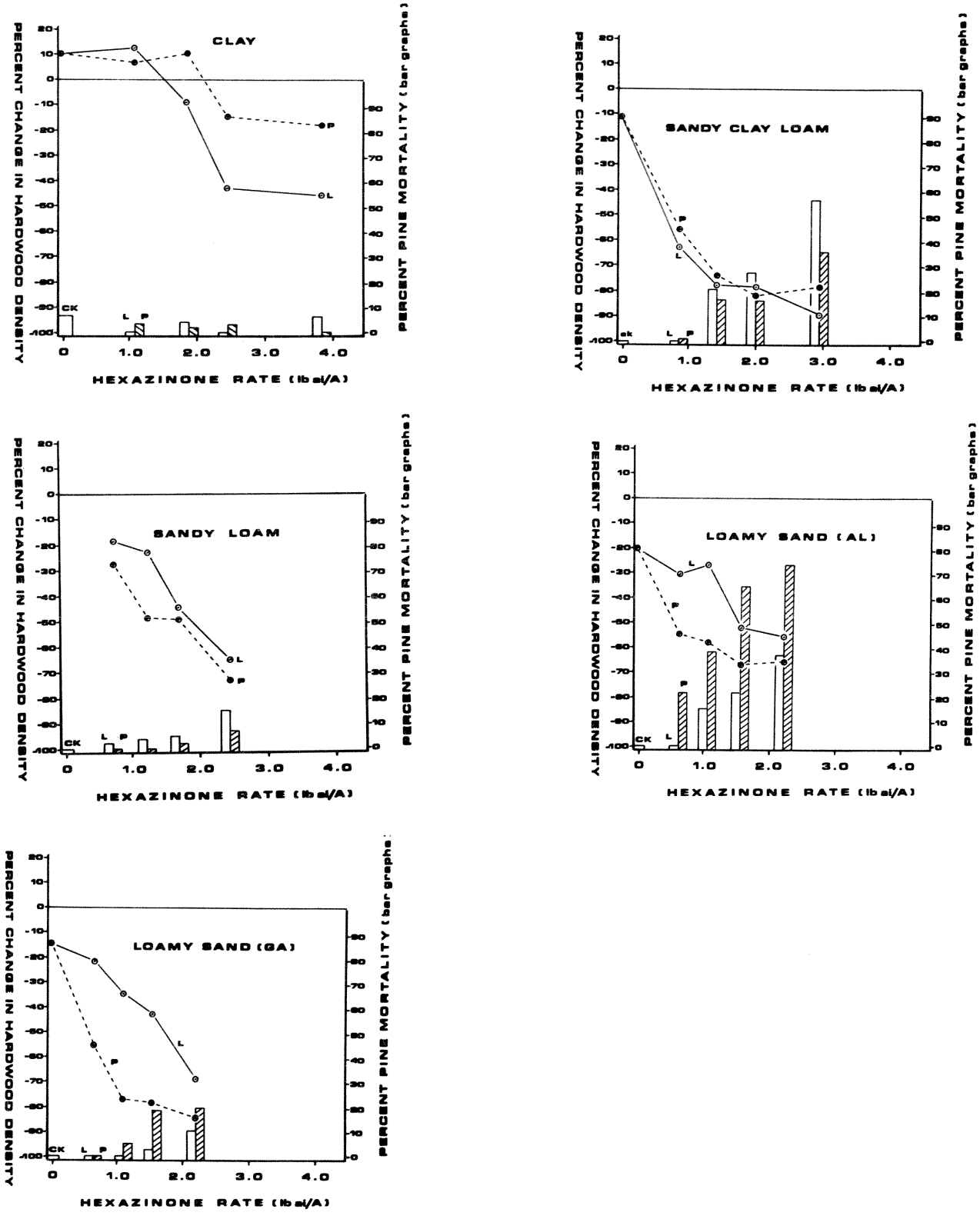

Figure 1.--Percent change in hardwood density (line graphs) and percent pine mortality (bar graphs) for various rates of liquid (L) and pelleted (P) hexazinone.

In order to examine the choice of hexazinone formulation in a quantitative fashion the difference in percent change in hardwood density was calculated as percent change in hardwood density with the pellet minus percent change in hardwood density with the liquid formulation. For those species common to all sites: sweetgum (Liquidambar styraciflua L.), oaks (Quercus spp.) and sumacs (Rhus spp.) the difference in percent change in hardwood density exhibited a linear relationship with percent sand when mean values for each of the five sites were plotted (Figure 2). When the difference in percent change in hardwood density is a positive value the liquid formulation provided the best hardwood control and when it is a negative value the pellet provided better control. The regression of difference in percent change in hardwood density and percent sand intercepted the 0 difference in percent change in hardwood density at 60 percent sand. The pellet and liquid formulation are expected to provide similar hardwood control when percent sand is near 60 percent. When percent sand is greater than 60 percent the pellet is expected to provide greater hardwood control and when percent sand is less than 60 percent the liquid formulation is expected to provide better hardwood control.

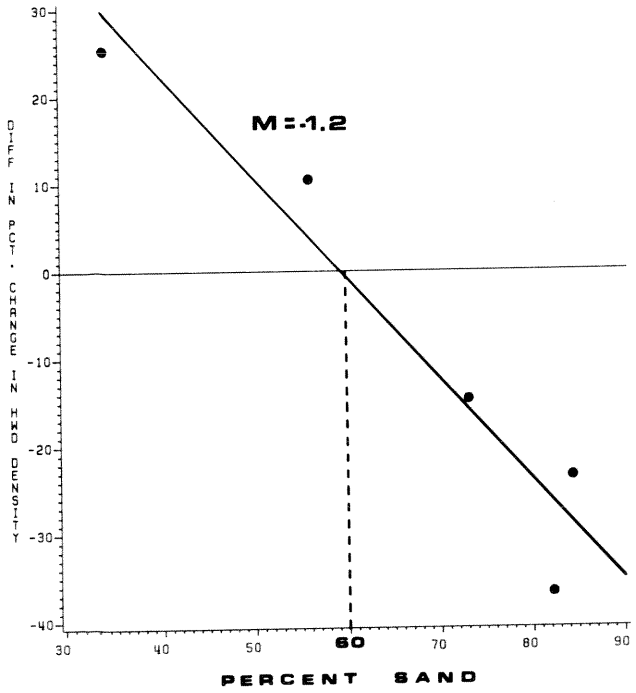

Figure 2.--Regression for the difference in percent change in hardwood density (density change with pellet minus density change with liquid) and percent sand. Points on the regression line are mean values for each of 5 study locations (M = slope).

Regressions were conducted to determine the proportion of variability in hardwood density change explained by herbicide rate, formulation and soil factors (Table 2). The variable P-L Density was used as a factor in the regression model to account for the difference in hardwood control obtained with the pellet and liquid formulation as a function of percent sand (Figure 2). P-L Density was calculated as: P-L Density = Product x -1.2 (% Sand - 60), where Product = 0 for liquid and 1 for pellet. R^2 values were determined for three species common to the five locations: sweetgum, sumacs and oaks. Single variable models could explain from 13 to 33 percent of the variation in hardwood density change. Percent clay explained more variation than percent sand. Two variable models could explain from 43 to 69 percent of the variation in hardwood density reduction while three variable models could explain from 52 to 78 percent. In two variable regression models incorporating rate and soil texture variables both variables were statistically significant which illustrates that the efficacy of a given rate is dependent on soil texture. Differences between species are shown for R^2 values obtained with a given model. Higher R^2 values were found for oaks than the other species, which is reasonable since oaks are a susceptible species. Morphological and phenological characteristics of a species influence the impact various factors have on herbicide efficacy.

Table 2.--Proportion of variation in hardwood density change explained by hexazinone rate, formulation and soil factors.

	Sweetgum	Sumac	Oak
	--------R^2 values------		
Rate	.17	.16	.22
% Sand	.15	.13	.20
% Clay	.24	.18	.24
P-L Density[1/]	.17	.33	.29
Rate % Sand	.47	.43	.63
Rate % Clay	.60	.51	.69
Rate P-L Density	.45	.62	.66
Rate % Sand P-L Density	.52	.63	.74
Rate % Clay P-L Density	.62	.66	.78
Rate % Sand % Clay	.72	.54	.70

[1/] P-L Density is defined in the text.

Pine Mortality

Very little pine mortality was observed for herbicide treatments at the site with clay soil. The untreated check resulted in the greatest pine mortality but there were no significant differences among treatments. At the site with sandy clay loam texture the liquid gave much greater pine mortality than the pellet at the 1.5, 2.0 and 3.0 lb ai/A rates although these differences were not statistically significant due to limited sample size and variability between replications. For the sandy loam soil the liquid resulted in greater pine mortality than the pellet but again comparisons of the two formulations at a given rate were not significantly different at the 5 percent level.

For a given herbicide rate greater pine mortality was observed on the site having a sandy clay loam texture than for the sandy loam site, even though a sandy loam is a more porous soil. This difference may be due to plantation age. The plantation on the sandy clay loam site was in its second growing season while the plantation on the site with a sandy loam texture was in its fourth growing season. Operational tests with hexazinone seem to indicate that pine tolerance to hexazinone treatments increases with plantation age.

For both locations on loamy sand soils the pellet resulted in greater pine mortality than the liquid formulation. At the Georgia site the pellet gave greater pine mortality at the 1.1, 1.6 and 2.2 lb ai/A rates although the difference was significant only for comparisons of the two formulations at 1.6 and 2.2 lb ai/A. At the Alabama site the pellet produced much greater pine mortality than the liquid at all rates but only comparisons of the two formulations at 1.6 and 2.2 lb ai/A were significantly different. Although the Georgia and Alabama sites had nearly identical soil texture, equal herbicide rates resulted in far greater pine mortality at the Alabama site. The Georgia site was treated at the beginning of the fourth growing season while the Alabama site was entering the third growing season. Better herbicide tolerance was obtained in the older stand.

The proportion of variation in pine mortality explained by regression models using herbicide rate, formulation and soil factors is given in Table 3. Single variable models could explain from 6 to 10 percent of the variability in pine mortality. As for hardwood density change percent clay showed a higher R^2 value than percent sand. Rate and texture had an effect on pine mortality as rate and texture variables were always statistically significant in 2 variable models. Two variable models could explain as much as 31 percent of the variation while three variable models explained 34 to 50 percent of the variation in pine mortality. With a four variable model 59 percent of the variation was explained. In general, regression models could explain more of the variation in hardwood density change than for pine mortality. It is unfortunate that pine heights were not evaluated before treatment because the size and vigor of pines greatly effects herbicide tolerance. Since pine height was not evaluated until 60 to 90 days after treatment pine height was not included as a variable in regression models.

Table 3.--Proportion of variation in pine mortality explained by hexazinone rate, formulation and soil factors.

	R^2 values
Rate	.10
% Sand	.06
% Clay	.10
Rate % Sand	.25
Rate % Clay	.31
Rate % Sand	.34
Rate % Clay	.37
Rate % Sand % Clay	.36
Rate % Silt % SA/ (% SI + % CL)	.50
Rate % Silt % SA % SA/ (% SI + % CL)	.59

Pine Height Growth

Pine height growth during the period 3 to 15 months after treatment for the various rates and two formulations at the five study locations is presented in Figure 3. Generally the greatest pine height growth was obtained with the liquid formulation. This was true even on the loamy sand sites where the pellet provided better hardwood control. Very early height growth response to release treatments is more likely to be affected by herbaceous weed control than by hardwood control. The liquid formulation is more effective for herbaceous weed control which may explain the trends in pine height growth response. For the sites with sandy loam and loamy sand texture high rates of the liquid formulation resulted in reduced pine height growth due to herbicide injury. On clay and sandy clay loam sites the liquid formulation resulted in increased pine height growth with increasing rate. Except for the sandy loam and loamy sand Alabama sites pine height growth increased with increasing rate with the pelleted formulation. With increasing rate the number of "grid spots" or pellet density increases providing greater levels of herbaceous weed control. An interesting trend shown at all locations is a convergence in pine height growth response for comparisons of the liquid and pelleted formulations at high rates. This may be the result of a direct negative effect on pine height growth with high rates of the liquid formulation as well as greater levels of herbaceous weed control obtained with increased pellet density.

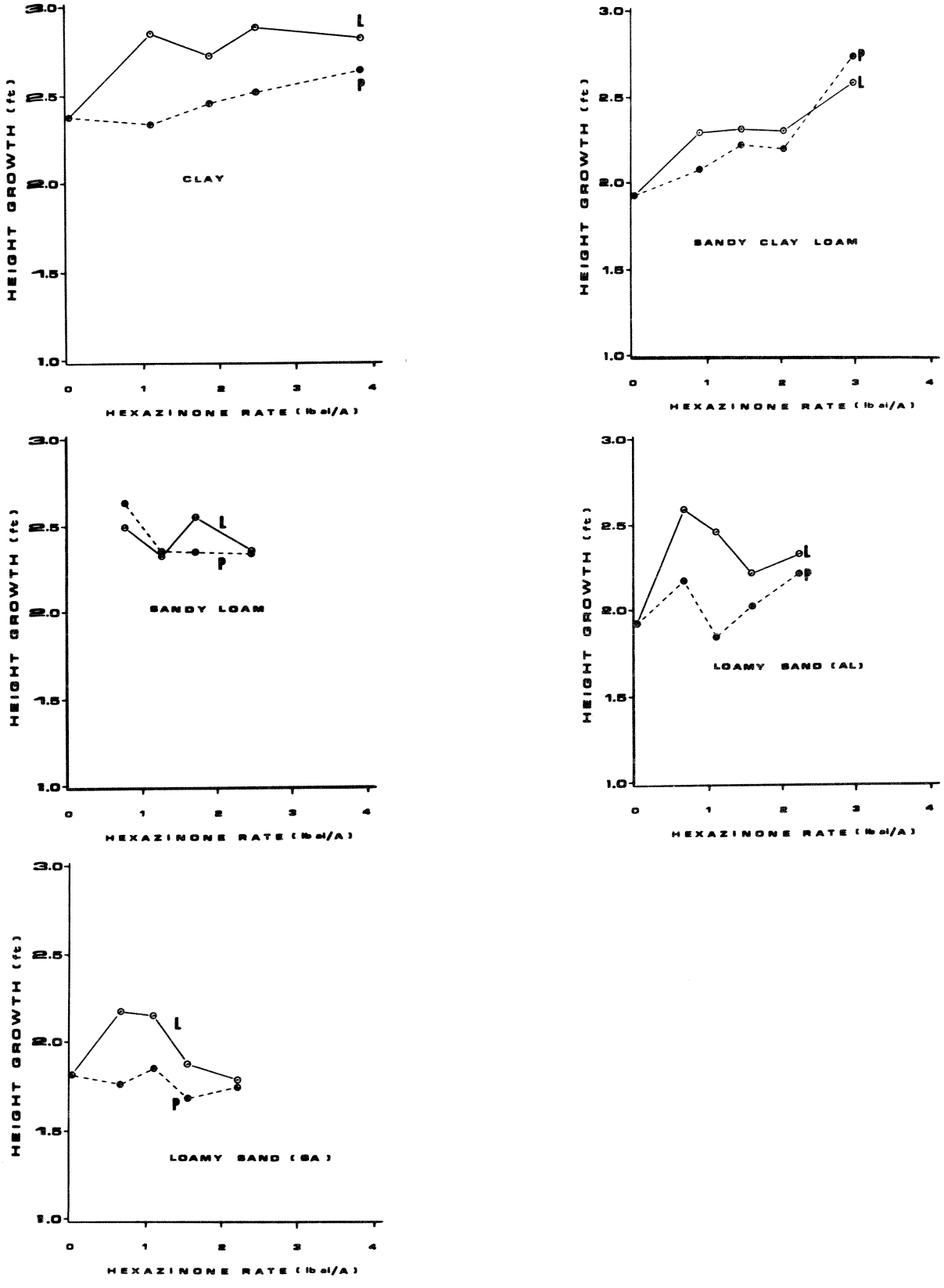

Figure 3.--Pine height growth 3 to 15 months following treatment for liquid (L) and pelleted (P) hexazinone formulations with the various rates tested at 5 locations.

CONCLUSION

The efficacy of liquid and pelleted hexazinone formulations is greatly influenced by soil texture. The concentration of herbicide in the soil solution available for uptake by undesirable hardwoods is effected by the rate of leaching, soil adsorption and herbicide degradation. On sandy soils the pelleted formulation provided greater hardwood control. Conversely, on clay soils the liquid formulation outperformed the pellet. A linear relationship was shown for the difference in percent change in hardwood density (density change with the pellet minus density change with the liquid formulation) and percent sand. Hardwood control is expected to be similar for the two formulations where percent sand is near 60 percent. The pellet is expected to be more efficaceous for soils with greater than 60 percent sand and the liquid formulation is favored for soils with less than 60 percent sand. Regression models incorporating herbicide rate, formulation and soil texture factors could explain up to 78 percent of the variation in hardwood density change.

Greater pine mortality was obtained at sites with sandy soil texture than for higher herbicide rates at sites with more finely textured soils. Except for the site with sandy loam texture the formulation providing the best hardwood control also resulted in the greatest pine mortality. Plantation age greatly influenced pine mortality with pine tolerance being better in older stands. Regression models incorporating herbicide rate, formulation and soil texture factors could explain up to 59 percent of the variation in pine mortality.

At all study locations pine height growth 3 to 15 months following treatment was greatest for the liquid formulation, even where pellets provided greater hardwood density change. Early height growth response to release treatments is thought to be due to herbaceous weed control which is better for the liquid formulation than comparable rates of the pellet. For both formulations pine height growth increased with increasing rate except for the sites with sandy loam and loamy sand textures. At these sites the 1.4x and 2.0x rates of both formulations resulted in less pine height growth when compared to the lower rates.

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JAPANESE HONEYSUCKLE AND ASSOCIATED GROUND COVER INHIBIT ESTABLISHMENT AND GROWTH OF PINE SEEDLINGS IN ALL-AGED STANDS[1/]

Michael D. Cain [2/]

Abstract.--The effects of Japanese honeysuckle and associated ground cover on establishment, survival, and growth of natural pine seedlings were investigated in an all-aged loblolly-shortleaf pine stand in south Arkansas. A mechanical treatment (cutting) and two herbicide treatments (Amitrol T® and Velpar® L, each applied at 4 lb a.e./acre) were compared to a control. After three growing seasons, mean total height and mean groundline diameter ranking of surviving pine seedlings by treatment was as follows: Velpar > mechanical > Amitrol > control. Survival of pine seedlings was not improved by release treatments. Throughout the 3-year study period, Velpar L was more effective than Amitrol T for reduction of Japanese honeysuckle.

INTRODUCTION

Natural regeneration of loblolly and shortleaf pine (*Pinus taeda* L. and *P. echinata* Mill.) often provides a more attractive reforestation alternative for the South's private, nonindustrial landowners than intensive artificial regeneration because of lower establishment costs. However, competing vegetation can have an adverse effect on the establishment and early growth of natural pine seedlings.

Control of herbaceous weeds in loblolly pine plantations during the first few years after planting has produced dramatic growth acceleration of pines (Nelson and others 1981). In addition to competing with pine seedlings for soil moisture, nutrients, sunlight, and growing space, some weeds may even pose parasitic (Musselman and Mann 1978) or allelopathic influences (Priester and Pennington 1978, Fisher 1980, Hollis and others 1982).

Japanese honeysuckle (*Lonicera japonica* Thunb.) is a problem in forest management because it forms a dense mat of vegetation that can smother shrubs, seedlings, and saplings, thus inhibiting the establishment of a new crop of trees. Even though this herbaceous species has been judged a serious problem to reforestation (Nelson 1953), it is an important year-round food item for a number of wildlife species (Sheldon and Causey 1974). Because it is a fast-spreading vine, Japanese honeysuckle can stabilize soil where erosion is imminent (Jackson 1974). The vine was introduced into the United States from Asia and became naturalized throughout the southeast. Since Japanese honeysuckle is moderate in shade tolerance (Blair 1982), it rapidly colonizes forest stands from seed disseminated by birds or vegetatively from stolons that may spread up to 15 feet a year (Brender 1961).

The problem with Japanese honeysuckle is that it cannot be confined to specific areas. Some temporary control methods for Japanese honeysuckle have included the use of herbicides, burning, plowing, mulching, grazing, and vegetative conversion (Brender 1961, Shipman 1962, Jackson 1974, Barden and Matthews 1980).

This paper discusses the effects of Japanese honeysuckle and associated ground cover on the development of natural pine seedlings in an all-aged (uneven-aged) loblolly-shortleaf pine stand.

1/ Paper presented at the Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Associate Silviculturist, Southern Forest Experiment Station, USDA Forest Service, Crossett, Arkansas 71635.

METHODS

Study Area

The study was located on the Crossett Experimental Forest, Ashley County, Arkansas, in a 34-acre loblolly-shortleaf pine stand managed under the selection system since the 1930's. Soil on the study area is Bude silt loam (Glossaquic Fragiudalfs); the site index is 90 feet at 50 years for loblolly pine.

Understory growth in the stand was reduced by rotary mowing in the summer of 1978, and a cutting-cycle harvest was made using single-tree selection in the fall of 1979. After the 1979 harvest, pine sawlog volume averaged 7,200 board feet per acre (Doyle) with 81 square feet of pine basal area per acre in stems $\geq$4 inches dbh.

When the present research study was installed in the spring of 1981, the stand appeared to be open and parklike, but had a moderate to dense ground cover of Japanese honeysuckle and other herbaceous species that ranged up to 4 feet in height. The ratio of Japanese honeysuckle to other prevalent herbaceous species (*Pteridium*, *Rhus*, *Rubus*, *Smilax*, and *Vitis* spp.) was about 4 to 1 in terms of percent ground cover. The presence of hardwood trees and shrubs was not obvious because of the mowing treatment 3 years earlier.

Study Installation

In the spring of 1981, sixteen 0.1-acre circular plots were established within the uneven-aged stand. A total of 15 pine seedlings (stems $\leq$0.5 inch dbh) was selected to monitor growth on the interior 0.05-acre subplot of each 0.1-acre gross plot. Prior to treatment, the 15 preselected seedlings per subplot were tagged, and total height of each was measured to the nearest 0.05 foot. Plots were then blocked on the basis of mean total heights of measured seedlings, and four treatments were assigned at random within each block.

Treatments

An undisturbed control was compared with one mechanical and two chemical treatments. In the mechanical treatment, all pine seedlings were released by cutting low-growing ground competition within a 1-foot radius of each stem. Cutting was done with a gasoline-powered, nylon-line trimmer (Weed Eater Model 657) plus hand trimming. Woody competition <0.6 inch dbh was also cut. Mechanical release was done four to five times during each of three growing seasons at intervals of approximately 4 to 6 weeks.

The two chemical treatments were Amitrol T® and Velpar® L. Manufacturers' labels specify that these two herbicides are suitable for control of Japanese honeysuckle. Each herbicide was applied at the rate of 4 pounds a.e. per acre in a 60-gallon water solution per acre. Since both herbicides can injure conifers, each pine seedling was shielded with a 7-inch diameter stove pipe at the time of spraying. Foliar spraying was done using hand-operated, backpack pumps (Solo Model 425). Chemical application was a one-time treatment (May 11, 1981) and was not repeated during the course of the study.

Measurements

At the end of the 1981, 1982, and 1983 growing seasons, survival of measurement seedlings was assessed and total heights were remeasured to the nearest 0.1 foot. In September 1983, groundline diameters were taken to the nearest 0.1 inch on all surviving measurement seedlings. Density of pine seedlings that became established during the 3 years following treatment was determined at the same time by sampling four systematically established milacres per 0.05-acre interior subplot.

Ocular estimates for percent reduction of Japanese honeysuckle were made on Amitrol and Velpar plots at the end of each growing season for 3 years. Untreated areas contiguous to the plots were used for judging percent reduction at 10-percent intervals.

At the beginning of the study, overstory pine basal area had been taken at each plot center using a 10-factor prism. These measurements were repeated in 1983 for calculation of basal area and competition index (Daniels 1976).

Analysis of variance was used to evaluate treatment effects on pine growth and survival at the 5-percent level of significance. Duncan's Multiple Range Test was used to partition differences between treatment means. Percent values were compared using the arcsine $\sqrt{\text{proportion}}$ transformation.

RESULTS AND DISCUSSION

Of the two herbicides tested in this study, Velpar L was about 30 percent more effective than Amitrol T for controlling Japanese honeysuckle throughout the 3-year study period (table 1). Even though both herbicides were labeled for control of Japanese honeysuckle, multiple applications are apparently required for long-term efficacy. This is especially true where low herbicide rates are used for releasing pine seedlings from honeysuckle competition.

Table 1.--Reduction of Japanese honeysuckle by chemical treatments after each of three growing seasons 1/

Treatment	Year 1981	1982	1983
	Percent reduction		
Amitrol T	55a2/	30a	25a
Velpar L	88b	62b	52b

1/ Chemicals were applied only once, in 1981.

2/ Column values followed by the same letter are not significantly different at the 0.05 level.

By the end of the first growing season following treatment, pine survival on Velpar plots was significantly less when compared to controls (table 2). Although pines were shielded during the foliar spray treatment, Velpar is also absorbed from the soil by plant roots, and the rate of application was apparently high enough to kill many smaller pines. By the end of the third growing season, survival among treatments was not significantly different. Regardless of the type of release treatment used in this study, nearly half of all measurement pine seedlings had died within 3 years (table 2).

Table 2.--Survival of measurement pines after each of three growing seasons following treatment.

Treatment	Year 1981	1982	1983
	Percent		
Control	85a1/	64a	52a
Mechanical	77a b	63a	57a
Amitrol T	83a b	72a	60a
Velpar L	59 b	48a	45a

1/ Column values followed by the same letter are not significantly different at the 0.05 level.

Overstory pine basal area in the spring of 1981 averaged 81 square feet per acre and had increased to 89 square feet per acre by the fall of 1983, but basal area differences among treatments were statistically nonsignificant. Similarly, the competition index among treatment means was nonsignificant. Since the recommended range of basal area stocking for uneven-aged management of loblolly-shortleaf pine stands is between 55 and 75 square feet per acre, the higher basal areas no doubt had a negative impact on the survival and growth response of pine seedlings in this study. Japanese honeysuckle, on the other hand, appears to thrive in the understory, even at rather high pine basal area levels.

Blair (1982) reported that Japanese honeysuckle was robust in growth form at a light intensity of 45 percent, but appeared to be severely stressed after 2 years of growth under a light intensity of 8 percent. In contrast, both loblolly and shortleaf pines are classified as intolerant of shade. Yet, competing vegetation such as Japanese honeysuckle may provide an initially favorable microclimate for conifer seedlings. For example, Bormann (1956) reported that loblolly pine seedlings can become established under dense forest canopies because of their ability to utilize low light intensities, but when secondary foliage develops, the seedlings are unable to photosynthesize effectively and they die out.

At the beginning of this study, there was no significant difference in mean total heights of measurement seedlings among treatments. During the 1982 growing season, height growth of pines on Velpar plots was significantly better than that on other treatments (table 3). In 1983, seedling height growth on Velpar plots averaged more than height growth in other treatments, but statistically, growth was better than that on control plots only. Over the 3-year study period, mean annual height growth on Velpar plots exceeded that of pines on control and Amitrol plots by 46 and 38 percent respectively.

Table 3.--Mean height growth and groundline diameter of surviving pines by year and treatment.

Treatment	Height growth by year 1981	1982	1983	Mean annual height growth 1981-1983	1983 mean groundline diameters
	Feet				Inches
Control	0.24a1/	0.40a	0.42a	0.37a	0.36a
Mechanical	0.23a	0.38a	0.64ab	0.41ab	0.45 bc
Amitrol T	0.24a	0.41a	0.50ab	0.39a	0.40ab
Velpar L	0.26a	0.57 b	0.70 b	0.54 b	0.50 c

1/ Column values followed by the same letter are not significantly different at the 0.05 level.

Three years after treatment, surviving pines on Velpar and mechanically treated plots had significantly larger groundline diameters than those on control plots (table 3). Although a 0.1-inch difference does not seem important in itself, the combination of increased pine diameter and height on Velpar and mechanically treated plots suggests more thrifty pines that should be better able to tolerate reinvasion by competing vegetation.

Velpar L may have a stimulating influence on pine growth in addition to its herbicidal effect on competing species because it is a triazine compound. McCormack (1977) reported that the application of the herbicide simazine, also a triazine compound, provided nutritional benefits to northern conifers by improving the nitrogen regime and habitat for mycorrhizal fungi.

Even though complete elimination of low-growing ground competition was not achieved during the study period, temporary and partial control of such competition by chemical or mechanical treatments was effective in stimulating height and diameter growth of natural pine seedlings in this uneven-aged stand.

In terms of area released from low-growing ground competition in this study, Velpar L was clearly the most effective treatment in preparing a seedbed for establishment of pine regeneration. Over 1,000 pine seedlings per acre became established during the 3 years that followed the initial treatment with Velpar L. No additional seedlings were established on the control or the mechanically treated plots during this same time period. Had the mechanical treatment been applied to the entire plot rather than restricted to within 1 foot of the individual pines, additional seedlings may have become established. Amitrol T, being the only other treatment applied on a plot-wide basis, had 125 additional pine seedlings per acre in the fall of 1983, but there was also a rapid reinvasion of competing vegetation following the single treatment in 1981.

CONCLUSIONS

To maintain optimum growth of pine regeneration in uneven-aged stands, both the competing vegetation and the overstory pine component must be managed. With release from low-growing ground competition such as Japanese honeysuckle, growth of pine seedlings can be increased in uneven-aged stands of loblolly-shortleaf pine. If overstory loblolly-shortleaf pine basal area averages from 81 to 89 square feet per acre in uneven-aged stands, then height growth of naturally regenerated pine seedlings averages less than 0.5 foot per year on good sites (site index of 85 to 90 feet at 50 years), even with release from low-growing ground competition.

Japanese honeysuckle and associated ground cover not only reduce pine seedling growth but can impede establishment of pine regeneration from natural seedfall. Nevertheless, where pine regeneration has become established following soil disturbance from logging, then about 50 percent of those established seedlings tend to persist for at least 3 years even when growing in a uniform ground cover of Japanese honeysuckle.

Although a number of techniques have been tested for controlling Japanese honeysuckle, herbicides may provide the most practical approach for releasing pine regeneration from honeysuckle competition. In this study, Japanese honeysuckle was not eradicated by a single application of Velpar L or Amitrol T at the rate of 4 pounds a.e. per acre on silt loam soil, but Velpar L gave significantly better honeysuckle control over a 3-year period.

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INTERACTION OF GENOTYPE AND VEGETATION CONTROL ON LOBLOLLY PINE SEEDLING PERFORMANCE[1/]

Stuart E. Duba, Larry R. Nelson, and Dean H. Gjerstad[2/]

Abstract. -- A split plot design was utilized to evaluate the effect of control of competing vegetation on first-year height and groundline diameter increments of three loblolly pine (Pinus taeda L.) families. Both families and timing of control differed significantly for height increment and groundline diameter increment. The earliest treatment dates (May and June) provided for better growth than later dates (July - September). Families interacted with control of competition for both height increment and diameter increment. Families showed differential response to control of competition and performance was altered depending upon whether competition was controlled or not.

INTRODUCTION

Accelerated growth of southern pines is being obtained by several means. The value of genetic improvement has been long accepted. Although genetic selections have been made to improve growth rate of southern pines, continual effort must also be made to ensure that selections are responsive to changing silvicultural treatments. Recently, the value of intensive control of weed competition as a means of increasing volume production has been elucidated (Nelson et al. 1981, Knowe et al. 1985). Hence, a regeneration system that integrates these practices should provide greater production than either practice alone. An important aspect of this integrated system is the likelihood of interactions among the components. Depending on the seasonal growth pattern of particular plants, timing of application of herbicides could interact with genotypes. Families will likely respond differentially to both the control of competition and to specific chemicals. These factors were evaluated in this study.

1/Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/Research Associate, Research Associate, and Associate Professor, Alabama Agricultural Experiment Station and School of Forestry, Auburn University, AL 36849.

METHODS AND MATERIALS

The planting was established on an old field site in the Alabama Piedmont near Auburn, Alabama. Site preparation consisted of mowing and disking during the fall before planting. Existing vegetation consisted primarily of ragweed (Ambrosia spp. L.), morningglory (Ipomoea spp.), blackberries (Rubus spp. L.), and grasses (Panicum spp. L.). Three families were utilized that had relatively stable performance in a series of progeny tests where weeds were not controlled. They were chosen as a good (family B), an intermediate (family C), and a poor (family A) performer for height growth. Each of 4 replications consisted of 7 treatment plots that were split into 3 single-row family plots (17 trees per family). The whole plots were randomly assigned to one of six treatment dates or a control where no herbicide was applied. On each treatment date herbicide was utilized to control all vegetation competing with the trees. The herbicide glyphosate was utilized as a directed spray so no phytotoxic effects on experimental trees would occur. Plots were kept weed free after the time of initial treatment. Both height and groundline diameter were measured at the time of planting in March, 1983. Trees were subsequently remeasured at least once a month from June through November. Height and diameter increments were evaluated to determine direct response to treatments. Nelson et al. (1981) have indicated that biomass or groundline diameter growth was more responsive than height growth to weed control in the first two years.

RESULTS AND DISCUSSION

Growth impact studies of weed control effects have shown significant increases in growth of pines after one year in the field (Zutter and Knowe 1982). Therefore, an analysis of this pilot study after one year was deemed valuable although subsequent analyses after a longer period in the field are certainly desirable. After one year in the field, all three families survived equally well with an overall average survival of 98.7 percent. Based on a split-plot analysis of variance, both height and groundline diameter increments were affected by treatment date and family.

Effect of Treatment Date

The question of interest with respect to treatment date was how late in the growing season could weed competition be controlled and still yield a substantial growth response from the trees. Intuitively, if competition was removed for a longer period of the growing season, the growth response should be greater. During the first growing season, the date of treatment significantly affected both height increment ($P<0.0003$) and groundline diameter increment ($P<0.001$). For diameter increment, a positive response resulted from the May and June treatment dates (fig. 1), but the May treatment resulted in the greatest response. Release from competition in July, August, or September did not result in growth increases that were significantly different from the control (no treatment). Height growth responded in the same manner as diameter growth. Depending upon their seasonal growth pattern and competitiveness for late season moisture, individual genotypes could respond differently to timing of control.

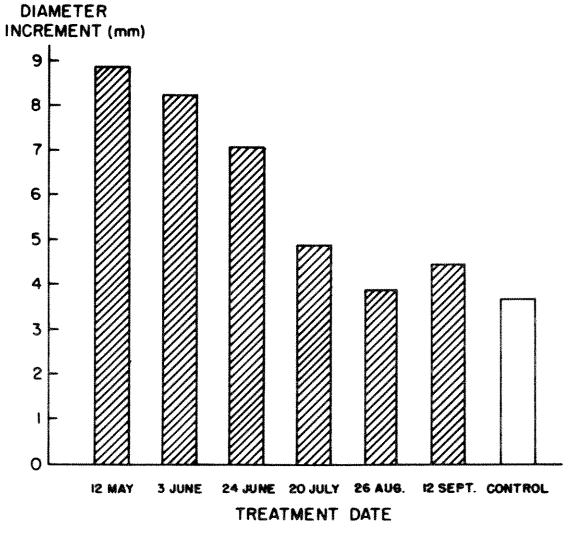


Figure 1. Effect of treatment date on first-year diameter increment of loblolly pine.

Effect of Genotype

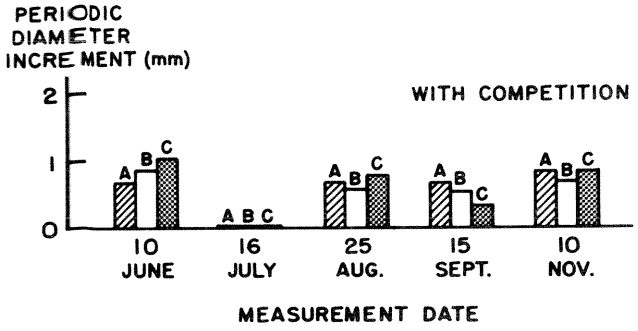
When attempting to integrate tree improvement and weed control practices, an important consideration is that of genotype response and degree of responsiveness. Whether or not a particular genotype responds favorably to control of competition, and the degree of responsiveness of each genotype should be considered when allocations of planting stock are being planned for chemically treated sites. Specific interactions of genotypes and chemicals must also be considered.

During the first year of this pilot study, family differences significantly affected both height increment ($P<0.001$) and groundline diameter increment ($P<0.0001$). A combination of family response and degree of responsiveness resulted in an alteration of family rankings depending upon whether or not vegetation was controlled. In plots where no measures were taken to reduce weed competition, periodic diameter increments of family C tended to be as large as or larger than either family A or B (fig. 2). Conversely, when weed competition was alleviated, family A tended to have the largest increments. When periodic increments were combined and expressed as cumulative growth, family C tended to grow more than either family A or B under conditions of weed competition(fig. 3). The opposite was again true when vegetation was controlled and family A grew better than either families B or C.

A similar situation existed for height increments. In plots where weed competition was heavy, families B and C tended to have larger periodic increments and greater cumulative growth than family A. Under conditions of season-long weed control, family A had larger periodic increments at each measurement date and subsequently a greater cumulative increment.

Interactions

It is apparent that growth of individual families changed in response to control of vegetation (fig. 4). Thus the expression of genetic potential of each family depended upon the presence or absence of competition, most likely reflecting changes in soil moisture. Family rankings were altered when a comparison was made between their response to the control (no treatment) and the longest treatment period (weed control). The estimate of interaction for groundline diameter increment had an actual P value of less than 0.07, and for height increment an actual P value of less than 0.10. These values are especially interesting when considering they are for only one year's growth.



a.

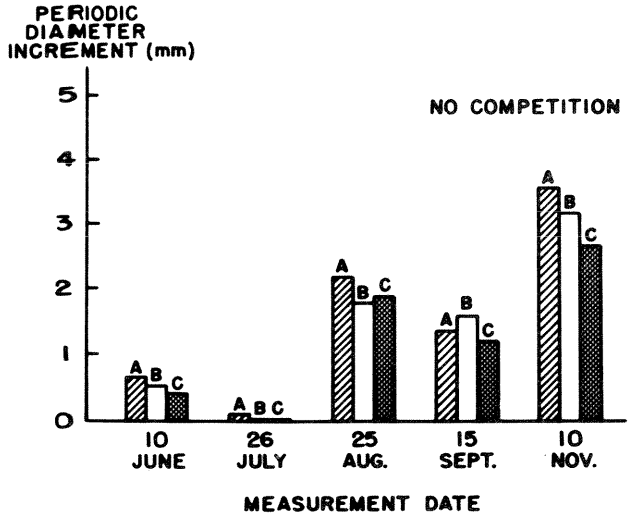


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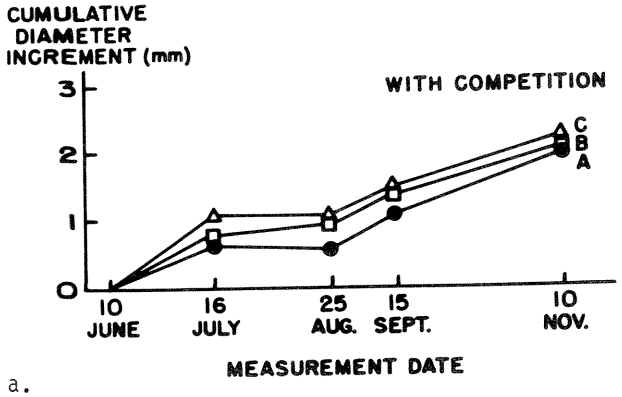
Figure 2. Periodic diameter increments of three loblolly pine families under conditions of a) herbacious weed competition, or b) no competition.



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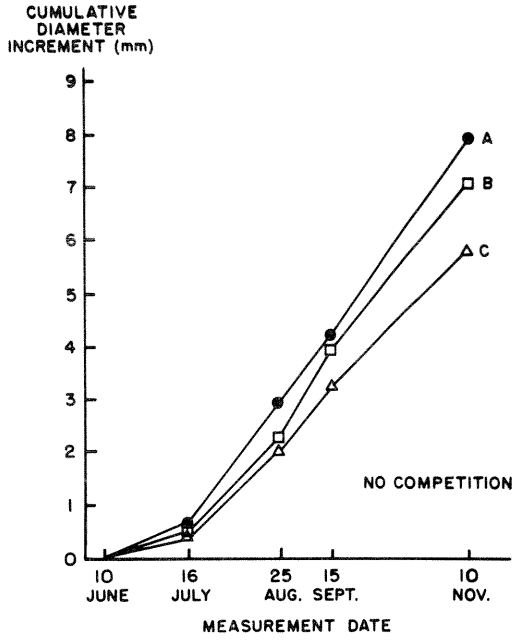

b.

Figure 3. Cumulative diameter increments of three loblolly pine families under conditions of a) herbacious weed competition, or b) no competition.

Even without drastic alterations in family rankings, certain genotypes are likely to be more responsive to conditions of no competition for moisture and nutrients and could be optimally utilized where vegetation control would be practiced. A large range in magnitudes of differential family response in height and diameter growth was evident in this study (Table 1). Family A was much more responsive to the control of competition. A group of similarly responsive families would be the best choice for utilization with weed control or intensive chemical site preparation.

Table 1. -- Family comparison of growth increments under the condition of vegetation control as a proportion of growth increments under the condition of no vegetation control

Family	Height increment	Diameter increment
	percent	percent
A	184	408
B	158	351
C	131	262

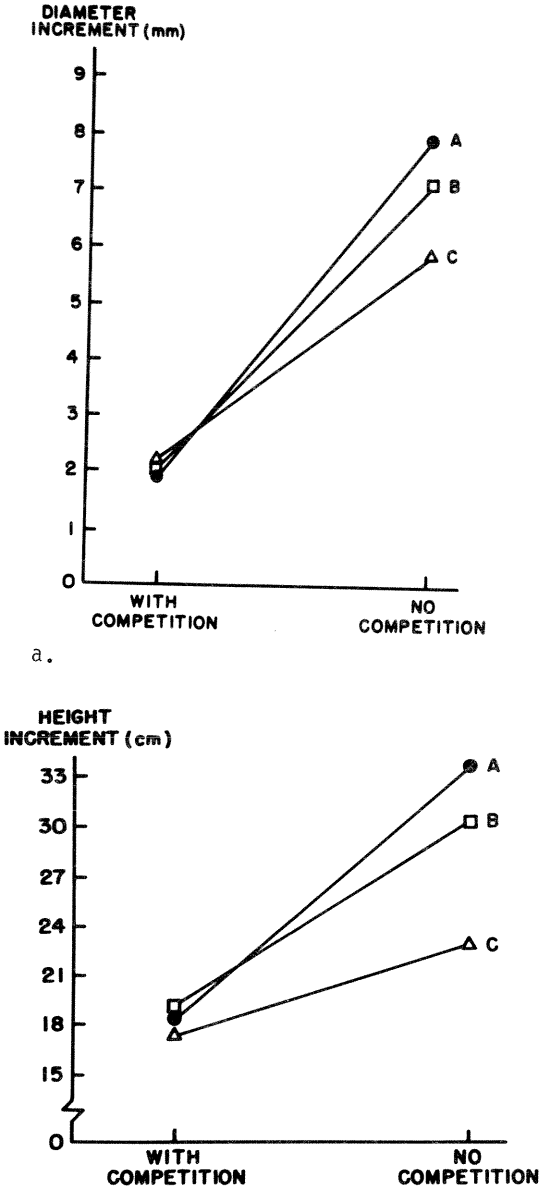

Figure 4. First-year growth response for a) diameter increment b) height increment of three loblolly pine families under the conditions of herbaceous competition or no competition.

Differential family responses indicate potential benefits of evaluating interactions between genotypes and control of competition, and the use of this information in the development of an integrated regeneration system. Although specific chemical by genotype interactions are also expected, they should not carry a negative connotation. Conversely, these interactions should be utilized to identify those genotypes that respond optimally when used in connection with a particular chemical. Additional studies are being conducted to further evaluate genotypic responses to the control of competition and to specific chemicals. In addition, evaluations must be made of seasonal growth patterns to ascertain the underlying physiological explanation for these growth responses.

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FIRST YEAR GROWTH RESPONSE OF YOUNG LOBLOLLY PINE (PINUS TAEDA L.) TO COMPETITION CONTROL ON THE VIRGINIA PIEDMONT[1/]

C. G. Bacon and S. M. Zedaker[2/]

Abstract.--To investigate the growth response of young loblolly pines to different amounts of release from competing vegetation, an experiment was initiated in plantations of three ages (0, 1, and 2 years since planting) on three tracts in the Virginia Piedmont. Competition control treatments involved the removal of all, two-thirds, one-third, or none of the hardwood stems in combination with either total or no herbaceous control. First year results showed a significant increase in pine growth with competition control. Treatments including herbaceous control resulted in better growth than the same treatments without herbaceous control. The best response, obtained with the two-thirds woody plus herbaceous control treatment, resulted in a 252% increase in volume growth in the two-year-old plantations and an 80% increase in volume growth in the one- and three-year-old plantations. Individual tree growth models based on various measures of competing vegetation are developed.

INTRODUCTION

The southern United States is a focal point in the production of forest products and will be increasingly important in the future, producing half of the nation's wood by the year 2000 (Barber 1979). This is due to environmental conditions which are excellent for the growth of fast-growing trees, and the presence of valuable and versatile species such as loblolly pine (Pinus taeda L.). In spite of the excellent growing conditions, intensive management of southern forest lands is necessary to maximize production.

Throughout the South numerous unwanted plants, or weeds, invade uncontrolled cropland. Forest lands are no exception; perennial hardwood vegetation dominated on 40 percent of the pine acreage cut between 1957 and 1977 (Knight 1977). These perennial, along with herbaceous, weeds compete with the crop seedlings for light, water and nutrients essential for growth (Newbold 1979). Because this interspecific competition limits the growth of loblolly pine, productivity can be improved by controlling these weeds (Nelson et al 1981; Cain and Mann 1980; Loyd et al 1978).

Considering the importance of pine production in the southeast, relatively few studies have quantified the competitive relationship between loblolly pine and weed species in young stands. Numerous early studies of competition in southern pine plantations have indirectly explored the growth relationships between loblolly pine and competing vegetation (see Walstad 1976 and Stewart 1981 for summaries). These studies evaluated growth response of the pine released from competition but did not measure the competitors or attempt to evaluate the level of competition present before or after treatment. Removal of competition was shown to improve growth but no recommendations on how much release is necessary for a maximum growth response were possible.

The removal of competing vegetation can be an expensive endeavor. This is especially true in small privately-owned tracts of land. Since seventy percent of the forest land of the South falls under non-industrial private ownership (USFS 1980) release work in these stands will probably involve simple techniques such as application of herbicides utilizing backpack sprayers. In such techniques cost increases directly with the amount of release (Balmer et al 1978). Therefore it is desirable to be able to determine if there is a critical level of competition removal above which the pine growth

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Graduate Research Assistant and Assistant Professor respectively, Department of Forestry, VPI & SU, Blacksburg, VA 24061.

does not significantly increase.

In an attempt to further analyze this competitive relationship, recent studies have included intensive measurements of the competing hardwood vegetation (Roberts 1960; Glover 1982). Roberts (1962) developed measurements designed to fully describe the competitive situation of a subject pine. These measurements included the size of the pines and hardwoods, hardwood species, and distance and direction from the pine to the hardwoods. Unfortunately, Roberts was unable to fully analyze the data and was only able to develop general recommendations for cleaning operations in loblolly pine plantations. Glover (1982) utilized multiple regression techniques as a variable screening procedure to determine that the sum of the hardwood groundline basal area, the number of hardwood rootstocks per square meter, and the sum of the hardwood heights were the best predictors of pine size and growth. In his most accurate estimation, Glover found that hardwood basal area alone explained 67 percent of the variation in pine diameter growth.

Measures of crown size have been developed as evaluations of competition in older stands. Crown size is an indication of a tree's ability to compete for light and may also give an indication of root competition, based on a hypothesized relationship between crown size and root area (Krajicek et al 1961). Therefore crown size should give an excellent description of the zone of influence of a tree. This zone of influence is the area over which a tree obtains or competes for resources (Opie 1968; Bella 1971; Arney 1973; Moore et al 1973). Previous studies have assumed that these zones were roughly circular in shape and, in size, proportional to the diameter at breast height (dbh) of the tree. Competitive pressure on a subject tree was then determined by summing the area of overlapping zones.

In the early years of plantation establishment, however, crown volume appears to be a more meaningful measure to determine zone size. Bentley and others (1971) utilized a brush volume index value in their study of brush competition in a ponderosa pine (Pinus ponderosa Laws.) plantation. The index value was calculated by multiplying crown height by crown area for each competitor. Pine height growth generally decreased with an increase in the index value but a more definite relationship was not established.

The objectives of this study were to compare the growth response of young loblolly pines to release from different amounts of woody and herbaceous competition, and to develop predictive equations for the growth response based on various measures of the competing vegetation. In addition, the effectiveness of the competing vegetation measures in predicting pine growth were compared utilizing multiple regression techniques.

MATERIALS AND METHODS

A study was designed and initiated in 1983 to investigate the growth response of young loblolly pines to different amounts of release from competing vegetation. This study was installed at three different sites on the Virginia Piedmont and included three ages at each site. Plantations in their first, second, and third growing seasons were divided into 0.1 hectare plots for the installation of eight release treatments in a split-plot design. These randomly assigned treatments controlled four different amounts of the hardwood vegetation, removal of all, two-thirds, one-third or none of the woody stems, and two levels of the herbaceous competition. All competition control was provided by chemical means utilizing ground application techniques. Woody stems were controlled by the use of a basal bark spray of a 4% solution (v/v) of triclopyr, as an ester, in diesel oil applied in June 1983. Herbaceous vegetation was also controlled in June with sulfometuron methyl at 6 oz ai/acre in a water carrier. An additional late season (August) application of a 1% (v/v) solution of glyphosate in water was required to ensure single season control of the herbaceous vegetation.

Growth response to release was evaluated at both the stand level and on an individual tree basis. Several height and diameter measurements were taken on each of twenty-five systematically located seedlings in each treatment plot. Remeasurement at the end of the first growing season following treatment provided data for calculations of current volume and volume growth utilizing Smalian's formula.

Competition was evaluated directly around five systematically selected seedlings in each plot. Each of these seedlings served as the center of circular plots with a radius of 1.5 m, or 1.5 times the height of pines taller than a meter, up to a 3 m maximum. The distance and bearing from each pine was recorded for all hardwood stems within this plot along with species, height, groundline diameter, and two perpendicular crown diameters. In addition, any hardwood stem with a height greater than its distance from the subject pine was included as a competitor. These plots were remeasured to give an indication of the change in competition due to the treatments and a current evaluation of the competition present.

RESULTS AND DISCUSSION

The first year pine height growth showed virtually no response to competition control (Table 1). Only the two-thirds woody control plus herbaceous control treatment resulted in a significant increase in height growth over the treatment without competition control. This lack of difference was expected since earlier studies have found height growth to be relatively insensitive to density stress.

Table 1 .--First year height growth response

Treatment	Height Growth[1/] Age 1 (cm)	2 (cm)	3 (cm)
Herbaceous control:			
+ Total woody control	7.0ab	42.4ab	54.5a
+ 2/3 woody control	8.7a	46.7a	57.7a
+ 1/3 woody control	8.6a	38.9bc	51.3a
only	6.8ab	37.3bc	52.1a
No herbaceous control:			
+ Total woody control	4.9bc	35.5bc	51.8a
+ 2/3 woody control	3.1c	35.4c	53.4a
+1/3 woody control	4.9bc	34.8c	40.7b
No control	6.6ab	36.4bc	54.5a

1/Means within ages followed by the same letter not significantly different at the 0.05 level

Groundline diameter growth, however, showed a definite differential response to competition control (Table 2). In all ages, the two-thirds woody control in combination with herbaceous control resulted in significantly greater growth than the treatment without competition control. This was the only treatment in the first year plantations exhibiting a better diameter growth. In the two-year-old plantations, all of the treatments except the one-third woody control without herbaceous control had significantly higher growth than the treatment without control. Only the treatments involving a combination of woody and herbaceous control resulted in better growth in the three-year-old plantations. The importance of herbaceous control is indicated by the better growth, in most cases, from treatments with herbaceous control than in the corresponding treatments without control. However, the need to combine at least some woody control with herbaceous control is suggested since the herbaceous control alone was significantly better than the control only in the two-year-old plantations, not in the one- and three-year-old stands.

Table 2.--First year groundline diameter growth response

Treatment	Groundline Diameter Growth[1/] Age 1 (mm)	2 (mm)	3 (mm)
Herbaceous control:			
+ Total woody control	2.20ab	5.37ab	6.01b
+ 2/3 woody control	2.46a	5.70a	7.01a
+ 1/3 woody control	2.25ab	4.96ab	5.11bc
only	1.86abc	4.35bc	4.95cd
No herbaceous control:			
+ Total woody control	1.37cd	4.01bc	5.05cd
+ 2/3 woody control	1.04de	4.27bc	5.05cd
+ 1/3 woody control	0.50e	3.42cd	4.72cd
No control	1.55bc	2.70d	4.11d

1/Means within ages followed by the same letter not significantly different at the 0.05 level

The volume growth response (Table 3) showed treatment differences that were similar to those in the diameter growth response. The total and two-thirds woody control with herbaceous control treatments exhibited the best growth, with the two-thirds woody control being best on the two- and three-year-old sites.

The actual amount of woody control obtained in each treatment was based on the amount of hardwood competition present before treatment. Since this amount was not the same for all plots, an analysis of covariance test was needed to ensure that the differential growth response was not due to the different amounts of initial competition. Using an estimate of the original hardwood groundline basal area per plot as a covariate, the analysis of covariance found the same significant differences in volume growth between treatments as the analysis of variance results (Table 3). This indicates that the pines responded in a similar manner to the same treatment, even when the original amount of competition was different.

When viewed as the percent increase in volume growth with competition control over no control, the best growth response was found in the two-year-old plantations (Table 4). The two-thirds woody plus herbaceous control resulted in a 252% increase in growth while the total woody plus herbaceous control treatment had a 227% increase. Even the one-third woody plus herbaceous control and the two-thirds woody control only resulted in a doubling

of growth over the untreated plots. The growth response was much less dramatic in the one- and three-year-old pines with the best response being only about an 80% increase in growth. These results seem to indicate that release treatments at the beginning of the second growing season may give the best growth response.

Table 3.--First year volume growth response

	Volume Growth[1,2]		
	Age		
Treatment	1 (cm^3)	2 (cm^3)	3 (cm^3)
Herbaceous control:			
+ Total woody control	0.0206a	0.5141b	1.2190b
+ 2/3 woody control	0.0205a	0.5526a	1.5840a
+ 1/3 woody control	0.0195ab	0.3130c	0.9893bcd
only	0.0155ab	0.2639cd	1.0015bcd
No herbaceous control:			
+ total woody control	0.0133ab	0.2569cd	0.9278bcd
+ 2/3 woody control	0.0072c	0.3124c	1.1870bc
+ 1/3 woody control	0.0048c	0.2387cd	0.8812cd
No control	0.0113bc	0.1570d	0.8558d

1/Volume calculated using Smalian's formula
2/Means within ages followed by the same letter not significantly different at the 0.05 level

Pine survival was generally quite high for all treatments (Table 5). As expected, survival was lowest overall for the first year plantations; however, there were no significant differences for survival between treatments for either the one- or three-year-old plantations. In the two-year-old plantation, there were significant differences with the total woody control plus herbaceous control and the treatment without control having lower survival than the one-third woody plus herbaceous control and the herbaceous control only. Overall, however, the survival percentages indicate that there was not a problem with herbicide damage to the pines. Therefore, herbicide damage does not explain the better growth response in the two-thirds woody control over the total woody control treatments. This better response was probably related to the beneficial effects of some degree of shading on moisture availability.

Table 4.--Percent increase in volume growth with competition control over no control. First year results.

	Percent Increase		
	Age		
Treatment	1	2	3
Herbaceous control:			
+ Total woody control	82	227	42
+ 2/3 woody control	81	252	85
+ 1/3 woody control	73	99	16
only	37	68	17
No herbaceous control:			
+ Total woody control	18	64	8
+ 2/3 woody control	-36	99	39
+ 1/3 woody control	-58	52	3

Table 5.--Survival of loblolly pines in competition control experiment by treatment.

	Seedling Survival[1]		
	Age		
Treatment	1 %	2 %	3 %
Herbaceous control:			
+ Total woody control	83a	93b	97a
+ 2/3 woody control	93a	96ab	100a
+ 1/3 woody control	92a	99a	97a
only	80a	100a	96a
No herbaceous control:			
+ Total woody control	76a	95ab	100a
+ 2/3 woody control	93a	96ab	96a
+ 1/3 woody control	72a	95ab	96a
No control:	84a	93b	96a

1/Means within ages followed by the same letter not significantly different at the 0.05 level

Equations to predict pine growth were developed on an individual tree basis utilizing the intensive competition measurements obtained for the five seedlings in each split-plot. The pine variables used were the natural logarithm of the initial stem volume (LV1), and the natural logarithm of the stem volume growth (LVG). The hardwood variables chosen reflected the change in the hardwood measurements within the competition plots of each tree. These were obtained by subtracting the pretreatment measurements from those taken at the end of the first growing season. The specific variables used were the change in the hardwood groundline basal area (CBA), the change in the relative groundline basal area (CRBA), where the basal area of each competitor was weighted by the inverse of its distance from the pine, and the change in the hardwood crown volume (CHCV).

The log of the initial volume (LV1) was the best predictor of volume growth with a coefficient of determination of .808 (Table 6). The addition of each of the hardwood variables resulted in only a slight increase in the R-squared. Partial F-tests, designed to test if the added variable contributed to the regression, were not significant at the 0.05 level for any of the hardwood variables.

Table 6.--Coefficients of determination and partial F-test significance for all ages and treatments

Model	R^2	Partial F
LVG = LV1	0.808	NS
LVG = LV1 + CBA	0.810	NS
LVG = LV1 + CRBA	0.813	NS
LVG = LV1 + CHCV	0.824	NS

Since this lack of significance may have been due to the different responses of the different aged seedlings, regressions were attempted for each age separately. With the same models, there were, once again, no significant partial F-tests for the hardwood variables. However, there appeared to be a trend of increasing coefficient of determination with increasing age of the pines.

The omission of herbaceous variables from these models may also be effecting the results. Therefore, the regressions were run separately on the treatments with herbaceous control and those without herbaceous control. With all ages included in the analysis there were still no significant partial F-tests with the addition of the hardwood variables. However, the hardwood variables contributed slightly more to the R-squared than the treatments without herbaceous control. For instance, the addition of the change in hardwood crown volume to the model including the initial volume resulted in a 1.6% increase in the R-squared in the treatments without herbaceous control but only a 0.1% increase in the R-squared in treatments with herbaceous control. When separated by both age and herbaceous control, a single significant partial F-test resulted with the change in hardwood crown volume making a significant contribution to explaining volume growth in the three-year-old pines without herbaceous control. All other partial F-tests were insignificant.

These results indicate that additional data and analysis are needed for the development of better predictive equations. An additional year of growth may result in better prediction, as may the addition of herbaceous variables. Also, more elaborate competition indices will be calculated and utilized in the models. These will include data from a biomass-leaf area study that is currently being processed. This data will be used to develop weighting factors of competitive ability by species reflecting differential resource use. These weighting factors will be combined with the hardwood measurements to develop new competition indices and will take into account the possibility of different competitive effects by different species. On the other hand, the lack of a significant contribution by the hardwood variables may be the result of a large amount of variation between individual trees. If this is the case, stand level models may provide better prediction of growth than individual tree models in very young plantations. To test this idea, a diameter distribution model will be developed.

CONCLUSIONS

Competition control resulted in a differential growth response to release in both groundline diameter growth and volume growth in the first growing season following treatment. The best response was found in the two-year-old plantations with a 252% increase in volume growth with the two-thirds woody plus herbaceous control treatment being the best improvement over the treatment without competition control. This seems to indicate that response to release treatments may be best when they are performed in plantations entering their second growing season and that total hardwood control is not necessary or even desirable. Control of herbaceous weeds increased volume growth over the same treatment without herbaceous control in most cases. This trend was strongest in the first and second year plantations becoming less obvious with age, and response was better in woody and herbaceous control combinations than in the herbaceous control treatment alone. The inclusion of hardwood variables in equations predicting pine volume growth on the individual tree basis did not significantly increase the ability to predict growth. However, different methods of approaching this problem were indicated and further analysis is planned.

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MULCHING IMPROVES THE GROWTH AND INTERNAL MOISTURE STATUS OF LOBLOLLY PINE AND YELLOW-POPLAR IN AN INTENSIVELY MANAGED BIOMASS PLANTATION1/

R. F. Walker, R. J. Luxmoore, and S. B. McLaughlin2/

Abstract. The effects of mulching, in conjunction with fertilization and induced mycorrhizal symbioses, on the growth and internal moisture status of loblolly pine (Pinus taeda) and yellow-poplar (Liriodendron tulipifera) were studied in a plantation managed for the enhanced production of woody biomass. Mulching with perforated black plastic during the third growing season resulted in an increase in soil water potential, measured tensiometrically, which subsequently resulted in an increase in the xylem pressure potential, as measured by the pressure chamber technique, and the growth of these species. Four applications of urea-N annually at the rate of 25 kg ha^{-1} $application^{-1}$ during the second, third, and fourth year following planting resulted in a significant increase in the growth of both the loblolly pine and the yellow-poplar, but the loss of the integrity of the mycorrhizal treatments in this study negated an effort to assess the response of these species to induced mycorrhizal associations.

INTRODUCTION

The potential benefits of mulching as a cultural practice are well documented and include the reduction of surface runoff and erosion, the conservation of soil moisture, the modification of extremes in surface soil temperatures, and the control of undesirable vegetation. Mulching has been routinely employed in general agricultural and nursery operations for many years (Hartmann and Kester 1975) and has also been used extensively for highway slope stabilization (Osborne and Gilbert 1978). More recently, it has received wide acceptance as an essential tool in the reclamation of surface-mined lands (Plass 1978), and it is only in the reforestation of these sites that its applicability as a silvicultural practice been investigated (Albers and Carpenter 1979, Tackett and Graves 1979). Another potential application of mulching in forestry is in silvicultural biomass plantations, where intensive cultural practices are mandated by the relative shortness of the crop rotations, but this potential has been neither explored nor exploited to any appreciable extent. Cognizant of these foregoing considerations, this study was conducted to assess the effects of mulching, in conjunction

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2/ The authors are University of Tennessee Research Associate stationed in the Environmental Sciences Division of the Oak Ridge National Laboratory, Research Staff Member, and Senior Research Staff Member, respectively, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831. This research was sponsored by the Biomass Energy Technology Division of the U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Incorporated. Publication No. 2444, Environmental Sciences Division, ORNL. The authors are indebted to the Institute for Mycorrhizal Research and Development of the USDA Forest Service and to Dr. Ronald L. Hay of the Department of Forestry, Wildlife, and Fisheries, University of Tennessee for their assistance. The use of trade names in this publication does not constitute an endorsement by the Oak Ridge National Laboratory.

with fertilization and induced mycorrhizal symbioses, on the growth and internal moisture status of loblolly pine (Pinus taeda L.) and yellow-poplar (Liriodendron tulipifera L.) in a plantation managed for the enhanced production of woody biomass.

MATERIALS AND METHODS

The site on which this study was conducted is located in Roane County, Tennessee on the Oak Ridge Reservation. Several soil series are represented on the site, all of which were derived from shale and/or sandstone, and most of which were badly eroded. Prior to the establishment of the plantation, the predominate vegetation consisted of secondary hardwood-pine scrub forest resulting from agricultural abandonment. After the harvest of all salvageable timber and pulpwood, the slash was windrowed and the soil was prepared for planting by disking. In February and March 1981, loblolly pine3/ and yellow-poplar4/ seedlings were machine planted in separate locations on the plantation site. The spacing within and between rows was approximately 2 m, and following planting, the seedlings of each species were divided into individual 20 x 20 m plots with a 6 m wide border separating each plot. Within each species, the plots consisted of seedlings previously inoculated in the nursery with a specific mycorrhizal fungus or a combination of mycorrhizal fungi, or of seedlings infected with mycorrhizal symbionts endemic to the nursery. For the inoculated loblolly pine, an ectomycorrhizal association of this host and Pisolithus tinctorius (Pers.) Coker and Couch was induced by the method of Marx and Bryan (1975) with modifications to accommodate the prevailing site factors and soil conditions of the nursery. For the inoculated yellow-poplar, an endomycorrhizal association of this host and both Glomus mosseae (Nicol. and Gerd.) Gerd. and Trappe and Glomus fasciculatus (Thaxter) Gerd. and Trappe was induced by the method of Kormanik et al. (1980a), again with modifications to accommodate the prevailing nursery conditions. After lifting from the nursery bed, the ectomycorrhizal development of the inoculated and noninoculated loblolly pine seedlings was evaluated by the method of Marx et al. (1976) and the endomycorrhizal development of the inoculated and noninoculated yellow-poplar was evaluated by the method of Kormanik et al. (1980b).

In 1982, a fertility variable was introduced in the study by dividing the plots of the noninoculated seedlings of both the loblolly pine and the yellow-poplar into fertilized and nonfertilized treatments. The fertilized plots received four applications of urea-N, applied by broadcasting at the rate of 25 kg ha^{-1} $application^{-1}$, at equal intervals throughout the year for a total annual rate of 100 kg ha^{-1}, while the nonfertilized plots served as the control treatment. These fertilization treatments were repeated in 1983 and again in 1984. In June 1983, paired mulched and nonmulched subplots were established within the plots of the inoculated seedlings, the fertilized seedlings, and the control seedlings of each species. Each subplot consisted of two adjacent seedlings, and perforated black plastic (0.152 mm in thickness) was applied over an area of 4 m^2 centered around each of the seedlings within the subplots designated to receive the mulching treatment. Each combination of inoculation, fertilization, and mulching treatment was replicated twice for each species. Between the two seedlings of each subplot, an Irrometer® Model S 12-inch soil tensiometer5/ and two Wescor PCT-55-15-SF soil psychrometers6/ were installed in order to monitor soil moisture and temperature. One psychrometer was installed at a depth of 15 cm and the other at a depth of 60 cm.

On each of two successive days in early September 1983, the xylem pressure potentials of the trees of one replication of every combination of species and treatment were measured at dawn and again at midday using a PMS Model 600 portable pressure chamber.7/ The general methodology used for these measurements was that of Waring and Cleary (1967). Small branches selected from mid crown were cut approximately 12 cm from the terminal bud for measurement, and the pressure within the chamber was increased at a constant rate of approximately 0.07 MPa s^{-1} until sap appeared uniformly on the cut surface. The dawn measurements were begun at 6:00 a.m. and completed by 7:30 a.m. and the midday measurements were begun at 1:00 p.m. and completed by 2:30 p.m. At the midpoint of each measurement period, the air temperature was determined using a mercury thermometer. Between the dawn and midday measurements of xylem pressure potential, readings of soil water potential were taken from the soil tensiometers, and readings of soil water potential and soil temperature were obtained from the soil psychrometers using a Wescor HR-33T dew point microvoltmeter. The first series of

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3/ The loblolly pine seedlings were grown by the South Carolina State Commission of Forestry at its Ridge State Forest Tree Nursery, P.O. Box 116, Trenton, South Carolina 29847.

4/ The yellow-poplar seedlings were grown by the Tennessee Division of Forestry at its Pinson State Forest Tree Nursery, P.O. Box 132, Pinson, Tennessee 38366.

5/ Irrometer Company, P.O. Box 2424, Riverside, California 92516.

6/ Wescor, Incorporated, 459 South Main Street, Logan, Utah 84321.

7/ PMS Instrument Company, 2750 NW Royal Oaks Drive, Corvallis, Oregon 97330.

measurements of xylem pressure potential and soil water potential (Day 1-2 measurements) was made on two successive days immediately following a major precipitation event, as monitored by an on-site rain gauge. A second series of these measurements, identical in method and sequence to the first series, was made on the eighth and ninth day following the precipitation event (Day 8-9 measurements). Immediately following the Day 8-9 measurements, an estimate of the percent ground cover of each of the nonmulched subplots was determined by the guided estimate method of Phillips (1959). Measurements of the height and root collar diameter of the trees in each subplot were made in June 1983 at the installation of the mulching treatments, in October 1983 at the end of the third growing season, and in October 1984. With the exception of the air temperature measurements, analyses of variance were done on all data and the differences among means were evaluated with Duncan's New Multiple Range Test (P=0.1).

RESULTS

Twenty-four percent of the short roots of the loblolly pine seedlings inoculated in the nursery with P. tinctorius were infected with this symbiont at lifting and 30% were infected with ectomycorrhizal fungi endemic to the nursery.8/ Seventy-one percent of the inoculated loblolly pine seedlings examined at lifting from the nursery bed were infected with P. tinctorius. Of the noninoculated loblolly pine, 5% of the short roots were found to be infected with P. tinctorius at lifting and 43% were infected with naturally occurring ectomycorrhizal fungi; 34% of the noninoculated loblolly pine examined at lifting were infected with P. tinctorius. During the third growing season after outplanting, examinations of the complete root systems of inoculated loblolly pine growing adjacent to the subplots of this treatment revealed that less than 5% of the short roots were infected with P. tinctorius and less than 20% were infected by any ectomycorrhizal symbiont. Conversely, examinations of the root systems of noninoculated loblolly pine growing adjacent to the subplots of this treatment revealed that more than 40% of the short roots were ectomycorrhizal, essentially none of which was the result of an infection by P. tinctorius. After the lifting of the yellow-poplar from the nursery bed, it was found that the overall level of endomycorrhizal development did not differ significantly between the inoculated and noninoculated seedlings, so any differences in the performance of these seedlings during this study can not be attributed to this treatment.9/

Fertilization significantly increased the growth of the loblolly pine and the yellow-poplar in this study after four growing seasons (Table 1). Conversely, the growth of the inoculated trees of both species was generally inferior, with respect to height and root collar diameter, to that of the control trees irrespective of the mulching treatment, although the differences were not always statistically significant. The growth of these two species was also expressed relative to that which had occurred prior to the installation of the paired mulched and nonmulched subplots in order to emphasize the effect of this treatment on the ensuing growth through the fourth growing season. Generally, the response of both species to mulching was strongly positive with respect to either growth parameter and irrespective of the main treatment, although statistically significant differences primarily occurred only in the loblolly pine.

The xylem pressure potential measurements made at midday on the eighth and ninth day following the precipitation event indicated that the internal moisture status of the mulched loblolly pine was significantly more favorable for growth than that of the nonmulched loblolly pine within every main treatment, and similar results were noted for the measurements made at midday on the first and second day (Table 2). Generally, the xylem pressure potentials of the mulched yellow-poplar were also more favorable (less negative) at midday than those of the nonmulched yellow-poplar, although the differences within main treatments were rarely significant. At dawn, the differences in pressure potential between mulched and nonmulched trees were usually relatively small, although sometimes significant, for both species during either the Day 1-2 measurements or the Day 8-9 measurements, but here again, the internal moisture status of the mulched trees was generally more favorable than that of the nonmulched trees. Overall, the xylem pressure potentials of the fertilized loblolly pine were marginally, and in some instances significantly, higher (less negative) than those of the control loblolly pine, but significant differences rarely occurred between the fertilized and control yellow-poplar. Routinely, soil water was more available (less negative soil water

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8/ The evaluation of the ectomycorrhizal development of the loblolly pine seedlings at lifting was done by Dr. Donald H. Marx, USDA Forest Service, Southeastern Forest Experiment Station, Institute for Mycorrhizal Research and Development, Forestry Sciences Laboratory, Carlton Street, Athens, Georgia 30602.

9/ The evaluation of the endomycorrhizal development of the yellow-poplar seedlings at lifting was done by Dr. Ronald L. Hay, University of Tennessee, Department of Forestry, Wildlife, and Fisheries, P.O. Box 1071, Knoxville, Tennessee 37901.

Table 1. The growth after four growing seasons and the relative growth through the fourth growing season following mulching during the third growing season of inoculated, fertilized, and control loblolly pine and yellow-poplar.1/

Treatment	Height (cm)	Root Collar Diameter (mm)	Relative Growth Following Mulching: Height	Relative Growth Following Mulching: Root Collar Diameter
----------Loblolly Pine----------				
P. tinctorius				
Mulched	211de	48bc	0.96a	1.08a
Nonmulched	190e	37c	0.66c	0.57c
Fertilized				
Mulched	331a	76a	0.84ab	0.92ab
Nonmulched	303ab	61b	0.73bc	0.69bc
Control				
Mulched	276bc	60b	0.95a	1.11a
Nonmulched	237cd	52b	0.82b	0.92ab
----------Yellow-Poplar----------				
Glomus spp.				
Mulched	143c	38b	0.36a	0.65ab
Nonmulched	154c	36b	0.35a	0.41b
Fertilized				
Mulched	267a	58a	0.77a	1.25a
Nonmulched	258a	50a	0.50a	0.67ab
Control				
Mulched	223ab	52a	0.67a	1.13a
Nonmulched	179bc	33b	0.36a	0.61ab

1/ Within a species and column, means with a common letter do not differ significantly at P=0.1.

potential) for tree growth in the mulched subplots of both the loblolly pine and the yellow-poplar than in the nonmulched subplots during either the Day 1-2 or the Day 8-9 measurements, but the differences within main treatments were significant in only a few instances. All soil water potential measurements shown in Table 2 were obtained from the soil tensiometers installed in each subplot; the study site was not sufficiently dry at the time of these measurements to obtain accurate readings from the soil psychrometers.

The mean air temperature at 6:45 a.m. during the Day 1-2 measurements of xylem pressure potential and soil water potential was 8°C, and the mean temperature at 6:45 a.m. during the Day 8-9 measurements was 9°C. The mean air temperatures at 1:45 p.m. during the Day 1-2 and Day 8-9 measurements were 26°C and 27°C, respectively. Due to the inadvertent malfunction of the soil psychrometers installed in some of the subplots of the loblolly pine, soil temperatures were obtained in the yellow-poplar subplots only. At a depth of 15 cm, soil temperature ranged from 18°C to 21°C in the yellow-poplar subplots and did not differ significantly between any of the treatments represented in this study. The percent ground cover within the nonmulched subplots of the inoculated, fertilized, and control loblolly pine was 78%, 74%, and 54%, respectively, but a significant difference existed only between the inoculated and the control loblolly pine. The percent ground cover within the nonmulched subplots of the inoculated, fertilized, and control yellow-poplar was 24%, 54%, and 45%, respectively; there were no significant differences in percent ground cover between any of the main treatments of the yellow-poplar.

DISCUSSION

It can be concluded that the perforated black plastic used as a mulch in this study conserved soil moisture in the mulched subplots sufficiently to effect a significant reduction in the internal moisture stress of the loblolly pine, and to a lesser extent the yellow-poplar, during dry periods. Subsequently, this enhanced internal moisture status was reflected in the increased growth of the mulched trees that followed the installation of this treatment. Plastic mulching materials are undoubtedly effective in reducing evaporative loss of soil moisture, but integrating the results of other studies (Carter et al. 1984, Nelson et al. 1981) and the results presented here suggests that the elimination of competing vegetation which accompanies the use of mulches is also of primary importance in the conservation of soil moisture. Comparisons of the xylem pressure potentials between the fertilized and control trees of both species indicated that the fertility regime employed in this study did not effect an imbalance in the shoot/root ratio to the extent that it impaired the ability of the root systems to supply water to the aboveground portions during dry periods. The lack of a significant difference between the soil temperatures of the mulched and nonmulched yellow-poplar subplots indicates that the use of black plastic as the mulching material did not result in an elevation of soil temperature, and subsequently that the increased growth of the mulched trees in this study can not be attributed to any increase in nutrient availability resulting from a temperature-induced increase in the rate of soil organic matter mineralization.

Any reasoning for the relatively poor performance of the inoculated loblolly pine and yellow-poplar in this study is largely a matter of speculation, and it is probable that several interacting factors contributed to this result. A relatively long cold storage period (approximately eight weeks) between the lifting and the outplanting of the loblolly pine may have

Table 2. The xylem pressure potentials and soil water potentials in paired mulched and nonmulched subplots of inoculated, fertilized, and control loblolly pine and yellow-poplar at two time intervals following a major precipitation event during the third growing season.1/

	Xylem Pressure Potential (MPa)				Soil Water Potential (MPa)	
	Day 1-2		Day 8-9			
Treatment	Dawn	Midday	Dawn	Midday	Day 1-2	Day 8-9
Loblolly Pine						
P. tinctorius						
Mulched	-0.41a	-1.30c	-0.41a	-1.38b	-0.048a	-0.054ab
Nonmulched	-0.48b	-1.38e	-0.53ab	-1.52c	-0.051a	-0.057b
Fertilized						
Mulched	-0.48b	-1.13a	-0.54ab	-1.24a	-0.033a	-0.054ab
Nonmulched	-0.52bc	-1.25b	-0.52ab	-1.47c	-0.057a	-0.066c
Control						
Mulched	-0.49b	-1.34d	-0.54ab	-1.42b	-0.045a	-0.047a
Nonmulched	-0.53c	-1.39e	-0.71b	-1.49c	-0.054a	-0.056b
Yellow-Poplar						
Glomus spp.						
Mulched	-0.46c	-1.29b	-0.54ab	-1.27a	-0.026a	-0.034a
Nonmulched	-0.49d	-1.38b	-0.60ab	-1.49a	-0.049b	-0.039ab
Fertilized						
Mulched	-0.40a	-1.00a	-0.47ab	-1.25a	-0.038ab	-0.043b
Nonmulched	-0.46c	-1.29b	-0.70b	-1.51a	-0.042ab	-0.055c
Control						
Mulched	-0.39a	-1.21ab	-0.45a	-1.43a	-0.035ab	-0.037ab
Nonmulched	-0.43b	-1.31b	-0.52ab	-1.52a	-0.039ab	-0.039ab

1/ Within a species and column, means with a common letter do not differ significantly at P=0.1.

resulted in a reduction in the viability of the *P. tinctorius* ectomycorrhizae present on the root systems of the inoculated seedlings, which subsequently resulted in a delay in the development upon outplanting of the ectomycorrhizal root systems considered indispensable for the growth of *Pinus* spp. under natural conditions (Meyer 1973). Ectomycorrhizal fungi differ markedly in their carbohydrate requirements (Hacskaylo 1973), and the *P. tinctorius* ectomycorrhizae may have largely exhausted available carbohydrate reserves during cold storage. It is also possible, despite appearances to the contrary (Marx 1977), that the site on which this study was conducted was not suitable for the growth and development of *P. tinctorius*. The lack of any quantitative difference in overall endomycorrhizal development between the inoculated and noninoculated yellow-poplar at outplanting leads to the conclusion that the relatively poor performance of the inoculated yellow-poplar was attributable to variation in site characteristics within the plantation, a factor which may have also contributed to the relatively poor performance of the inoculated loblolly pine. In contrast to the disappointing results of the mycorrhizal treatments employed in this study, the response of both loblolly pine and yellow-poplar to fertilization was strongly positive and, in light of the poor growing conditions prevailing on the site, needs no further elaboration.

In woody biomass plantations where intensive silvicultural practices are mandated by the relative shortness of the crop rotations, the results presented here indicate that mulching can result in a substantial increase in site productivity, and in many locations, may eliminate the need for more costly irrigation systems. This cultural practice may prove particularly applicable in climatic regions typified by adequate yearly precipitation but subject to uneven distribution, such as the southeastern United States, where it may effectively extend the growing season through the frequently dry months of August and September.

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INTENSIVE CULTURE GIVES SLASH PINE PLANTATIONS A FAST START[1/]

James D. Burton and Glenn A. Snow[2/]

Abstract.--Container-grown slash pine seedlings planted on a cutover forest site in central Louisiana received 4 levels of culture (check, weeded, weeded-bedded, or weeded-bedded-fertilizer) in all possible combinations with no spraying or repeated sprayings of a systemic fungicide for protection against fusiform rust. Four years after planting, mean tree height and total stemwood volume per acre increased from 5.5 feet and 20 cubic feet/acre on check plots to 13.2 feet and 193 cubic feet/acre on weeded-bedded-fertilized plots. On fungicide-sprayed plots, the percentage of planted trees surviving and free of stem galls decreased from 95 in the check plots to 90 in the weeded-bedded-fertilized treatment. In unprotected plots, the comparable percentages were 76 and 51.

INTRODUCTION

Slash pine (*Pinus elliottii* Engelm. var. *elliottii*) plantations in the western Gulf Coastal Plain can reach economic maturity faster if the rotation is shortened by site preparation, weeding, and fertilization. Rapid growth also has insurance value and planning value: the juvenile period of extreme vulnerability to wildfire and disease is shortened, while the latitude for decision making by the landowner is correspondingly increased. An example is provided by an ongoing study that was begun in central Louisiana in 1979. Results through the first 4 years of that study are presented in this paper.

MATERIALS AND METHODS

Study Area

The study area is on the Palustris Experimental Forest near Alexandria, Louisiana. Soils are silt loams in the Beauregard-Caddo association. Slopes range only from 0.2 to 0.6 percent, averaging 0.4 percent, and consistently face a single direction. Nutrient-supplying capacity of the soils is low: total nitrogen in the uppermost 6 inches averaged 0.09 percent and available phosphorus 0.9 p/m. Although these soils are droughty in summer, the water table is at or near the surface in winter.

The area was prepared by harvesting the volunteer oak-pine forest. Every tree, living or dead, standing or fallen, 2 inches d.b.h. and larger, was dragged off the site; woody stems smaller than this were cut and left.

Seedling Production

Seeds from a bulk lot, labeled South Mississippi Slash Pine 1973, were sown in styroblock containers with 4-cubic-inch cavities. Previous experience had shown that trees grown from seeds of this lot were vigorous, hardy, and susceptible to fusiform rust infection in central Louisiana. Seedlings were grown for 14 weeks in a greenhouse and outplanted in April 1979, spaced 6 feet apart in rows 8 feet apart. Each plot contained 168 trees (equals 908 trees/acre) in 12 rows of 14 individuals.

Treatments

Eight plots, each 96 by 84 feet (equals 0.185 acre), were laid out in each of three blocks. Eight treatments representing four levels of culture with no spraying or repeated sprayings of a systemic fungicide for protection against fusiform rust were randomly assigned within each block. The culture levels were:

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[2/] Burton is Research Forester, USDA Forest Service, Southern Forest Experiment Station, Pineville, LA. Snow is Supervisory Research Plant Pathologist, Southern Forest Experiment Station, Gulfport, MS.

C - Check,

W - Weeding,

WB - Weeding and bedding, and

WBF - Weeding, bedding, and fertilizing.

In October 1978, 6 months before outplanting, the W plots were flat-disked, and the WB and WBF plots were bedded. The WBF plots were given 96 lb/acre of phosphorus before bedding, so that the forming of the beds would mix the 0-46-0 triple superphosphate with the soil. The WBF plots also received ammonium nitrate, which is 33 percent elemental nitrogen, in July 1979, 3 months after outplanting of the slash pine seedlings. Twenty grams (0.0441 lb) of ammonium nitrate pellets were applied in a circle 1 foot in radius around each of the 908 seedlings per acre. This rate amounted to a nitrogen application equivalent to 200 lb/acre within these circles or 13 lb/gross acre.

The plots to be weeded (W, WB, and WBF) were sprayed with a mixture of dalapon (6 lb a.i./acre) and simazine (3 lb a.i./acre) in April and with glyphosate (5.5 lb a.i./acre) in late July in each of the first 4 years.

The systemic fungicide triadimefon, trade name Bayleton[3/] WP50 (50-percent wettable powder), was prepared by mixing 6 g with 6.3 ml of Agri-Dex sticker in 1 gal of water. Hand-pumped backpack sprayers were used to apply the suspension in the first and second years, and a high-volume power sprayer was used in the third and fourth years. During the first year, fungicide was applied to the seedlings the day before planting and then four more times at 0.05 lb/acre at intervals of about 2 weeks. There were 5 sprayings at 0.2 lb/acre the second year, 4 at 1.9 lb/acre the third year, and 3 at 1.0 lb/acre the fourth year. During the first 3 years, each spraying applied enough of the suspension to wet the entire crown. In the fourth year, each spraying wetted only the growing tips. The sprayings began in the first week of April and ended in the third week of May, thus spanning the period when basidiospore dissemination usually occurs.

Measurements and Analysis

All measurements were made on the 48 trees (6 rows of 8) at the center of each plot.

Tree survival was observed and total height measured to the nearest 0.1 foot at the end of each growing season; d.b.h. of trees >4.5 feet tall was measured to the nearest 0.1 inch after the third and fourth growing seasons. For comparisons between treatments, the quadratic mean d.b.h. (d.b.h. of the tree of mean basal area) was calculated. Stemwood volumes were obtained by the slash pine formula of Schmitt and Bower (1970). Fusiform rust galls for each year were observed in March, 15 months after the end of the year of infection.

Analysis of variance employed a factorial model. When the fungicide x culture interaction was significant at the 0.05 level, differences between culture means within a fungicide level were tested by Duncan's new multiple range test. When the interaction was not significant, the main effect of culture, with 3 degrees of freedom (d.f.), was tested by Duncan's test, and the main effect of fungicide, with 1 d.f., was tested by the error mean square, with 14 d.f. Throughout this paper, treatment means, main effects, and their differences are reported only if these differences are significant.

RESULTS

Survival and Growth

After 4 years, survival was 91 percent in the check and averaged 95 percent in the other culture levels (table 1). It averaged 91 percent in unprotected and 97 percent in protected treatments. The fungicide x culture interaction was not significant.

Mean height at age 4 was 5.5 feet in the check, was nearly doubled by W, was more than doubled by WBF, but was not affected by WBF or fungicide (table 2). Fourth-year height growth of surviving trees >4.5 feet tall increased with W and again with WBF; it also was increased by fungicide (table 3). In the check, 79 percent of surviving trees were >4.5 feet tall; in all other culture levels, 99 percent were >4.5 feet tall. Seedling height responded strongly to W and again to WBF in each of the 4 years (fig. 1). Through the first 4 years, the gain over C due to W was still increasing, but the advantage of WBF over W and WB was decreasing, the reward for fertilizer

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[3/] Bayleton is a registered trademark of Farbenfabriken Bayer GmbH, Leverkusen. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the USDA of any product or service to the exclusion of others that may be suitable.

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being greatest in the third year. This suggests that a second application of fertilizer, in the sixth or seventh year, might be worthwhile.

Table 1.--Survival after 4 years by culture and fungicide level[1/]

Fungicide level	Culture level: Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Percent of planted trees				
No	86	95	92	0	91 a
Yes	95	97	99	6	97 b
Culture mean	91 a	96 b	96 b	93 ab	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level.

Table 2.--Mean height after 4 years by culture and fungicide level[1/]

Fungicide level	Culture level: Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Feet				
No	5.7	9.7	10.0	13.5	9.7 a
Yes	5.3	10.6	10.4	12.8	9.8 a
Culture mean	5.5 a	10.2 b	10.2 b	13.2 c	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level.

Table 3.--Mean fourth-year height growth of surviving trees >4.5 feet tall by culture and fungicide level[1/]

Fungicide level	Culture level: Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Feet				
No	2.4	4.0	3.9	4.5	3.7 a
Yes	2.4	4.5	4.3	4.7	4.0 b
Culture mean	2.4 a	4.2 b	4.1 b	4.6 c	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level.

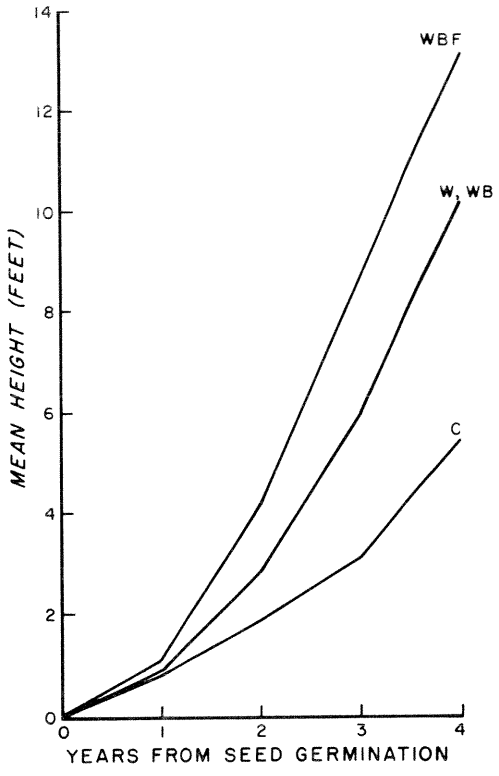

Figure 1.--Average tree height by year in check, weeded, weeded-bedded, and weeded-bedded-fertilized treatments

The quadratic mean d.b.h. at age 4 was 0.7 inch in C, 1.8 inches in W and WB, and 2.6 inches in WBF (table 4). It was not affected by fungicide, and the interaction was not significant Fourth-year growth in d.b.h. was 0.7 inch in C and 1.1 inches in cultivated (W, WB, and WBF) plots (table 5).

Table 4.--Quadratic mean d.b.h. of surviving trees >4.5 feet tall at age 4 by culture and fungicide level[1/]

Fungicide level	Culture level: Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Inches				
No	0.70	1.69	1.83	2.65	1.71 a
Yes	.65	1.94	1.87	2.50	1.74 a
Culture mean	.67 a	1.81 b	1.85 b	2.57 c	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level.

Table 5.--Fourth-year d.b.h. growth of surviving trees >4.5 feet tall by culture and fungicide level[1/]

Fungicide level	Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Inches				
No	0.68	1.03	1.09	1.09	0.97 a
Yes	.65	1.16	1.16	1.19	1.04 a
Culture mean	.66 a	1.10 b	1.12 b	1.14 b	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level.

Stemwood volume in trees >4.5 feet tall was 20 ft^3/acre in C, and was increased fivefold by W and tenfold by WBF (table 6).

Table 6.--Total stemwood volume per acre at age 4 in trees >4.5 feet tall by culture and fungicide level[1/]

Fungicide level	Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Cubic feet[2/]				
No	21	83	103	208	104 a
Yes	20	107	98	177	101 a
Culture mean	20 a	95 b	101 b	193 c	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level.

2/ Inside bark, including leader, computed as $V = 0.02408D^2H$. This equation was calculated for slash pine by Schmitt and Bower (1970).

Fusiform Rust

Most of the stem infections occurred in the first year. Only 15 percent of these first-year stem galls were from infections that originated in branches and then grew into the stem. Trees protected with fungicide developed significantly fewer stem galls than unprotected trees: 1.6 percent versus 27 percent (table 7). The interaction was not significant. Rust incidence was not affected by culture in the first year.

Table 7.--Stem infection of fusiform rust in slash pine plantations in the first year by culture and fungicide level[1/]

Fungicide level	Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Percent of planted trees				
No	23.6	26.4	34.7	23.6	27.1 b
Yes	0.7	1.4	1.4	2.8	1.6 a
Culture mean	12.2 a	13.9 a	18.1 a	13.2 a	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level.

Rust-associated mortality through age 4 showed a significant fungicide x culture interaction: in protected plots, the percentage of trees dead and stem-galled was practically zero and was not affected by culture; in unprotected treatments, nearly 10 percent of the trees in check and about 5 percent of those in all other culture levels were dead with stem galls (table 8).

Table 8.--Rust-associated mortality (dead trees with stem infections) through the first 4 years by culture and fungicide level[1/]

Fungicide level	Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Percent of planted trees				
No	9.7 b	4.2 a	6.9 ab	4.9 a	-
Yes	0 a	0.7 a	0 a	0 a	-
Culture mean	-	-	-	-	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level. The fungicide x culture interaction is significant.

After 4 years, about 93 percent of the trees planted in fungicide-protected plots were alive and had no stem infections (table 9). Among unprotected trees, 76 percent of those in the check and only 54 percent in the other culture levels were alive and free of stem galls.

Table 9.--Trees living and free of stem infection after 4 years by culture and fungicide level[1/]

Fungicide level	Culture level: Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Percent of planted trees				
No	75.7 a	56.9 b	52.8 b	51.4 b	-
Yes	95.1 a	92.4 a	93.7 a	89.6 a	-
Culture mean	-	-	-	-	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level. The fungicide x culture interaction is significant.

Forty-three percent of the trees in unprotected check plots were alive and had one or more fusiform rust infections in either stem or branch, compared to 70 percent in other culture levels (table 10). In protected treatments, less than 1 percent of the trees in check plots were infected, while 18 percent of the trees in W and WB plots and 27 percent of those in WBF plots were infected.

Table 10.--Living trees infected in stem or branch after 4 years by culture and fungicide level[1/]

Fungicide level	Culture level: Check	Weeding	Weeding, bedding	Weeding, bedding, fertilizing	Fungicide mean
	Percent of planted trees				
No	43.0 a	72.2 b	68.0 b	69.4 b	-
Yes	0.7 a	17.4 b	18.7 b	27.1 c	-
Culture mean	-	-	-	-	

1/ Means followed by the same letter within a row or column are not significantly different at the 0.05 level. The fungicide x culture interaction is significant.

DISCUSSION

The fungicide x culture interaction was not significant in any of the analyses of survival or growth.

The fact that fertilizer significantly increased mean tree height in the first growing season attests to the thoroughness of the weeding.

Bedding had no effect, other than as a method of disking, on survival or growth. Although the slope of the land was very slight, water did not remain ponded on the surface; hence, drainage apparently was of no value. Bedding also had no effect on first-year stem infection, on rust-associated mortality through the first 4 years, or on percentage of infected trees at age 4.

In the cultivated (W, WB, and WBF) plots after 4 years, all the pines were in the 2-inch d.b.h. class and larger, the period of highest mortality was past, the risk of regeneration failure could be discounted, and expected losses from fusiform rust could be assessed.

The WBF plots with fungicide protection were far along toward becoming stands of sawtimber nearly free of stem galls. The 100 tallest trees per acre in the WBF treatment averaged 16 feet tall, and 90 percent of the protected trees had no stem infections. They had formed bark over a 16-foot butt log. [Table 1 of Mesavage and Girard (1946) indicates that 58 percent of the board-foot volume of a 2-log tree is in the first 16-foot log.]

In the W and WB plots, the 100 tallest trees per acre averaged 12.8 feet tall. They are virtually assured of 12-foot butt logs, and where protected by fungicide, 93 percent of them will be free of stem galls. However, if the landowner in this case were prepared to do thorough, repeated weeding, he may as well apply fertilizer also, if the soil is one on which a strong response to fertilizer can be expected. Weeding is expensive, and fertilizing is cheap. If fungicide protection is not employed, weeding probably will increase incidence of stem rust, but fertilizer probably will not increase it further.

Through the first 3 years, the amount of fungicide required for each spraying increased as the trees grew larger. At the beginning of the third year, the trees in all treatments except C were three times as tall as they were at the beginning of the second year. The amount of fungicide sprayed in the third year was substantial and may appear excessive because only 1.4 percent of the unprotected trees incurred stem infections in the third year. However, the potential for infection was high; 35 percent of the unprotected trees in the W, WB, and WBF treatments had branch infections in third-year tissue, compared to 5.8 percent of the protected trees. Many of these third-year branch infections will grow into the stem.

Landowners accustomed to planting 400 to 500 trees per acre may regard the 908 per acre (6 x 8 foot spacing) in these plantations as excessive. However, in localities where fusiform rust incidence is frequently high--and when the soil is stirred, bedded, and ditched--and followup understory control is planned, increased rust incidence must be expected. Moderately dense initial stands are desirable because many stems will be lost to disease if fungicidal chemicals are not employed. Infections in dense stands tend to form branch galls, rather than stem galls; the infected branches die very early; and the branch galls die before the fungus reaches the stems (Czabator 1971). If an effective systemic fungicide is used, and if thorough weeding is planned, the initial spacing may be widened to 7 x 10 or 8 x 10 feet (622 to 544 trees per acre).

In this study, canopy closure occurred before the end of the fourth growing season in W, WB, and WBF plots and no understory existed. The heavy litter will inhibit formation of herbaceous understory, even if no further weeding is done. Trees in the WBF plots are large enough to withstand a low-intensity prescribed burn. Although this study does not include burning, most landowners probably would burn. In the protected plots, the abundance of large trees free of stem galls makes these stands very attractive to manage for sawtimber.

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SOIL COMPACTION FROM TRACKED AND RUBBER-TIRED TRACTORS AND ITS INFLUENCE ON SEEDLING SURVIVAL AND GROWTH[1/]

R. E. Kreh, J. A. Burger, and J. L. Torbert[2/]

Abstract.--The effect of multiple passes of tracked and rubber-tired harvesting and site preparation equipment, operating under known soil moisture conditions, on tree survival and growth after two growing seasons was evaluated. A skidder and crawler compacted the soil to the same extent despite differences in contact pressure. The number of passes over the same area did not affect survival, but volume was reduced by 34% after one pass and 54% after nine passes. Higher soil moisture resulted in higher compaction, but growth was not significantly affected.

INTRODUCTION

Harvesting and site preparation are operations that can adversely affect soil structure, density, and porosity and subsequent reforestation success. The diversity of equipment, soil types, and the dynamic nature of soils, especially soil water movement, can result in a variety of soil and tree growth responses to soil compaction. Forest soils with a shallow litter layer, low amount of organic matter in the mineral soil, and a moisture content around field capacity are most susceptible to compactive forces. The result of this force can be substantial even after one trip over an area. Foil and Ralston (1967), Mitchell (1979) and Lockaby and Vidrine (1984) reported reductions in loblolly pine growth as compaction levels increased. A critical bulk density of 1.49 g/cm^3 was identified by Foil and Ralston (1967) above which growth was reduced. Zisa et al. (1980) showed that bulk densities above 1.2 g/cm^3 in a silt loam soil greatly restricted depth of root penetration of Austrian pine.

The increase in bulk density from compactive forces is mainly a result of collapsing large pore spaces. As the percentage of pores greater than 0.002 in in diameter (aeration porosity) is reduced, water and gas movement are slowed. Chancellor (1977) found that a bulk density increase from 1.2 to 1.5 g/cm^3 caused a 40-fold decrease in infiltation rate. Once absorbed, water is held at higher tensions in compacted soils with small pores causing trees to experience stress at an earlier point.

The objective of this study was to determine the effect of multiple passes of tracked and rubber-tired harvesting and site preparation equipment, operating under known soil moisture conditions, on tree survival and growth after two growing seasons.

SITE DESCRIPTION

A 3.5 acre forested area located on the Reynolds Homestead Research Center in Patrick County, Virginia, was clearcut and used for the study. The 30-year-old forest stand consisted of 95% Virginia pine (*Pinus virginiana* Mill.), with mixed hardwood species making up the remainder. Stocking was 949 trees/acre with an average DBH of 5.3 in for a basal area of 110 ft^2/acre. The forest floor (01 and 02 horizons) was measured at 169 randomly selected sampling points. The average depth and dry weight were 1.30 in and 0.67 lb/ft^2, respectively.

The predominant soil series was Cecil which is a member of the clayey, kaolinitic, thermic, Typic Hapludult family. Associated soil series in the area are Hayesville, Hiwassee, and

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Research Associate, Assistant Professor, and Research Assistant, respectively, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

Madison. The soil textural class is a sandy clay loam with a moderately eroded surface.

A 590 x 360 ft rectangular study area was surveyed. Three vehicle corridors were located on either side and bisected the plot through its longest dimension. The corridors provided harvesting and study-area access to the two 590 x 100 ft subplots. All trees with a breast height greater than 1 inch were felled. All above ground vegetation was then remotely skidded or hand carried from the plots to avoid soil compaction from harvesting equipment.

METHODS AND MATERIALS

Seedling survival and growth as affected by two machine types (rubber-tired skidder and crawler) making multiple passes (0, 1, 3, and 9 passes) on soil adjusted to two soil moisture contents (18 and 21% by weight), were evaluated. The two 590 x 100 ft main plots were irrigated with 8016 and 12,042 ft^3 of water pumped from a nearby stream to raise the moisture content of the surface soil from an average of 12% by weight to 18% and 21%, respectively. The irrigation water, added over a 24-hour period, simulated rainfalls of 0.9 and 1.3 in.

A John Deere model 540B log skidder and a Komatsu model D53A crawler with gravitational loads of 16,814 and 32,767 lb, respectively, were used. The skidder was fitted with 23.1 - 26 tires inflated at 20 psi. The mean ground pressures for the skidder and crawler were 33.3 and 8.7 psi, respectively. Each machine, driven unloaded at a constant speed of 2 mi/h, was used to make tracks consisting of 0, 1, 3, or 9 consecutive passes with 0 passes serving as the control. Tracks formed by vehicle traffic were 100 ft long with an 8.2 ft spacing between tracks.

The experimental design was a split-split plot. The machine-type times number-of-passes combinations were subplots within moisture main plots. The experiment was replicated three times. The experimental unit for soil properties consisted of an average value of three soil samples taken systematically at 20 ft intervals from one of the two 100 ft tracks formed by the passage of the machines. At each sampling location, a core sampler was used to obtain an 8.4 in^3 undisturbed soil core from the soil surface.

In the laboratory, a tension table was used to determine noncapillary porosity by evacuating soil macropores. A 19.7 inch water column was used to create the tension. Bulk density was determined by drying the soil samples to a constant weight in a 105 C oven.

Nursery run loblolly pine, were planted in the spring, 6 mo after the soil compaction occurred. One track of each soil treatment combination was hand planted and its companion track was machine planted (foot type wildland planter) on a 5 ft spacing within rows. Survival and tree height and diameter values were based on approximately 20 trees planted per vehicle track (experimental unit).

RESULTS

As bulk density is increased and aeration porosity decreased, tree volume is decreased. The relationship between these soil properties and tree volume, as measured on this study site after two growing seasons, is depicted in Figure 1. Although highly variable due to heterogenous field conditions, functional relationships are significant.

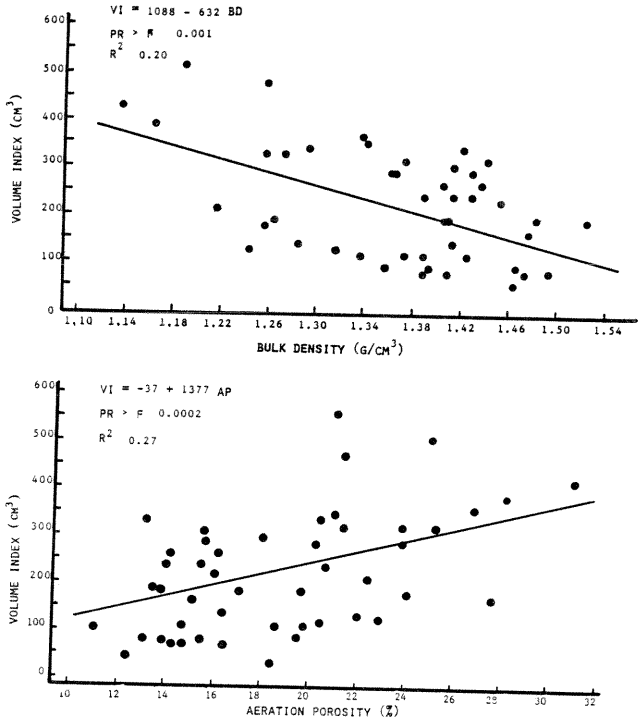

Figure 1.--Relationship between tree volume index and soil bulk density and porosity.

The two machines (skidder and crawler) compacted the soil to the same extent despite differences in contact pressure (Table 1). No interactions between machine type and number of passes occurred. Both the skidder and crawler had the same effect on bulk density and aeration porosity at all moisture and pass levels.

The number of passes significantly affected soil density and aeration porosity (Table 1). After nine passes there was a 13% increase in bulk density and a 37% decrease in aeration porosity. The number of passes did not affect survival, but volume index was reduced by 34% after one pass and 54% after nine passes.

Table 1.--Effect of Machine Type, number of passes, moisture level and planting method on surface soil bulk density, aeration porosity and second year survival and growth of loblolly pine on a clearcut forest site.

Treatment	Soil		Tree	
	Bulk Density	Aeration Porosity	Survival	Volume Index
	(g/cm^3)	(%)	(%)	(cu. in)
Machine Type				
Skidder	1.37 a*	19 a	50 a	12.7 a
Crawler	1.36 a	19 a	52 a	11.9 a
Number of Passes				
0	1.27 a	24 a	50 a	18.3 a
1	1.35 b	20 b	54 a	12.5 b
3	1.42 b c	16 c	48 a	9.9 b
9	1.43 c	15 c	52 a	8.4 b
Moisture Level				
18%	1.35 a	20 a	48 a	11.1 a
21%	1.38 b	17 b	54 b	13.5 b
Planting Method				
Hand	NA	NA	58 a	13.7 a
Machine	NA	NA	44 b	10.9 b

* Values followed by different letters in any column are different at the 0.05 level.

The higher moisture level (21%) at time of compaction resulted in a greater increase in bulk density and decrease in aeration porosity than the lower moisture level (18%). However, survival and volume index were greater on plots compacted at the higher moisture level. The site that was irrigated to the higher moisture level is slightly downslope from the drier site and may have provided better growing conditions.

Hand planted seedlings had 25 per cent higher survival and 26 per cent more volume than machine planted trees. (Table 1).

DISCUSSION

The surface soil on this Piedmont site was already relatively dense (1.27 g/cm^3) before any treatments were imposed. One pass significantly reduced tree volume and three passes raised surface soil bulk density above 1.4 g/cm^3, a value that greatly reduced root and top growth of Austrian pine (Zisa et al. 1980) growing in soils of similar texture. Surface-soil aeration porosity was at a reasonable level (24%) before treatments were applied, but by the ninth pass it had been reduced to 15% which greatly restricts water infiltration and gas exchange.

If only one pass by either type of machine results in a 32% reduction in tree volume, large reductions on a stand basis could result if a large enough area is covered. Equipment that is fast, maneuverable, capable of operating on wet soil and steep slopes will tend to cover more land area. Coverage also tends to increase as the slope percent decreases. Estimates range from 10 to 50 percent coverage by at least one pass of harvesting equipment. (Hatchell et al. 1970, Campbell et al. 1973, Froehlich 1976 and Switzer et al., 1979).

Site preparation operations can also contribute to the area compacted. Shearing, raking, and chopping require machinery to pass over a large portion of a site at least once.

The effect of soil moisture level at the time treatments were applied was not detected because differences in site quality confounded the responses. In addition, the irrigation did not achieve the range in soil moisture that was intended. However, the 3% difference was enough to cause significantly higher compaction and reduction in aeration porosity, thus showing the importance of soil moisture content.

Extensive traffic on inherently dense soils, common on the eroded Piedmont Plateau, could reduce yields. Consequences of soil compaction at the end of the rotation are not well documented. In one study Perry (1964) showed that the growth of 26-year-old loblolly pine growing on compacted soils was reduced by 52%. If the 32% reduction in volume persists over a pulpwood rotation, a potential yield of 30 cords/acre would be cut by 10 cords.

CONCLUSIONS

Despite the greater contact pressure of the skidder, changes in soil density and aeration porosity caused by the machines were the same.

Soil density inceased and aeration porosity decreased after only one pass and changed at a decreasing rate with successive passes.

Soil compaction had no significant effect on survival of planted seedlings.

Bulk density and aeration porosity both significantly affected tree growth at age two. However, aeration porosity appears to have the greater effect.

Higher bulk density and lower aeration porosity occurred at the higher level of soil moisture; however, the changes resulting from only a 3% difference in soil moisture did not affect tree growth.

Hand planted seedlings survived and grew better than machine planted seedlings. Therefore, there is no evidence to suggest that the machine planter benefits seedlings by shattering compacted soils.

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GEOMORPHIC FACTORS ASSOCIATED WITH QUALITY OF YELLOW-POPLAR SITES IN THE SOUTHERN APPALACHIANS[1/]

W. Henry McNab[2/]

Abstract.--This study determined the relationship of yellow-poplar site index to topographic variables as a prerequisite to the development of a landform classification system for the Southern Appalachians. Data from 140 permanent plots from northeast Georgia to central Virginia were used. Stand age and three topographic variables--landform surface shape, slope aspect, and slope gradient--were significantly related to yellow-poplar tree height at age 50 and accounted for 70 percent of the variation. After accounting for age, yellow-poplar height was most responsive to plot surface shape, which resulted in up to a 20 point change in site index.

INTRODUCTION

Site index is probably the most widely used and best measure of forest site productivity. Where suitable sample trees are not available, site index must be estimated by using soil-site relationships. Previous soil-site studies of yellow-poplar (Liriodendron tulipifera L.) have shown that much of the variation in height growth may be explained by soil and topographic variables that are related to the soil moisture regime during the growing season (Auten 1945, Tryon et al. 1960, Della-Bianca and Olson 1961, Phillips 1966). For the Blue Ridge Mountains of Georgia, Ike and Huppuch (1968) reported that 71 percent of variation in total height of yellow-poplar at 50 years was explained by soil series and topographical variables including elevation, slope position, and exposure of the site.

Geometric shape of the land surface is a topographic variable that accounts for concentration or dilution of surface water and nutrients, but which has seldom been included in yellow-poplar soil site studies. Surface shape was included in one study of yellow-poplar site index in the gently rolling topography of southeastern Ohio, but was not found to be significant (Munn and Vimmerstedt 1980). Of all the topographic variables usually included in site index studies, landform shape has received least attention.

Site index estimates for yellow-poplar based only on topographic variables seem to be feasible in the Appalachian Mountains because many soil characteristics are closely related to topography. For example, depth of the soil A1 horizon may be correlated with slope position and land surface shape. Suitable equations applicable over a wide geographic area would be beneficial for broadly evaluating site productivity by remote sensing and for cutover areas which lack adequate site trees. Also, recent interest in land classification based on ecological principles (Driscoll et al. 1984) increases the need for topographic descriptions of landforms with similar environmental characteristics.

The objectives of the study were to (1) determine methods to qualitatively describe surface shape of landforms, and (2) develop the relationship between topographic variables and site productivity for yellow-poplar in the Southern Appalachian Mountains.

METHODS

Field Plots

Long-term growth and yield plots for yellow-poplar (Beck and Della-Bianca 1972) were used in this study. Plots had been installed throughout the Southern Appalachian Mountains

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2/ Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, Asheville, NC.

from north Georgia to central Virginia in even-aged yellow-poplar stands that showed no evidence of recent disturbance (fig. 1). A wide range of environmental conditions is represented where yellow-poplar may form almost pure stands. Site index curves developed by Beck (1962) were used as a measure of productivity of each plot.

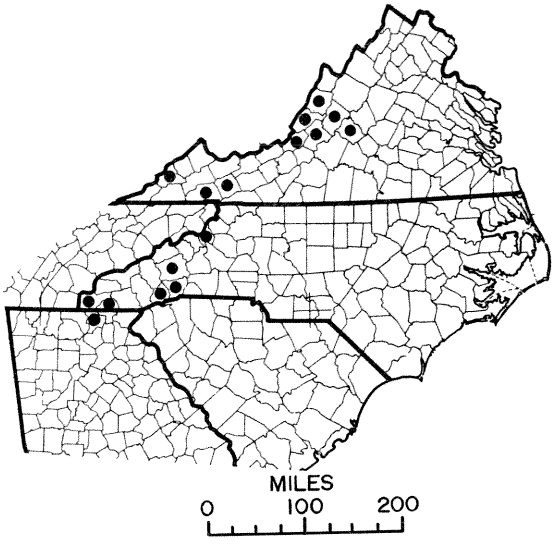

Figure 1.--Location of sample plots in yellow-poplar stands in the Southern Appalachian Mountains.

Topographic variables measured on each plot during the winter and spring of 1984 were:

(1) Aspect (azimuth from north in degrees)

(2) Gradient (slope steepness in direction of aspect, in percent)

(3) Slope position (distance from ridge to stream bottom, in percent)

The surface shape of each plot was determined in two directions, parallel and perpendicular to the aspect, and classified as convex, linear, or concave. With these three geometric shapes, the surface configuration of each plot was described by standard, recognizable shapes of landforms common to mountainous terrain (fig. 2).

Other site variables were determined from USDI Geological Survey topographic quadrangle maps (1:24,000 scale):

(1) Elevation (nearest 20 feet)

(2) Latitude and longitude (in degrees and hundredths)

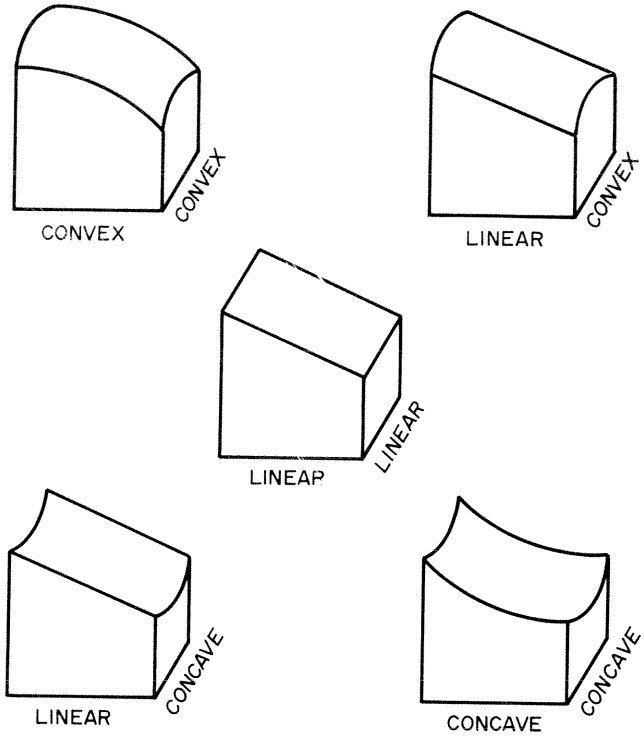

Figure 2.--Geometric shapes for components of mountainous landforms.

Annual total solar radiation for each plot was calculated from aspect, gradient, and latitude by using an algorithm developed by Swift (1976). Mean age and height of the yellow-poplar stand on each plot were obtained from basic field data when the plots were originally established.

A total of 140 1/4-acre plots was measured. Means and ranges of the timber stand and site characteristics for all plots are shown in table 1. Site index ranged from 74 to 138 and covers the range of higher quality sites where essentially pure stands of yellow-poplar occur in the Southern Appalachians. Although the topographical variables indicate a wide range of values, the plots were originally installed to obtain a uniform distribution of stand ages, stockings, and site indexes. Consequently, topographical variables were not uniformly replicated over all sites.

Most of the plots were in the intermediate quality class which ranged from site index 100 to 120 (fig. 3). Soils were typically in the Tusquitee series, which are Umbric Dystrochrepts that are deep, well drained, and formed in colluvium originating from granite and metamorphic rock including schist and gneiss.

Table 1.--Mean and range of stand and site characteristics of sampled yellow-poplar plots

Item	Mean	Minimum	Maximum
Site index	107	74	138
Age (years)	47	17	76
Height (feet)	99	56	140
Shape index	0.6	-2.0	2.0
Aspect (azimuth)	130	1	360
Gradient (%)	30	2	67
Elevation (feet)	2630	1120	3720
Latitude (degrees)	35.4	34.1	38.0

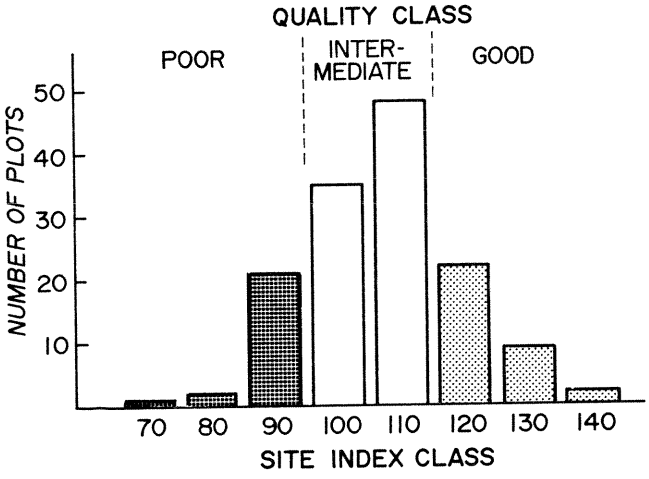

Figure 3.--Distribution of yellow-poplar sample plots by site index and quality class.

Data Analysis

Prior to analysis, extensive plotting of the field data was done to determine which topographic variables showed a relationship to tree height and if data transformations were necessary to account for nonlinear effects. Plot aspect was transformed by a procedure proposed by Stage (1976).

An index of surface shape was calculated for each plot by assigning code values to the two surface shape determinations:

Shape	Code
Convex	-1
Linear	0
Concave	+1

The shape index, which consists of the algebraic sum of the parallel and perpendicular component codes, can range from -2 to +2, as shown in table 2.

Table 2.--Shape index developed from code values for landform surface shape parallel and perpendicular to aspect

Parallel shape	Perpendicular shape		
	Convex	Linear	Concave
Convex	-2	-1	0
Linear	-1	0	+1
Concave	0	+1	+2

Shape codes:
Convex, -1; Linear, 0; Concave, +1.

About 10 percent of the field data (14 plots) were randomly selected and excluded from the data set to allow for testing the preliminary regression relationships. After testing, the excluded data were recombined with the other data for derivation of final regression coefficients. The field data were analyzed with standard correlation and multiple regression analysis by the following equation:

$$\text{Tree height} = b0 + b1*age + b2X2 + \ldots bnXn$$

Stand mean height, instead of plot site index, was used as the regression dependent variable to avoid problems associated with assuming that a single set of height/age curves adequately describes tree height growth in response to changing environmental conditions present on various sites.

RESULTS AND DISCUSSION

Regression analysis indicated that total height of yellow-poplar is a function of stand age and topographic variables as shown in the following model:

$$\begin{aligned} THt = 1/\{&0.0047300 + (0.203638/AGE) \\ &+ (0.000034315*AGE) - (0.00048860*SHAPI) \\ &- (0.00046387*\cos[ASP]*GRAD) \\ &- (0.000054494*\sin[ASP]*GRAD) \\ &- (0.0019392*GRAD)\} \end{aligned} \quad [1]$$

where:

THt = total tree height (feet)

AGE = stand age (years)

SHAPI = surface shape index (discrete value ranging from -2 for strongly convex to +2 for concave shape)

ASP = plot aspect from north (degrees)

GRAD = plot slope gradient (percent/100)

This equation has a coefficient of multiple correlation (R2) of 0.70, and standard error of the mean of 0.0011. Site index may be predicted from the model by holding age constant at 50 years.

All of the independent variables in equation [1] are significant at the 0.10 level. Following age, which was the single most important variable in the model, surface shape index accounted for a large proportion of the variation in tree height. The total variation explained by including successive independent variables in the model is:

Variable	R2
AGE	0.639
AGE + SHAPI	0.682
AGE + SHAPI + ASP	0.694
AGE + SHAPI + ASP + GRAD	0.702

There was little correlation among the independent variables. The highest correlation was between gradient and aspect (r = -0.24).

The accuracy of this equation was evaluated by using data from plots not included in the analysis. Shown in figure 4 is a plot of predicted versus observed site index for the 14 test plots. For most predictions, estimates of site index were within ± 10 percent of that observed. There was a tendency, however, for estimates to be overpredicted at the low range and underpredicted for higher values of site index. Estimates of site index for other plots not included in this random test sample could vary widely from actual site index, especially at the limits of data used to develop the model.

Additional testing of this prediction equation is desirable before application, although accuracy appears to be adequate for identification of poor, intermediate, and good classes of sites within the higher quality sites in the Southern Appalachians.

Independent Variables

The topographic variables in the equation are biologically important in that each has an influence on the soil moisture relationship of the site. Since no transformations were significant in the analysis, the effect of each variable in the model, with the exception of aspect, is linear. Soil-related variables are not considered in this model, but soil characteristics are associated with several of the topographic variables in the model.

Shape Index (SHAPI)

The effect of shape index on site quality is shown in figure 5. Over the range of sites measured, site index increased by more than 20 points as surface shape index changed from -2 on convex ridgetops to +2 in concave coves. Site

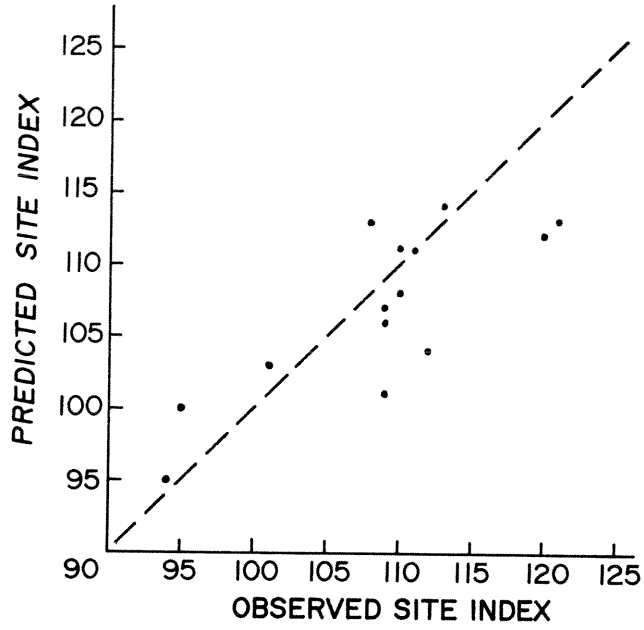

Figure 4.--Observed and predicted yellow-poplar site index using equation [1] and data from 14 plots not included in original analysis.

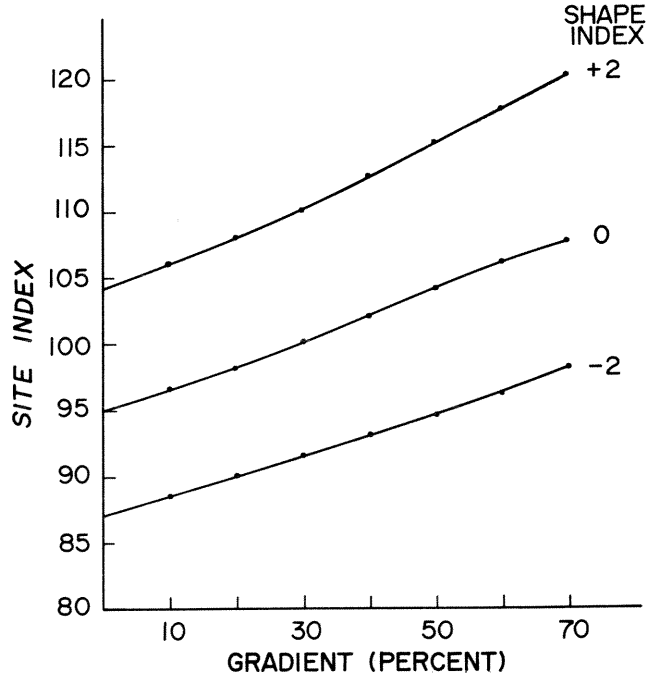

Figure 5.--Relation of site index to gradient and shape index for yellow-poplar in the Southern Appalachians.

index was more responsive to landform shape than any other variable. Surface shape has an important effect on the soil moisture regime as movement of runoff tends to be concentrated by concave landforms. During the midgrowing season, trees on some sites may be under stress as brief summer droughts reduce available moisture. On concave landforms, increased soil moisture would allow continued height growth, resulting in an increase of the site index.

Aspect (ASP)

Other researchers have found the optimum aspect for tree growth is in the northeast quadrant, usually between 45 and 58 degrees. The aspect for optimum height growth of yellow-poplar on the study plots was 6 degrees to the east. This shift then places the least productive sites at 186 degrees, or slightly to the southwest. The data show very slight changes in site quality, however, even within 30 to 40 degrees of the direction of theoretical minimum and maximum height growth. For the average slope gradient of this study, about 30 percent, site index decreased only about 3 to 4 points from the best to the poorest aspects.

On sloping landforms, aspect, along with slope gradient and latitude, affects solar radiation received by the site and indirectly affects soil moisture losses resulting from evaporation and transpiration. Throughout the growing season, southern exposures receive the most solar radiation, while northern exposures receive the least. East and west aspects receive equal amounts of radiation, but western aspects tend to be more xeric because of greater moisture losses resulting from higher afternoon temperatures.

Gradient (GRAD)

The effect of slope gradient on site index is shown in figure 6. Sites with little gradient are commonly associated with stream bottoms, where poor internal soil drainage reduces yellow-poplar height growth. Site index increases with slope gradient because, for one reason, soils are better drained.

Perhaps the main effect of gradient on site index is to modify the effect of aspect. As gradient increases on northern aspects, mean site index increases from 94 to 110. On southerly aspects, however, site index increases only to about 104. Soils on steep, south-facing slopes have higher evaporation rates than soils on similar north slopes because their angle to the sun is more perpendicular and allows them to receive a greater proportion of total available radiation per unit surface area.

The effect of gradient on site quality seems to be inconsistent among species in mountainous terrain. Ike and Huppuch (1968) found that site index of two species was directly correlated with gradient; but for two other species in the same geographical area, site index was inversely correlated with gradient. For yellow-poplar in this study, the main significance of gradient seems to be that increasing gradient indicates well-drained soils, which are conducive to better height growth. Further study is needed to determine if site index continues to increase at a linear rate over a wide range of gradients.

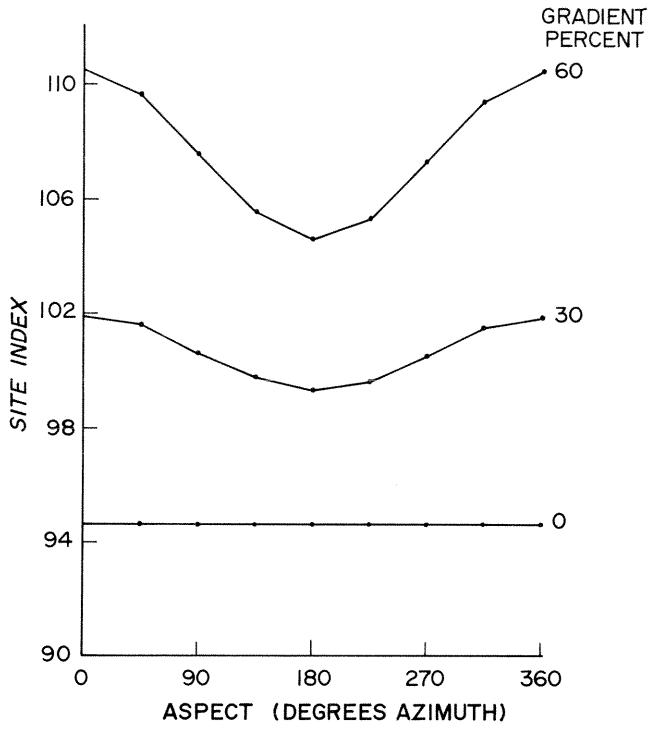

Figure 6.--Relation of site index to aspect and gradient for yellow-poplar in the Southern Appalachians.

Nonsignificant Variables

The effect of two independent variables, elevation and slope position, was not significant, and their importance was unclear in this study. However, these variables have usually been found significant in other studies of site index and topography. In studies where plots were measured over large vertical distances, elevation has been a significant topographic variable. For example, Ike and Huppuch (1968) reported about a 6-point increase in yellow-poplar site index as elevation increased from 2,000 to 3,000 feet.

Slope position has typically been important in every study where it was included as an independent variable. Sites at lower slope positions tend to have more favorable soil

moisture regimes than do upper slope positions for several possible reasons, including deeper A1 horizons resulting from accumulation of colluvial material, subterranian movement of moisture downslope, and concave surface shapes. These favorable conditions decrease for upslope positions, and surface shape tends to be linear or convex near the ridgetop. In this study, slope position was weakly correlated with tree height and much of the variation in site index normally accounted for by this variable apparently was explained by the shape index.

Final Equation

For the final analysis, data from all 140 plots were combined. The resulting regression equation of best fit was:

$$THt = 1/\{0.00509 + (0.19693/AGE) + (0.00003044*AGE) - (0.0004866*SHAPI) - (0.000382\cos[ASP]*GRAD/100) - (0.0001856\sin[ASP]*GRAD/100) - (0.00198*GRAD/100)\} \quad [2]$$

The regression coefficients changed very little from those shown in equation [1]. Equation [2] has an R2 of 0.702 and sy.x of 0.00105.

Application of Equation

The present form of the model for estimation of total height for yellow-poplar in the Southern Appalachians is primarily useful for grouping land areas into broad categories of site classes:

Site class	Site index range
Poor	< 100
Intermediate	100 - 120
Good	> 120

Other factors that are known to affect site index, such as soil and climatic variables, were not considered in this paper but may alter effects of topography for local areas. Until this equation has been evaluated for application in various local situations, the user should exercise proper judgment in application of predicted values of site index.

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MICROSITE VARIATION AND HEIGHT OF LOBLOLLY PINE SEEDLINGS WITHIN THE SOUTH CAROLINA PIEDMONT[1/]

M. K. Augspurger, G. R. Kellogg, W. D. McDade, and D. H. Van Lear[2/]

Abstract.--Soil-site characteristics were correlated with heights of four-year-old loblolly pine (Pinus taeda L.) seedlings on two South Carolina Piedmont sites. Both sites had been rootraked, windrowed and planted with improved stock. Seedling height was significantly greater on microsites where penetrometer resistance was least and depth to the argillic horizon was greatest. Organic content and water supplying capacity index had little to no significant effect on seedling height.

INTRODUCTION

Piedmont sites have a high degree of microsite variation partially due to dendritic erosion patterns which formed when the area was in cultivation. Artificial regeneration of loblolly pine in the Piedmont is typically accomplished by clearfelling, site-preparation, and planting. These harvesting and regeneration practices may result in increased microsite variation. A large variation in the height of loblolly pine seedlings has been observed on these mechanically prepared plantations. Since site preparation has reduced the vegetative competition, height differences may be related to microsite variation.

Many studies have related numerous soil-site characteristics to the height or site index of older loblolly pine (Pinus taeda L.) stands (Carmean 1975). However, few studies have attempted to relate soil and site characteristics to the height growth of seedlings. Early growth studies are needed to identify soil-site factors important to seedling growth. They may also indicate potential beneficial or adverse effects of site preparation treatments on early plantation development. The objective of this study was to evaluate effects of several soil-site characteristics on early height growth of loblolly pine seedlings on South Carolina Piedmont sites.

[1/]Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/]Research Forester, Former Graduate Assistant, Graduate Assistant, and Professor, Department of Forestry, Clemson University, Clemson, South Carolina.

METHODS

Study Area

Four-year-old loblolly pine seedlings were studied on two small clearcuts located on the Clemson Experimental Forest in the upper Piedmont of South Carolina. Prior to clearcutting, these stands contained 90 and 77 ft^2/ac of shortleaf pine (Pinus echinata Mill.) with a mixed hardwood understory component. Site indices at age 50 were 70 and 60 ft, respectively. The areas were clearcut, rootraked, and machine planted at 6 x 6 ft spacing with 1-0 improved loblolly pine seedlings in 1979 (site A) and 1980 (site B).

Soils on both sites are Cecil sandy loams (Typic Hapludults) with southeast exposures and slopes of 5-10 percent. Because of past farming practices, these soils have undergone severe surface and gully erosion and the argillic horizon (subsurface horizon of an illuvial accumulation of clay) in many areas is at or near the surface. As shortleaf pine seeded in on these old fields, erosion rates declined and gullies stabilized. Soil and organic matter gradually accumulated in these erosion channels, further increasing site variability.

Sampling Procedures

In each of three height classes, twenty seedlings were randomly selected for measurement on each site. Three seedling height classes were established as representative of three microsites. The three height classes were: (1) seedlings < 3 ft, (2) seedlings 3-5 ft, and (3) seedlings > 5 ft in height. Relative soil density, depth to the argillic horizon, organic matter content, and water supplying capacity were assessed at each tree.

Four penetrometer cone index readings were taken around the drip-line of each seedling to a depth of 4 inches while the soil was near field capacity. Index readings were then averaged to give one reading for each sampled tree.

Soil cores were taken within the drip-line of each seedling using an auger to determine depth to the argillic horizon (Bt). In addition, four 3-inch soil cores were taken around the drip-line of each seedling and composited for determination of the organic matter content of the surface soil using the Walkley-Black method (Allison 1965).

As an index to the potential ability of the micro-site to supply available water and nutrients to the seedling, the following subjective ranking system was used:

RANK	DESCRIPTION
1	Highly eroded site with Bt at the surface and little to no surface vegetation
2	Eroded site with Bt less than 2 inches below the surface and less than 25% vegetative cover
3	Level microsite with Bt 2-5 inches below the surface and 25-50% vegetative cover
4	Slight depression with Bt 2-5 inches below the surface and 50-75% vegetative cover
5	Slight depression with Bt deeper than 5 inches and vegetative cover greater than 75%

Analysis of variance was used to test the effects of soil-site characteristics on seedling height. All testing was at the 0.05 percent level of significance. Differences between height class means for each soil variable were tested using Duncan's new multiple range test. Regression analyses were used to determine how closely each soil variable related to height at each site.

RESULTS AND DISCUSSION

Loblolly seedling height was significantly greater on microsites where penetrometer resistance was least and depth to the argillic horizon was greatest (Table 1). Organic matter content of soils around seedlings in the two larger size classes was significantly greater than that in soils around smaller seedlings. The water supplying capacity index had no significant effect on seedling height.

On fine textured soils, the cone penetrometer has been found to be an accurate estimator of relative soil density (Davidson 1965). Penetrometer resistance values were significantly lower for trees in the larger height category.

Table 1. Height class distribution by soil variables in a four-year-old loblolly pine plantation.

Height Size Class	Penetrometer Resistance	Depth to Bt	Organic Matter	Water Supply Capacity Index
(ft)	(lb/in^2)	(in)	(%)	
< 3.0	62.8a	3.0a	1.7a	3.1a
3.0-5.0	49.3b	4.0b	4.0b	3.4a
> 5.0	43.4c	5.4c	2.0b	4.0a

NOTE: Means followed by the same letter in columns are not significantly different at the 0.05 level.

Roots generally penetrate soils by moving through existing pore spaces or by displacing soil particles from their path. Increased soil density inhibits root development as well as seedling height because of reduced porosity, moisture storage capacity, infiltration rates, and root penetration (Foil and Ralston 1967, Simmons and Ezell 1983).

Seedling heights were greatest on microsites with thicker surface soil horizons (Table 1). Most Piedmont surface soil horizons are characterized by higher percentages of sand and silt than the lower horizons, which have accumulations of clay (Campbell et al. 1973, Boul et al. 1980). The ability of a soil to facilitate gas exchange and water infiltration is largely dependent upon soil texture (Pritchett 1979, Burger 1983). If the surface soil horizon is thin or nonexistant, as is the case in many eroded Piedmont soils, oxygen may not be able to diffuse into the soil in sufficient quantities to provide an adequate supply for root growth. Reduced root growth due to poor aeration adversely affects height growth not only because of reduced oxygen but also because of reduced nutrient and water uptake (Zahner 1958, Foil and Ralston 1967, Sands 1983). Therefore, soils with thicker surface horizons tend to provide greater rooting volume than highly eroded soils.

Water supplying capacity index showed no significant effect on seedling height (Table 1), apparently because of confounding between factors used in the rating system. Even though surface soil depth significantly affected seedling height, when combined in the subjective rankings with the presence of vegetation, no significant effects were found. Associated vegetation on the microsite appeared to have a negative effect on seedling height, rather than being an indicator of a favorable microsite, as envisioned when the rating system was developed.

Organic matter content around seedlings varied only from 1.7 to 2.0 percent across the three height categories (Table 1). The less eroded sites associated with the two taller classes of seedlings had significantly higher organic matter concentrations, even though actual numerical differences were small.

Even though penetrometer resistance and surface soil depth showed good correlations with seedling height on site A, regression analysis indicated that soil density and surface soil depth accounted for only 0.28 and 0.32 of the variation in seedling height on site B (Table 2). These differences may be partially explained by the fact that sites were sampled in different years. Soil conditions during sampling periods may have affected ease of sampling, or possibly differences in the personnel taking the measurements, may have resulted in the lower R^2 values on site B.

Table 2. Coefficients of determination (R^2) with total height as the response variable.

Concomitant Variable	Site A	Site B
Penetrometer Resistance	.55	.28
Depth to Argillic Horizon (Bt)	.55	.32
Water Supply Capacity Index (WSC)	.42	.11
Organic Matter (OM)	.14	.00

CONCLUSIONS

Results indicate that microsite variability, as expressed by penetrometer resistance and depth to the argillic horizon, significantly influenced loblolly pine seedling height. These factors are indirectly related to available water, nutrients, and aeration, which directly influence microsite quality and subsequently growth (Carmean 1975). The fine-textured soils of the Piedmont are very susceptible to compaction and often have a thin surface soil horizon. During moist conditions, Piedmont soils are particularly vulnerable to the adverse effects of poorly prescribed site treatments. Forest managers should be aware of soil-site characteristics which are limiting to growth and prescribe silvicultural treatments accordingly.

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IMPACT OF INTENSIVE SILVICULTURAL PRACTICES ON SOIL COMPACTION[1/]

Timothy T. Ku, R. Scott Beasley, and Timothy J. Lomax[2/]

A study was initiated in South Arkansas in 1980 to determine the effects of intensive silvicultural practices on water and site quality. Nine natural mature pine-hardwood watersheds, ranging in size from 2.56 to 4.05 ha were located in Drew County, 6 miles north of Monticello on industrial lands. Three watersheds were clearcut, site prepared and replanted to pine; three were selectively harvested to achieve an uneven age structure; and three were left undistrubed to serve as controls. The predominant soil series was Tippah silt loam, a member of the Fine-silty, mixed, thermic, Aquic Paleudalfs.

In conjunction with the project, a study on the effects of logging operation and subsequent site preparation on soil compaction was begun. Bulk soil samples and in situ cores were taken at 3 points and 2 depths (0-7.5 cm and 15-22.5 cm) near each of 10 stations separated at 20.3 m (1 chain) intervals along a transect through the approximate axis of each watershed, before and after silvicultural operations.

Statistical analysis of the 1080 bulk density samples indicated a significant impact of clearcut-and-site preparation operations on soil compaction. Bulk density on all watersheds before treatment averaged 1.13 g/cc for the upper 7.5 cm and 1.37 g/cc for the 15-22.5 cm zone. Immediately after treatment the respective values were 1.35 g/cc and 1.50 g/cc for the clearcut-and-site prepared watersheds, 1.18 g/cc and 1.38 g/cc for the selectively-harvested watersheds and 1.12 g/cc and 1.37 g/cc for the controls.

Additional soil sampling and analysis will be done to study the recovery time from such compactions.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Professors and Research Specialist, respectively, Department of Forest Resources, Agricultural Experiment Station, University of Arkansas at Monticello, Monticello, AR 71655.

LONG TERM RESPONSE OF LOBLOLLY PINE TO COLLOIDAL PHOSPHATE [1/]

M. Victor Bilan and Marcey A. Gillespie [2/]

Abstract.--Three or six ounces of colloidal phosphate were applied either in planting hole or on soil surface while planting loblolly pine in East Texas. Combination of phosphate in the planting hole with NK on soil surface increased diameter growth for four years and the height growth for 18 years after planting.

INTRODUCTION

This study was initiated in 1960, during the period of intensified interest in commercial forest fertilization stimulated by rapidly increasing demand for forest products and by shrinking forestry land base. Calphos [3/] fertilizer was donated by the cooperator to test its effect on growth of loblolly pine seedlings in East Texas. Calphos, which is a brand of naturally occurring colloidal phosphate, contains at least about 8% of phosphorus, 17% of calcium and lesser amounts of 18 other elements. Beneficial effect of colloidal phosphate on growth of slash pine in Florida was reported by Pritchett and Swinford in 1961.

EXPERIMENTAL PROCEDURES

The study was established on a Woden sandy loam soil of old field in Nacogdoches County, Texas. The site was burned and cleared of brush just prior to establishment of the study in February, 1961. The sandy loam surface soil was classified as very low on nitrogen and phosphorus and low on potassium and calcium.

The study consists of four blocks each 160 feet by 100 feet, in a four-replicate split plot design. Ten furrows spaced eight feet apart were plowed parallel to the short side of each block, thus subdividing each block in two plots and the entire experimental field into eight plots each 100 feet by 80 feet. Ten rows of 25 one-year-old loblolly pines were hand planted on each plot with eight-foot intervals between rows and four-foot intervals between pines in the same row. One of the following treatments was applied at random to one pair of rows of seedlings in each plot:

1. 3 oz. of Calphos placed in the planting hole of each seedling.
2. 6 oz. of Calphos placed in the planting hole of each seedling.
3. 3 oz. of Calphos spread on soil surface in 12-inch radius around each seedling.
4. 6 oz. of Calphos spread on soil surface in 12-inch radius around each seedling.
5. Control.

One week after planting 1 oz. of 60% muriate of potash and 1.5 oz. of 40% ammonium sulfate were spread on soil surface in 12-inch radius around each pine in one of the two rows given similar Calphos treatments.

Height and survival of all trees were recorded annually from the first through the fourth year after treatments, while the diameter at breast height was recorded during the third,

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[1/] Paper presented at Southern Sivlicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] The authors are, respectively, Professor of Forestry and former Graduate Assistant, School of Forestry, Stephen F. Austin State University, Nacogdoches, Texas 75962.

[3/] Thompson Sales Company, Inc., P. O. Box 246, Montgomery, Alabama 36101.

fourth and eleventh year after treatments. Data obtained 18 years after the treatments are based on the diameter of all surviving trees and on the height of five dominant trees per row. Factorial analysis of variance was used for the final measurements, while all data obtained previously were subjected to a split-split plot statistical analyses.

RESULTS AND DISCUSSIONS

Height Growth

Combination of placing Calphos in the planting hole and spreading potassium and nitrogen on soil surface increased height growth of loblolly pine seedlings during the first four years after treatment (Table 1). Either 3 oz. or 6 oz. of Calphos were equally effective on the furrowed and on the unfurrowed plots. Spreading of Calphos on the soil surface did not prove to be effective either with or without nitrogen and potassium regardless of furrowing. Furrowing alone did not seem to affect height growth of planted seedlings during their first four years of growth.

Eighteen years after treatment, trees that received 3 oz. or 6 oz. of Calphos in the planting hole were still significantly taller than the control trees (Table 2). At this time, Calphos proved to be effective with or without addition of nitrogen and potassium. According to an equation developed by Lenhart (1972), site index at base age 25 was improved from 61 feet for control trees to 63 feet for trees that received Calphos in the planting hole.

Brendemuehl (1970), Bengston (1970), and Pritchett (1961) have demonstrated the importance of placing fertilizer material, especially phosphorus, in contact with the rooting zone of the soil for the best response. Pritchett and Swinford (1961) reported that broadcasting and disking of colloidal phosphate at the rate of 1/2 ton per acre just before planting increased significantly height growth of slash pine in Florida, and that superior height growth was evident 15 years after the treatment.

Diameter and Basal Area

Application of either 3 oz. or 6 oz. of Calphos in the planting hole and of nitrogen and potassium on the soil surface increased significantly diameter growth of the planted loblolly pines during the third and the fourth growing season on both, the furrowed and unfurrowed plots (Table 3). However, no significant differences were evident among the average diameter growth of any treatments 11 or 18 years after planting.

Close (4 feet by 8 feet) original spacing 74% average survival 18 years after treatment resulted in an average of 1,007 trees per acre and a basal area of 224 square feet (Table 4). The excessive stand density inhibited diameter growth and probably resulted in the absence of statistial differences among the treatments for the diameter growth and basal area per acre. When expressed as percentage of control, Calphos application at the rate of 6 oz. on surface and 3 oz. or 6 oz. in planting hole produced between 10% and 16% more basal area.

Volume

Volume in cunits was determined by the equation:

$$\text{cunits} = 0.008 + 0.0002\ D^2H$$

Statistical analysis did not detect any significant differences among average volume per acre produced by individual Calphos treatments 18 years after fertilization. However, like diameter and basal area, volume produced by 6 oz. and 3 oz. of Calphos in the planting hole was 10% and 19% greater than the volume produced by control trees.

Merchantable volume in cords was determined by the equation:

$$\text{cords} = 0.75\ (\text{cunits/tree})\ \frac{\text{dbh}-3.5}{\text{dbh}} \text{ assuming uniform taper}$$

and a top diameter limit of 3.5 inches. Although differences among treatment means were statistically not significant, 6 oz. of Calphos on soil surface produces 21% more cord volume than the control. Trees treated with 3 oz. in the planting hole produced 10% more cord volume than the control trees. Pritchett and Swinford (1961) also reported increase in cord wood volume of slash pine in Florida 15 years after application of 0.5 to 1.0 ton of colloidal phosphate per acre disked into fine sand before planting.

Table 1.--Average height of loblolly pine plantation by treatments during the first four years after planting.

Age of Trees	TREATMENTS				
	0 control	3oz. surface	Calphos 6oz. surface	3oz. hole	6oz. hole
years	feet				
	No Furrowing no NK				
2	1.4 a[1]	1.3 a	1.5 a	1.4 a	1.4 a
3	3.6 a	3.6 a	3.5 a	3.6 a	3.7 a
4	7.0 a	6.7 a	6.9 a	7.0 a	7.3 a
5	10.8 a	10.4 a	10.6 a	11.0 a	11.3 a
	Furrowing no NK				
2	1.5 a	1.5 a	1.5 a	1.5 a	1.5 a
3	3.9 a	3.9 a	3.7 a	3.9 a	3.8 a
4	7.4 a	7.4 a	7.2 a	7.4 a	7.3 a
5	11.2 a	11.1 a	11.0 a	11.0 a	11.1 a
	No Furrowing + NK				
2	1.3 a	1.3 a	1.4 a	1.5 b	1.6 b
3	3.4 a	3.3 a	3.4 a	3.8 b	3.9 b
4	6.9 a	6.7 a	6.6 a	7.4 b	7.6 b
5	10.7 a	10.4 a	10.3 a	11.3 b	11.6 b
	Furrowing + NK				
2	1.4 a	1.5 a	1.4 a	1.8 b	1.7 b
3	3.7 a	3.8 a	3.7 a	3.6 ab	4.2 b
4	7.1 a	7.2 a	7.2 a	7.3 ab	7.8 b
5	10.8 a	10.9 a	10.8 a	11.9 b	11.6 b

1/ Treatment means followed by a common letter do not differ significantly according to Duncan's multiple range test.

Table 3.--Average diameter of loblolly pine plantation by treatments and age.

Age of Trees	TREATMENTS				
	0 control	3oz. surface	Calphos 6oz. surface	3oz. hole	6oz. hole
years	inches				
	No Furrowing no NK				
4	0.68 a[1/]	0.58 a	0.62 a	0.69 a	0.73 a
5	1.58 a	1.50 a	1.52 a	1.56 a	1.62 a
12	5.10 a	4.98 a	5.38 a	5.27 a	5.13 a
19	5.91 a	6.12 a	5.94 a	5.96 a	6.28 a
	Furrowing no NK				
4	0.72 a	0.71 a	0.72 a	0.73 a	0.70 a
5	1.62 a	1.57 a	1.55 a	1.48 a	1.57 a
12	4.82 a	4.80 a	5.33 a	4.63 a	4.85 a
19	5.88 a	5.81 a	6.26 a	5.77 a	6.00 a
	No Furrowing + NK				
4	0.62 a	0.58 a	0.59 a	0.80 b	0.79 b
5	1.53 a	1.44 a	1.47 a	1.73 b	1.72 b
12	5.09 a	4.99 a	5.26 a	5.53 a	5.14 a
19	5.92 a	6.09 a	6.14 a	6.73 a	6.02 a
	Furrowing + NK				
4	0.64 a	0.74 a	0.64 a	0.85 b	0.79 b
5	1.52 a	1.49 a	1.53 a	1.73 b	1.69 b
12	5.12 a	4.78 a	4.79 a	4.86 a	5.20 a
19	6.10 a	6.21 a	5.78 a	5.93 a	6.03 a

[1/] Treatment means followed by a common letter do not differ significantly according to Duncan's multiple range test.

Table 2.--Average height of loblolly pine trees after fertilizing for all furrowing and nitrogen-potassium treatments combined.

Calphos Treatments				
0 control	3oz. surface	6oz. surface	3oz. hole	6oz. hole
feet				
53.2 c[1/]	53.8 abc	53.4 bc	54.6 a	54.5 a

1/ Treatment means followed by a common letter do not differ significantly according to Duncan's multiple range test.

Table 4.--Average parameters of loblolly pine trees 18 years after treatment for all furrowing and NK treatments combined.

Treatment	Height	Diameter	Basal Area	Volume
Calphos	feet	inches	sq. feet/ acre	cords/ acre
control	53.2 c[1/]	6.0 a	211 a	16.6 a
3oz. surface	53.8 bc	6.1 a	198 a	15.3 a
6oz. surface	53.4 bc	6.0 a	237 a	20.2 a
3oz. hole	54.6 a	6.1 a	244 a	18.3 a
6oz. hole	54.5 a	6.1 a	232 a	17.2 a

1/ Treatment means followed by a common letter do not differ significantly according to Duncan's multiple range test.

CONCLUSIONS

Height and diameter growth of loblolly pine were significantly increased during the first four years after planting when Calphos was applied in the planting hole and nitrogen and potassium were applied to soil surface. Beneficial effect of Calphos was also evident in the height growth 18 years after treatment with or without nitrogen and potassium application.

Average tree survival was 95% four years after fertilizing and 74% eighteen years later, and none of the applied treatments affected the stand density. Due to close spacing and a very low mortality, original significant effect of Calphos applied in the planting hole was not as consistent 11 and 18 years after treatment as it was during the initial four years. Yet, application of 6 oz. of Calphos to soil surface and 3 oz. or 6 oz. of Calphos in the planting hole produced 10% - 20% increase in basal area, total volume and merchantable cordwood volume 18 years after treatment.

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BOTTOMLAND HARDWOOD FERTILIZATION--THE STONEVILLE EXPERIENCE[1/]

John K. Francis[2/]

Abstract.--A number of fertilization experiments have been conducted in plantations of cottonwood, sweetgum, and sycamore and in natural stands of oak and sweetgum. Responses to nitrogen or nitrogen + phosphorus have been obtained more frequently in stands established on old fields than on undisturbed sites. Accelerated growth was maintained only a year or two.

INTRODUCTION

The hardwood surplus is not permanent. Every demand projection shows increased use of wood products in the future. Much forest land continues to be withdrawn for uses other than timber production. Unless technology brings forth inexpensive alternatives to the many uses of hardwoods, tight supplies and higher prices will be the eventual result. The wood supply crunch may bring into use management techniques, such as fertilization, that usually have been too expensive. Potentially, fertilization could accelerate growth so that rotations would be shortened, and thus more hardwood timber could be harvested per acre of commercial forest.

Over the last 25 years in Stoneville, Mississippi, 20 studies were conducted by USDA Forest Service scientists to evaluate the response of bottomland hardwoods to fertilization. Nitrogen (N), phosphorus (P), potassium (K), and lime were applied to natural stands and to plantations in various combinations and at different rates. I shall summarize the results of these studies and comment on their relevance to bottomland hardwood management.

1/ Paper presented at Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Principal Soil Scientist, Southern Hardwoods Laboratory, maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

COTTONWOOD STUDIES

Four greenhouse studies pointed to the possibility of responses of cottonwood to fertilizer in the field. The first, a solution culture study, demonstrated as much as 5.5 feet of height growth from seed in 9 weeks (Bonner and Broadfoot 1967). Normal growth in soil for this period might be 10 inches. The greatest dry weight was accumulated with solution concentrations of 100 ppm N, 75 ppm P, and 100 ppm K. Minimum foliar nutrient concentration for "good" growth was 3.0% N, 0.3% P, and 1.2% K. The best growth occurred with 4.2% N, 0.7% P, and 3.0% K. In three pot studies, cottonwood planted in fertile alluvial soils (Commerce, Sharkey, Adler, and Convent) from the Mississippi River floodplain either did not respond or responded little, even to high rates of N, P, or K. Cottonwood in a Coastal Plain alluvial soil (Bibb) having low natural fertility responded with 500% to 800% increases in total weight to lime or lime + complete fertilizer (N, P, and K) but not to complete fertilizer alone (Blackmon and Broadfoot 1969).

Foliar nutrient levels from the above studies, from fertilizer trials on plantations, and from natural stands growing on good and poor sites are summarized in table 1. These data tend to confirm the previously established threshold level of 2.0% for N (White and Carter 1970) but are not complete enough to establish critical levels of P and K.

In eight studies, some with multiple trials, fertilizer was applied to cottonwood in plantations. Soils represented were Commerce, Convent, Sharkey, and Urbo. Rates of N used ranged from zero to 600 lb/acre. The N source used in all these studies was NH_4NO_3. In some of the studies, P and K were added to a treatment, and in one study a lime treatment was included. The most important cause of success or failure of a treatment was site history. Of the nine fertilizer trials

Table 1.--Representative foliar nutrient levels from cottonwood in several fertilizer experiments.

Stand description	Soil series	Treatment N-P-K	N	P	K
			----------%----------		
Natural stand (large trees)	Commerce	-	1.6	0.13	0.84
	Sharkey	-	1.6	.12	.85
Solution culture	-	25 ppm-50 ppm-100 ppm	2.4	.65	2.90
	-	100 ppm-75 ppm-100 ppm	4.3	.70	3.20
	-	100 ppm-50 ppm- 50 ppm	3.9	.70	1.95
Potted	Commerce	Control	1.4	.16	1.79
	Commerce	100 lb/ac-50 lb/ac-100 lb/ac	2.2	.21	1.95
Plantations (avg. 2-, 3-, & 4-yr-old)	Sharkey	Control	1.7	-	-
	Sharkey	300 lb/ac-0-0	2.1	-	-
	Commerce	Control	2.0	-	-
	Commerce	300 lb/ac-0-0	2.4	-	-
Plantation (6-yr-old)	Commerce	Control	1.6	.18	-
	Commerce	150 lb/ac-0-0	2.2	.17	-
Plantation (7-yr-old)	Commerce	Control	1.4	-	-
	Commerce	150 lb/ac-0-0	2.1	-	-
Plantation (10-yr-old)	Convent	Control	1.3	-	-
	Convent	150 lb/ac-0-0	1.7	-	-

in plantations established in sites recently cleared from forest, only one showed a significant response to fertilizer. Plantations on old fields fared considerably better; in three of four trials, significant growth increases were recorded. The greatest responses occurred on the medium-textured Commerce and Convent soils. The old-field plantations grew slowly, and fertilization stimulated them briefly to perform similarly to trees on cleared sites. Cottonwood in the first year on Urbo, a Coastal Plain alluvial soil (pH 4.5), did not respond to added N or P but did respond significantly to 3 tons of lime per acre.[3/] Benefit was not derived from the addition of P or K in any of the trials. The best rates of N fertilizer were 150 or 300 lb/acre.

The significant increases in diameter growth obtained in these experiments ranged from 26% to over 200%. However, responses were short-lived. Most of the benefit was obtained in the first year after treatment. Apparently, enhanced growth did not occur in the third year after fertilization. (Even though growth returns to normal, the volume advantage remains with the fertilized trees.) Blackmon (1977b) reported that fertilizer treatments of 84 to 672 kg N/ha produced from 0.15 m^3 to 0.03 m^3 of additional wood per kilogram of N applied. This translates to 1 lb of N producing an additional 60 lb of wood at the lowest rate and 12 lb of wood at the highest rate. An 8-year-old, slow-growing cottonwood plantation in another experiment contained 73 lb of N in 14 tons of dry mass of the trees, including roots.[4/] Assuming the same N concentration, the additional wood and supporting tissue produced for each pound of N would contain only 0.15 and 0.03 lb of N for the low and high treatments. Thus efficiency of N use for this experiment ranged from about 3% to 15%.

The treatments in the Stoneville experiments were mostly applied in April and early May.

3/ Blackmon, B. G. The effect of fertilizer and lime on an eastern cottonwood plantation on a Coastal Plain alluvial site. Study FS-SO-1111-2.15. Data on file at Southern Hardwoods Laboratory, Stoneville, Mississippi. 1979.

4/ Francis, John K. Characterization of biomass and nutrient accumulation in a developing eastern cottonwood plantation. Study FS-SO-1110-43. Data on file at Southern Hardwoods Laboratory. 1981.

Research conducted by Crown Zellerbach Corporation in the same area suggests that better results could be obtained by fertilizing in March (Crown Zellerbach 1973). Blackmon (1977a) found that plantation cottonwood are more likely to respond at 4 years old than at younger ages.

OTHER SPECIES

Cherrybark oak seedlings grown in liquid culture achieved their best growth from 100 ppm N, 5-25 ppm P, and 50-100 ppm K in solution.[5/] Sycamore planted in pots containing a sandy loam Coastal Plain soil were treated with various rates of N, P, K, and lime. Phosphorus at rates of 25 and 100 lb/acre caused a 250% increase in height growth. Potassium had no effect. Lime and N caused slight growth reductions.[6/] In a contrasting example, sycamore recently planted on a Coastal Plain alluvial soil were treated with N, P, and lime. Heights at the end of the first growing season were significantly increased (29%) by 150 lb N/acre. Lime at 4,000 lb/acre increased growth when applied with N, but not alone. Phosphorus did not increase growth at any of the rates tried.[7/] The reason for the difference in response of the two soils is unknown but presumably relates to nutritional differences.

Dominant willow oak in a green-tree reservoir were fertilized in 2 consecutive years with a complete fertilizer (8-24-24) in a 30-foot-diameter circle around their trunks at a rate of 1,000 lb/acre. Radial growth increased by 32% over a 4-year period. Production figures indicated an increase in acorns, although the counts were not thought to be reliable.[8/]

A 20-year-old, naturally regenerated stand of sweetgum, willow oak, and water oak on an old field (Tunica soil) was treated at various rates with N and an N-P-K fertilizer. The fertilizer was applied each April for 5 years. All fertilizer treatments increased the diameter and height of both sweetgum and oak (Broadfoot 1966). Greatest diameter growth was obtained with 300 lb N/acre. During the next 5-year period, in which no fertilizer was applied, the previously treated plots grew no faster than the control. Two more fertilizer treatments were applied at the same rates (stand ages 30 and 35), but without effect.

Sweetgum in pots of Sharkey clay soil received treatments of 250 lb N/acre, 100 lb P/acre, 250 lb K/acre, or combinations of N, P, and K. Seedlings in pots with N-P or N-P-K grew better than either the control or seedlings with any single nutrient. A single fertilizer treatment (N-P-K formulated at the above rates) was applied to the old-field sweetgum stand from which the Sharkey soil was obtained. After 6 years, the pole-sized stand was thinned and refertilized. N and P were used this time, plus Mg, Zn, Cu, and B. Two years later, the stand was measured. Average height growth for the 8 years of the experiment was not significantly affected by the treatments. Average diameter growth was greater for treated plots, 0.30 inch/year versus 0.24 inch/year for paired controls. Foliar data indicate that N may have been responsible for the difference.[9/]

Five-year-old sweetgum planted on Henry soil (an old field) were fertilized in March with 250 lb N/acre, 150 lb P/acre, N + P, or nothing (control). The trees responded to N and N + P (but not to P alone) with increased height and diameter growth and crown expansion. Acceleration of growth lasted just 1 year. Three years after fertilization, trees that had received N + P, the best treatment, contained 60% more dry weight than trees in the control treatment (Ku et al. 1981).

In the last study, wood ash was tested as a fertilizer alone and in combination with N. (Wood ash from wood-waste burning boilers, currently a waste product, is a useful liming agent;

5/ Blackmon, B. G. Cherrybark oak nutrition. I. Response of seedlings to N, P, and K in solution culture. Establ. and Final Rep. FS-SO-1111-2.4. Data on file at Southern Hardwoods Laboratory. 1973.

6/ Blackmon, B. G. American sycamore nutrition. I. Soil fertility requirements on an alluvial soil of the Coastal Plains. Establ. and Final Rep. FS-SO-1111-1.4. Data on file at Southern Hardwoods Laboratory. 1972.

7/ Blackmon, B. G. American sycamore nutrition. II. Response of plantations on Coastal Plain alluvium to additions of N, P, and lime. Final Rep. FS-SO-1111-1.15. Data on file at Southern Hardwoods Laboratory. 1977.

8/ Blackmon, B. G. Fertilization of willow oak for mast production in a green-tree reservoir. Final Rep. FS-SO-1111-2.7. Data on file at Southern Hardwoods Laboratory. 1979.

9/ Francis, John K. Fertilization of sweetgum on an old-field soil. Final Rep. FS-SO-1110-46. Data on file at Southern Hardwoods Laboratory. 1981.

it contains about 4% K and small amounts of many other nutrients.) Rates used were 2,000 lb ash/acre and 200 lb N/acre. These treatments were applied to a cottonwood plantation on Commerce soil, a sycamore plantation on Erno soil, a natural bottomland hardwood stand on Alligator soil, and a natural hardwood stand on Loring soil. None of the stands grew better as a result of the wood ash or nitrogen. Potassium was not deficient except possibly on the Erno soil, where the sycamore were also growing poorly because of soil physical problems associated with a fragipan.[10/]

DISCUSSION

Generally, alluvial soils of the South, the principal habitat of bottomland hardwood species, are nutritionally sound. These are normally young soils derived from sediment of diverse sources. Vegetation and organic matter help maintain nutrient reserves at relatively high and nearly stable levels. When bottomlands are cleared and farmed, not only are nutrients removed in the crops, but most of the organic matter quickly disappears, together with the nitrogen it held. Our research at Stoneville has shown a high probability of response from the fertilization of plantations or natural regeneration occurring on old fields. Our experience also suggests that sites that have never been cultivated are less likely to respond to fertilizer.

Species in natural stands more than a few years old have been through rigorous competition and, by virtue of their survival, are usually well adapted to local soil conditions. This may not be true in plantations where competition is controlled. Off-site and slow-growing plantations might sometimes be saved by fertilization. A better approach, however, is to plant species only on sites where they will do well without expensive amendments. A measured high site index is a good assurance of site adaptability by a species. Where site indexes cannot be determined directly, soil-site evaluation systems may be applied (Baker and Broadfoot 1979, Broadfoot 1976).

In one of our most successful fertilizer trials on old-field cottonwood (Blackmon 1977a), 75 to 600 lb N/acre resulted in 1.5 to 6 cords/acre of additional standing volume in 2 years' growth. With current pulpwood stumpage at less than $8/cord, that response would not even pay for the cost of the fertilizer.

Twenty studies cannot answer all the questions that might be asked about best rates of fertilizer and how to predict where a response would occur and its magnitude. Nor do they give us the confidence we need to recommend fertilization. In fact, much of the evidence indicates that this expensive practice is unnecessary in the bottomland hardwoods except in special circumstances. Fertilization of bottomland hardwoods certainly remains in the research stage. Identifying those special circumstances where response will justify investment should be the continuing mission for research.

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10/ Francis, John K. Response of southern hardwoods to wood ash and nitrogen. Final Rep. FS-SO-1110-50. Data on file at Southern Hardwoods Laboratory. 1983.

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INFLUENCE OF VARIOUS ECONOMIC COMPONENTS ON THE PROFITABILITY OF MIDROTATION FERTILIZATION [1/]

Duane R. Dippon and Kenneth R. Munson [2/]

Abstract.--As a forest stand matures nutrients are removed from the soil and stored in the standing biomass. Over much of the lower coastal plain of the southeast U.S., this often leads to midrotation deficiencies of several nutrients, most notably nitrogen and phosphorus. Fertilization at this time frequently results in additional growth. This paper investigates the effect of various economic components on the profitability of midrotation fertilization of slash pine. Results show that profitability is sensitive indirectly to site types, and directly to regeneration and management costs, tax treatments, interest rates and most importantly product type. More often than not it is the combination of increased growth rate and movement of this volume into higher valued stumpage classes which determines whether midrotation fertilization is profitable.

INTRODUCTION

The practical consideration of any forest fertilization program is one of profitability. Unless profitable by some economic standard, such as rate of return, forest fertilization is not likely to be a viable management activity. To this end, Dippon and Shelton (1983) evaluated the economics of a series of semimature slash pine (Pinus elliotii var. elliotii Englem) fertilization trials maintained by the Cooperative Research In Forest Fertilization (CRIFF, University of Florida) program. They concluded that the profitability of a fertilizer treatment, as measured by rate of return, varies by soil type, investment period and the mixture of merchantable products.

As with any economic analysis, several assumptions must be made concerning reforestation costs, annual management fees, fertilizer costs and tax treatments for various activities. Assumptions used by forest industry, where much of the forest fertilization has centered, are often not applicable (or available) to the non-industrial private forest (NIPF) owner. Since over half of the forestland in the South is controlled by NIPF owners, it seems necessary that procedures are developed to assist these owners in making forest fertilization decisions.

In evaluating fertilizer response data, Dippon and Shelton (1983) point out that volume growth alone doesn't tell the whole story. More importantly is the change in diameter class distribution within a stand, since the relative value of a unit of wood increases with tree diameter. To improve the sensitivity of response data analysis, Mollitor et al. (1985, these proceedings) have developed a mathematical model for use in evaluating changes in diameter distribution.

The purpose of this paper is to merge the model developed by Mollitor et al. (1985) with economic variables pertinent to the NIPF owner, and illustrate the influence these economic components exert on profitability of forest fertilization.

APPROACH

Fertilizer response data used in this analysis were obtained from trials established in semimature (15 to 18 years of age) slash pine as described in detail by Mollitor et al. (1985, these proceedings). One representative trial from each of six CRIFF soil groups will be used

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Assistant Professor, Department of Forestry, School of Forest Resources and Conservation, University of Florida, Gainesville, Florida 32611, and Research Forester, International Paper Company, P. O. Box 3860, Portland, Oregon 97208.

in the analysis (Table 1). A brief summary of the CRIFF soil groups is presented in Table 2; more detail can be found in Kushla and Fisher (1980). Modeling of growth response by change in diameter class distribution was accomplished using a three-parameter Weibull probability function described by Mollitor et al. (1985, these proceedings).

Table 1.--CRIFF fertilization trials used for the economic evaluation of growth response in semimature slash pine.

TEST	LOCATION	CRIFF SOIL GROUP	AGE AT ESTAB.	DATE FERT.
B150	Chatham Co., GA	B	15	6/73
B202	Wayne Co., GA	D	16	74
B219	Baldwin Co., AL	E	15	4/74
B224	Hamilton Co., FL	C	9	4/74
B227	Gulf Co., FL	A	13	4/74
B230	Madison Co., FL	G	13	6/74

Table 2.--Brief CRIFF soil group definitions.

SOIL GROUP	MAJOR LAND AREA	DRAINAGE	IMPORTANT FEATURES
A	Savannas	Very Poor To Poor	Sandy surface horizon less than 20 inches deep with clayey soil below.
B	Savannas	Very Poor To Poor	Sandy surface horizon greater than 20 inches deep with clayey soil below.
C	Flatwoods	Poor	Spodic horizon below the surface horizon, clayey soil below the spodic.
D	Flatwoods	Poor to Moderate	Spodic horizon below the surface horizon, sandy soil below the spodic.
E	Uplands	Moderate to Well	Sandy surface horizon less than 20 inches deep, with clayey soil below.
F	Uplands	Moderate to Well	Sandy surface horizon greater than 20 inches deep, with clayey soil below.
G	Sandhills	Excessive	Sandy surface horizon at least 60 inches deep.
H	Depressions	Very Poor	High in decomposing plant residues.

Economic analysis of the growth response, expressed in terms of Present Value (PV), was performed using the following assumptions:

Regeneration Costs = $100/acre
Taxes and Administration = $5/acre
Nitrogen = $0.35/lb.*
Phosphorus = $0.70/lb.*
Uninflated Discount Rate = 0.05

*(Material plus application cost)

Product Class	DBH Range (in)*	Price/Cord**
Pulpwood	4.51 - 6.5	$32
Chip-n-saw	6.51 - 10.5	$53
Sawtimber	10.51+	$65

* (Merchantable volume inside bark, 2 in. top)
** (From mid-1984 issue of Timber Mart South, Florida area)

Present Value calculation is for the acre at the year of fertilization;

Assume all tests were treated in the same calendar year.

These assumptions are used in the Results section of this paper; variations of several components are used in the Sensitivity Analysis section. Also, the analysis does not consider land acquisition costs.

The principal shortcoming of this procedure is that the growth response predictions are based on only three data points: 3, 5, and 8 years after treatment. A more confident estimate of duration and magnitude of response would be possible with annual measurements for 10 to 15 years after treatment. As it is though, we can still examine how time affects the fertilizer investment realizing that extrapolations beyond the 8th year results are somewhat risky.

RESULTS

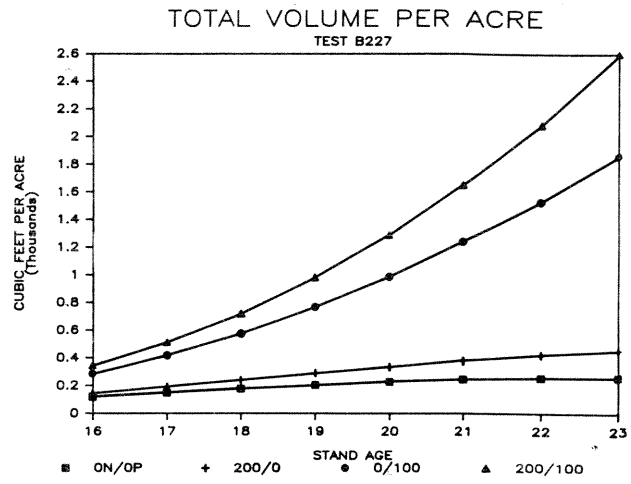
The real issue here is not simply whether forest fertilization pays, but rather how we should analyze this activity so as to maximize profits. The response of a stand to fertilization depends on site, stand age and density, fertilizer material applied and time. From an economic standpoint it is necessary to evaluate the magnitude and duration of increased growth and the nature of that growth (i.e., into which product classes the growth occurs) relative to regeneration and annual management costs, cost of fertilization, interest rates, stumpage prices and tax treatments. The assumptions used in this section of the paper were presented earlier.

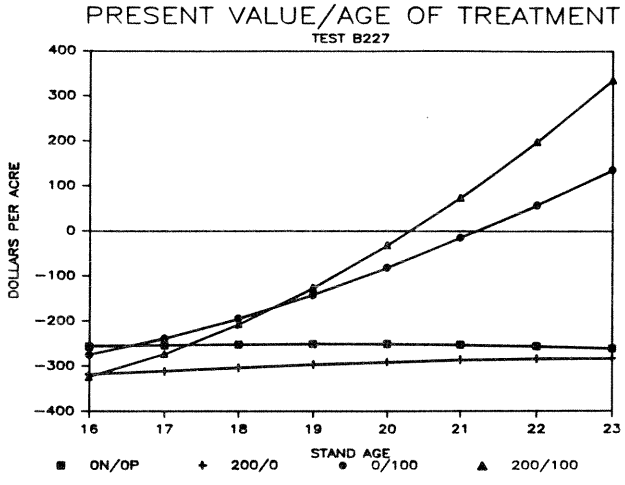
Of the biological factors mentioned above, site type is the most important component affecting growth response (assuming an adequately stocked stand exists on the site). For this reason the results of our analysis will be categorized according to the CRIFF soil groups. For each group, with the exception of F and H, three figures will be presented from a single test within each soil group. The first figure will compare the total volume per acre for four treatments: control (non-fertilized), 200 lbs N/acre, 200 lbs P/acre, and 200 lbs N + 100 lbs P/acre. The second figure compares the present value/acre of each treatment up to 10 years after treatment. The third figure shows the change in volume by product class for the control and N + P treatment in the third, fifth and eighth year after treatment.

The analysis for soil group A is presented in Figures 1-A, B and C. The addition of N caused a slight linear increase in growth, whereas P resulted in the primary, non-linear growth response. The profitability of fertilization in this case is clear: no fertilizer or the addition of N alone did not produce a merchantable stand. In contrast, addition of N + P or P alone resulted in an increase in PV above zero, although this did not occur until 7-8 years after treatment. The PV of the latter two treatments is still increasing after 10 years. The value increase is due to greater volume in the pulp and chip-n-saw product. The non-fertilized treatment had no volume in diameter classes greater than 6 inches. Obviously, fertilization with N + P or P is essential to production of a merchantable stand on these soils.

The evaluation for soil group B is presented in Figures 2-A, B and C. The volume peak at age 23-24 is presumably an artifact of having only three real data points at 2, 5 and 8 years after treatment. One would expect that, on these soils and with the given treatments, volume growth should still be increasing but at a slower rate than the first 5-6 years after treatment. Taking the model predictions at face value, however, suggests that the maximum PV was attained by N or N + P 7-8 years after treatment. No treatment was more profitable than the control until after 5 years following treatment. The profitability was due to a gradual increase in chip-n-saw and sawtimber products.

The analysis of soil group C is presented in Figures 3-A, B and C. Total volume/acre increased linearly for all treatments, with N showing greater importance than P. All N-treatments were profitable by 4-5 years after application, with the rate of increase decreasing with time. Although volume growth was greatest with N + P together, the most profitable treatment was N alone. The increase in value was largely a result of volume growth in the chip-n-saw product class. Considering the risk involved, fertilizing C-group soils with P alone would not be a good investment decision.





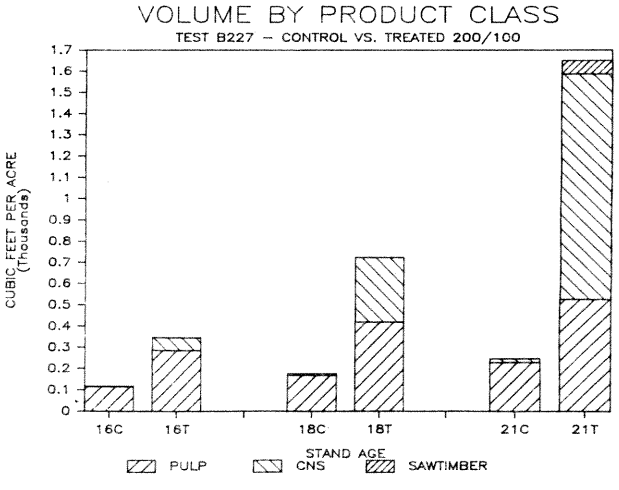
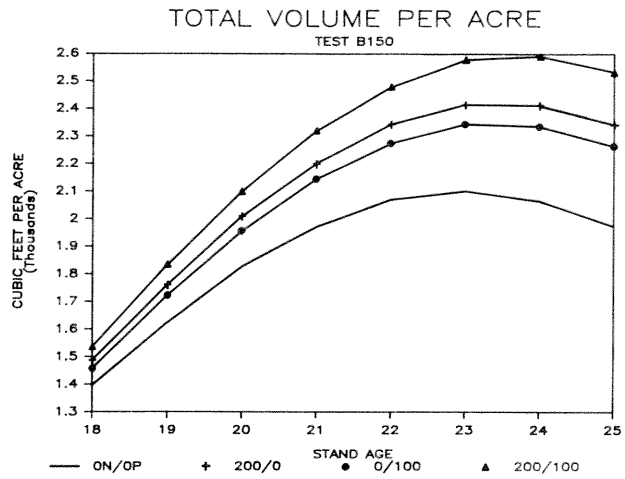
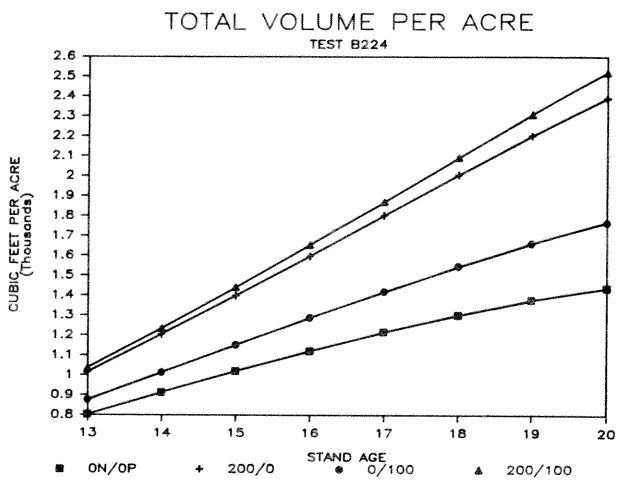
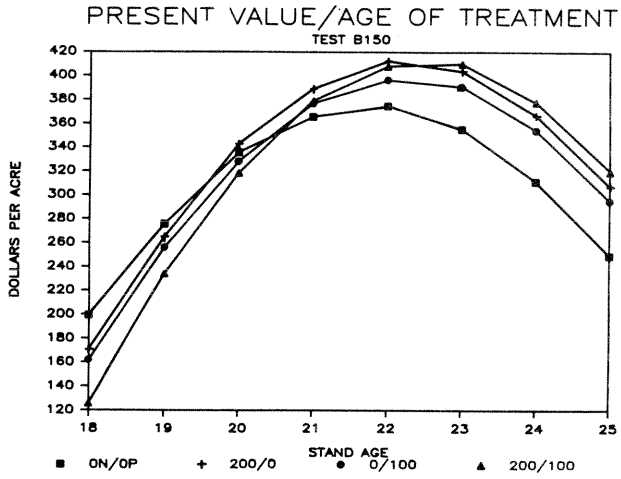
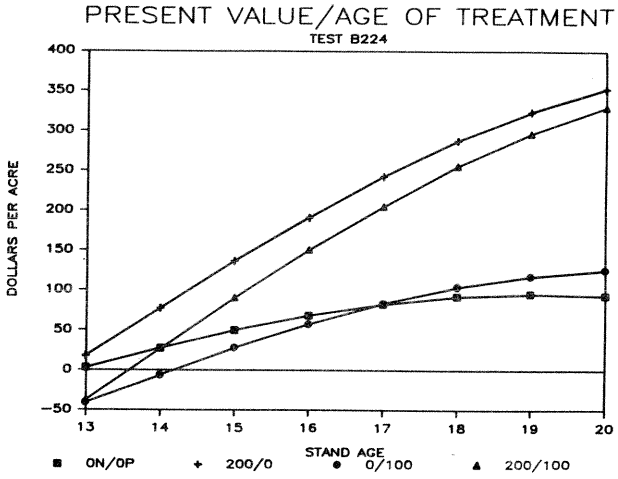


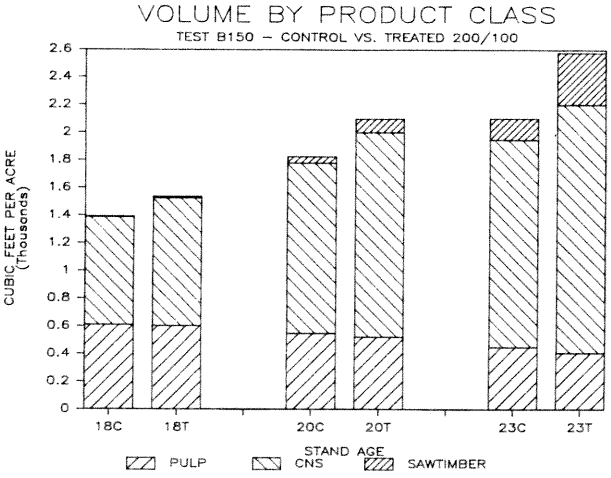
Figure 1.--(A) Total volume per acre, (B) present value, and (C) volume by product class for Test B227, CRIFF soil group A.











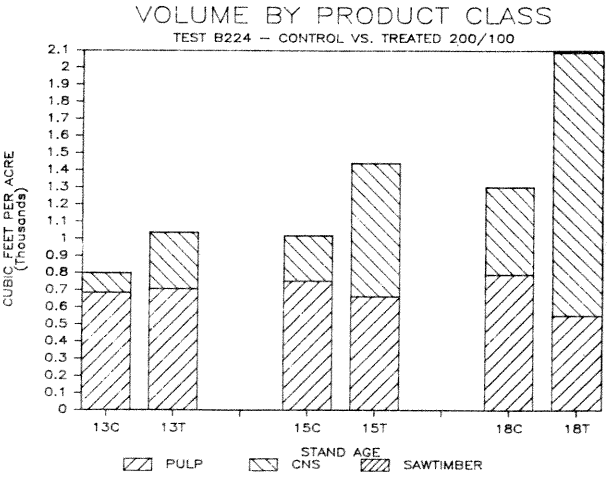


Figure 2.--(A) Total volume per acre, (B) present value, and (C) volume by product class for Test B150, CRIFF soil group B.

Figure 3.--(A) Total volume per acre, (B) present value, and (C) volume by product class for Test B224, CRIFF soil group C.

The evaluation of soil group D is illustrated in Figures 4-A, B and C. Volume growth increased similarly for the N and P treatments, but slightly more than doubled for the N + P treatment relative to the control. The combined increase in both volume and product value made the N + P treatment the most profitable at an earlier age as well as in absolute value. In this case it appears that fertilization with N + P is the only treatment with prospects for a good payoff.

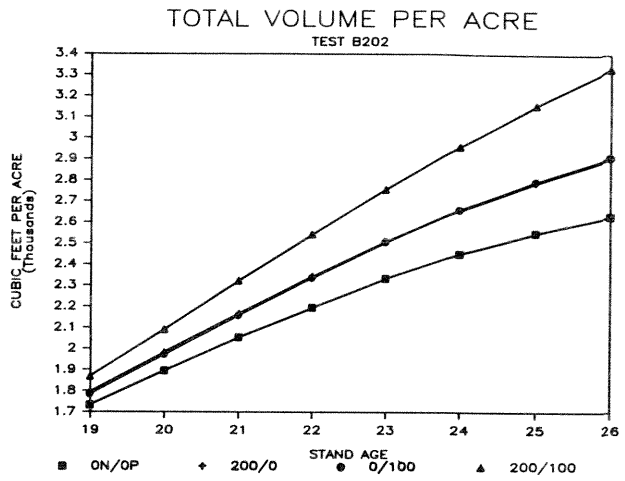
The soil group E analysis is presented in Figures 5-A, B and C. The N and N + P treatment showed a positive and more or less linear volume response relative to the control and P-only addition. Despite this positive growth response, the fertilizer treatments were not as profitable as the control as of the 8th-year measurement. The model suggests (as shown in 5-B), however, that the value of the N + P treatment is increasing at a greater rate than the other treatments. The slight increase in value is due exclusively to growth in the chip-n-saw product class. In any event, an investment in fertilizer for this example would be a gamble; certainly with P only it would be a losing proposition.

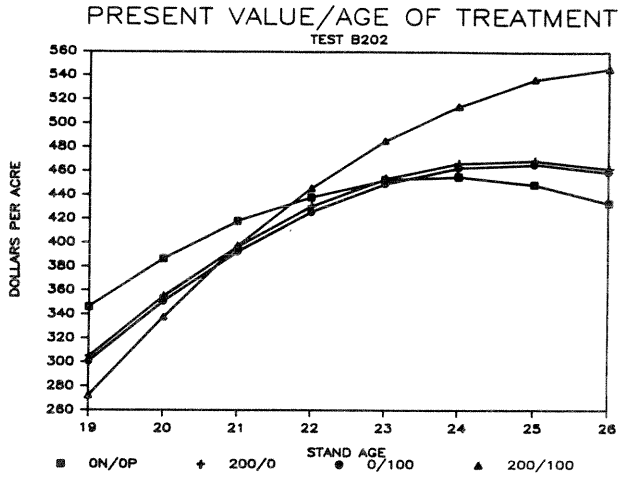
The model projections for soil group G (Figures 6-A, B and C) show a positive, non-linear response to all fertilizer treatments compared to the control. Based on growth response alone, one might initially speculate that any fertilizer addition to these soils is a good investment. The PV comparison, however, tells a different story. In this example, the value of a 22-year old stand of slash pine is zero and any further capital input only lowers the PV. The obvious conclusion is that slash pine is off-site on G-group soils.

These results illustrate the variation in volume growth and PV for fertilized and non-fertilized stands on six different site types. Of further interest is the sensitivity of an economic analysis to changes in some basic economic assumptions. This will be the topic of the following section.

SENSITIVITY ANALYSIS

Any forest fertilization investment has risk. For the A and B group soils (wet savannas), a decision to fertilize has relatively little risk relative to increased value over a non-fertilized stand. Similarly, a decision not to fertilize a G group soil (dry sandhills) has a low risk factor since few studies on these sites have reported significant growth responses. The challenge lies in predicting the profitability of fertilizer additions to the C, D, E and F soil groups where relative volume response to fertilizer application is more variable than for the other soil groups.





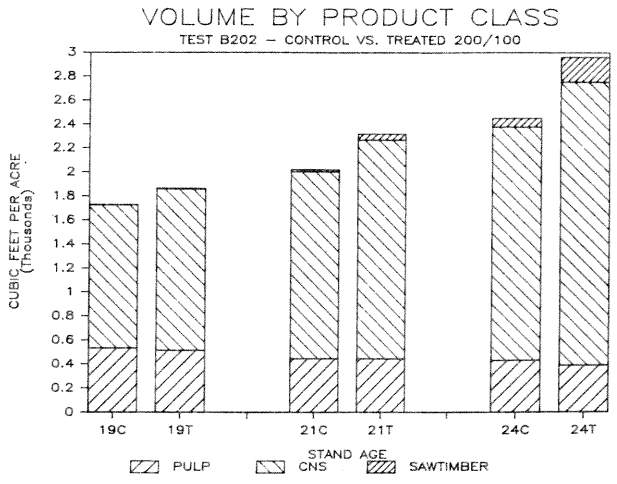
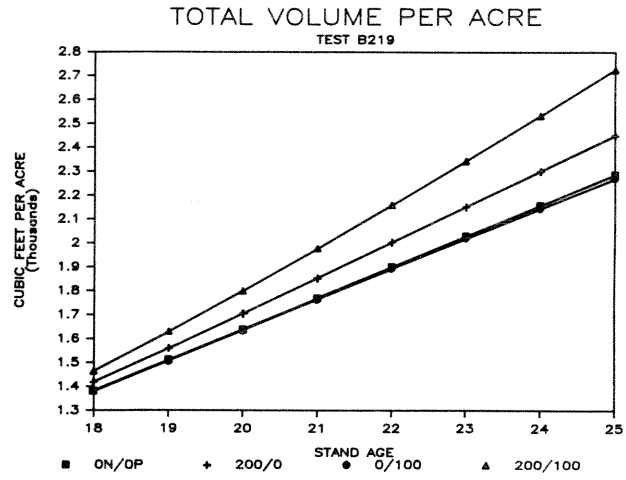
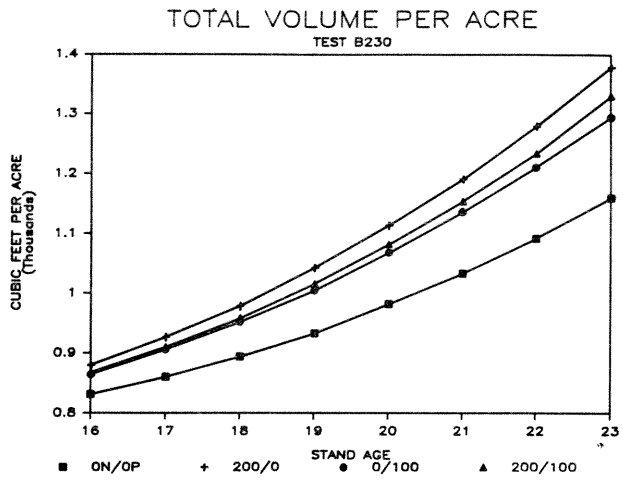
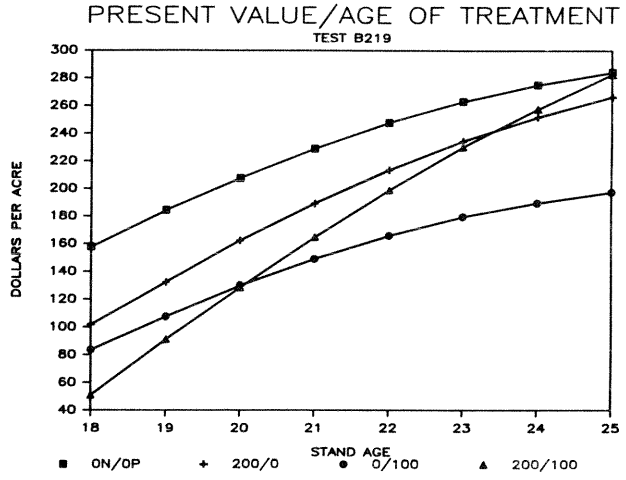
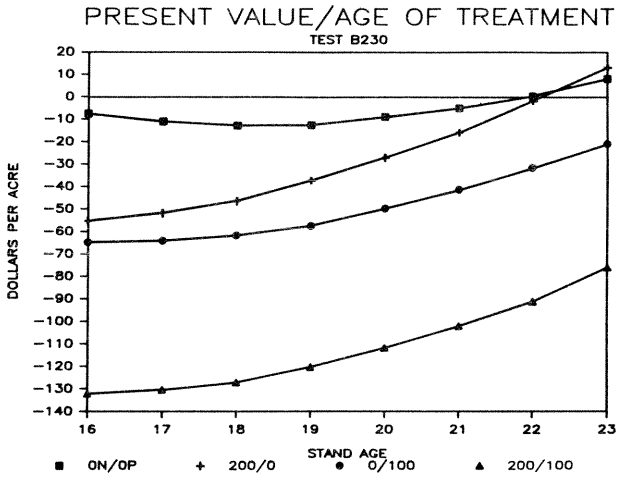


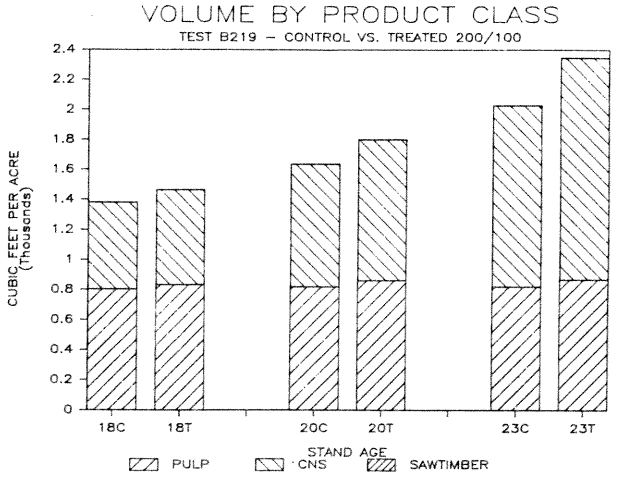
Figure 4.--(A) Total volume per acre, (B) present value, and (C) volume by product class for Test B202, CRIFF soil group D.











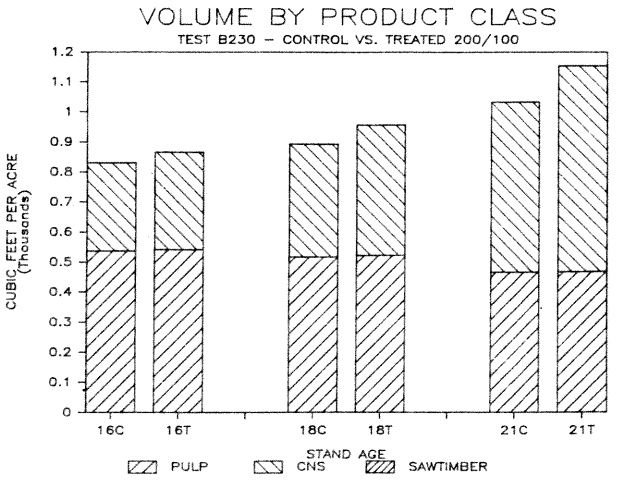


Figure 5.--(A) Total volume per acre, (B) present value, and (C) volume by product class for Test B219, CRIFF soil group E.

Figure 6.--(A) Total volume per acre, (B) present value, and (C) volume by product class for Test B230, CRIFF soil group G.

As mentioned earlier, growth response must be evaluated along with various economic components in order to assess the potential profitability of fertilization. Forest industry has financial considerations quite different than those of the NIPF owner. The purpose of this sensitivity analysis is to illustrate the influence that regeneration and management costs, interest rates, tax treatment and product type have on the value of a fertilized and non-fertilized stand. Data from the B202 Test (Table 1), which is in soil group D, will be used in this analysis.

The first step is to consider the difference in volume growth between the control and the three fertilizer treatments (N, P, N + P). Figure 7 shows that at, for example, age 24 the N and P treatments increased volume nearly 200 cubic feet, while N + P produced roughly 500 cubic feet more than the control.

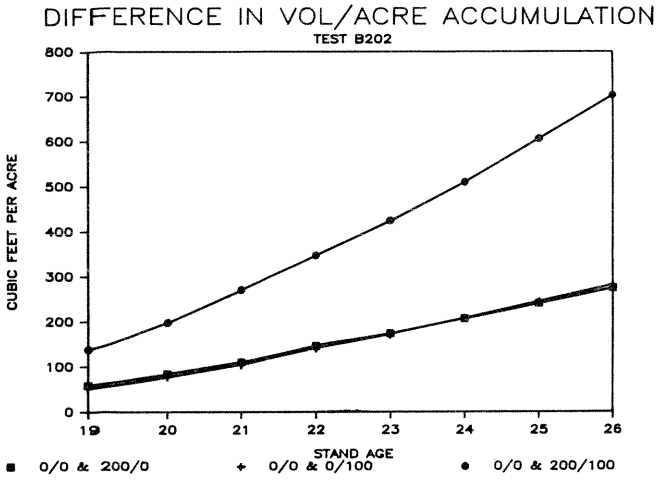


Figure 7.--Difference in volume per acre accumulation between the control and fertilized stand. 0/0 = control, 0/100 = 100 lbs P/acre, 200/0 = 200 lbs N/acre, 200/100 = 200 lbs N + 100 lbs P/acre.

The next step is to estimate the difference in PV between the control and treated condition. To make this comparison we used the cost and price assumptions presented earlier. Figure 8 illustrates that either of the three fertilizer treatments increased PV, but that N + P was superior for two reasons. First, a positive PV is achieved at an earlier age and, second, the value is increasing at a faster rate than either the P or N treatments.

Since regeneration and annual management costs vary, it is informative to consider the sensitivity of a PV estimate to changes in these costs. For this purpose we have selected three realistic regeneration/annual management cost scenarios of $120/$6, $100/$5 and $80/$4.

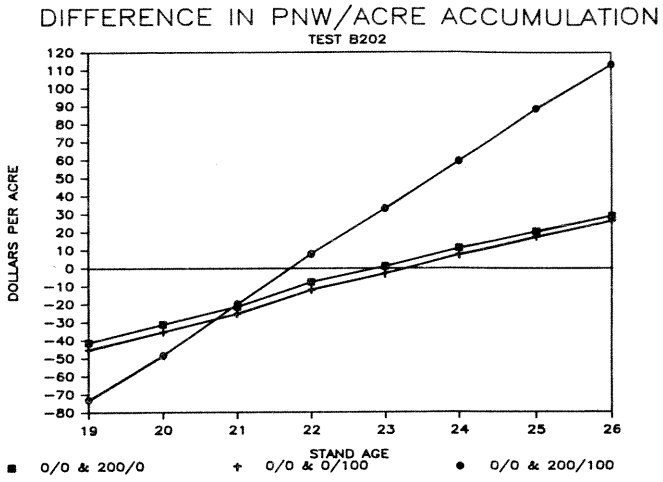


Figure 8.--Difference in present value between the control and fertilized stand. Symbols refer to treatments as in Figure 7.

Figure 9-A shows the change in PV of a non-fertilized stand under the three cost assumptions. Important to note is that the PV curves are parallel and peak near the 24th year. Figure 9-B shows the PV change if the stand were fertilized with 200 lbs N and 100 lbs P. The curves are also parallel, but still climbing 10 years after treatment. In this case, fertilization enhanced and lengthened the economic life of the stand. This also illustrates the time value of money; reducing regeneration costs by $20/acre can yield increased profits of $75+ at harvest.

The influence of interest rate, or discount factor, on the PV of a non-fertilized (Figure 10-A) and fertilized stand (Figure 10-B) further illustrates the time value of money. There are several points of interest in common to both figures. First, the curves are diverging with the PV differential increasing with time. Second, as the discount factor increases, the curves peak at an earlier age. Third, there is a substantial difference in PV depending on the discount factor selected for the analysis. A comparison of Figures 10-A and B shows that fertilization moves the peak of the curve roughly 2 years later. Additionally, the change in PV due to fertilization was inversely related to the discount factor.

Figure 10-B indicates that the interval between fertilizer application and harvest age is shortened as the discount factor increases. This is an important consideration when deciding on a time to fertilize relative to a predetermined harvest age. This analysis shows that a PV calculation is quite sensitive to the discount factor assumption.

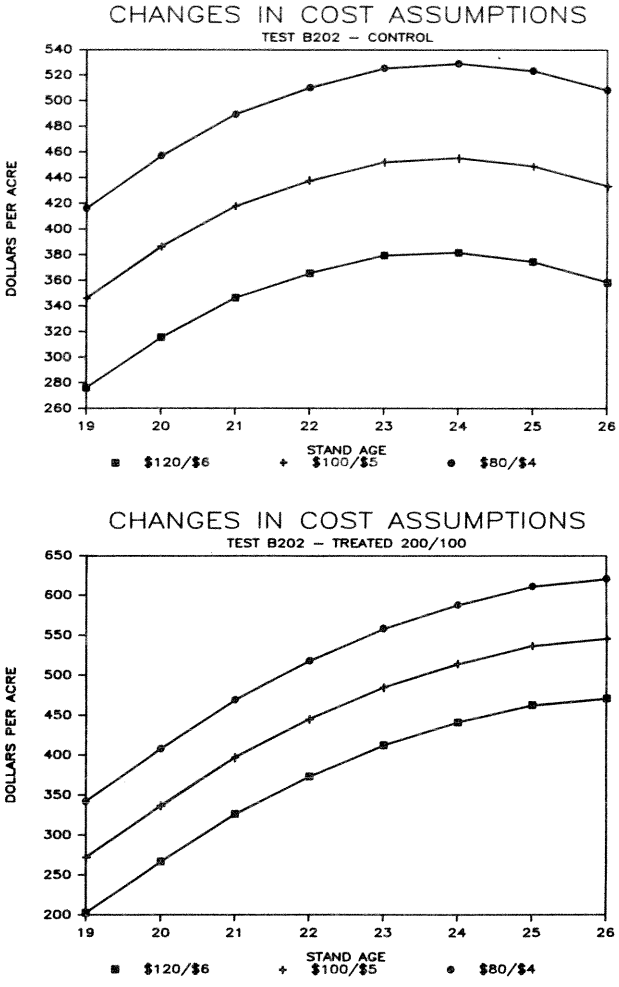


Figure 9.--Influence of cost assumptions on the present value of an (A) non-fertilized stand and (B) fertilized stand treated with 200 lbs N and 100 lbs P per acre. Cost figures indicate regeneration/annual administration assumptions.

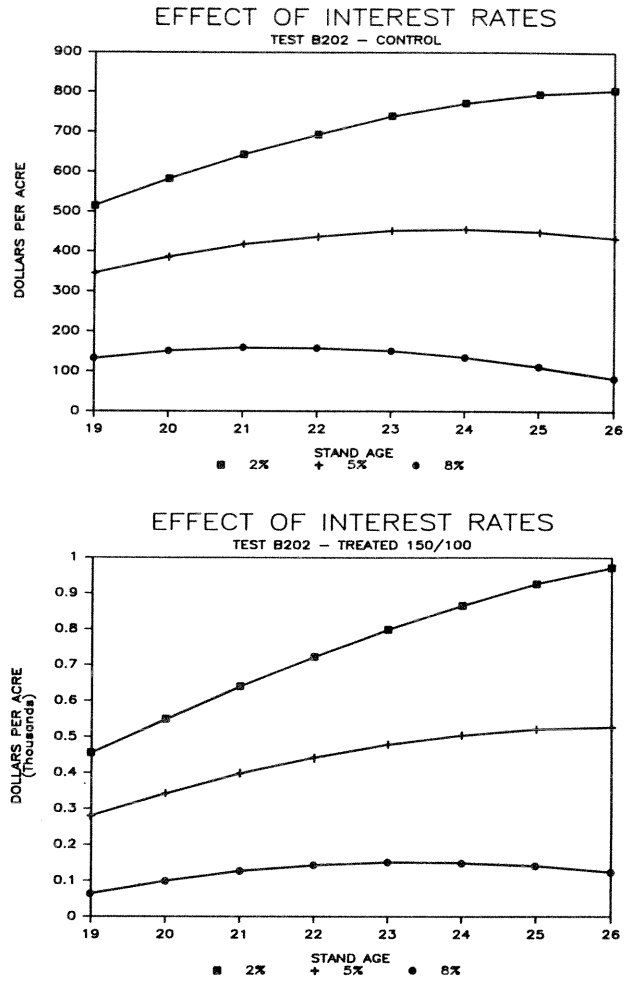


Figure 10.--Effect of interest rates on the present value of an (A) non-fertilized stand and (B) fertilized stand treated with 150 lbs N and 100 lbs P per acre. Symbols refer to interest rates (2, 5 and 8%).

The effect of taxation on a fertilizer investment is shown in Figure 11. In this example, taxes were paid on 40% of the profit (capital gains) and a 50 percent tax bracket was assumed. The four curves represent the control and fertilized (200 lbs N + 100 lbs P) before-tax values and the after-tax value of the fertilized stand with the fertilizer capitalized or expensed. Three years after fertilization (stand age 16) the control was the most profitable investment. By age 21, the fertilized stand, regardless of tax treatment, was more valuable and peaked at a later age relative to the control. Ignoring the control, the before-tax curve converges with the after-tax capitalized curve at age 24. Thus, the benefit of capitalizing the fertilizer is diminishing with time. The after-tax expensed curve is significantly higher (greater PV) and later peaking than the latter two curves. Therefore, expensing fertilizer costs has the clear advantage over capitalization.

Of key interest in this analysis is the sensitivity of PV to changes in product type and associated values. No attempt is made to vary product prices per se, but rather to show the importance of merchandising the products. Figure 12 illustrates the change in PV for a fertilized and non-fertilized stand under the two marketing strategies. Two important interpretations can be made. First, fertilizing this stand and valuing the volume as pulpwood would be less profitable than not fertilizing at all. Second, if the stand is fertilized, the products must be merchandized in order to take full advantage of the profit potential. Thus, if an NIPF owner chooses to practice forest fertilization, then plans should also be made for knowledgeable marketing of the wood products.

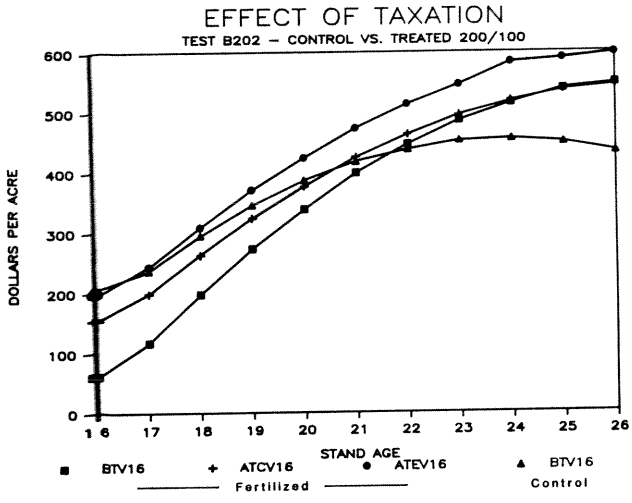


Figure 11.--Effect of tax treatment on the present value of a non-fertilized and fertilized (200 lbs N and 100 lbs P per acre) stand. BTV16 = before tax value at age 16, ATCV16 = after tax value at age 16 with fertilizer capitalized, ATEV16 = after tax value at age 16 with fertilizer expensed.

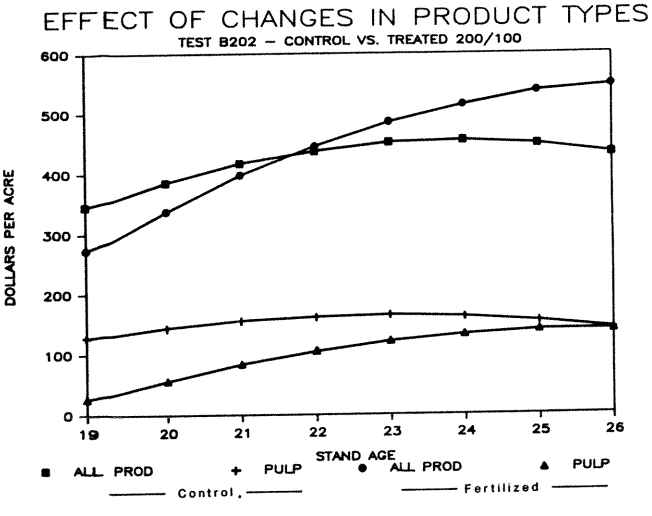


Figure 12.--Effect of merchandising on the present value of a non-fertilized and fertilized (200 lbs N and 100 lbs P per acre) stand. All Prod = all products merchandised, Pulp = volume priced as pulpwood.

CONCLUSION

A decision to engage in forest fertilization is a dynamic process. It should incorporate the best biological information available along with practical economic assumptions particular to an individual landowner. Forest industry is driven by unique economic conditions quite unlike those of an NIPF owner. For this reason, NIPF owners must be informed of the biological and economic factors which influence the profitability of a forest fertilization investment.

At the present time, we must rely on the biological data we have in hand. One component of this paper is to use the mathematical model described by Mollitor et al. (1985, these proceedings) to better describe changes in tree diameter class in response to fertilizer addition. The primary thrust of this paper is to illustrate how the present value of a stand can be influenced by fertilization as well as some key economic components.

When predicting present value, it appears that the discount factor assumption has the greatest influence on the PV estimate. Based on the example in this paper, the bottom line on profitability lies with merchandising of the products. While many individuals already have an understanding of this critical point, we suspect that many do not. For this reason it is necessary that NIPF owner education efforts emphasize the value of sound forest management and marketing strategies. Increasing NIPF owner profits may well provide an incentive to reinvest in forestry.

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FERTILIZER PLACEMENT IN YOUNG SLASH PINE PLANTATIONS [1/]

A. V. Mollitor and N. B. Comerford [2/]

Abstract.--In 1971 and 1973 the Cooperative Research in Forest Fertilization (CRIFF) program established one experiment in Wayne County, Georgia and one in Franklin County, Florida to compare five fertilizer application techniques for newly planted slash pine. Placement techniques were: (1) broadcast after planting, (2) broadcast before bedding, (3) band before bedding, (4) band after planting, and (5) spot treatment of individual seedlings. Fertilizers used were (1) control, (2) concentrated super phosphate, and (3) diammonium phosphate. After ten years, both sites had demonstrated phosphorus responses but little difference in response due to fertilizer placement or material. These studies suggest that foresters have many options available when developing a phosphorus fertilization program for young slash pine plantations.

INTRODUCTION

Dramatic response of young slash pine (*Pinus elliottii* var. *elliottii*) plantations to phosphorus (P) fertilization was observed on wet flats in western Florida in the late 1950's and early 1960's. The magnitude of these responses stimulated much interest in the use of P fertilization as a standard silvicultural treatment. It was soon determined that although many sites respond favorably to P, the resonse was not always as dramatic as on the coastal savannas. Aiming to develop forest fertilization technology to the point that it would enhance fiber production on a wide variety of sites, the Cooperative Research in Forest Fertilization (CRIFF) program at the University of Florida initiated several series of experiments designed to examine various aspects of young stand fertilization, including:

- Application rates for N and P,
- Micronutrient fertilization,
- Potassium fertilization,
- Site preparation interactions,
- N and P sources,
- Species interactions, and
- Application timing.

One other question about time-of-planting fertilization concerned application technique. Where is the best place to apply fertilizers in a new slash pine plantation? Should the material be broadcast or banded, or should it be applied to individual seedlings? Should it be applied to the surface or incorporated into beds?

METHODS

Two experiments were installed to study fertilizer placement in young slash pine plantations:

Test	Location	Soil Subgroup	Date Planted
K001	Wayne Co. GA	Arenic Paleaquult	02/71
K003	Franklin Co. FL	Arenic Haplohumod	12/72

At each location, placement and fertilizer treatments were applied in a split-plot design with four randomized blocks. Five placement treatments were applied to main plots as follows:

A. Fertilizers broadcast soon after planting,
B. Fertilizers broadcast just prior to bedding,
C. Apply in 4-foot bands just prior to bedding,
D. Apply in 4-foot bands soon after planting,
E. Spot-treat individual seedlings.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, GA, November 7-8, 1984.

[2/] Corresponding author: A. V. Mollitor, Dept. of Forestry, University of Florida, Gainesville, FL 32611

The Georgia site (K001), was bedded in September, 1970. At the Florida site (K003), the initial fertilization was conducted in October, 1972 and the second fertiliziation in January, 1973. Three fertilizer treatments were applied to subplots:

1. Control,
2. Concentrated superphosphate (CSP), and
3. Diammonium phosphate (DAP).

Rates were adjusted to equalize total per-acre application rates for all treatments. Both CSP and DAP treatments supplied 40 lb. P per acre. DAP also supplied 36 lb. N per acre.

Tree heights and diameters were measured 8 and 10 years after treatment. Total outside-bark stem volumes to a 3-inch top were calculated using the formula of Bennett et al. (1959). Treatment effects were determined by analysis of variance and Duncan's multiple range test (Freund and Littell 1981).

RESULTS

Analyses of variance showed that, for both experiments, there were no significant interactions between placement and fertilizer treatments. It is therefore appropriate to examine these two effects independently.

Fertilization Effects

Fertilization had significant effects on both mean tree height (Fig. 1) and total stand volume (Fig. 2) in both tests. There were no significant differences between responses to CSP and DAP. Average height response after 10 years was about 2 feet at the Georgia site, and about 7 feet at the Florida site. Volume response was about 250 cubic feet per acre (22%), and about 325 cubic feet per acre (360%) at the Georgia and Florida sites, respectively.

Placement Effects

Effects of fertilizer placement were minimal. After 10 years, the Florida site showed no significant placement effects on either height or volume.

At the Georgia site, trees on plots where fertilizers were broadcast after planting were significantly taller than trees on other plots by 1 foot (Fig. 3). In the same experiment, tenth-year total volume on plots where fertilizers were broadcast after planting, banded before bedding, or banded after planting averaged 1370 cubic feet per acre, while volume on plots where fertilizers were broadcst before bedding or spot-placed averaged 1247 cubic feet per acre (Fig. 4). Stocking rate was fairly consistent for all placement treatments with an average of 525 stems per acre.

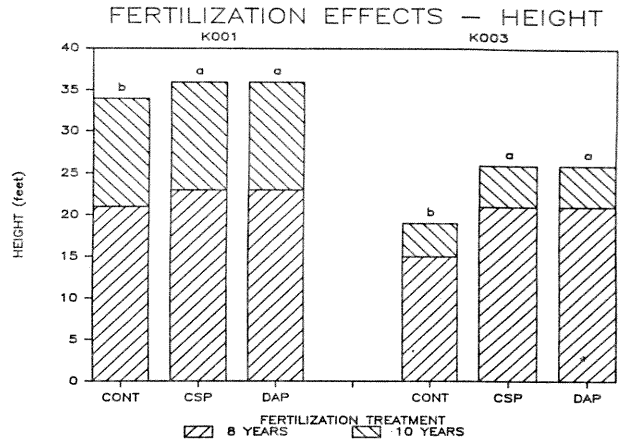

Figure 1.--Effect of fertilizer tretament on mean tree height at the Georgia (K001) and Florida (K003) sites. Bars with different letters are significantly different at the 0.1 level for tenth-year measurements.

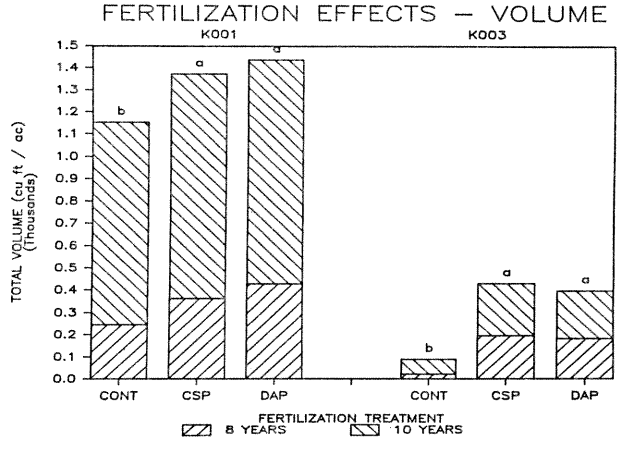

Figure 2.--Effect of fertilizer treatments on total stand volume at the Georgia (K001) and Florida (K003) sites. Bars with different letters are significantly different at the 0.1 level for tenth-year measurements.

DISCUSSION

It has often been suggested that by placing fertilizer close to young seedlings, either by banding or spot placement, they will benefit from the ready availability of higher nutrient concentrations and gain an early advantage over competing vegetation. It has also been suggested that these effects may be enhanced by incorporating fertilizers into beds rather than broadcasting them on the soil surface. These studies indicate

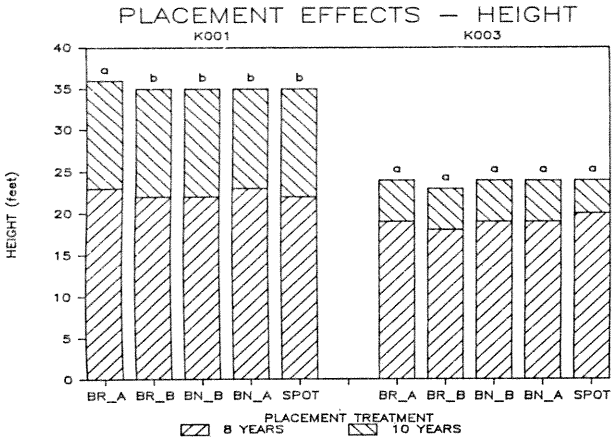

Figure 3.--Effect of fertilizer placement on mean tree height at the Georgia (K001) and Florida (K003) sites. Bars with different lettes are significantly different at the 0.1 level for tenth-year measurements. BR_A = broadcast after planting, BR_B = broadcast before bedding, BN_B = band before bedding, BN_A = band after planting, SPOT = spot placement.

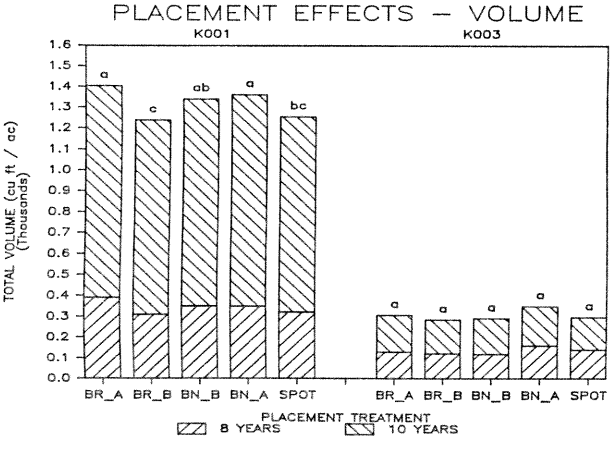

Figure 4.--Effect of fertilizer placement on total stand volume at the Georgia (K001) and Florida (K003) sites. Bars with different letters are significantly different at the 0.1 level for tenth-year measurements. BR_A = broadcast after planting, BR_B = broadcast before bedding, BN_B = band before bedding, BN_A = band after planting, SPOT = spot placement.

that fertilizer placement is of little importance when fertilizing young slash pine plantations. One study (the Florida site) showed no significant growth differences among placement techniques, and while the other (Georgia) site had significant differences among placement treatments, the magnitude of these differences was only about 125 cubic feet per acre at ten years. It appears that in young, mechanically site-prepared, slash pine plantations, either only low quantities of added P are needed for early response, or that young seedling root systems exploit larger soil volumes than generally realized.

Many experiments have been conducted to compare response to P-only with response to N-plus-P. Results have been variable, but most often, as in the studies reported here, response to the two treatment types have been about equal. It is often thought that competing vegetation responds more rapidly to added N than do the pines. Another hypothesis is that N released from decomposing logging slash and forest floor material incorporated into beds is adequate for the needs of young slash pine. Results from a series of CRIFF experiments (N series) show that the timing of fertilizer application is critical for N response (CRIFF 1983). Responses to N added with P were observed only for applications conducted between planting time and mid-June of the first year. N in earlier applications may be lost by leaching, and N in later applications may be lost to competing vegetation.

This timing effect is important in the design and interpretation of fertilizer placement studies. Fertilizers incorporated into beds must be applied before fertilizers applied after bedding or after planting. N applied too soon before, or too late after planting may not be used efficiently by the target crop trees. In the studies reported here, the application before bedding may have been too soon (September and October), but the applications after planting (February and January) should have been ideal for N response. The lack of placement-by-fertilizer interactions indicate that leaching was probably not a problem on these sites. Because the latest application was conducted well before weeds were active, these experiments do little to elucidate interactions between placement and weed competition.

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SERICEA INFLUENCES EARLY SURVIVAL, GROWTH, AND NUTRITION OF SAND PINE[1]

Jacques R. Jorgensen[2]

Abstract.--Sericea established with seedling sand pine on a droughty sand significantly reduced tree height growth through the third growing season. Sericea stands that developed with nine or more plants per square foot reduced tree survival, but stands with six plants had no significant effect. The use of both sericea and P fertilizer significantly increased the N and P contents of foliage of 3-year-old sand pine. Increases due to sericea were related to an increase of N in understory biomass, and those due to fertilizer related to increased soil P. Plots with sericea had about 140 more pounds of N per acre in the understory biomass and 0-8 inch soil layer than did controls.

INTRODUCTION

About 8 million acres of sandhills in the Southeast extend from central Florida to North Carolina. This area is sometimes referred to as a rain desert. In many areas annual rainfall approaches or exceeds 50 inches, but due to the low moisture-holding capacity of the soil, vegetation is often sparse.

Much of the sandhill area was originally covered with open, low-volume stands of longleaf pine (*Pinus palustris* Mill.)--a species not only adapted to poor droughty soils but also resistant to the repeated fires that may have eliminated those species with higher growth potentials. It is this land that presents some of the greatest challenges to forest management in the South.

On deep sand sites, longleaf pine is often difficult to establish; its initial growth may be slow and influenced by competition and disease. On some sites, sand pine (*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.) may be an alternative to longleaf. Although sand pine does not have the long-term growth potential and the many desirable features of long-rotation longleaf, it can be established more easily and will produce pulp and small timber within a reasonable time.

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[2]Research Soil Scientist, U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Research Triangle Park, N.C.

OBJECTIVES

The objectives of this study were to measure the effects of disking, P fertilization, and sericea (*Lespedeza cuneata* (Dum.-Cours.) G. Don) on the early survival, growth, and foliar nutrient concentrations of sand pine. Secondary objectives were to determine how seedbed preparation, form of phosphorus fertilizer, and seed inoculum and coating affect sericea establishment and growth, and how sericea affects site nutrients and understory biomass.

METHODS

Study Site

The experimental area was south of Aiken, S.C., near the Savannah River Project. Soil on the site was a member of the Lakeland series (thermic, coated family of Typic Quartzipsamments). The sand in the typical profile exceeds 80 inches in depth and the site had been covered with a scattered stand of longleaf and scrub hardwood. In preparation for planting, merchantable timber was removed, remaining trees sheared, and residues rootraked and windrowed.

Treatments and Plot Layout

There were three basic treatments: phosphorus fertilization, sericea seeding, and disking. Phosphorus (P) was applied at rates of 0 and 100 pounds of P/acre with P as triple superphosphate (TSP) and ground rock phosphate (GRP). Sericea was sowed at 0 and 20 pounds of actual seed/acre with seed inoculated immediately before sowing and with preinoculated seed coated with lime. Half of the plots were prepared with a light farm disk, and half were not disked.

Plots were established in January-March of 1981 in a split-split design with three replications. The initial split was based upon disking. Each of the three disked or undisked plots had an area of 0.58 acre. Each of the 12 fertilized x sericea plots in a replication had an area of 0.058 acre and each of the 6 unfertilized x sericea plots were 0.077 acre in size.

Year-old seedlings of Choctawhatchee sand pine (P. clausa var. immuginata D. B. Ward), obtained from a private nursery in north Florida, were planted on February 23, 1981. Seedlings were planted in rows 10 feet apart with a 6-foot within-row spacing.

Following fertilizer distribution and tree planting, designated plots were disked lightly to incorporate fertilizer into the soil and to prepare a seedbed for the sericea. Sericea seed were sowed with a cyclone seeder immediately after disking. Seed sowed on disked plots tended to roll to the bottom of furrows and become covered with soil.

Study Measurements

Measurements of sericea stocking in the first and second growing seasons were made in July and August of 1981 and 1982. Four 1-ft^2 measurement areas were located in the central portion of each plot. Up to 10 sericea plants were counted and their heights to the nearest inch measured. If there were more than 10 plants/ft^2, this was noted without further counting.

In the fall of 1983, the third growing season, all vegetation in each of the four square-foot areas on each plot was clipped, collected, and separated into living sericea and nonsericea vegetation. Dead material, litter, and organic residues to the mineral soil depth from each of the four areas per plot were composited. Soil from the 0-4 and 4-8 inch depths were sampled after litter was removed. Vegetation and organic residues were ovendried at 158°F for 24 to 48 hours, and then ground in preparation for chemical analysis. Soils were air dried.

After the third growing season in the winter of 1983-84, tree survival and height were measured and foliage sampled. Foliar samples were obtained from trees in the central area of each plot by removing 10 needle fascicles from each of two first-flush branches of the current year's growth. Soil samples were analysed for total nitrogen (N), double acid extractable P, potassium (K), calcium (Ca), and magnesium (Mg). Total N, P, K, Ca, and Mg contents of vegetation and organic residues are reported. Due to varying amounts of mineral contamination present in litter and organic residues, their weights and nutrient concentrations are reported on an ash-free equivalent basis calculated from loss on ignition.

Analysis of variance with a split-split plot model and Duncan's multiple range test were used to determine significance of treatments and differences between means.

In the summer of the fourth growing season, the percentage of each plot dominated by sericea, weeds, or bare soil was estimated.

RESULTS AND DISCUSSION

Sericea Stand Development

All treatment-combination plots in which sericea was planted were successfully stocked with legumes (Table 1). One- and 2-year-old stands derived from coated, preinoculated seed were much more dense than data indicate because only up to 10 plants/ft^2 are reported. In the first growing season, 78 percent of the plots sowed with coated seed had more than 10 plants/ft^2. None of the plots sowed to uncoated seed had this high density. During the second growing season, average plot density based upon a maximum of 10 plants/ft^2 remained unchanged but the proportion of plots that had more than 10 plants/ft^2 was reduced by over half to 33 percent. Again, no plots sowed with uncoated seed contained more than 10 plants/ft^2. The reduction in stand density over the 2-year period was probably related to a late first-season drought, which damaged the young sericea plants, and to sericea attrition from competition. By the middle of the fourth growing season, sericea was dominant and weeds made up only a small portion of the living understory. Both seed-inoculation treatments resulted in sericea dominating 88 percent of the plots with less than 5 percent of the area having no plant or litter cover. On plots which were not sowed to sericea, bare soil without vegetation or litter protection made up 25 percent of the area. Grasses or grasslike plants dominated nonsericea plots.

Disking had no important influence on sericea density at any of the three measurement periods. This lack of measurable effect was probably related to the intensive site preparation carried out in anticipation of tree planting, which had eliminated most ground cover and bared the mineral soil. At the end of the fourth growing season, sowed sericea occupied 89 percent of the area on disked plots and 86 percent on the undisked plots.

Sericea density increased slightly as a result of fertilization with P. A tally the first year showed seven plants/ft^2 on nonfertilized plots compared with eight in fertilized areas. In the second year, comparable results were 6.5 and 8.5/ft^2. At the end of the fourth growing season, sericea occupied 78 percent of unfertilized plots, 95 percent of plots fertilized with GRP, and 89 percent of plots treated with TSP. Although density data were not analysed statistically, differences probably did exist between fertilized and unfertilized

Table 1.--Plot cover, by sericea treatment and growing season

Sericea treatment	1st	2d	4th	
	Sericea		Sericea	Bare
	No./ft^2		Percent	
None	--	--	--	25
Uncoated seed	6.3	6.5	88	<5
Coated seed	9.2	9.0	88	<5

plots but not between plots treated with the two forms of P.

Sand Pine Survival Growth

Height of 3-year-old sand pine was significantly reduced by stands of sericea regardless of sericea density (Table 2). Trees grown without sericea were 4.1 feet tall, significantly taller than the 3.6-foot height of trees grown in sericea. Survival was significantly influenced by the sericea but only in the dense stands produced by sowing coated seed. Survival in these latter stands was about half that of plots without sericea.

Fertilization had no significant influence on height or on survival: 3.7-foot height for trees on P treated plots compared with 3.8 on control plots, and 67 percent survival for trees on fertilized areas compared with 60 percent for trees grown without fertilizer. It is not known if or when trees will respond to the addition of P.

Disking in addition to rootraking and windrowing produced no significant increase in survival or height growth of the pines. On disked plots, across all sericea and fertilizer treatments, survival was 11 percentage points higher than the 50 percent obtained on the undisked plots.

The 0.5-foot reduction in height in the 3-year-old stand as a result of sand pine-sericea competion, although significant, is of little consequence. Jorgensen (1981) found no negative effects of sericea on loblolly pine growth on a site with a site index of 90 (age 50)--much better than the 60 for longleaf on the present site. Jorgensen also reported no growth response to treatments until 4 years after application; at that time, the response to sericea could still not be separated from that of P.

The reduction in pine survival due to sericea competition is, however, a serious porblem. There may be two approaches to its solution if sericea is to be used for long-term site improvement. Sowing of sericea can be delayed until the young pines are established, usually the beginning of the second growing season, or the sowing rate can be reduced to permit a gradual increase in sericea stand density by self-seeding.

Sand Pine Nutrition

Although sericea had a negative influence on growth and survival of sand pine, its effect on foliar nutrient content was positive (Table 3).

Table 2.--Influence of sericea lespedeza on survival and height of 3-year-old sand pine

Sericea treatment	Survival	Height
	--Percent--	--Feet--
None	80b	4.1b
Uncoated seed	72b	3.6a
Coated seed	39a	3.6a

Means within a column followed by the same letter do not significantly differ at the 5 percent level.

Table 3.--Influence of sericea lespedeza on nutrients in sand pine foliage

Treatment	N	P	K	Ca	Mg
	Percent				
No sericea	1.30a	0.12a	0.41	0.25	0.087
Sericea	1.41b	.13b	.42	.23	.086

Means within a column followed by the same letter do not significantly differ at the 5 percent level.

Both N and P were significantly increased. The other elements were unaffected by treatment. Phosphorus application also increased foliar N and P uptake but did not influence K, Ca, or Mg (Table 4). Disking had no influnce on uptake of any of the five nutrients.

Foliar nutrient concentrations of both fertilized and unfertilized trees are in the general ranges found in pine growing in the Florida sandhills (Brendemuehl 1973). Overall, nutrition does not appear to limit sand pine growth on the present site.

Site Biomass and Nutrients

Seeding sericea produced 50 percent more biomass--the sum of ash-free organic residues, weeds, and sericea--than was produced on control plots (Table 5). This increase was not, however, significant. The lack of significance can be attributed to spotty growth, a late summer drought that preceded the sampling, and a small sample size with high variability.

Although site biomass was not significantly increased due to treatment, its N and Ca contents were. Nitrogen more than doubled from 43 to 99 pounds per acre and concentration increased from 0.92 to 1.41 percent. Calcium content was also doubled and concentration increased from 0.62 to 0.84 percent. Phosphorus, K, and Mg contents were not significantly affected by growing sericea.

Fertilization had no significant influence on understory biomass or the amount of biomass nutrients. There was, however, an increase in P concentration. Where no fertilizer was applied, there was an average of 6,546 pounds of biomass per acre which contained 4.8 pounds of P or a concentration of 0.073 percent. Fertilization with P produced an average of 6,182 pounds of biomass which contained 5.2 pounds of P or a concentration of 0.084 percent. Lack of response to P fertilization through increased biomass or P uptake indicates that P is not a major factor limiting growth on these sandy soils with low moisture-holding capacity.

Disking had no significant effect on understory biomass but undisked plots averaged 5,685 and disked 6,932 pounds of biomass per acre. These variations in biomass were accompanied by proportional changes in N, P, K, Ca, and Mg contents.

Soil nutrient concentrations were not significantly influenced by sericea (Table 6) or disking,

Table 4.--Influence of phosphorus fertilization on nutrients in sand pine foliage

Treatment	N	P	K	Ca	Mg
	Percent				
No P	1.34a	0.12a	0.41	0.23	0.086
TSP or GRP	1.39b	.13b	.42	.24	.085

TSP = triple superphosphate; GRP = ground rock phosphate.

Means within a column followed by the same letter do not significantly differ at the 5 percent level.

Table 5.--Influence of sericea lespedeza on biomass and nutrients in understory vegetation and forest floor

Sericea treatment	Biomass	N	P	K	Ca	Mg
		lb/acre				
None	4693	43a	3.6	16	29a	5
Uncoated seed	6893	96b	5.6	17	58ab	8
Coated seed	7160	102b	5.8	16	61b	9

Means within a column followed by the same letters do not significantly differ at the 5 percent level.

Table 6.--Influence of sericea lespedeza on nutrient concentrations in soil

Sericea treatment	N	P	K	Ca	Mg
	ppm				
	0-4 INCH DEPTH				
None	461	18.8	21	165	25
Uncoated seed	478	17.2	23	151	27
Coated seed	475	12.9	21	143	27
	4-8 INCH DEPTH				
None	269	5.3	8.4	57	13
Uncoated seed	331	5.3	9.8	69	15
Coated seed	316	5.4	8.5	71	17

There is no significant difference between means in a column and depth.

but were influenced by fertilization (Table 7). Applying GRP, a Ca-containing amendment, significantly increased Ca in the 0-4 inch layer but resulted in a decrease in Mg concentration. The decrease in Mg was probably due to competition for soil exchange sites from the added Ca. Decreased K concentration in the 4-8 inch layer was probably also related to the increased Ca from the GRP fertilizer. Phosphorus increases were related to P additions by fertilizers. The decreased N in the 4-8 inch depth on plots where GRP was applied cannot be explained. When N in the 0-4 and 4-8 inch soil layers is summed, however, there is no significant difference due to fertilizer treatment.

Sericea was associated with a nonsignificant increase of 90 pounds of N in the surface 8 inches of soil. This was similar to the 94 pound increase reported by Jorgensen (1981) where P-fertilized sericea had been grown on a much better site for 4 years. In that study, however, there was a large increase of biomass, with biomass N + soil N augmenting site N by more than 400 pounds per acre, compared with only about 140 pounds at the end of a 3-year period in the present study.

SUMMARY AND CONCLUSIONS

Sericea established on a droughty sand the same year as sand pine significantly reduced tree height growth by the end of the third growing season. Dense sericea stands also reduced tree survival to about half that of control plots, but stands of moderate density had no significant effect on survival. At the end of the third growing season, important differences in sericea stand density, as measured by biomass, were no longer evident. Both sericea and P fertilizer significantly increased the N and P contents of foliage of 3-year-old sand pine. The N increase

Table 7.--Influence of fertilization on nutrient concentration in soil

Treatment	N	P	K	Ca	Mg
	ppm				
	0-4 INCH DEPTH				
No fertilizer	484	2.8a	23	138a	29b
GRP	491	26.8b	20	208b	21a
TSP	438	19.9b	21	108a	28ab
	4-8 INCH DEPTH				
No fertilizer	317b	2.1a	9.3b	64ab	16
GRP	281b	5.4ab	8.1a	75b	15
TSP	325b	8.8b	9.4b	61a	15

GRP = ground rock phosphate; TSP = triple superphosphate.

Means within a soil-depth column followed by the same letter do not significantly differ at the 5 percent level.

was related to an increase of N in understory biomass. Plots with sericea gained a total of 140 pounds of N per acre in understory biomass and surface 8 inches of soil compared with control plots. On this deep sand where moisture is the most important factor limiting growth, additional time is needed to determine if the N fixed and the soil protection offered by sericea can eventually outweigh its initial negative effects on growth and survival of planted pines.

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EFFECT OF OVERBURDEN TYPE AND ORGANIC AMENDMENTS ON THE GROWTH OF PINES ON A RECLAIMED SURFACE MINE[1/]

J. L. Torbert, J. A. Burger, and W. L. Daniels[2/]

Abstract.--A Rock Mix Study and a Surface Treatment Study were designed to evaluate the effects of various sandstone (SS)/siltstone (SiS) overburden mixtures, several surface treatments (topsoil, sawdust, and municipal sludge), and infection with Pisolithus tinctorius on the growth and survival of loblolly pine (Pinus taeda L.) and pitch X loblolly pine hybrids (Pinus xrigitaeda) on a reclaimed surface mine in Southwestern Virginia. After two years, the best growth in the Rock Mix Study occurred in the pure sandstone plots and the worst growth was in the pure siltstone plots. In the Surface Treatment Study, seedlings planted in 12 inches of topsoil showed no growth differences from those planted in an unamended 2:1 SS:SiS spoil. Seedling growth was increased by application of municipal sewage sludge at rates of up to 25 t/acre, but higher applications of sludge had detrimental effects. The best surface treatment was sawdust (25 t/acre). Mycorrhizae improved seedling growth in the Surface Treatment Study where fertilizer pellets were not applied. Pitch X loblolly pine hybrids survived better and began growth earlier in the Spring than loblolly pine.

INTRODUCTION

Reclamation managers, who want to establish pine plantations on strip-mined lands, have many opportunities that are not available to most foresters. Selective overburden placement (Chang and Kelly, 1982) during the reclamation phase can create a deep, uncompacted spoil with desirable chemical and physical properties. Application of surface amendments, seedling inoculation with mycorrhizal fungi, and the use of fertilizer pellets are additional options that can aid seedling establishment and growth. Unlike most reforestation efforts where expensive site preparation and planting costs must be capatilized through the rotation, reforestation costs on strip-mined land can usually be deducted in the year they occur as expenses required for reclamation (Zipper, 1983).

Coal seams in Southwestern Virginia and surrounding areas of Kentucky and West Virginia are generally overlain by strata of sandstone and siltstone. These layers are blasted and removed during the mining phase and must be moved back into position during reclamation. Sandstone and siltstone spoil differ in their physical and chemical characteristics, and can have an effect on revegetation success. Preve and co-workers (1984) found that sandstone overburden was a better growth medium than siltstone spoil for Pinus spp. seedlings. The sandstone spoil had fewer coarse fragments, better aeration porosity, and lower levels of soluble salts.

Reclamation law requires topsoil replacement, unless a topsoil substitute will be at least as productive as the original soil. All hard rock overburden materials are very low in organic matter and plant available nitrogen. Some organic amendments, such as municipal sewage sludge, can improve soil moisture retention, increase CEC, and depending on the nature of the

[1/] Paper presented at the Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Research Assistant and Assistant Professor, Department of Forestry, and Research Associate, Department of Agronomy, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

Table 1.--Summary of treatments in the Rock-Mix and Surface Treatment Studies.

Treatment	Overburden Type	Other Additions[1/]
	Rock-Mix Study	
Pure Sandstone (SS)	100% Sandstone	N, P, K
2:1 SS:SiS	67% SS: 33% SiS	N, P, K
1:1 SS:SiS	50% SS: 50% SiS	N, P, K
1:2 SS:SiS	33% SS: 67% SiS	N, P, K
Pure Siltstone (SiS)	100% Siltstone	N, P, K
	Surface Treatment Study	
Control	67% SS: 33% SiS	N, P, K
Topsoil[2/] (12 in)	67% SS: 33% SiS	N, P, K + 3.5 t/acre Ag lime
Sawdust (25 t/acre)	67% SS: 33% SiS	N, P, K + 300 lbs/acre Slow-N
Sewage Sludge (10 t/acre)	67% SS: 33% SiS	None
Sewage Sludge (25 t/acre)	67% SS: 33% SiS	None
Sewage Sludge (50 t/acre)	67% SS: 33% SiS	None
Sewage Sludge (100 t/acre)	67% SS: 33% SiS	None

[1/] N, P, K fertilized plots all received 1000 lbs/acre of 15-30-15 fertilizer. All plots were straw mulched and hydroseeded to Kentucky-31 tall fescue on May 13, 1982.

[2/] The "Topsoil" material used in this experiment is a mixture of A, E, B, C and CR soil horizons.

material, supply future nutrients (Halderson and Zenz, 1978).

Ectomycorrhizae have been found to increase forest tree survival and growth under many different site conditions (Ruehle and Marx, 1979). Pisolithus tinctorius (Pers.) Coker and Couch, has been used succesfully for improving the performance of pines on reclaimed surface mines (Marx and Artman, 1979). Early pine growth can also be stimulated by application of a fertilizer pellet in the planting slit (Berry, 1979). Controlled placement of nutrients with fertilizer pellets can reduce the overtopping of seedlings by surrounding vegetation, which often occurs when fertilizer is broadcast applied.

The objective of this study was to compare the effects of various sandstone/siltstone overburden mixtures, organic surface amendments, and Pisolithus tinctorius ectomycorrhizae on the growth of loblolly pine (Pinus taeda L.) and pitch X loblolly pine hybrid (Pinus xrigitaeda) seedlings after two years on a reclaimed surface mine in Southwestern Virginia.

METHODS

The field layout consisted of two subtrials; a Rock Mix Study and a Surface Treatment Study (Table 1). The Rock Mix Study consisted of four replications of five overburden mixes; pure sandstone (SS), 2:1 SS:Siltstone (SiS), 1:1 SS:SiS, 1:2 SS:SiS, and pure SiS. The Surface Treatment Study consisted of four replications of seven surface amendments applied to a 2:1 SS:SiS rock mix. The amendments included a control, 12 inches of topsoil (A + E + B + C + CR horizons), 25 t/acre of sawdust, and four rates of municipal sewage sludge (10, 25, 50, 100 t/acre).

The study plots were constructed during the winter of 1982 on a flat bench in Wise County, Virginia, that was surface mined in 1973. Overburden material for the study was collected from a mining operation adjacent to the site. Sandstone and siltstone overburden were loaded and dumped into separate piles. Once a sufficient amount of spoil was collected, the spoils were mixed in the required ratios and placed in the center of each 10 X 20 ft plot. After all spoil mixtures were in place, each pile was graded flat with a small (D-4) bulldozer, taking extreme care to minimize compaction. Once grading was completed, the area was essentially flat, with a spoil depth of 4 ft over a highly compacted underlying bench.

The twenty plots of the Rock Mix Study and the control plots of the Surface Treatment Study

each received 1000 lbs/acre of 15-30-15 (N-P-K) granular fertilizer, consisting of ammonium nitrate, diammonium phosphate, and potassium chloride. The topsoil was limed with 3.5 t/acre of agricultural lime to bring the native pH (4.5) up to that of the 2:1 SS:SiS rock mix, and fertilized the same as the control and Rock Mix plots. Sawdust plots (25 t/acre) were also fertilized and received an additional 300 lbs N/acre as urea to compensate for anticipated N immobilization. No fertilizer was applied to the sludge treatments. During May, 1982, all plots were mulched with 80 lbs/acre straw, and hydroseeded with a water slurry containing 150 lbs/acre Kentucky-31 fescue and 750 lbs/acre wood fiber mulch.

In April, 1983, pine seedlings were planted in half of each plot on a 2.5 X 2.5 ft spacing. Seedlings in the Rock Mix Study were planted with an Agriform 21 g fertilizer pellet. Containerized loblolly pines and three families of pitch X loblolly pine hybrids were grown in Spencer-Lamaire root trainers (Hillson model, 150 cc/cavity) for 16 wk prior to outplanting. Half of the seedlings were infected with Pisolithus tinctorius by mixing basidiospores with the growth media (vermiculite and peat; 1:1 v/v) Each of the three families of hybrids and the loblolly pines were randomly assigned to one of four rows with four planting spots in each row. Each plot was split such that one side contained mycorrhizal trees and the other side non-mycorrhizal trees. The plot layout provided two planting spots for each species/mycorrhizae combination. All herbaceous vegetation was eliminated with several applications of glyphopsphate. After the second growing season, survival was assessed and heights and diameters were measured.

The Rock Mix and Surface Treatment Study were analyzed separately as split-plot designs. Duncan's Multiple Range Test was used to separate means for each treatment effect in each of the two studies.

RESULTS AND DISCUSSION

Overburden rock type had no effect on survival but greatly affected seedling growth after two years (Table 2). Growth was lowest on the pure SiS plots and improved as the SS component increased. Average volume index on pure SS plots was almost 300% greater than on SiS plots. According to Daniels and co-workers (1983), the pH and soluble salt levels of subsurface soil samples (10-12 in) collected in October, 1982, were much higher on the SiS plots (8.1 and 202 ppm, respectively, versus 6.0 and 64 ppm on SS). This may have caused the poor growth and chlorotic banding observed on needles of some trees in the pure SiS plots.

Table 2.--Treatment effects on tree survival, height, diameter, and volume on the Rock-Mix Study.

Treatments	Seedlings			
	Survival	Height	Diameter	Volume[2/]
	%	cm	mm	cm^3
Rock-Mix Effect				
Pure Sandstone (SS)	95 a[1/]	55.9 a	12.9 a	107 a
2:1 SS:SiS	89 a	52.0 ab	11.6 b	93 a
1:1 SS:SiS	88 a	48.3 bc	10.4 c	61 b
1:2 SS:SiS	88 a	46.9 cd	9.8 cd	54 b
Pure Siltstone (SiS)	94 a	43.6 d	8.7 d	39 b
Mycorrhizae Effect				
Control	88 a	49.8 a	10.7 a	74 a
Pisolithus tinctorius	93 a	49.0 a	10.7 a	68 a
Species Effect				
71x22 Hybrid	89 ab	49.5 a	10.8 a	72 b
78x22 Hybrid	92 ab	48.3 a	10.9 a	71 b
78x26 Hybrid	98 a	51.3 a	11.8 a	92 a
Loblolly pine	84 b	48.3 a	9.2 b	50 c

[1/] For each effect, values within a column followed by the same letter are not significantly different ($\alpha = 0.05$).

[2/] Volume = $(\text{Diameter})^2$ x Height.

Table 3.--Treatment effect on tree survival, height, diameter, and volume on the Surface Treatment Study.

Treatments	Seedlings			
	Survival	Height	Diameter	Volume[2/]
	%	cm	mm	cm^3
Amendment Effect				
Control	88 a[1/]	35.4 d	6.8 cd	21 cd
Topsoil (12 in)	92 a	36.0 cd	5.8 d	16 d
Sawdust (25 t/acre)	97 a	42.3 a	10.4 a	59 a
Sludge (10 t/acre)	95 a	38.4 bc	8.0 b	32 b
Sludge (25 t/acre)	89 a	41.1 ab	8.2 b	35 b
Sludge (50 t/acre)	70 b	39.9 ab	7.3 bc	30 bc
Sludge (100 t/acre)	56 c	39.5 ab	6.3 d	17 d
Mycorrhizae Effect				
Control	82 a	38.2 a	7.0 a	25 b
Pisolithus tinctorius	86 a	39.8 a	8.2 a	36 a
Species Effect				
71x22 Hybrid	96 a	37.4 b	7.7 a	32 a
78x22 Hybrid	88 a	38.7 ab	7.9 a	32 a
78x26 Hybrid	86 a	39.1 ab	7.8 a	29 a
Loblolly pine	66 b	41.2 a	7.0 a	29 a

[1/] For each effect, values within a column followed by the same letter are not significantly different ($\alpha = 0.05$).

[2/] Volume + $(\text{Diameter})^2$ x Height.

There was no significant volume difference between trees on the pure SS and the 2:1 SS:SiS mix. We believe that the 2:1 mix will eventually develop into the most desirable soil after additional years of weathering. Other research indicates that some of the most productive post-mining sites have formed on a 2:1 SS:SiS mixture (Howard, 1979).

In the Surface Treatment Study, a 2:1 SS:SiS mix served as the control. The topsoil treatment is similar to "normal" operational reclamation procedures; native surface soil is replaced and then limed and fertilized to support a ground cover. In this study, the topsoil treatment was one of the poorest with respect to pine seedling performance (Table 3). There was no difference in growth between trees planted in topsoil and those planted in the unamended overburden. The best growth occurred in the sawdust plots, where volume index averaged almost 300% higher than the control and topsoil treatments.

Municipal sewage sludge benefited seedlings at the lower application rates (10 & 25 t/acre), but had a detrimental effect at the highest rates (50 & 100 t/acre). Seedling volume at the two lowest rates was significantly greater than that on control and topsoil plots. There was no difference in survival between the low rate sludge treatments and the non-sludge treatments; but as sludge rate increased to 50 t/acre, a significant decline in survival (70%) and growth occurred. At 100 t/acre, survival declined to 56% and the average volume index was equivilent to the control and topsoil plots.

An application rate of 100 t/acre included 4225 lbs N/acre. We believe that mineralization of this large quantity of N resulted in high levels of nitrates which were toxic to the pine seedlings. If only 10% of the applied N was available during the first year, there would have been approximately 425 lbs N/acre in solution. A toxicity problem could have been aggravated by the elimination of all herbaceous vegetation which would have absorbed some of the nitrates as they were released from the sludge.

The effect of the fertilizer pellet on seedling growth was apparent when comparing the

average tree volumes of 2:1 SS:SiS plots of the Rock Mix Study (93 cm) with the control plots of the Surface Treatment Study (21 cm). These treatments were identical except that the trees in the Rock Mix Study were planted with a fertilizer pellet. The fertilizer pellet increased tree height by 50%, diameter by 70%, and volume index by 350%. Marx and Artman (1979) found that fertilizer pellets stimulated loblolly pine growth for several years on an acid coal spoil in Kentucky, but once nutrients from the pellet were depleted, growth increments decreased and N deficiency symptoms appeared in the foliage. Fertilizer pellets enhance early growth, allowing the seedlings to compete with the surrounding vegetation; however, additional nutrients will have to be added or otherwise supplied by the site.

Mycorrhizae have been found to aid survival and growth of pines on reclaimed surfaces in many instances; however, they did not have an effect on seedling growth in the Rock Mix Study. Roots growing rapidly due to high soil fertility are not susceptable to infection (Marx, 1977); furthermore, seedlings would not be expected to benefit nutritionally from mycorrhizae when a readily available source of nutrients are present. Mycorrhizal trees not planted with a fertilizer pellet had significantly greater volumes due to enhanced diameter growth; however, fertilized non-mycorrhizal seedlings in the Rock Mix Study had greater heights, diameters, and twice the volume of non-fertilized infected trees in the Surface Treatment Study.

There is some concern about the feasability of planting loblolly pine in the cold climate of Southwestern Virginia. In other studies, pitch X loblolly pine hybrids have shown potential to grow as rapidly as loblolly pine and retain the cold hardiness of pitch pine (Little and Trew, 1979). This study indicates that the hybrid may out-perform loblolly pine during establishment. The hybrids were more successful in surviving the winter and began growth earlier in the Spring. In the Rock Mix Study, all of the hybrid families had greater diameter growth and volume indices than loblolly pine. One particular family (76 X 26) had a greater volume than the other families and survived significantly better than the loblolly pines. Without the fertilizer pellet, the differences between loblolly pine and the hybrids were not as great. The hybrids tended to have greater diameters, but the loblolly pines were taller. Although loblolly pine survival in the Surface Treatment Study (66%) was significantly lower than the average of all the hybrids (90%), there were no significant volume differences.

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LEGUME INTERPLANTING REDUCES GROWTH OF YOUNG LOBLOLLY PINE ON ERODED PIEDMONT SITES[1/]

L. E. Nix[2/]

Abstract.--After six growing seasons, interplanting a hardy perennial legume (sericea lespedeza) has reduced the height and diameter growth of young loblolly pines on eroded, upland sites by 9.2% and 13.2%, respectively. Control pine seedlings averaged 9.8 ft (300 cm) height, while the best treatment seedlings (legume and fertilization) averaged 9.2 ft (282 cm) height. Fertilization with 50 lbs/acre (56 kg/ha) NPK partially offset the inhibiting effects of the strip-sown sericea, but foliage analysis of pine needles showed no difference in elemental nutrient content among treatments. Quantity and composition of competing aboveground biomass differed significantly among treatments with legumes comprising 50 to 80% of plot differences, indicating that legumes may have provided significant competition for soil moisture and nutrients. Soil moisture and compaction measurements showed no significant improvement of those features due to the legume plantings.

INTRODUCTION

The Piedmont Region of the southeastern United States includes substantial acreage of overworked, abandoned farmland that is characterized by shallow or no topsoil, low fertility, and poor soil physical properties. Many such acres, exhibit poor forest productivity and symptoms of littleleaf disease (*Phytophthora cinnamomi*) where old-field shortleaf pine (*Pinus echinata*) has become established. Subsequent replanting of these eroded old fields with loblolly pine (*P. taeda*) has not alleviated the symptoms caused by the poor soils (Goebel et al. 1974). Increasing demands for forest products and the diminishing land base for forest production argue for increasing productivity of these neglected forest lands.

In 1975, when this study began, evidence indicated that fertilization could alleviate nutrient deficiency on most of the marginal sites in the Piedmont (Bengston 1968); but poor physical properties, e.g. soil compaction, poor aeration, and poor moisture relations, would limit the effectiveness of such fertilization (Froehlich 1973). In addition, the rising cost and world-wide shortage of commercial fertilizer suggested that increased cost would make artificial fertilization economically questionable for widespread use on the marginal Piedmont sites, i.e. the cost of nitrogen fertilizer had risen 600 percent from 1971 to 1975 (Douglas 1975). As a result of these considerations, a less expensive, biological method of increasing soil fertility and ameliorating poor soil physical properties seemed desirable for improving forest productivity on the marginal Piedmont sites.

A review of the literature indicated that deep-rooted, nitrogen-fixing perennials might increase soil fertility while ameliorating the adverse physical properties of poor soils (Kittredge 1948, Chapman and Lane 1951, Lull 1959, Pimentel et al. 1973). In addition, observations of the beneficial effects of planting nitrogen-fixing legumes, such as lupines, along with forest tree species on poor sites in Europe indicated that considerable gain in forest productivity could be achieved over several decades (Baule and Fricker 1970). Earlier literature reviews suggested that agriculturally important N-fixing legumes offered much in the way of soil improvement and that the *Lespedeza* species might be suitable for the eroded, low pH, somewhat droughty heavy clays of the Piedmont (Whyte et al. 1953, Lull 1959). Shortleaf pine in North Carolina appeared to greatly benefit from association with sericea lespedeza (*Lespedeza cuneata*), which continued to grow well under the trees for a number of years (Kittredge 1948). Vogel (1973)

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[2/] Associate Professor, Department of Forestry, Clemson University, Clemson, South Carolina.

reported that sericea lespedeza stimulated the growth of loblolly pine on coal mine spoils in Kentucky. Casual observation by the author of various erosion control plantings of sericea and pine in the Piedmont of South Carolina indicated that loblolly pine benefitted from the ameliorative effects of the legume.

The current study was initiated in order to quantify the potential benefits of interplanting a hardy, deep-rooted nitrogen-fixing legume, such as sericea, with loblolly pine, a desirable commercial timber species well-suited for reforesting eroded Piedmont sites.

METHODS

The study area consists of two eroded, heavy clay upland forest sites on the Clemson University Experimental Forest in the upper Piedmont of South Carolina. Both sites were formerly abandoned agricultural land which had 60 to 70-year-old, mixed-upland hardwoods and shortleaf pine growing on them. Much of the shortleaf pine exhibited symptoms of littleleaf disease, indicating the poorness of the soil, an eroded clay-loam of the Cecil-Madison association. The study sites were clearcut, sheared and disked, and hand-planted along the contour with 1,0 bare-root loblolly pine seedlings at 7 x 8 feet spacing in late Spring of 1975. A randomized complete block experimental design was imposed on the study areas with 4 blocks, three on one site and one on the other to account for possible minor site quality changes. Four experimental treatments were randomly installed in each block. Treatments were installed on one-eighth acre rectangular plots with one-half chain buffer strips. Treatment conditions consisted of (1) a control with no treatment, (2) broadcast fertilization with 50 lbs per acre (56 kg/ha) of NPK in commercial form, (3) strip-sowing innoculated sericea lespedeza seed at 25 lbs per acre (28 kg/ha) between rows of planted pines, and (4) fertilization and strip-sowing sericea at the preceding rates.

Survival and height of all seedlings and basal diameter of every fifth seedling were measured at 1, 3, 5, and 6 yrs. After 5 growing seasons, pine seedling aboveground biomass was determined from 5 seedlings harvested at random from each treatment plot (20 seedlings per treatment). Seedling biomass was separated into total, stem, limb, and needle components and dried at 105°C for 72 hrs in a forced air oven before weighing. Pine foliage was subsampled for macro-nutrient analysis according to suggestions of Wells (1969). Sericea, other herbaceous, and non-pine woody aboveground biomass was determined at age 5 years by clipping and weighing 20 randomly-selected, one-half meter square plots (0.25 m^2) from each one-eighth acre treatment plot. During the summer of the third growing season soil moisture measurements were taken weekly from Bouyoucos blocks buried at 6 and 18 inches depth at four locations in each treatment plot; soil compaction was measured monthly at five randomly selected locations in each plot with a proving ring penetrometer; and soil organic matter was determined by the Walkley-Black method from 5 composite soil samples taken at 4-6 inches depth in each plot. The significance of treatment mean differences was tested at the .05 level with analysis of variance procedure and treatment means were individually compared with Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

Pine height and diameter at age six were reduced by 9.3 percent and 13.2 percent, respectively, after interplanting on an eroded Piedmont site with strip-sown sericea lespedeza (Table 1). Addition of NPK fertilizer at the time of strip-sowing the legume improved growth of legumes and the pines, but pine heights were still significantly less than those on the control plots. Survival, which was below normal on all plots, was unaffected by site treatments. The reduced survival was probably due to an extended dry period that occurred following the tree planting in early May.

Table 1. Mean Height, Diameter and Survival of Loblolly Pine Seedlings Six Years After Interplanting with Sericea Lespedeza on an Eroded Piedmont Site.

Treatment	Height[1/] (cm)	Basal Diameter (mm)	Survival (%)
Control	300a	68a	53a
Fertilizer	278bc	63bc	59a
Sericea	272c	59c	59a
Sericea + Fertilizer	282b	65ab	57a

[1/] Means within columns followed by same letter are not significantly different at the .05 level. Mean heights are based on an average of 221 seedlings per treatment, mean diameters on an average of 42 seedlings.

Aboveground biomass of sericea, other herbaceous, and non-pine woody plants was greatest after five growing seasons on the plots which were fertilized and strip-sown with sericea (Table 2). Total non-pine aboveground biomass was 52 percent greater on fertilized and sericea-sown plots than that on the control plots. Sericea comprised 63 percent of the treatment biomass differences. The strip-sown sericea was, thus, additive to total aboveground biomass rather than substituting for other herbaceous biomass which was, in fact, increased 21 percent by the fertilizer and sericea treatment. Except for the addition of the sericea

on the strip-sown plots, the other treatments did not differ in total non-pine biomass.

Table 2. Mean Oven Dry Weight of Sericea, Other Herbaceous, and Non-pine Woody Plants Five Years After Interplanting Loblolly Pine Seedlings and Sericea Lespedeza on an Eroded Piedmont Site.

Treatment	All[1/]	Sericea	Woody Stems	Other Herbaceous
	- - - - O.D. gms/0.25 m^2 - - - -			
Control	53.7a	0.0a	8.0a	45.6a
Fertilizer	53.5a	0.3a	6.5a	46.7a
Sericea	57.1a	4.9b	7.9a	44.2a
Sericea + Fertilizer	81.6b	17.7c	8.8a	55.1b

[1/]Column means adjacent to same letter are not significantly different at the .05 level. Means are based on clippings from 80-0.25 m^2 plots per treatment.

Mean dry weight of planted pine seedlings was inexplicably greater after 5 growing seasons on plots which had been fertilized and sericea-sown than that on plots treated in any other manner (Table 3), in spite of the fact that six year height growth was greatest on the control plots (Table 1). The nearly 15 percent increase in pine mean dry weight on the fertilized and sericea-sown plots was comprised almost equally of the increased dry weight of needles and stem tissues.

Table 3. Mean Oven Dry Weight of Needles, Limbs, Stems, and Total Seedlings of Loblolly Pines Five Years After Interplanting with Sericea Lespedeza on an Eroded Piedmont Site.

Treatment	Total Seedling[1/]	Needles	Limbs	Stem
	- - - - - - gms O.D. wt - - - - - -			
Control	1171.3a	440.1ab	247.7a	483.4a
Fertilizer	1099.1a	411.8a	238.0a	449.3a
Sericea	1054.5a	402.1a	215.5a	436.9a
Sericea + Fertilizer	1345.2b	511.6b	265.1a	568.5b

[1/]Column means adjacent to same letter are not significantly different at the .05 level. Means are based on 20 seedlings per treatment.

As these results were difficult to reconcile with the six year pine height and diameter comparisons and because the biomass determinations represented a small subsample of the treatment plot populations (20 seedlings versus 221 seedlings per treatment), the mean heights and diameters of the seedlings sampled for dry weight determinations were statistically compared. Results of these comparisons showed that, although the biomass sample seedling heights did not differ among treatments, seedling basal diameter was significantly greater on fertilized and sericea-sown plots than on fertilizer treated or sericea-sown plots. However, tree diameter was not greater than that on the control plots. Closer examination of the data in Table 1 indicates a very similar result in comparing 6-year pine basal diameters among treatments, but seedling height is obviously greatest on control plots.

Five-year pine stem mean dry weight was definitely greater on plots that were fertilized and sericea-sown than on plots with the other treatments. These results indicate that in some manner the sericea is causing conditions under which the pine seedlings develop more foliage and heavier stems after five years, yet are shorter than control seedlings after 6 years. The reduced height is symptomatic of early height growth inhibition through soil moisture competition, which remains evident even after six years. The increased seedling foliage and stem dry weight on fertilized and sericea-sown plots may be due to an improving nutritional status of the pine seedlings. However, measurements of soil moisture, organic matter and soil compaction after 3 years failed to detect any treatment effects on these soil parameters. Foliar nutrient analysis indicated no difference in foliage nitrogen content among treatments after five growing seasons. Pine foliage from all treatments averaged 1.1-1.2 percent nitrogen content, dry weight basis.

Results similar to those of the present study have been reported earlier. Vogel (1973) reported that sericea lespedeza inhibited the growth of young loblolly pine for the first three years after planting on mine spoils in Kentucky; but, thereafter, the pines planted with the sericea have grown significantly taller than those planted with grasses alone. Jorgenson and Craig (1983) reported that after seven years loblolly pine trees fertilized with ground rock phosphate and sown with sericea lespedeza were significantly greater in mean cubic volume than those fertilized only or not treated. In that study, tree diameter increase due to the treatment was more important than height increase in contributing to mean tree volume differences. Results of the present study confirm this finding as the increase in total tree dry weight caused by fertilizer and sericea was due to an increase in stem and foliage dry weight but not to an increase in stem height, which was in fact inhibited by the treatment.

Jorgenson (1978) reported that the addition of low rates of fertilizer, particularly phosphorus, was essential for establishment of most legumes. Results of the present study confirm the need for an initial "starter" fertilization to firmly

establish lespedeza on eroded marginal sites as sericea biomass was increased 360 percent by NPK fertilization. Soil nutrient analysis indicated the sites were low in phosphorus.

Jorgenson (1981) mentions that sericea can compete vigorously with planted trees if not managed properly. In the present study, although the sericea was carefully strip-sown between rows of pine seedlings, it was seeded at the same time the pines were planted and in a few years had seeded itself densely around the pines, thus, becoming a strong competitor in addition to the native herbaceous vegetation. Although Jorgenson (1981) reported that at no time in a similar five-year study did dense stands of sericea have a negative influence on tree growth, the present study clearly shows an inhibitory effect, at least on height growth, that persisted even after six years on the eroded Piedmont soils. It is hoped, however, that the enhanced tree stem and foliage biomass, apparently resulting from the fertilizer and sericea treatment, will manifest itself in a growth acceleration over the next several years as crown closure occurs and herbaceous vegetation is shaded out. The plantings will be followed for another 5-10 years to ascertain the long term benefits of sowing the legume and to assess the economic implications of the biological site amelioration.

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FERTILIZATION, IRRIGATION, AND SITE FACTORS CONTINUE TO AFFECT TREE GROWTH AFTER 18 GROWING SEASONS[1/]

by J.P. Groton Jr. and E.R. Buckner[2/]

Abstract.--At the end of 18 growing seasons, significant growth differences were still apparent from fertilizer applied at planting time and/or irrigation treatments applied the first seven years following planting. Two south facing slope positions were planted with loblolly pine (Pinus taeda L.), sweetgum (Liquidambar styraciflua L.), and yellow-poplar (Liriodendron tulipifera L.). The upper slope position was originally a relatively undisturbed oak-hickory forest; the lower slope site was an eroded old field with a 20-year-old stand of shortleaf and Virginia pine. Soils in the area are Typic Paleudults.

Loblolly pine was the least responsive species to treatments. However, it outgrew all species under all conditions tested except for yellow-poplar on the fertilized and irrigated upper slope position. Irrigation appeared to retard its growth on the lower slope position.

Sweetgum appeared to be somewhat more responsive to treatments. While there were no apparent treatment influences on the upper slope position; this was not the case on the lower slope. There the tallest trees were in fertilized plots while irrigation appeared to have a negative influence on growth.

Yellow-poplar appeared to be highly sensitive to treatments on both slope positions. On the lower slope tree height was significantly greater in fertilized plots, both with and without irrigation, while tree height appeared to be reduced in lower slope plots receiving only irrigation. The tallest trees in the study were in fertilized and irrigated plots on the upper slope position. Their relative advantage was much less after 18 years than was the case after seven years.

Analysis of growth rates since 1971 shows that the growth advantage (for all species) has shifted from the undisturbed forest soil on the upper slope to the old field soil on the lower slope. This indicates the lower slope soils are recovering from the old field condition. If present trends continue within ten years all growth differences between treatments will disappear and trees on lower slope plots will outgrow trees on the upper slope site. This is already true for loblolly pine and sweetgum. Any treatment effects evident today are apparently the result of a carry over effect from the early treatments and are not due to a continued treatment response.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Graduate Assistant and Professor of Forestry respectively, The University of Tennessee, Dept. of Forestry, Wildlife & Fisheries; Knoxville, TN 37901

INTRODUCTION

Alternate uses combined with the high value of forest land encourage the forest manager to reduce rotation length and increase wood volume production. Shortages of soil moisture and nutrients frequently limit plant growth. Irrigation and fertilization have been used successfully and increase crop yields. The use of these practices in forestry have been primarily confined to specialty crops such as seedling nurseries and seed orchards (Pritchett, 1979).

Buckner and Maki (1977) demonstrated significant increases in tree growth when irrigation and/or fertilization treatments were applied at the time of stand establishment and during the early growth period in a forest plantation in east Tennessee. Long-term effects and economic feasibility of such practices in forest plantations are largely unknown. The present study was initiated to re-evaluate tree growth 18 years after planting and to identify changes in growth patterns that have occurred in the 11 years since the last measurement.

SITE DESCRIPTION

Buckner and Maki (1977) established an experiment to evaluate the extent to which deficiencies of soil moisture and nutrients limit the early growth of four widely distributed forest species: loblolly pine (Pinus taeda L.), sweetgum (Liquidambar styraciflua L.), yellow-poplar (Liriodendron tulipifera L.), and northern red oak (Quercus rubra L.). The study was conducted on the south-facing slope of an east-west oriented ridge in the Ridge and Valley Province of east Tennessee. Two slope positions were cleared for planting, an upper slope site near the ridge crest and a lower slope site on the toeslope and valley floor. Prior to clearing, the upper-slope position supported a mature mixed oak-hickory stand that indicated a relatively undisturbed forest condition over the past century.

In contrast the lower slope site was an old field that supported a 20-year old mixed shortleaf and Virginia pine stand. While this was the potentially better of the two sites, past agricultural practices had caused significant site degradation. Sheet erosion had been the primary agent responsible for the removal of most of the original A soil horizon. These differences in the two sites attributable to previous land-use, were confounded with differences due to slope position.

The predominant soil on the upper slope was Claiborne silt loam (Typic Paleudult, fine-loamy, siliceous, mesic), a well-drained forest soil formed in the residuum of dolomite. It has a thick A horizon, rich in organic matter, and has a silt loam texture allowing for rapid infiltration. The thick B horizon is also highly permeable.

Lower slope soils were Fullerton and Minvale cherty silt loam (Typic Paleudult, clayey, kaolinitic, thermic and fine-loamy, siliceous, thermic, respectively). These soils are characterized by a thin A horizon overlying a moderately thick E horizon. The Fullerton soil has a thick clayey B horizon which is correspondingly less permeable than the Claiborne soil. While the Fullerton soil has a higher CEC than the Claiborne soil, the physical properties are not as good. This is aggravated when most of the A horizon has been eroded. The Minvale soil had a lower clay content then the Fullerton. The chert content of both soils was so high that it interfered greatly with soil moisture storage and rooting volume.

PROCEDURE

All four species were represented in each treatment plot as 25-tree "species" subplots with five rows of five trees each; spacing was 7 ft. x 7 ft. A randomized complete block design was used with four replications on both slope positions. Treatments were: 1) fertilization, 2) irrigation, 3) fertilization and irrigation in combination, and 4) controls. The fertilizer treatment, applied only at planting, consisted of N at 33 pounds per acre, 45 pounds per acre of P, and 4 pounds per acre of Mg placed in the closing hole. Irrigation treatments were applied for the first seven years during the summer months as needed to maintain soil moisture tension below two atmospheres (Buckner and Maki, 1977).

Figures 1A and B show the height of the four species after seven growing seasons. The tallest trees in the study at seven years were yellow-poplar growing where irrigation and fertilizer treatments were applied to the undisturbed forest soil (upper slope position). Yellow-poplar generally performed better on the upper slope site than on the eroded lower slope old field soil.

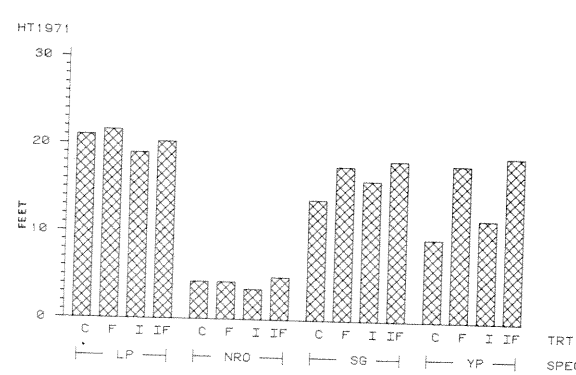


Figure 1A.--Total height after seven growing seasons for all species-lower slope site.

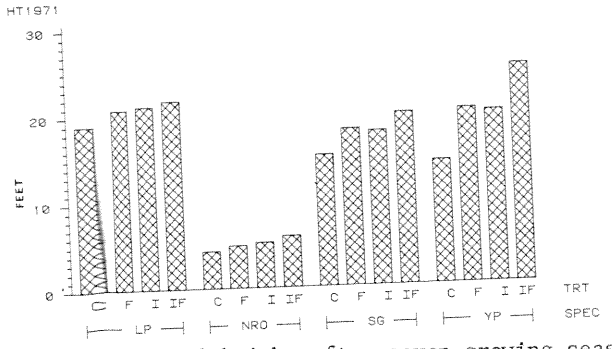


Figure 1B.--Total height after seven growing seasons for all species-upper slope site.
(Note - for all figures - TRT=treatments, C=control, F=fertilized, I=irrigated, IF=irrigated and fertilized, SPEC=species, LP=loblolly pine, NRO=northern red oak, SG=sweetgum, YP=yellow-poplar)

Sweetgum had a response pattern similar to that of yellow-poplar but appeared less sensitive to the site/treatment variables tested. Sweetgum grew better than yellow-poplar on the poor sites but could not compete with yellow-poplar on the better sites. Loblolly pine showed little response to any of the site/treatment combinations tested. It outgrew all other species over the range of site/treatment variables tested except on the upper slope, irrigated and fertilized plots where the yellow-poplar was taller. Northern red oak performed poorly under all conditions tested and was not included in further analyses.

Since treatments were apparently stimulating significant growth responses after seven years, this study was initiated to determine if growth responses were still evident after 18 years and to evaluate changes in relative growth rates. Trees at the study site were remeasured in the winter of 1982-1983. Growth was evaluated using total height of dominant and co-dominant trees. Only dominant and co-dominant trees were used to eliminate effects of inter-tree competition.

RESULTS AND DISCUSSION

Growth in this discussion will be confined to total tree height because this is a frequent measure of site porductivity (Husch et al, 1982). This also facilitates the comparison of growth data at seven years with 18-year data since height growth was used as an indicator of site quality after seven growing seasons (Buckner and Maki, 1977). Figures 2-4 present the comparitive height growth for the three test species during the two growth periods being compared (1965-1971 and 1971-1982) and their total height at the end of 18 growing seasons (1982). In comparing the two growth periods, it should be recognized that many more trees were the basis for height averages after seven years than was the case for 18-year averages. Essentially all of the planted seedlings that lived were still free to grow after the seventh growing season, while competition had suppressed or killed many stems by the 18th season. Had only these stems free-to-grow after the seventh season been used in the 18-year measurement, growth differences between the two periods would have been less.

Yellow-poplar:--Figure 2A presents average height growth per year for yellow-poplar for the period 1965 to 1971. During these seven growing seasons, better growth occurred on the undisturbed forest soil, the upper slope site, than on the old field soil. Growth was greater in fertilized plots on both slope positions but growth on irrigated plots was significantly better only on the upper slope. The greatest height growth for all species/site/treatment variables tested was yellow-poplar in irrigated and fertilized plots on the upper slope.

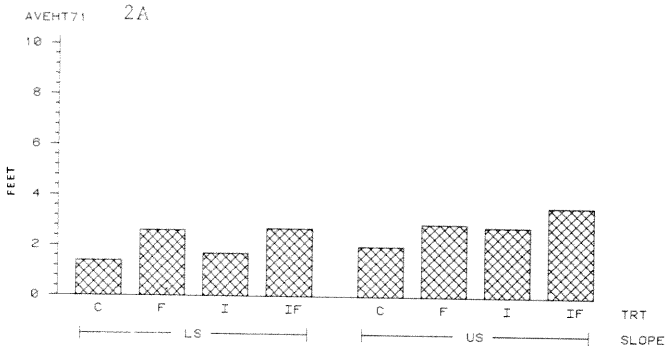
The poor performance of this species was attributed to soil conditions related to past land use. Russell (1977) reported old fields were often poor sites for yellow-poplar usually due to erosion, soil compaction, or depletion of soil nutrients. These are possible reasons why growth of this species did not perform well on a land form where yellow-poplar has typically performed well in this region (Smalley 1964). Better growth in fertilized plots likely reflects the inherently low fertility of soils in the study area (Typic Paleudults). Significantly greater growth in irrigated plots on the upper slope compared to no apparent response on the lower slope indicates the influence of slope position on available water for tree growth. The effects of irrigation and fertilization were apparently additive when supplied together on the upper slope suggesting their independent influence on growth on this site.

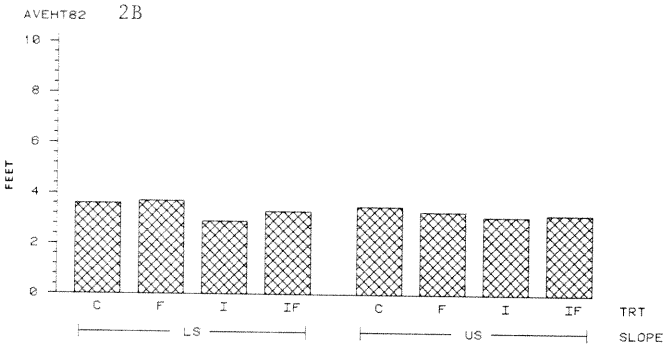
Significant changes in relative growth rates among treatments were apparent during the second growth period (1971-1982) (Figure 2B). No additional fertilizer applications were made (fertilized only at planting time) and irrigation was discontinued at the end of the 6th growing season. The growth advantage attributed to the undisturbed forest soil on the upper slope that was apparent for the first growth period was no longer present. The recovery of the lower slope may be due to the restorative influence of trees and associated soil micro-organisms on the old field soil (Clark, 1964; Carmean et al, 1976).

Treatment effects were no longer apparent during the second growth period. The only significant change in growth during this growth period was slow growth in the lower slope plots that were irrigated during the first growth period. Growth was somewhat better where fertilizer was added. Although less evident this same pattern occurred on the upper slope. If real it may reflect a leaching effect that carried over from the earlier irrigation treatment.

Differences in total height after the 1982 growing season are due largely to carry-over site

and treatment differences that existed at the end of the first growth period. If growing conditions on the lower slope continue to improve over the next decade as they have over the last growth period, these trees will be considerably taller than those on the upper slope at that time.





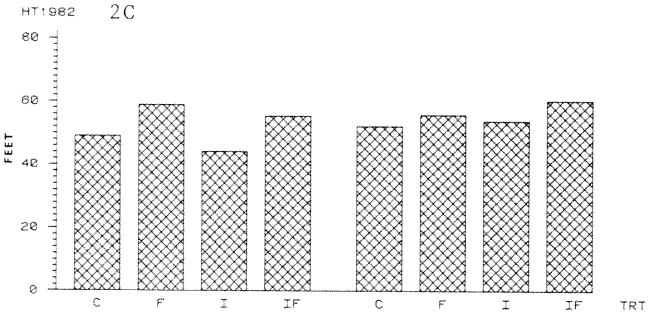
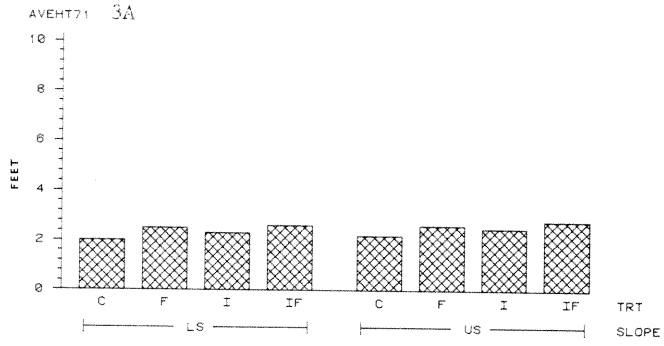


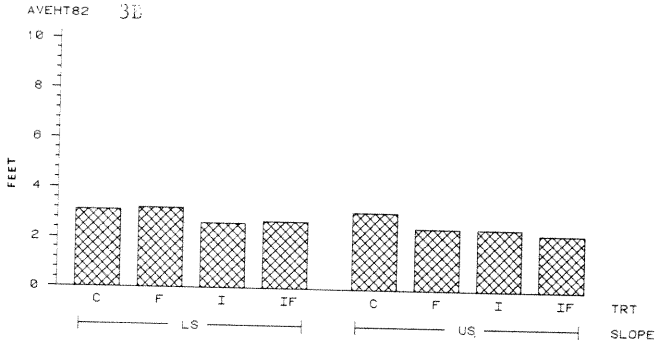
Figure 2A.--Mean annual height growth for yellow-poplar (1965-1971).
Note LS = lower slope, US = upper slope.

Figure 2B.--Mean annual height growth for yellow-poplar (1971-1982).

Figure 2C.--Total height of yellow-poplar after 18 growing seasons.

Sweetgum.--After seven growing seasons, sweetgum showed a response to treatments on both sites that was similar to that of yellow-poplar, although differences were not as great. Growth was generally better on the upper slope, forest soil. Fertilization and irrigation appeared to have positive influences on both slope positions with the best growth on the upper slope where both treatments were applied. Additive effects where both treatments were applied were less apparent than for yellow-poplar. The subdued response of sweetgum to the site variables tested indicates that it is less sensitive to site conditions than yellow-poplar.





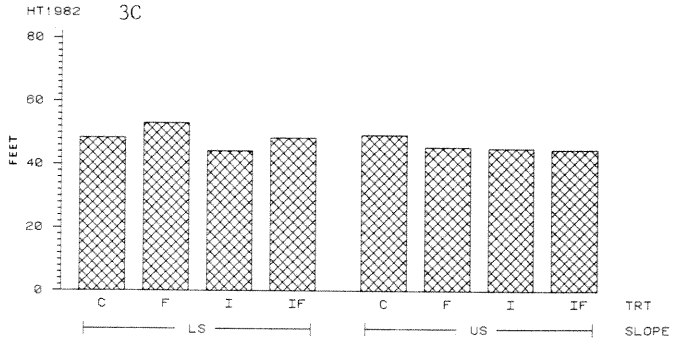


Figure 3A.--Mean annual height growth for sweetgum (1965-1971).

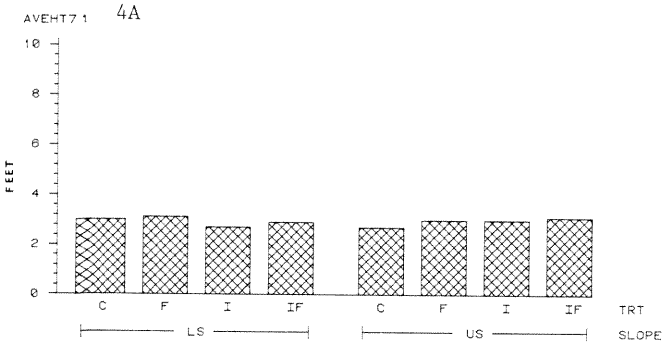
Figure 3B.--Mean annual height growth for sweetgum (1971-1982).

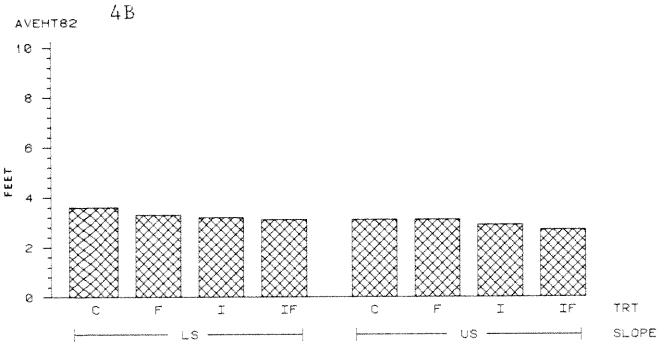
Figure 3C.--Total height of sweetgum after 18 growing seasons.

In the second growth period, several reversals in performance were observed. Growth was considerably better on the lower slope position. There were no significant differences between treatment effects with the best growth generally occurring in the controls.

Total height after 18 seasons shows little effect of the site variables tested with the possible exception of fertilization on the lower slope position. As was true for yellow-poplar, irrigation appeared to have a negative influence on growth on the lower slope.

Loblolly Pine:--After seven growing seasons, loblolly pine showed little response to the site variables tested. However, it outgrew all other species under all conditions tested except yellow-poplar on the fertilized and irrigated upper slope position. Once again, irrigation on the lower slope position appeared to retard growth. If the other growth differences observed during this period were related to the site variables tested, the differences were so small that they would be of little practical significance.





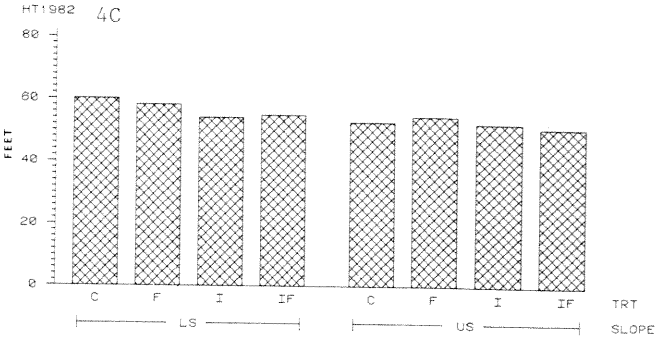


Figure 4A.--Mean annual height growth for loblolly pine (1965-1971).

Figure 4B.--Mean annual height growth for loblolly pine (1971-1982).

Figure 4C.--Total height of loblolly pine after 18 growing seasons.

During the next growth period, the best growth was in control plots on both slope positions and overall growth was better on the lower slope. This further supports the recovery of the lower slope from old field conditions that suppress growth. As was true for sweetgum, total height after 18 seasons was now greater on the lower slope. If present growth trends continue, this will also be true for yellow-poplar within the next few years.

SUMMARY AND CONCLUSIONS

1) At the end of 18 growing seasons, growth differences due to early treatments have dissipated over time.

Yellow-poplar still exhibits greatest sensitivity to site/treatment variables tested, sweetgum only moderate sensitivity while loblolly pine performed well under all conditions, exhibiting little sensitivity to site differences and treatments.

2) While total height is still greatest on the undisturbed upper slope, forest soil growth since 1971 is now occurring on the lower slope site. This indicates this old field site is recovering under the influence of the forested condition (Clark, 1964; Carmean et al, 1976).

3) Height for trees on the lower slope should be greater than that on the upper slope position within the next few years as trees and associated organisms more fully occupy and recondition the lower slope site.

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PROGRESS IN TISSUE ANALYSIS TO DETERMINE THE RESPONSE OF LOBLOLLY PINE TO NITROGEN FERTILIZATION[1]

Cosimo Cotrufo[2]

Abstract.--Several tissue methods for N assay of loblolly pine (Pinus taeda L.) were evaluated under the assumptions that tests indicating increased tissue N from fertilization reflect the N nutrition of the trees. Nitrogen concentration in recently fallen needles sampled in November, total N in xylem, and total soluble N and arginine N of twigs and needles were greater in fertilized than unfertilized trees; however, drainage and P nutrition seriously complicate the interpretation of arginine N as an assay for N nutrition.

INTRODUCTION

Traditionally, total needle nitrogen (N) and soil N are used for the N assay of a loblolly pine stand. Total needle N, however, is not always a good indicator of the N status of loblolly pine (Pinus taeda L.) (Ballard 1980, Wells et al. 1976). Obviously, then, to develop a diagnostic test for N in a loblolly pine stand, other tree tissues and N compounds need to be examined (Cotrufo 1983, Cotrufo and Wells 1984). This report summarizes several alternative methods for assaying N status: total N in needlefall, needles, twigs, and xylem; and soluble and arginine N in the needles and twigs. Soil N was not considered in this work.

TOTAL N IN LITTERFALL

Nitrogen in fallen needles has been suggested as a means of evaluating the N status of trees (Miller and Miller 1976). In November 1976, over a 3-day period, we sampled freshly fallen needles on duplicate plots located on two well-drained Piedmont sites--a Whitestore soil located at Research Triangle Park, N.C. (RTP), fertilized at 138 and 275 pounds N/acre 3 years earlier; and a complex of Cecil, Appling, and Durham soils located near Saxapahaw, N.C., at the International Biological Program (IBP) site fertilized with 200 pounds N/acre 5 years earlier (Cotrufo and Wells 1984) (Table 1).

Nitrogen fertilization increased the concentration of total N in needlefall at the IBP location. At the RTP location, needles from fertilized and unfertilized litterfall showed no significant differences in their lower values for N concentrations compared with controls. Litterfall N tended to be lower at the 138 pound/acre rate and higher at the 275 pound/acre rate than the control. The lower N concentration for the 138 pound/acre rate possibly can be attributed to soil and stand variability compared with the control and the 275 pound rate. On the IBP plots, studies in nutrient cycling showed a significant effect of N fertilization on November needlefall N concentration for 3 years after treatment (Table 2), and no significant difference thereafter. The nutrient cycling data were for needlefall collected monthly, thus allowing for some leaching to take place. The significant difference due to treatment in the freshly collected needles was probably due to minimal leaching after litterfall, although differences in N related to treatment are still small compared with those found during the first 3 years.

Results from the two locations indicate the change in N status of the trees following fertilization was reflected in litterfall. The change could still be measured when recently fallen needles were collected in November, more than 5 years after fertilization, but not in needles exposed to leaching.

TOTAL, SOLUBLE, AND ARGININE N

If the effect of fertilization lasts 3 or possibly 5 years in needlefall, then how long would it last in other tissue? On these same IBP plots, 5 years after fertilization, the total N in 2- to 3-year-old xylem, and current needles and twigs was significantly greater where fertilizer was applied (Table 3). After 9 years, the increase in total N was significantly greater only in the xylem, with no difference in N content of twigs and current needles.

Total soluble and arginine N were measured in needle and twig samples collected 9 years after fertilization (Table 4). Arginine N appeared to

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[1]Paper presented at Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2]Plant physiologist, U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Research Triangle Park, N.C.

Table 1.--Concentration of total N in fresh needlefall in November for fertilized and unfertilized trees at two locations

Location	Fertilizer N (lb/acre)			
	0	138	200	275
	N%			
RTP	0.52	0.44	--	0.59
IBP	.52	--	0.58*	--

*Significantly different by location at the 5 percent level.
RTP = Research Triangle Park, IBP = International Biological Program, N.C.

Table 2.--Effects of time on the total N in November needlefall for 6 years after fertilization beginning in April 1971, at the International Biological Program site, N.C.

November	Unfertilized	Fertilized	Difference
	N%		% change
1971	0.470	0.645**	37
1972	.480	.670*	36
1973	.475	.605*	28
1974	.350	.390	11
1975	.505	.560	11
1976	.525	.520	-1

**Significant at 1 percent level.
* Significant at 5 percent level.

Table 3.--Total nitrogen in wood, needles, and twigs 5 and 9 years after fertilization, at the International Biological Program site, N.C.

Tissue	5 years		9 years	
	Fertilizer N (lb/acre)			
	0	200	0	200
	N%			
Wood, 2-3 years old	0.078	0.102**	0.076	0.103*
Needles, current	1.27	1.39**	1.32	1.45
Twigs, current	.54	.69**	.58	.59

**Significant at 1 percent level.
* Significant at 5 percent level.

Table 4.--The concentrations of total soluble and arginine N in loblolly pine needles and twigs 9 years after fertilization, at the International Biological Program site, N.C.

N-fraction and tissue	Fertilizer N (lb/acre) 0	N-200	Δ%
	N%		
Soluble N			
Needles	0.138	0.136	-1
Twigs	.069	.066	-3
Arginine N			
Needles	.0060	.0068	13
Twigs	.0050	.0070	40

be greater in the fertilized treatment; however, due to high sample and analytical variability, the increases were not statistically significant.

In the evaluation of total soluble and arginine N 9 years after fertilization, only total N in the 2- to 3-year-old wood from the fertilized plots was signiticantly greater than from the corresponding tissue of the nonfertilized treatments.

In a study on the Santee Experimental Forest, South Carolina, a comparison was made between nonfertilized and loblolly pine fertilized with N, P, and K and grown on well-drained and very poorly drained sites (Files, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Charleston, S.C.). Needle samples were collected in March from the first flush of the previous growing season and from those of the current growing season in August and November. Results from means of the three sample dates are summarized in Table 5. Total needle N was greater on pine grown on the wet site, although tree growth was less. Total and soluble N were not greatly influenced by fertilization with N, P, and K although fertilization tended to increase soluble N on the well-drained site and decrease it on the poorly drained site. Fertilization had no effect on the arginine N concentration in needles from the well-drained sites. Fertilization of the wet site reduced the concentration of arginine N by a factor of 6.6, probably as a result of improved P nutrition.

The addition of fertilizer did increase needle P for both sites; however, with P fertilization the wet site needles had a P concentration only slightly greater than did those on the nonfertilized dry site. Needles on both sites had P concentrations below 0.1 percent, which is considered essential for proper growth of loblolly pine.

The data show that total N is not a good indicator of the N status of trees. While no data are offered here, the trees on the wet site were rather

Table 5.--The effects of fertilizer on N fraction and on P in loblolly needles taken from well-drained and very poorly drained sites, Santee Experimental Forest, S.C.

Site condition	Total N		Soluble N		Arginine N		Total P	
	Fertilizer	No fertilizer	Fertilizer	No fertilizer	Fertilizer	No fertilizer	Fertilizer	No fertilizer
	N%							
Well drained	1.115	1.082	0.164	0.144	0.0053	0.0056	0.096	0.086
Very poorly drained	1.283	1.306	.146	.191	.0104	.0684	.088	.065

scrawny looking, whereas those on the drained site were fuller. The high arginine N appears to be more of an indicator of P deficiency rather than that of N status.

XYLEM N TEST ON SIX FERTILIZATION SITES

Xylem N as an assay for N status was evaluated in an investigation of six fertilization tests by the North Carolina State Forest Fertilization Cooperative (Files, NCSFFC, School of Forest Resources, N.C. State University, Raleigh, N.C.). Increment cores were collected in February, 2 years after fertilization. The core rings were separated by years, and the N concentration of 2- and 3-year-old wood of the control plots was related to volume response due to N fertilization. There were three or four replicates per site in these 11- to 21-year-old stands.

Percentage N in the 2- and 3-year-old xylem of five of the six tests was 0.060 to 0.067 (Table 6). Response to N fertilization increased volume growth from 13 to 206 percent, but there was no relationship of growth to xylem N percentage. The site with 0.083 percent N in the xylem failed to respond to N fertilization.

A 6-year-old study with legumes and fertilization treatments was sampled (Files, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Research Triangle Park, N.C.). One-year-old xylem contained 0.086, 0.102, and 0.109 percent N, respectively, for the untreated, fertilized (150 pounds of N per acre), and sericea lespedeza treatments. Significant volume responses were obtained for fertilization and sericea treatments.

SUMMARY

(1) The results showed that in freshly collected needlefall, an increase in N concentration persisted for 5 years after N fertilization. This suggests native N nutrition is reflected in litterfall.

(2) Total N in the xylem was increased by fertilization; however, limited investigations failed to show strong relationships between xylem N and a response to N fertilization.

(3) Total soluble N in needles and twigs did not show a response to N fertilizer applied 9 years earlier in the Piedmont or 2 years earlier in the Coastal Plain. The arginine fraction of soluble N appeared sensitive to fertilization; however, sample and analytical variability were high.

(4) In a comparison between a very poorly drained and a well-drained coastal plain site, each with and without fertilization, arginine was increased in needle samples low in P. The effects of drainage and P nutrition complicate the interpretation of arginine as an assay for N nutrition.

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Table 6.--Volume growth response to fertilization and total N concentrations in 2- and 3-year-old xylem

Study	Xylem N	Growth response
	---N%----	----% change---
Chesapeake R-9	0.083	-30
Continental R-9	.060	69
Chesapeake R-3	.067	16
Union Camp R-9	.061	206
Weyerhaeuser R-9	.063	19
Westvaco R-9	.064	13

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PHOSPHORUS REQUIREMENTS FOR ESTABLISHMENT OF DUAL-CROPPED LOBLOLLY PINE[1/]

Allan E. Tiarks[2/]

Abstract.--An ongoing field experiment was established in 1982 to find the potential of dual-cropping pine for sawtimber and biomass production. Also, the effect of phosphorus fertilizer on early growth of the two crops was analyzed. Genetically superior loblolly pine seedlings were planted at a spacing of 2 by 3 m. In the same year, genetically unimproved loblolly pine was direct-seeded in a 1.5-m-wide swath between the planted rows on two-thirds of each plot. The seeded subplots will be harvested at two different times to determine the biomass production and the effect on the planted trees. Phosphorus was applied at rates of 0, 81, 162, and 324 kg/ha. The two laboratory methods used to predict the phosphorus requirement were the phosphorus sorption curves and the desorption of added phosphorus with an available phosphorus extracting solution.

Both planted and direct-seeded pines responded to phosphorus in the first year, but in the second year phosphorus increased the height of only the planted pines. The phosphorus sorption curve method accurately predicted the amount of phosphorus fertilizer required for the planted trees. The desorption method seriously underestimated the phosphorus requirement.

INTRODUCTION

As costs of establishing pine plantations increase, it becomes more important to derive some income from the stands as soon as possible. Systems that have successfully produced returns in the early phase of a rotation include range utilization in southern pine and intercropping with annual crops in northern hardwoods. Range utilization is not always compatible with management objectives because of access requirements, and southern pine sites often will not support agronomic crops because the soils often have low water holding capacity or low nutrient status. Koch (1980) proposed a technique of dual-cropping planted pines for sawtimber and direct-seeding pines for energy. The present availability of normal sources of energy has reduced the immediate interest in using forest land to produce biomass as an energy source. However, the long lead time inherent in forest research requires that work continue so that the potential of using the forest for energy will be known should the need become more apparent. Recently, a feasibility study (McConnell 1984) has shown the dual-cropping option to offer economic promise, especially after the system has been field proven.

This paper presents interim results on the methods of establishing a dual-cropping system of pine for biomass production and for sawtimber. The effect of phosphorus fertilizer on the early growth of the two pine crops is analyzed. Two methods of predicting the phosphorus requirement of newly established pines are also evaluated.

METHODS

The site, located on Beauregard silt loam (fine-silty, siliceous, thermic Plinthaquic Paleudult) in central Louisiana, had been in native grasses with scattered small hardwoods. The plots were plowed in the fall of 1980 and disked three times in the summer of 1981 to control the grasses.

The experimental design is a completely randomized split plot with three replications. Four levels of phosphorus were applied to the main plots and three levels of direct-seeding were applied to the subplots. The main plots are 22 m

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[2/] Soil Scientist, Southern Forest Experiment Station, USDA--Forest Service, Pineville, LA 71360.

by 45 m. The planted tree spacing is 2 by 3 m, so there are 15 rows of 11 trees each per main plot. The main plots are divided into three subplots, and the measurement plots are comprised of five trees in each of the center three rows (fig. 1).

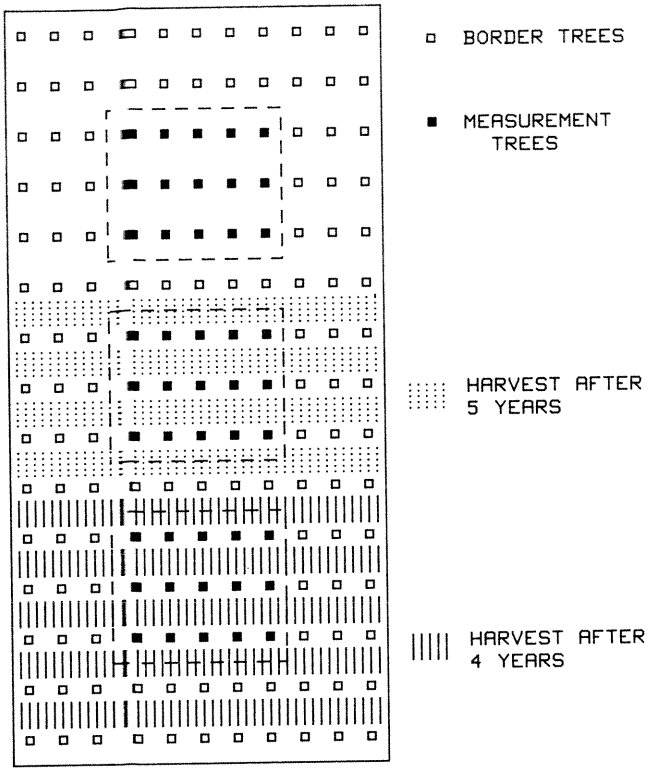

Figure 1.--Layout of a typical plot

Loblolly pine seedlings (1-0) were grown in a nursery from open-pollinated seed collected from a single clone (K-36) at the Stuart Seed Orchard in Louisiana. The seedlings were lifted in January 1982, sorted for grade 1 seedlings, and randomized. The trees were planted 2 days after lifting. To insure a sufficient number of measurement trees, two trees were planted 10 cm apart in designated measurement tree spots. The smaller tree was removed during the age 1 measurement. For fusiform rust prevention, the planted trees were sprayed with Bayleton® at 3-week intervals during the spring of 1981 and 1982. Tipmoth was controlled by incorporating Furadan® around the base of each planted tree. The height and diameter of the planted trees were measured at ages 1 and 2.

The three levels of direct seeding applied were no seeding and two seedings to be harvested at different times. On two of the three subplots on each main plot, the middle of the rows were direct-seeded with loblolly pine, but the third subplot was not seeded. Seeded trees on one of the subplots will be cut for biomass measurements at age 4 and on the other subplot at age 5. Genetically unimproved loblolly seeds were stratified and coated with Arasan 42-S®, endrin, latex and aluminum powder (Campbell 1979).[3/] In February 1982, seeds were placed in spots spaced 25 by 50 cm apart in a 1.5-m swath in the middle of the planted tree rows, with one live tree per spot desired. In an attempt to get an even distribution of direct-seeded pines on all plots, a random pinch of 3 to 10 seeds was placed on each spot. The spots were about 5 cm in diameter. The number of live trees and their heights were measured on each of the 6 spots in 10 randomly selected rows in the 24 direct-seeded subplots 1 and 2 years after seeding. After the second measurement, the direct-seeded pines were thinned to the tallest tree per spot.

Soil samples to determine the phosphorus requirement were collected in the spring of 1982 from 15 randomly chosen locations within each main plot and grouped by plots. The phosphorus requirement was determined by phosphorus sorption curves (Tiarks 1982a) in which the soil was equilibrated with phosphorus solutions ranging from 0 to 10 mg/liter. (The phosphorus requirement for 95% of optimum growth, as estimated by this method, is the amount needed to maintain a soil solution concentration of 0.2 mg/liter.) The amount of phosphorus applied to the plots was 0, 81, 162, and 324 kg/ha, which is 0, 1/2, 1, and 2 times the estimated phosphorus requirement. The phosphorus was applied as triple superphosphate in April 1982. Nitrogen as urea was also applied at the rate of 40 kg/ha at the same time to all of the plots.

For comparison, the phosphorus requirement was also determined by the method outlined by McLean et al. (1982). For this determination, 2.5 g of soil was placed in a centrifuge tube, and 0.15 mg of phosphorus in 1 ml of water was added. After 2 hours, phosphorus was extracted by shaking the soil in 20 ml of Bray 2 extractant for 15 minutes. The amount of phosphorus extracted was compared with the amount of phosphorus extracted by the Bray 2 solution from a comparable sample that had been treated with 1 ml of distilled water. The phosphorus requirement was determined by multiplying the fraction of added phosphorus recovered by the difference between the sufficiency level and the level in unfertilized soil. The sufficiency level used was 10 mg/kg based on unpublished data dealing with similar soils.

[3/] The Arasan-endrin-latex-aluminum treatment is labeled by the Environmental Protection Agency for pine seed in direct-seeding operations.

Analysis of variance was used to test the effects of phosphorus and the direct-seeded pines on the growth of the planted pines, with significance level set at 0.05. When the effects of phosphorus were significant, regression was used to fit the relationship between phosphorus applied and tree growth.

RESULTS AND DISCUSSION

During the first 2 years, the presence of direct-seeded trees in the middle of the rows had no effect on the growth of the planted trees. Therefore, the data analyses of the phosphorus on the planted trees were done on the main plot averages. The phosphorus significantly increased tree height both years. One year after plantation establishment, the heights of the planted pines increased from 0.60 m on plots receiving no phosphorus to 0.85 m on plots fertilized with 324 kg/ha (fig. 2). The quadratic regression of the first year's heights indicates a maximum response at 262 kg of phosphorus per hectare. After 2 years, the unfertilized trees were 1.5 m tall, and the trees on plots receiving 324 kg of phosphorus per hectare were 1.9 m tall. The quadratic equation again maximized at 262 kg/ha.

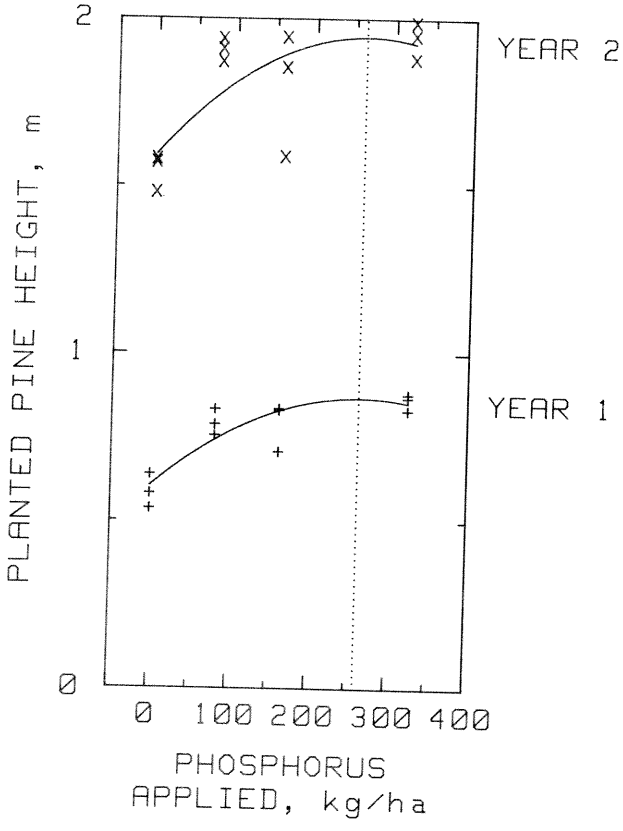

Figure 2.--The effect of phosphorus on the height of planted pine 1 and 2 years after establishment. The dotted line shows the quantity of phosphorus needed for maximum response (see text).

At age 1, the quadratic mean of the root-collar diameters of the planted trees increased from 1.3 cm to 1.6 cm as the amount of phosphorus increased from 0 to 324 kg/ha (table 1). The linear component of the regression was significant but the quadratic component was not. In the second year, the addition of phosphorus did not significantly affect the root-collar diameter.

Table 1.--Effect of phosphorus on the quadratic mean of root-collar diameters of planted loblolly pine 2 years after establishment

P applied	Root-collar diameter	
	Year 1	Year 2
-kg/ha-----	----------cm----------	
0	1.3	3.5
81	1.4	4.2
162	1.4	3.8
324	1.6	4.1

The lack of response of the diameters of the planted pines to phosphorus in the second year might have been caused by a nitrogen deficiency or by increased weed competition. Only 40 kg of nitrogen per hectare was applied in the first year, so little carry over to the second year would be expected. However, because diameter growth response to phosphorus in the second year was not significant while height growth response was, weed competition probably caused the reduced response. Site preparation was intense, so the pines had little competition in the first year. By the second year, grasses and other herbaceous competition were reestablished, especially on plots that had received phosphorus fertilizer.

Data on the direct-seeded pine were analyzed on the averages of the two direct-seeded subplots within a major plot because they were treated the same for the first 2 years. The average frequency of spots without any survival was 24 percent after the first year. On spots that had live pines, the number of trees per spot averaged 2.5. During the second growing season, the occurrence of spots without live trees increased to 27 percent, and the number of trees per spot declined to 2.3. Neither the frequency of the blank spots nor the number of trees per spot was affected by the phosphorus treatment. The frequency of spots without any live trees ranged from 2 to 52 percent after the first year. Thus, the attempt to establish a uniform density of seedlings on all plots by spot seeding was not successful. Broadcasting the seed or row-seeding would be more practical and probably give as uniform a density of seedlings.

The direct-seeded pines were thinned to the tallest tree per spot at the beginning of the third year as planned; therefore, only the

height of the tallest tree per spot is reported here. After 1 year, the height of the direct-seeded pines increased from 0.15 m on plots not fertilized with phosphorus to 0.24 m on plots receiving 324 kg of phosphorus per hectare (fig. 3). The quadratic equation maximized at 272 kg/ha. By the end of the second year, the height of the direct-seeded pines across all plots was 0.53 m. The quadratic component of the regression equation did not account for a significant portion of the regression equation, and the linear component was significant only at the 0.089 level (fig. 3). The direct-seeded pine probably did not respond to phosphorus because of the increased herbaceous competition in the second year. Since the direct-seeded pines were smaller than the planted pines, they would be affected more by the competition, as the data indicate.

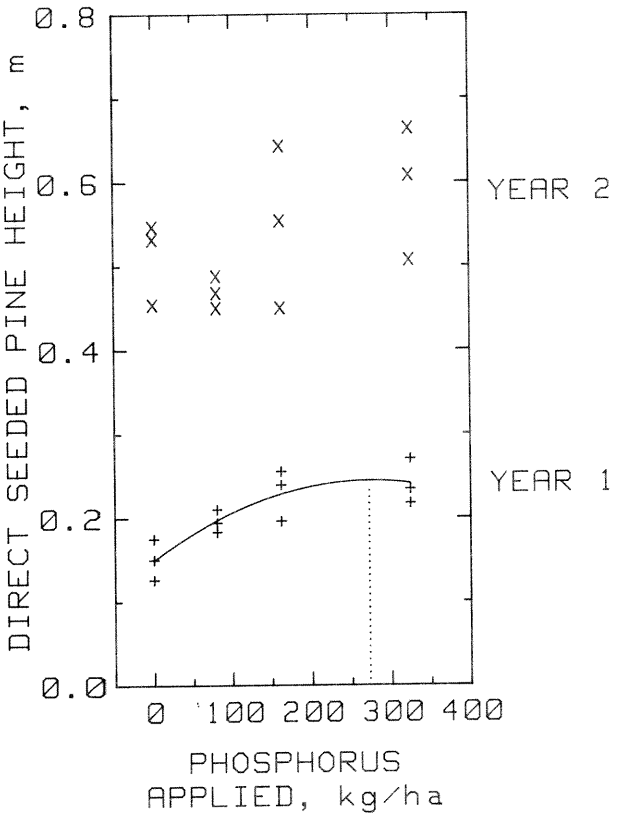

Figure 3.--The effect of phosphorus on the height of the tallest seeded pine per spot 1 and 2 years after establishment. The dotted line shows the quantity of phosphorus needed for maximum response for age 1 (see text). Phosphorus did not affect height at age 2.

After the first year, the direct-seeded pines on unfertilized plots were 25 percent as tall as the planted pines. The highest rate of phosphorus (324 kg/ha) increased the relative height of the direct-seeded pines to 27 percent. By the end of the second year, these pines were 30 percent as tall as the planted pines on all plots. Phosphorus had no influence on the relative height of the direct-seeded pines to planted pines after 2 years.

The success of using direct-seeded pines between the rows of planted pines requires that planted-pine growth not be reduced by the interseeding. For the first 2 years, this was the case and probably will remain so if the heights of the direct-seeded pines remain at less than the heights of the planted pines.

The relationship between the estimated phosphorus concentration in the soil solution and the amount of phosphorus applied is shown in figure 4. As previously stated, the relationship is determined in the laboratory by adding a range of phosphorus concentrations, and then after equilibration, measuring the concentration of phosphorus in solution and the amount of phosphorus sorbed by the soil. To estimate the phosphorus required to reach a desired level of phosphorus in solution, the phosphorus that needs to be applied is assumed to be equal to the amount of phosphorus sorbed. The relationship for the soils from these plots was defined by the following equation:

$$P \text{ required} = -6.6 + 3.45 \, [\log_e(1000 \times P \text{ in solution})]^2.$$

The equation accounted for 84 percent of the variation between the phosphorus in solution and the phosphorus sorbed or required. The phosphorus in solution is estimated to be 0.004, 0.048, 0.20, and 1.5 mg/liter for the four rates of phosphorus applied in the field (fig. 4). When the plots were established, the phosphorus required in solution was thought to be 0.2 mg/liter for loblolly pine (Tiarks 1982a). Later work (Tiarks 1982b) showed that 0.1 mg/liter is sufficient for loblolly pine to grow at 90 percent of the maximum. Using the quadratic relationship between phosphorus applied and height after 1 year for the planted pines to interpolate, at 117 kg/ha or a solution concentration of 0.1 mg/liter, the height would have been 0.78 m or 90 percent of the maximum. At this rate, the direct-seeded pines would have been 0.21 m or 87 percent of their maximum height after 1 year. By age 2, the height of the planted pines would have been 1.84 m or 94 percent of their maximum at 117 kg of phosphorus per hectare. The height response of the direct-seeded pines is not significant after 2 years, so the reliability of the sorption curve method cannot be determined. Thus, the sorption curve method of determining the phosphorus requirement has potential for predicting the amount of phosphorus to apply when the pine growth is not limited by other factors such as weed competition.

The alternative method of determining the phosphorus requirement (McLean et al. 1982) estimates that 25 kg of phosphorus per hectare would

be sufficient. In the first year, this rate would have given only 75 percent of the maximum height growth of the planted pines and 68 percent of the maximum of the direct-seeded pines. In an unpublished greenhouse experiment, the simpler method of McLean et al. (1982) for determining the phosphorus requirement was as good as the sorption curve method. However, in this field experiment, the simpler method did not accurately predict the phosphorus requirement, while the sorption curve method did. Both methods should be tested through significant portions of the rotation and in other field situations. The preliminary results of this study indicate that the sorption curve method has good potential for predicting the amount of phosphorus required for near maximum growth of loblolly pine.

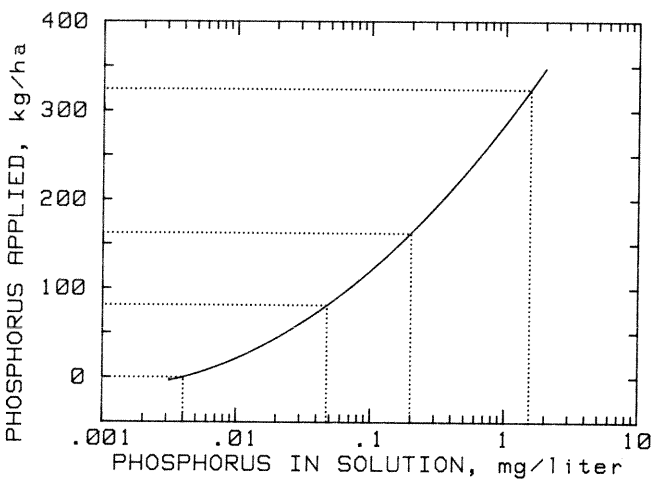

Figure 4.--The relationship between phosphorus in solution and the quantity of phosphorus applied. The dotted lines show the 4 rates that were applied in the field.

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SEEDLING QUALITY AND FIELD PERFORMANCE OF LONGLEAF PINE SEEDLINGS AFFECTED BY ECTOMYCORRHIZAE AND NURSERY CULTURAL PRACTICES[1/]

Glyndon E. Hatchell[2/]

Abstract.--Results and preliminary findings of nursery and outplanting studies of longleaf pine (*Pinus palustris* Mill.) indicate that inoculation of fumigated nursery soil with *Pisolithus tinctorius* (Pt) during spring sowing coupled with optimum cultural practices in the nursery greatly increase survival and early growth of planted 1-0 bare-root stock. In addition to inoculation, other nursery cultural treatments being evaluated include: (1) low seedling density (6 to 12 seedlings/ft^2), (2) lateral-root pruning, and (3) maintenance of nutrient balance throughout growing season. Root pruning increases the development of second- and third-order lateral roots and of short roots on severed lateral roots. These root changes increase the number of Pt ectomycorrhizae on the root system. Desirable characteristics of 1-0 stock for planting on deep sandy sites are root-collar diameter of 0.5 inch or larger, numerous lateral and short roots, and abundant Pt ectomycorrhizae.

INTRODUCTION

Wakeley (1954) suggested 30 seedlings/ft^2 as the optimum seedling density in nursery beds for longleaf pine (*Pinus palustris* Mill.) and specified grade 1 stock with minimum root-collar diameter of 0.25 inch. Scarbrough and Allen (1954) found that lower seedling density in the nursery (<30/ft^2) increased field survival of longleaf pine, and Shoulders (1963) reported that undercutting nursery beds also increased survival. Mann (1969) stated that "At last longleaf pine can be planted successfully." However, this was obviously an overstatement because in the following decade average survival of planted stands was only about 50 percent, with stocking generally below the acceptable level.

Recent studies on nursery cultural practices have provided useful information for the production of high-quality longleaf pine planting stock. Marx (1977) reported that inoculation of seedlings with *Pisolithus tinctorius* (Pers.) Coker & Couch ectomycorrhizae (Pt) in forest nurseries offers an excellent opportunity for improving survival and growth of pines on a variety of adverse and routine reforestation sites. Marx and Bryan (1971) observed that Pt formed more ectomycorrhizae on southern pines at higher temperatures than *Thelephora terrestris* Ehrh. ex Fr., a common fungus from natural sources forming ectomycorrhizae on pines in southern nurseries (Marx *et al.* 1984). Kais *et al.* (1981) found that abundant Pt ectomycorrhizae on longleaf pine improved seedling survival and early height growth on two sites in Mississippi. Tinus (1981) reported that pruning lateral roots and undercutting nursery seedlings increased seedling survival and initial growth in pine plantations in New Zealand. White (1981) found that longleaf pine seedlings with root-collar diameter $\geq$ 0.5 inch were required for satisfactory field survival when seedlings had been in cold storage for 3 weeks before planting.

During the past 30 years, attempts to regenerate pine in the sandhills region of the Carolinas and Georgia have generally failed because of extensive offsite planting of slash pine (*P. elliottii* var. *elliottii* Engelm.) beyond its indigenous range, the use of wrong seed sources of loblolly pine (*P. taeda* L.), and severe decimation of loblolly and slash pine stands by fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*) infection (Kellison *et al.* 1977). Choctawhatchee sand pine (*P. clausa* var. *immuginata* D. B. Ward) has performed well in the South Carolina sandhills and no serious problems have been observed during the first 15 years after planting (McNab and Carter 1981, Hebb 1982). Longleaf pine, however, might be a better choice for operation planting in the Carolina sandhills because of concern over possible lack of cold resistance in sand pine (Kellison and Jett 1978). Although longleaf pine has natural resistance to fusiform rust infection and is well

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2/ Research Forester, Institute for Mycorrhical Research and Development, Southeastern Forest Experiment Station, Athens, Georgia 30602

adapted to deep sandy sites, this desirable species is still not planted extensively in this region because survival is generally poor and seedlings usually remain in the grass stage for several years.

This paper summarizes preliminary results of longleaf pine research conducted by the Institute for Mycorrhizal Research and Development during the past 7 years. The objective of these studies was to develop nursery cultural practices for production of high-quality longleaf pine stock suitable for planting on deep sandy sites and other stress sites. The results of two outplanting studies and one nursery study are presented.

FIELD PERFORMANCE OF LONGLEAF AND SAND PINES WITH PT

Seedling Production

Seedlings were produced at the Whitehall Experimental Nursery, Athens, Georgia, during the 1978 growing season. Nursery beds containing a uniform mixture of forest topsoil, sand, and milled pine bark (2:1:1, volume ratio) were fumigated with methyl bromide under clear plastic. Two pairs of nursery beds were randomly assigned the following ectomycorrhizal treatments: vegetative inoculum of Pt (Marx and Bryan 1975, Marx and Rowan 1981) applied (0.10 ℓ/ft^2) on soil surface and mixed with the upper 4 inches of soil, or natural inoculation (NI) by airborne spores. A pair of Pt and NI nursery beds were hand sown (in drills 6 inches apart) during April to the following species and seed sources: longleaf pine, Jackson County, Florida, and Choctawhatchee sand pine, Washington County, Florida. During July, nursery beds were thinned to uniform densities with 14 longleaf pine seedlings/ft^2 and 15 sand pine seedlings/ft^2.

Fertilizer (10-10-10) was applied before sowing to all nursery beds at 500 lb/A and mixed with the upper 4 inches of soil. All seedlings received top dressings of fertilizer: ammonium nitrate with N at 50 lb/A on July 6, July 28, August 24, and September 14; and muriate of potash with K at 25 lb/A on September 20. Observations in September indicated that Choctawhatchee sand pine seedlings exhibited pronounced symptoms of potassium deficiency, and longleaf pine seedlings also showed some symptoms of K deficiency.

On February 2, 1979, seedlings were lifted, graded to a minimum abundance of ectomycorrhizal development, and culled to minimum root-collar diameter (RCD) of 0.31 inch for longleaf pine and 0.12 inch for Choctawhatchee sand pine. Five bundles of 25 seedlings of each species and treatment were packed in wet peat moss, sealed in shipping bags, and placed in cold storage for 4 days before planting.

Study Area and Experimental Design

The outplanting study was installed on a sandhills site near New Ellenton, South Carolina. The Lakeland and Kershaw soil series on the study area are excessively well drained and infertile, with sand extending to depths of 6 to 20 feet. An immature, poorly stocked slash pine plantation with severe fusiform infection was clearcut. Site preparation consisted of burning the logging debris, roller chopping, and disking.

A factorial experiment with the two pine species and two ectomycorrhizal treatments was established as a randomized block design with five replications. Forty-nine seedlings were planted per plot at an 8- x 8-foot spacing. Isolation strips, 24 feet wide between plots, were not planted. Characteristics of seedlings at planting are shown in table 1. The Pt index was 76 for the Pt-longleaf pine treatment and 82 for the Pt-sand pine treatment, both well above the threshold of 50 needed for measurable growth improvement.

RESULTS AND DISCUSSION

Choctowhatchee sand pine performed well on the deep sandy site. Sand pine has shown significant growth response to Pt ectomycorrhizae after 4 years; Pt inoculation in the nursery increased seedling volume index 54 percent and plot volume index 41 percent compared with NI treatment (table 2). Both survival and growth of longleaf pine seedlings were significantly improved by Pt treatment. Longleaf pine seedlings with the Pt treatment showed an increased survival of 22 percentage points and an increased seedling volume index and plot volume index of 154 and 217 percent, respectively, over NI seedlings (table 2). The percentage of longleaf pine seedlings in active height growth during the third growing season was significantly increased by Pt treatment compared with NI treatment.

FIELD RESPONSE OF LONGLEAF PINE TO INOCULATION AND OTHER NURSERY TREATMENTS

Seedling Production

Longleaf pine seedlings were produced at the Whitehall Experimental Nursery, Athens, Georgia, during the 1982 growing season under conditions and procedures similar to those described above, with respect to soil mixture, fumigation, and inoculation. Treatments were factorial combinations of two ectomycorrhizal treatments (Pt or NI) x four nursery bed densities (6, 9, 12, or 15 seedlings/ft^2) x two lateral-root pruning treatments (pruned or unpruned); treatment combinations were randomly assigned to plots. Longleaf pine seed (Richmond County, North Carolina source) was hand sown in drills 6 inches apart on March 30, and seedlings were thinned to assigned densities on May 25. Lateral-root pruning was done by severing with a shovel to an 8-inch depth midway between drills of seedlings on August 16 and October 8. Seedlings were not undercut and their needles were not clipped.

Table 1.--Characteristics of pine seedlings planted on a deep sandy site in the South Carolina sandhills, by species and ectomycorrhizal treatment

Pine species and nursery treatments	Height	Root-collar diameter	Percent of feeder roots ectomycorrhizal with: Pt	All fungi	Pt index
	------Inches-------				
Sand - Pt	8.0	0.17	50	60	82
Sand - NI	5.4	0.13	0	30	0
Longleaf - Pt	<0.6	0.41	35	45	76
Longleaf - NI	<0.6	0.35	0	30	0

Pt = *Pisolithus tinctorius*; NI = natural inoculation.

Table 2.--Fourth-year survival and growth of pine seedlings planted on a deep sandy site in the South Carolina sandhills, by species and ectomycorrhizal treatment

Nursery treatments	Survival	Height	Root-collar diameter	Seedling volume index1/	Plot volume index2/
	Percent	Feet	Inches	---Cubic inches---	
		Choctawhatchee Sand Pine			
Pt	76a	5.64a	1.54a	207a	3,910a
NI	82a	4.82b	1.38b	134b	2,780b
		Longleaf Pine			
Pt	84a	1.54a	1.57a	61a	1,300a
NI	62b	0.85b	1.34b	24b	410b

Pt = *Pisolithus tinctorius*; NI = natural inoculation.
Ectomycorrhizal treatment means for a species followed by a common letter are not significantly different at $P = 0.05$.
1/ Seedling volume index = (root-collar diameter)^2 x height.
2/ Plot volume index = sum of seedling volume index per plot.

Before sowing, 10-10-10 fertilizer was applied at 500 lb/A and mixed with the upper 4 inches of soil. Top dressings of ammonium nitrate with N at 50 lb/A and muriate of potash with K at 25 lb/A were applied on June 8, June 29, July 28, August 16, and September 15. Muriate of potash was applied as side dressings to avoid K deficiency; the amount applied was a modification of recommended nursery practices for Choctawhatchee sand pine (Brendemuehl and Mizell 1978).

Seedlings were lifted on January 3, 1983, and graded. Seedlings with an RCD <0.39 inch or with fusiform rust galls were culled. Average percentage of plantable seedlings was 88.1, 68.4, 58.2, and 47.5 for nursery bed densities of 6, 9, 12, and 15/ft^2, respectively. Taproots were cut at 10 inches, but needles were not clipped. Five bundles of 25 plantable seedlings per treatment were packed in shipping bags and stored at 40 °F for 2 days before planting.

Study Area and Experimental Design

The outplanting study was installed on a sandhills site located on the Savannah River Forest Station, Aiken, South Carolina. The soil series is Blanton; sand extends to a depth of 40 to 80 inches. An understocked longleaf stand was clearcut, and the site prepared for planting by shearing, rootraking debris into windrows, and disking twice.

A split-plot experiment with a randomized block design with five replications was installed. Pt and NI ectomycorrhizal treatments were assigned to major plots, and subplots were assigned factorial combinations of the four nursery bed densities and two lateral-root pruning treatments. Twenty-five seedlings were planted on a single row at 3-foot spacing on each subplot, with rows for subplot treatments at 8-foot spacing. Isolation strips, 20 feet wide between main plots, were not planted.

Mean root-collar diameter and Pt index are shown in table 3. Pt seedlings receiving the lateral-root pruning treatment had an overall Pt index of 59 compared with 32 for unpruned seedlings. Lateral-root pruning had no effect on RCD. As seedling density increased, RCD decreased to <0.50 inch for seedlings grown at the 15/ft^2 density. However, the 0.49-inch RCD for the seedlings with 15/ft^2 density was larger in this study than for stock produced at the same density in the previous study (table 1). This increase in size probably resulted from additional fertilizer (+50 lb N/A and + 100 lb K/A) applied as side dressings in this study.

Table 3.--Characteristics of longleaf pine seedlings before planting on a sandy site in the South Carolina sandhills

Nursery treatments	Nursery bed density and lateral-root pruning treatments							
	6/ft^2		9/ft^2		12/ft^2		15/ft^2	
	Pruned	Unpruned	Pruned	Unpruned	Pruned	Unpruned	Pruned	Unpruned
	Root-collar diameter (inches)							
Pt	0.59	0.57	0.52	0.55	0.50	0.52	0.49	0.48
NI	0.55	0.55	0.50	0.52	0.49	0.49	0.50	0.48
	Pt index							
Pt	65	25	65	30	60	40	45	35
NI	0	0	0	0	0	0	0	0

Pt = *Pisolithus tinctorius*; NI = natural inoculation.

RESULTS AND DISCUSSION

Density of seedlings in nursery bed, lateral-root pruning, and Pt inoculation significantly (P = 0.01) affected survival of longleaf pine seedlings 2 years after outplanting on the sandy site. Overall, survival of seedlings with 6, 9, or 12/ft^2 density was 9 percentage points higher than with 15/ft^2 density, survival of seedlings with lateral-root pruning was 23 percentage points higher than for unpruned seedlings, and survival of Pt seedlings was 13 percentage points higher than for NI seedlings. Pt-pruned seedlings with densities of 6 to 12/ft^2 had 90 or 91 percent survival contrasted to 42 percent for the NI-unpruned treatment with 15 seedlings/ft^2 density in nursery beds (table 4).

Root-collar diameter was a more reliable measurement of growth than height because only 37 percent of seedlings on all plots were in active height growth after 2 years (table 4). Density of seedlings in nursery bed and lateral-root pruning significantly (P = 0.01) affected RCD, whereas ectomycorrhizal treatments had no significant effect on RCD. The main effect of seedling density on RCD showed a linear relationship, and means for RCD with seedling densities of 6, 9, 12, and 15/ft^2 were 1.08, 1.03, 0.98, and 0.96 inch, respectively. The overall means for RCD with respect to lateral-root pruning treatments were 1.04 inch for pruned seedlings and 0.98 inch for unpruned seedlings.

EFFECTS OF NURSERY CULTURAL PRACTICES ON QUALITY OF LONGLEAF PINE STOCK

The objectives of this study were to determine promising combinations of treatments for producing high-quality bare-root longleaf pine seedlings for planting on droughty sandy sites.

Materials and Methods

Longleaf pine 1-0 bare-root seedlings were produced in the Brunswick Pulp and Land Company Nursery, Jesup, Georgia. Longleaf pine seed (company seed orchard source) was sown on October 21, 1981 (fall sowing) or March 8, 1982 (spring sowing) in eight drills, spaced 6 inches apart, and mulched with fumigated pine straw.

Treatment combinations were: (1) ectomycorrhizae-Pt inoculation with vegetative inoculum broadcast at 0.075 ℓ/ft^2 of soil surface and mixed with the upper 4 inches of soil after fumigation with methyl bromide under clear plastic, natural inoculation (NI) with airborne spores of ectomycorrhizal forming fungi after soil fumigation, or nonfumigated (NF) soil and naturally occurring ectomycorrhizae; (2) nursery bed densities of 8, 12, or 16 seedlings/ft^2 after fall sowing and thinning on March 24, 1982, or density of 12 seedlings/ft^2 after spring sowing and thinning on May 20, 1982; and (3) lateral-root pruning midway between seed drills to an 8-inch depth during late July and late October 1982, or unpruned control. Pt and NI plots were fumigated 1 week before sowing in either fall or spring. Biological assay (Marx *et al.* 1984) of soil samples collected in October 1981 and March 1982 (pre- and post-fumigation samples) was made to determine fumigation effectiveness.

A split-plot experiment with three major plot treatments (ectomycorrhizae, nursery bed density, and season of sowing) was replicated five times in a randomized block design. Main plots were 4- x 10-foot sections of nursery bed, with 4- x 4-foot

Table 4.--Survival and growth of longleaf pine seedlings after 2 years on a sandy site in the South Carolina sandhills

Nursery treatments	Survival	Height	Seedlings in active height growth[1/]	Root-collar diameter
	Percent	Feet	Percent	Inches
$6/ft^2$ - pruned - Pt	91	0.48	62	1.12
unpruned - Pt	66	0.40	54	1.04
pruned - NI	86	0.46	61	1.12
unpruned - NI	51	0.35	38	1.02
$9/ft^2$ - pruned - Pt	90	0.37	42	1.04
unpruned - Pt	63	0.30	27	1.00
pruned - NI	78	0.33	40	1.07
unpruned - NI	61	0.32	35	1.00
$12/ft^2$ - pruned - Pt	91	0.33	39	1.05
unpruned - Pt	81	0.33	28	0.97
pruned - NI	79	0.27	27	0.97
unpruned - NI	57	0.28	21	0.95
$15/ft^2$ - pruned - Pt	84	0.32	37	1.01
unpruned - Pt	65	0.31	27	0.94
pruned - NI	74	0.31	34	0.96
unpruned - NI	42	0.28	27	0.92

Pt = *Pisolithus tinctorius*; NI = natural inoculation.
1/ Seedlings in active height growth have root-collar diameter $\geq$ 1.0 inch and height $\geq$ 0.33 feet.

isolation strips between plots. Root-pruning treatments were installed on 4- x 5-foot subplots in each major plot.

When nursery beds were prepared in October 1981, all plots received 20-20-20 fertilizer at 500 lb/A. Samples of the 0- to 6-inch soil depth were collected from each plot on October 21, 1981, and composite samples for each block showed little variation in soil properties. Chemical analyses showed total N, 340 ppm; available P, 65 ppm; exchangeable K, Ca, and Mg, 24, 220, and 26 ppm, respectively; pH was 5.1; and organic matter was 1.6 percent (analyses by A&L Agricultural Laboratories, Inc., Memphis Tennessee). During the growing season of 1982 all seedlings received top dressings of fertilizer: in June, 10-10-10 at 150 lb/A; in July, 18-46-0 at 100 lb/A; and in August, ammonium nitrate with N at 33 lb/A. Needles were mowed to a 4- to 6-inch length in July and in September 1982, and seedlings were undercut at an 8-inch depth in August 1982.

In December 1982, 24 seedlings were collected from each subplot (3 seedlings lifted together from random points within each of the eight drills). Root-collar diameter and weight of shoots and roots were measured, shoot/root ratio was determined, and the abundance of ectomycorrhizae was assessed visually.

Analysis of variance was conducted on all data, and Duncan's multiple range test was used to compare means of main-plot treatments.

RESULTS AND DISCUSSION

Both seedling density in nursery bed and ectomycorrhizal treatments had significant effects on RCD of 1-0 longleaf pine seedlings, whereas lateral-root pruning did not. Means for RCD by treatment combinations (sowing season, nursery bed density, and ectomycorrhizal treatments) are presented in table 5. Overall, significantly larger RCD resulted with nursery bed density of $8/ft^2$ than with 12 or $16/ft^2$ densities, and with Pt or NI ectomycorrhizal treatments than with the NF treatment. The Pt and NI treatments produced a greater quantity of plantable seedlings with minimum size of 0.35 or 0.47 inch than NF seedlings produced at the same density and sowing season; the greatest number of seedlings with RCD $\geq$ 0.47 inch resulted from fall-sown Pt or NI treatments at nursery bed density of $8/ft^2$. Comparison of fall versus spring sowing with $12/ft^2$ density showed that sowing season did not affect RCD.

Shoot and root fresh weights and shoot/root ratio, as influenced by sowing season, nursery bed density, ectomycorrhizal treatment, and lateral-root pruning are presented in table 6. Pt and NI seedlings produced at the same density and sowing season showed significantly heavier weights of shoots or roots than did the NF seedlings. Roots

Table 5.--Effects of season of sowing, nursery bed density, and ectomycorrhizal treatment on root-collar diameter and quantity of plantable 1-0 longleaf pine seedlings in an industrial forest nursery

Nursery treatments	Root-collar diameter	Plantable seedlings by minimum RCD 0.35 (inch)	0.47
	Inch	No. seedlings/ft^2	
Fall sown, 8/ft^2 - Pt	0.49a	7.9d	5.1a
- NI	0.48a	7.9d	4.7ab
- NF	0.43bc	7.2d	2.7d
Fall sown, 12/ft^2 - Pt	0.44b	10.2bc	4.4abc
- NI	0.43bc	10.8ab	3.7bcd
- NF	0.40de	9.2c	1.2d
Spring sown, 12/ft^2 - Pt	0.43bc	9.7bc	3.0d
- NI	0.43bc	9.8bc	3.4cd
- NF	0.40de	6.6d	1.0e
Fall sown, 16/ft^2 - Pt	0.43bc	11.5a	3.1d
- NI	0.42cd	11.9a	3.1d
- NF	0.39e	6.9d	0.6e

Pt = *Pisolithus tinctorius*; NI = natural inoculation after soil fumigation; NF = nonfumigated soil.
Treatment means in a column followed by a common letter are not significantly different at $P = 0.05$.

of NF seedlings exhibited severe feeder-root necrosis, but soil fumigation a week before either fall or spring sowing effectively controlled Pythiaceous fungi and plant parasitic nematodes, thus reducing the incidence of the feeder-root disease. Mean separation ($P = 0.05$) of fresh shoot weight of Pt and NI seedlings by sowing season and nursery bed density showed fall-8/ft^2 density > fall-12/ft^2 density > fall-16/ft^2 density > spring-12/ft^2 density; and mean separation of fresh root weight showed fall-8/ft^2 density > fall-12/ft^2 density > spring-12/ft^2 density or fall-16/ft^2 density. Lateral-root pruning significantly increased the fresh weight of roots and significantly decreased shoot/root ratio. The lowest shoot/root ratios were for Pt and NI seedlings sown in spring at 12/ft^2 density.

Lateral-root pruning significantly increased the percentage of feeder roots with ectomycorrhizae but had no significant effect on Pt index (table 7). Seedlings in spring-sown plots had 33 percent total ectomycorrhizal development on Pt seedlings compared with 24 percent on NI or NF seedlings. The lowest (16%) ectomycorrhizal development was observed on fall-sown NI seedlings grown at the 8/ft^2 density. Pt index of fall-sown seedlings with Pt ectomycorrhizal treatments is low due to natural competition from airborne spores of other fungi, which produced abundant fruiting bodies in the nursery, and to slow growth of seedlings during fall and winter. Pt index was significantly higher on seedlings in spring-sown plots

Table 6.--Effects of season of sowing, nursery bed density, ectomycorrhizal treatment, and lateral-root pruning on fresh weight of shoots and roots and shoot/root ratio of 1-0 longleaf pine seedlings

Nursery treatments	Fresh weight of shoots (g) Pruned	Control	Means	Fresh weight of roots (g) Pruned	Control	Means	Shoot/root ratio Pruned	Control	Means
Fall sown, 8/ft^2 - Pt	38.4	39.8	39.1a	13.2	11.9	12.6a	2.93	3.36	3.14cd
- NI	34.0	38.6	36.3b	11.8	12.1	12.0a	2.88	3.24	3.06de
- NF	24.8	24.8	24.8de	8.2	6.8	7.5c	3.02	3.69	3.35abcd
Fall sown, 12/ft^2 - Pt	28.7	29.0	28.8c	9.2	8.7	9.0b	3.13	3.36	3.25bcd
- NI	26.0	28.1	27.1cd	8.7	8.5	8.6b	3.01	3.37	3.19bcd
- NF	19.4	20.0	19.7g	5.7	5.3	5.5d	3.37	3.85	3.61a
Spring sown, 12/ft^2 - Pt	20.2	20.3	20.2g	7.4	7.2	7.3c	2.71	2.85	2.78f
- NI	22.8	20.4	21.6g	8.6	6.7	7.7c	2.66	3.04	2.85ef
- NF	13.8	15.7	14.8h	4.6	4.7	4.6de	3.00	3.37	3.18bcd
Fall sown, 16/ft^2 - Pt	24.0	22.5	23.3ef	7.3	6.3	6.8c	3.27	3.59	3.43abc
- NI	21.9	24.4	23.1ef	6.9	6.8	6.9c	3.15	3.58	3.36abc
- NF	15.1	14.3	14.7h	4.6	4.0	4.3e	3.32	3.65	3.48ab
Means for root pruning	24.1A	24.9A		8.0A	7.4B		3.04B	3.41A	

Pt = *Pisolithus tinctorius*; NI = natural inoculation after soil fumigation; NF = nonfumigated soil.
Treatment means in a column followed by a common lowercase letter are not significantly different at $P = 0.05$; means for root-pruning treatments followed by a common uppercase letter are not significantly different at $P = 0.01$.

Table 7.--Effects of season of sowing, nursery bed density, ectomycorrhizal treatment, and lateral-root pruning on ectomycorrhizal abundance of 1-0 longleaf pine seedlings

Nursery treatments		Percent of feeder roots with ectomycorrhizae			Pt index		
		Pruned	Control	Means	Pruned	Control	Means
Fall sown, $8/ft^2$	- Pt	21	14	18def	34	27	31b
	- NI	18	13	16f	0	0	0c
	- NF	25	16	21cd	3	0	2c
Fall sown, $12/ft^2$	- Pt	19	15	17ef	37	25	31b
	- NI	18	15	17ef	0	0	0c
	- NF	24	15	20de	3	1	2c
Spring sown, $12/ft^2$	- Pt	35	31	33a	56	54	55a
	- NI	26	21	24bc	0	0	0c
	- NF	29	20	25b	10	2	6c
Fall sown, $16/ft^2$	- Pt	21	16	18def	24	26	25b
	- NI	18	16	17ef	0	0	0c
	NF	21	20	20de	3	0	2c
Means for root pruning		23A	18B		14A	11A	

Pt = *Pisolithus tinctorius*; NI = natural inoculation after soil fumigation; NF - nonfumigated soil.
Treatment means in a column followed by a common lowercase letter are not significantly different at $P = 0.05$; means for root pruning treatments followed by a common uppercase letter are not significantly different at $P = 0.01$.

compared with the other Pt inoculation treatments, and the Pt index of 55 for spring-sown seedlings exceeded the acceptable minimum (>50); these seedlings should exhibit improved performance on reforestation sites.

Lateral-root pruning significantly increased root weight and ectomycorrhizal development and reduced shoot/root ratio, attributes that are likely to benefit survival of longleaf pine on droughty sandy soils. Lateral-root pruning greatly increased the number of second- and third-order lateral roots, which produced feeder roots and ectomycorrhizae in abundance. Brown (1964) observed that longleaf pine produced at nursery bed density $<16/ft^2$ have a high percentage of "carrot-rooted" seedlings or other seedlings with deeply penetrating fibrous roots. He stated that lateral-root pruning during the growing season induces more abundant fibrous roots that remain attached to seedlings during the lifting operation. When lateral roots are not pruned, up to 80 percent of the fibrous roots remain in the soil after seedlings are lifted. This study confirmed Brown's observation that lateral-root pruning causes a compact, fibrous root system and showed that it promoted ectomycorrhizal development on roots likely to withstand the lifting operation.

CONCLUSIONS

Although these findings are preliminary, they indicate that optimum density of seedlings in nursery beds for producing high-quality longleaf pine stock is within the range of 6 to $12/ft^2$. Pruning lateral roots increases root weight and ectomycorrhizae and reduces shoot/root ratio, attributes desired on high-quality seedlings. Row seeding of longleaf pine to obtain uniform seed distribution will be needed to permit pruning of lateral roots. Application of Pt vegetative inoculum in fumigated soil at spring sowing will improve seedling quality, but careful nursery management is required for maximum effectiveness of this treatment. Application of Pt inoculum during fall sowing is not likely to be effective because of competition with airborne spores of other ectomycorrhizal fungi which fruit abundantly in the fall. Seedlings produced in nonfumigated soil may suffer from feeder-root necrosis or other root diseases and become stunted. Production of large (RCD $\geq$ 0.5 inch), high-quality seedlings requires effective disease control and maintenance of optimum soil fertility. Pt inoculation at spring sowing, 6 to 12 seedlings/ft^2 in nursery bed, and lateral-root pruning result in greatest survival and growth of longleaf pine seedlings in field studies.

Effective soil fumigation and inoculation with Pt during spring sowing, nursery bed densities of 6 to $12/ft^2$, lateral-root pruning, and optimum soil fertility should result in production of high-quality longleaf pine seedlings, thus eliminating the need for fall sowing. A better understanding

of longleaf pine seedling quality should result from outplanting studies with morphological and physiological characteristics of stock assessed.

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INFLUENCE OF *PISOLITHUS TINCTORIUS* AND FERTILIZATION ON THE DEVELOPMENT OF CONTAINER GROWN RED OAK SEEDLINGS[1/]

P. E. Pope and W. R. Chaney[2/]

Abstract.--Stratified *Quercus rubra* L. seed were sown in polyethylene-coated paper bands (4 x 4 x 10 1/2") filled with coarse silica sand previously inoculated with *Pisolithus tinctorius* (0, 100, 200 or 300 ml/2,500 cm^3 sand). Modified Hoagland's solution was added weekly after shoot emergence to provide nitrogen levels of 0, 100 and 200 ppm and phosphorus levels of 0, 50 and 100 ppm. After 17 weeks, percent colonization was erratic and was not correlated with the rate of inoculation. Height growth, stem diameter and dry weight of the various tissue components were significantly increased by either nitrogen, phosphorus or the amount of inoculum added. All parameters investigated showed significant interaction between nitrogen and rate of inoculation. The greatest growth response and stem caliper were achieved with 300 ml of Pt inoculum at moderate fertility.

INTRODUCTION

Containerized oak seedlings may be an alternative to bare-rooted seedlings, particularly to rectify the problems of poor survival and slow initial growth following outplanting (Forbes and Barnett 1974; Johnson 1979; Dixon et al. 1981). Garrett et al. (1979) postulated that the growth potential of containerized oak seedlings after outplanting could be greatly improved with well-developed mycorrhizal root systems. Preliminary investigations with red oak (*Quercus rubra* L.) indicate that this species is a host for the ectomycorrhizal fungus *Pisolithus tinctorius* (Pers) Coker and Couch (Marx 1979; Pope and Chaney 1980). Subsequent studies have demonstrated the superior survival and growth of container grown red oak seedlings inoculated with *P. tinctorius* (Pope 1981; Anderson et al. 1983).

Cultural practices used in producing containerized seedlings (e.g., use of artificial growth media, frequent applications of concentrated inorganic fertilizers, and a greenhouse environment) often restrict the development of normal mycorrhizal root systems and/or cause a high degree of variability in the extent of mycorrhizae formed. Information is needed on the culture techniques for containerized seedlings to insure consistency in seedling size and development, and extent of mycorrhizae formed.

This study concentrated on two of the factors which influence seedling development -- (1) rates of mycorrhizal fungal inoculation and (2) varying concentrations of nitrogen and phosphorus in the growing media. The purpose of the study was to determine the interactive roles of rooting media inoculation with *P. tinctorius* at various rates and variable concentrations of elemental nitrogen and phosphorus on the development of red oak seedlings grown in sand culture.

MATERIAL AND METHODS

Seed and Rooting Media Preparation

Red oak (*Quercus rubra* L.) seed were collected from five parent trees located in West Lafayette, Indiana in early November and screened for potentially sound seed by the flotation

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[2/] Associate Professor and Professor, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana 47907.

method. To kill insect larvae, all acorns which sank were submersed for 40 minutes in water maintained at a temperature of 46-48°C (Olson 1974). Following soaking the seeds were stratified in moist sand for 50 days at a temperature of 2°C.

The rooting media was a very coarse (1 mm) quartz sand. The sand was acid washed with 0.5 N HCl and rinsed with distilled water until the pH of the rinse water was equal to the pH of the distilled water prior to its addition to the sand. The acid washed sand was double autoclaved and stored in sealed containers until used.

Mycorrhizal Fungal Inoculation and Container System

The Pisolithus tinctorius (Pers) Coker and Couch fungal inoculum was obtained from Abbott Research Laboratories, North Chicago, Illinois and consisted of fungal mycelium cultured in a vermiculite medium. At the time of inoculation the moisture content was 23%. The P. tinctorius (Pt) inoculum was incorporated throughout a volume of quartz sand (10 x 10 x 25 cm = 2,500 cm^3) at rates of 0, 100, 200 or 300 ml. The uninoculated control treatment was "inoculated" with 200 ml of sterilized inoculum per 2,500 cm^3 volume. Each 2,500 cm^3 of quartz sand/inoculum was placed in a 10 x 10 x 27 cm open bottomed, plastic coated paper container obtained from Monarch Manufacturing Company, Denver, Colorado. Previous research on root growth of red oak grown in containers indicated no obstruction of root growth for this size container (Douglass and Pope 1979).

Seeding and Nutrient Amendments

Three red oak seeds were planted in each container and covered with 1.5 cm of the sand inoculum. Following a three week germination period, two seedlings were removed from each container leaving one seedling which most nearly represented the average seedling.

Following seedling thinning, 500 ml of a modified Hoaglands nutrient solution (Arnon 1950), adjusted to pH 5.8 with 0.05 N NaOH or 0.05 N HCl, was added to each container. Nutrient treatments consisted of all possible combinations of N and P at 0, 100 and 200 mg/kg, N and 0, 50 and 100 mg/kg, P. Nutrient additions were made every 3-7 days to maintain the original nutrient concentration of the quartz sand medium. Immediately prior to nutrient applications the sand was leached with 1000 ml of distilled H_2O to remove any nutrients. Seedlings were grown in a greenhouse for 17 weeks at a photoperiod of 16 h and maximum and minimum temperatures of 34 and 21°C, respectively.

Experimental Design and Seedling Measurements

The study was arranged in a randomized block factorial design with 4 replications of each treatment combination, 144 individual seedlings in total. The treatments consisted of 4 rates of fungal inoculation (0, 100, 200, and 300 ml of vermiculite inoculum per 2500 cm^3 of quartz sand), 3 nitrogen concentrations (0, 100 and 200 mg/kg) and 3 phosphorus concentrations (0, 50 and 100 mg/kg). The data were analyzed by an analysis of variance (ANOVA) and means were separated by Duncan's new multiple range test.

At the termination of the study, seedlings were evaluated for chemical and physical characteristics and the extent of mycorrhizae formed. Chemical characteristics measured included the N (Wilde et al. 1972) and P (Wilde et al. 1972) concentrations and methanol extractable carbohydrates (Priestly 1965) in stems, foliage, taproot and lateral roots. Physical characteristics quantified included stem height and diameter (1 cm above root collar), number of leaves and dry weight of stem foliage, taproot and lateral roots following oven drying at 80°C to a constant weight. The mycorrhizal colonization was assessed following the methods of Grand and Harvey (1982).

RESULTS AND DISCUSSION

Seedling physical and chemical characteristics were significantly influenced by nutrient concentrations and rates of P. tinctorius inoculation. To simplify the discussion, only the physical characteristics of the seedlings associated with the balanced nitrogen (N) and phosphorus (P) nutrient treatments will be discussed (i.e., N-0, P-0; N-100 mg/kg, P-50 mg/kg; N-200 mg/kg, P-100 mg/kg). Stem height, caliper and total dry weight of seedlings were significantly effected by nutrient availability and rate of Pt inoculation (Table 1). For each inoculation treatment, stem height and total plant dry weight tended to increase with increases in N and P available for seedling uptake. Increases in rates of Pt inoculation stimulated seedling height growth and total dry weight for the N-0, P-0 treatment. The largest seedlings (height and dry weight) were associated with the N-100, P-50 nutrient treatment and an inoculation rate of 300 ml/2,500 cm^3 quartz sand. The responses of stem caliper to variation in available nutrients and rates of Pt inoculation are less clear. For each inoculation rate, when compared to the control, stem caliper significantly increased at the N-100, P-50 nutrient treatment but showed no additional increases at the highest (N-200, P-100) nutrient treatment. Increasing rates of Pt inoculation stimulated stem caliper growth only for the N-100, P-50 nutrient treatment.

Table 1.--Influence of nitrogen and phosphorus fertilization and mycorrhizal fungal inoculation with P. tinctorius on selected growth parameters of red oak seedlings after 17 weeks.

N and P Fertilization (mg/kg)	Physical Characteristics											
	Stem Height (cm)				Stem Caliper (mm)				Total Dry Weight (g)			
	I_0 [1/]	I_{100}	I_{200}	I_{300}	I_0	I_{100}	I_{200}	I_{300}	I_0	I_{100}	I_{200}	I_{300}
N-0, P-0	15a [2/]	18ab	23b	20ab	2.9a	3.4ab	4.2b	3.2ab	3.4a	4.0a	6.6c	5.0b
N-100, P-50	50cd	38c	49cd	75e	4.8b	5.2bc	5.3bc	6.3c	10.0cd	10.6cd	13.7d	21.2c
N-200, P-100	52cd	48cd	58d	40c	5.0b	5.3bc	5.2bc	5.4bc	14.0d	14.6d	15.3d	8.1cd

[1/] P. tinctorius mycelial inoculum applied at I_0 = control, I_{100} = 100 ml/2,500 cm^3 quartz sand, I_{200} = 200 ml/2,500 cm^3 quartz sand, and I_{300} = 300 ml/2,500 cm^3 quartz sand.

[2/] For a specific plant variable, values not followed by the same letter are significantly different by Duncan's new multiple range test ($\alpha = 0.05$).

Available N in the sand culture and Pt inoculation rate interacted to significantly influence the total dry weight of red oak seedling roots (Table 2). At nitrogen levels of 0 and 100 mg/kg, total root dry weight increased with increasing rates of inoculation except for roots grown at 100 mg/kg nitrogen and an inoculation rate of 300 ml/2,500 cm^3 quartz sand. At a solution nitrogen concentration of 200 mg/kg, root dry weight tended to decrease with increasing rates of Pt inoculation except for the 300 ml/2,500 cm^3 rate. The pattern of root growth becomes less clear for the high inoculation, high nitrogen solution treatments. The greatest overall root dry weights were achieved at solution nitrogen concentrations of 100 mg/kg in combination with 200 ml's of Pt mycelial inoculum and 200 mg/kg nitrogen with 300 ml's of Pt inoculum.

The root dry weight was separated into components, taproot and lateral root. Averaged over all treatments, the taproot weighed 2.37 grams and was not significantly influenced by phosphorus treatment (1.62-2.55 g), rate of Pt mycelial inoculation (2.03-2.81 g), the interaction of solution nitrogen and phosphorus concentrations (1.11-3.08 g), or the interaction of solution nitrogen cencentration and inoculation rate (1.34-3.89 g).

The significant differences associated with treatment effects and total dry weight of root systems is a function of differences in dry weight associated with lateral roots (Table 3). For either the 0 mg/kg nitrogen treatment or 0 ml of Pt inoculation treatment, as the other interactive component increased, so did the dry weight of the lateral roots. At the 100 mg/kg nitrogen treatment, lateral root weight was not affected by inoculation rate except for the 200 Pt mycelium/2,500 cm^3 rate. Similarly, lateral root weight was unchanged by rates of inoculation at the 200 mg/kg nitrogen concentration except for the 300 ml Pt mycelium/2,500 cm^3 treatment.

Shoot to root ratio (S/R) increased with increasing concentrations of N in the nutrient solution but declined as P concentrations increased. S/R ratio increased from 1.43 at the N-0 treatment to 1.97 at N-100 treatment and declined slightly to 1.90 at the N-200 treatment. S/R ratio followed the reverse trend with increasing concentrations of available P. As P concentrations increased from 0, 50 and 100 mg/kg in the sand culture, R/S ratio declined from 1.73 to 1.25, to 0.96. Increases in available nitrogen increased shoot (stem and foliage) growth relative to root growth thereby increasing the S/R ratio. Increases in available P are often associated with the stimulation of root growth relative to stem and foliage growth.

Total plant dry weight was significantly influenced by the interaction of nitrogen and phosphorus in solution (Table 4). When averaged over all inoculation treatments, as nitrogen concentrations increased from 0 to 200 mg/kg, and phosphorus concentrations increased from 0 to 50 mg/kg, total plant dry weight also increased. Except for the N-0 treatment, increases in phosphorus concentration to 100 mg/kg resulted in declines in total dry weight of oak seedlings.

Inoculation rate interacted significantly with nitrogen and phosphorus to influence leaf weight (Table 4). There was generally little effect of Pt inoculation rate on leaf dry weight

Table 2.--Interaction of inoculation rate and solution nitrogen on total root dry weight (grams) of red oak seedlings grown in containers in the greenhouse for 17 weeks.

N Content of Sand Culture (mg/kg)	*Pisolithus tinctorius* Inoculation (ml/2,500 cm^3 quartz sand)				
	0	100	200	300	Mean
0	1.75a[1/]	2.74ab	3.22b	3.85b	2.89
100	3.24b	3.01ab	5.06c	2.69a	3.50
200	3.95b	3.19b	3.01ab	5.55c	3.92
Mean	2.98	2.98	3.76	4.03	

[1/] Values not followed by the same letter are significantly different (α = 0.05) by Duncan's new multiple range test.

Table 3.--Interaction of inoculation rate and solution nitrogen on the lateral root dry weight (grams) of red oak seedlings grown in containers in the greenhouse for 17 weeks.

N Content of Sand Culture (mg/kg)	*Pisolithus tinctorius* Inoculation (ml/2,500 cm^3 quartz sand)				
	0	100	200	300	Mean
0	0.41a[1/]	0.79ab	0.88ab	1.18bc	0.81
100	0.98ab	0.95ab	1.80c	0.79ab	1.13
200	1.26bc	1.09abc	1.07abc	1.66c	1.27
Mean	0.88	0.95	1.21	1.25	

[1/] Values not followed by the same letter are significantly different (α = 0.05) by Duncan's new multiple range test.

for plants grown in the N-0 treatment but at the nitrogen concentration of 100 to 200 mg/kg (N-100 and N-200 treatments), increasing rates of mycorrhizal inoculation are associated with greater leaf weights. The greatest leaf weight is associated with the N-200 nitrogen treatment and the I-200 (200 ml/2,500 cm^3 sand) mycorrhizal fungal inoculation treatment. Increases in inoculation rate for the N-200 nitrogen treatment resulted in decline in total leaf weight.

An increase in inoculation rate at the P-0 phosphorus treatment resulted in a steady but nonsignificant increase in leaf weight (Table 4). At the P-50 (50 mg/kg) phosphorus treatment, increases in inoculation rate resulted in increases in leaf dry weight. For the P-100 phosphorus treatment, inoculation rate did not significantly influence leaf dry weight for the I-0, I-100 or I-200 inoculation treatments but showed a marked increase in leaf weight for the

Table 4.--Interaction of solution nitrogen and phosphorus concentrations on total seedling dry weight and the interaction of Pt inoculation rate and nitrogen, and phosphorus concentration of the nutrient solution on leaf dry weights of seedlings.

Concentration of Nitrogen in Quartz Sand (mg/kg)	Total Dry Weight (g) P conc. (mg/kg)			Leaf Dry Weight (g) Inoculation Rates ($ml/2,500\ cm^3$ sand)			
	0	50	100	0	100	200	300
N-0	4.8a[1/]	6.4ab	6.8ab	2.4a[1/]	1.5a	2.6a	2.3a
N-100	4.6a	13.6d	11.3c	3.6ab	3.7ab	5.7c	4.2bc
N-200	7.4b	13.0d	13.0d	4.7bc	4.3bc	6.8c	4.7bc

Concentration of Phosphorus in Quartz Sand (mg/kg)	Leaf Dry Weight (g) Inoculation Rates ($ml/2,500\ cm^3$ sand)			
	0	100	200	300
P-0	2.0a[1/]	2.2a	3.3ab	2.8a
P-50	3.7ab	3.7ab	5.6c	5.3c
P-100	4.0ab	4.4bc	4.8bc	4.8bc

[1/]For a particular set of interactive variables, values followed by a different letter are significantly different by Duncan's new multiple range test ($\alpha = 0.05$).

I-300 inoculation treatment. For the control (I-0) and the I-100 (100 $ml/2,500\ cm^3$ sand) inoculation treatment, leaf dry weight increased with increasing phosphorus concentrations. At the I-200 inoculation treatment, leaf dry weight increased as phosphorus concentration increased to 50 mg/kg and then declined at P concentrations of 100 mg/kg. At the highest rate of inoculation, I-300 (300 $ml/2,500\ cm^3$ sand) leaf dry weight increased with increasing concentrations of phosphorus.

The results of this study appear to be in conflict with the growth data presented by Beckjord et al. (1980) who found that red oak seedlings uninoculated with Pt and receiving no N fertilizer were larger than the inoculated and fertilized seedlings. The author concluded that the levels of N, all less than 53 mg/l, were probably suboptimal for good growth. Comparison of the data from the two studies yield several differences. The present study utilized higher rates of Pt inoculation, a different isolate of Pt (isolate #138 instead of isolate #185) and higher rates of N fertilization. These differences could account for the differences observed in the study. High rates of fertilization appeared to reduce the beneficial effects associated with Pt inoculation. Except for the N-0 and P-0 treatments the seedlings were not nutrient stressed.

The colonization of seedlings by mycorrhizal fungi is often associated with changes in the percentage of extractable carbohydrates in plant tissue. These differences were not evident for any of the treatment combinations for root or foliage tissue but tended to show an effect for stem tissue. On the average 23.5% of the dry weight of stem tissue is attributed to methanol extractable carbohydrates (MEC) and ranged from 12.5-34.7%. While inoculation rate had no significant influence on the percentage of methanol extractable carbohydrates in the stem tissue, it did influence the number of seedlings with MEC values greater than the average of 23.5%. The maximum number of occurrences for any one inoculation treatment is 36. The number of occurrences of seedlings with stem methanol extractable carbohydrates greater than the mean was 20 for the 300 ml inoculation treatment, 36 for the 200 ml inoculation treatment, and 12 for the uninoculated control and the 100 ml inoculation treatment.

The extent of the mycorrhizae formed on the root systems was determined as a percentage of the total number of short roots, i.e., number of lateral roots which formed mycorrhizae divided by the total number of lateral roots. On the average, 48% of the lateral roots of all inoculated seedlings was colonized by the fungus P. tinctorius and ranged from 21 to 63%. No mycorrhizae formed on the uninoculated control seedlings. Because of the high degree of variability among treatments, there were no significant differences in the percentage of mycorrhizae formed for any of the inoculation treatments. At low concentrations of P in the nutrient solution, the % of Pt colonization tended to increase with increasing amounts of Pt inoculum and N concentration in the nutrient solution (range 31-50%). At high concentrations of N and P in the nutrient solutions, the amount of mycorrhizae formed was low (21-33%) and showed no relationship to inoculation treatment. The greatest development of mycorrhizae occurred at the moderate nutrient treatment where the N to P ratio was 2:1 (100 mg/kg, N and 50 mg/kg, P). The percentage of Pt colonization averaged 57% and ranged from 48%, at the 100 ml Pt inoculum per 2,500 cm^3 sand, to 63% at the 300 ml inoculation rate.

The absence of any significant difference among treatments means in the amount of Pt ectomycorrhizae formed (measured as % of total lateral roots) is disappointing but not totally surprising. Grand and Harvey (1982) indicate the percentage figure may be statistically overwhelmed because of such overriding factors as size of seedling and number of roots. This is apparently the case in this study. Even with a small genetic base (5 parent trees), the genetic variability appeared to be significantly large enough to cause a large variability in seedling size and number of short roots for a nutrient and inoculation treatment combination causing such variability in the % colonization figure that it was not significant.

CONCLUSIONS

From these data it appears that inoculation rate and solution nitrogen concentration interact positively to increase total plant dry weight and the percentage of root dry weight occurring in lateral roots. Secondly, increases in solution nitrogen concentration and decreases in solution phosphorus concentrations significantly increased plant shoot to root ratios. And finally, the physical parameters of red oak seedlings grown at moderate levels of fertility are significantly increased by inoculation with Pisolithus tinctorius.

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THE PERFORMANCE OF LOBLOLLY, VIRGINIA, AND SHORTLEAF PINE ON A RECLAIMED SURFACE MINE AS AFFECTED BY *PISOLITHUS TINCTORIUS* ECTOMYCORRHIZAE AND FERTILIZATION[1]

R. F. Walker, D. C. West, S. B. McLaughlin, and C. C. Amundsen[2]

Abstract. The effects of an induced *Pisolithus tinctorius* infection and broadcast fertilization on the survival and growth of loblolly (*Pinus taeda*), Virginia (*Pinus virginiana*), and shortleaf (*Pinus echinata*) pine outplanted on an east Tennessee coal surface mine which had been regraded and hydroseeded with a mixture of ground cover species were studied. After six years, the survival and growth of loblolly pine with *P. tinctorius* ectomycorrhizae were significantly improved in comparison with control loblolly pine infected by other ectomycorrhizal symbionts, but fertilization at outplanting resulted in a significant reduction in the survival of this species. The response of the Virginia pine to the infection by *P. tinctorius* was negligible after five years, but fertilization at outplanting also significantly reduced the survival of Virginia pine. Fertilization of the shortleaf pine at the start of the third growing season did not result in the drastic mortality exhibited by the loblolly pine, and to a lesser extent the Virginia pine, in response to fertilization at outplanting, but this treatment was still detrimental to the survival of this species after five years. There was a marginal improvement in the survival and growth of the shortleaf pine in response to the infection by *P. tinctorius*. The effect of fertilization on the growth of all three species was negligible. These results indicate that the magnitude of the response exhibited by pines on harsh sites to an ectomycorrhizal infection by *P. tinctorius* is species dependent. Also, broadcast fertilization is inefficient on surface-mined sites where a vegetative ground cover has been established, and there is a need for further research concerning the methods, timing, and rates of fertilization employed on these sites when both ground cover and pine species are included in post-mining revegetation.

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2/ The authors are University of Tennessee Research Associate stationed in the Environmental Sciences Division of the Oak Ridge National Laboratory, Oak Ridge, TN 37831; Research Staff Member and Senior Research Staff Member, respectively, Environmental Sciences Division, Oak Ridge National Laboratory; and Associate Professor, Graduate Program in Ecology, University of Tennessee, Knoxville, TN 37996.
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INTRODUCTION

Mycorrhizal relationships are receiving major consideration in the development of improved reforestation techniques for surface-mined lands. Due to mining practices which frequently result in the burial of surface strata, the status of mine spoils in relation to their ability to promote these symbiotic associations is questionable. Subsequently, the inoculation of selected species of forest tree seedlings with the appropriate mycorrhizal fungus prior to outplanting has considerable potential as an invaluable tool in the revegetation of these sites. There is ample evidence which suggests that certain ectomycorrhizal fungi have a superior ability to provide benefits to their

hosts under the adverse growing conditions prevalent in mine spoils, which are often characterized by a low pH, low nutrient status, high concentrations of toxic substances, elevated surface temperatures, and droughtiness. Marx (1977) has reported the occurrence of Pisolithus tinctorius (Pers.) Coker and Couch in association with several forest tree species on a variety of mine spoils, and in preliminary studies, pine seedlings with an induced infection by P. tinctorius have exhibited survival and growth superior to that of noninoculated seedlings infected with naturally occurring fungal symbionts on several surface mine sites (Berry 1982, Marx and Artman 1979, Walker et al. 1981). The study reported here was designed to assess the effect of an induced infection by P. tinctorius on the survival and growth of loblolly (Pinus taeda L.), Virginia (Pinus virginiana Mill.), and shortleaf (Pinus echinata Mill.) pine outplanted in conjunction with the establishment of a vegetative ground cover on a surface mine in Tennessee. Due to the demonstrated response of forest trees to nutrient amendments on such sites (Zargar et al. 1973), a fertility variable was introduced to permit an examination of the interactions of P. tinctorius ectomycorrhizae and fertilization as they affected the performance of these species.

MATERIALS AND METHODS

The P. tinctorius inoculums used in the production of the loblolly and shortleaf pine seedlings in this study, designated GA 100, were produced by the Institute for Mycorrhizal Research and Development (IMRD) of the USDA Forest Service.3/ The P. tinctorius inoculums used in the production of the Virginia pine seedlings consisted of three formulations; the GA 100 produced by the IMRD, and the ABB 100 and AB 200, produced by Abbott Laboratories.4/ All of the P. tinctorius inoculums consisted of fungal mycelia grown on a vermiculite-peat moss-nutrient medium substrate such that the hyphae permeated the vermiculite particles. For the loblolly, Virginia, and shortleaf pine seedlings, GA 100 designates the application of the inoculums produced by the IMRD to the nursery bed at the rate of 1.08 l m^{-2}. For the Virginia pine seedlings, ABB 100 and ABB 200 designates the application of the inoculum produced by Abbott Laboratories to the nursery bed at the rate of 1.08 l m^{-2} and 2.16 l m^{-2}, respectively. The methods of production of the seedlings of each of the three species used in this study were described in detail by Marx et al. (1984). The loblolly pine seedlings, grown by the Weyerhaeuser Company5/ at their Fort Towson, Oklahoma Nursery, were lifted in January 1978. The Virginia pine seeldings, grown by the Indiana Division of Forestry at their Vallonia State Nursery6/, and the shortleaf pine seedlings, grown by the Missouri Department of Conservation at their George O. White State Nursery7/, were lifted in March and April 1979, respectively. Control seedlings of each of the three species were grown identically to their inoculated counterparts except that no inoculums were incorporated into the nursery bed. At lifting, the degree of ectomycorrhizal development of the seedlings of all species and treatments was evaluated by the IMRD by the method of Marx and Bryan (1975), and the seedlings to be outplanted were graded to uniform heights and root collar diameters.

The outplanting site was a surface mine located on a west-facing slope in Campbell County, Tennessee (36°19'30"N, 84°17'30"W). All mining ceased in the fall of 1977 and the spoil was returned to the approximate original contour. The site was immediately hydroseeded with a mixture of Kentucky 31 tall fescue (Festuca arundinacea Schreb.), perennial ryegrass (Lolium perenne L.), and sericea lespedeza (Lespedeza cuneata [Dumont] G. Don), and then a straw-cellulose fiber-asphalt mulch was applied. The loblolly pine seedlings were hand planted in April 1978 in a randomized block design with five replicate blocks. Each block consisted of four plots of 25 seedlings each planted in five rows of five seedlings each with a spacing within and between rows of approxiamtely 1.25 m and a spacing between plots of approxiamtely 6 m. The treatments of the loblolly pine consisted of the GA 100 seedlings fertilized at the rate of 336 kg ha^{-1} NPK, nonfertilized GA 100 seedlings, control seedlings also fertilized at the rate of 336 kg ha^{-1} NPK, and nonfertilized control seedlings. Each of the four treatments was represented in individual plots within each block. Prior to the application of the fertilizer, five soil subsamples were collected from each plot at a depth of 0 to 20 cm and combined into one composite sample per plot. These samples were analyzed for pH by use of a glass electrode on a 1:1 mixture of soil and distilled water; total N by macro-Kjeldahl digestion; weak bray P colorimetrically after extraction with NH_4F and HCl; K by atomic absorption after extraction with $NH_4C_2H_3O_2$; Fe and Mn by atomic absorption after extraction with HCl; and Al by atomic absorption after extraction with KCl.8/ After the collection of the soil samples, 82 g of 15-15-15 (NPK) granular fertilizer was evenly distributed over 0.37 m^2 around each of the appropriate seedlings to achieve the fertilization equivalent of 336 kg ha^{-1} NPK (as N, P_2O_5, and K_2O). The Virginia pine seedlings were hand planted in April 1979 in a

3/ Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Carlton Street, Athens, Georgia 30602.

4/ Agricultural Research Center, 6131 RFD Oakwood Road, Long Grove, Illinois 60047.

5/ Southern Forestry Research Center, P.O. Box 1060, Hot Springs, Arkansas 71901.

6/ Route 1, Vallonia, Indiana 47281.

7/ Route 2, Box 465, Licking, Missouri 65542

8/, 9/, and 10/ All soil analyses were done by A&L Agricultural Laboratories, Incorporated, 411 North Third Street, Memphis, Tennessee 38105.

split plot design with three replicate blocks. Each block consisted of four plots of 50 seedlings each planted in five rows of 10 seedlings each with a spacing within and between rows of approximately 1.25 m and a spacing between plots of approximately 6 m. The mycorrhizal treatments of the Virginia pine consisted of the GA 100, ABB 100, ABB 200, and control seedlings, and each of the four mycorrhizal treatments was represented in individual plots within each block. Each plot was then divided into two subplots, one of which was fertilized at the rate of 336 kg ha^{-1} NPK by the method described above for the loblolly pine.9/ The shortleaf pine seedlings were planted in May 1979 in a split plot design identical to that of the Virginia pine except that there were only two replicate blocks, the mycorrhizal treatments consisted only of the GA 100 and control seedlings, and the fertility treatments were not initiated until the start of the third growing season. The rate and method of fertilization and the collection and analyses of the soil samples10/ for the shortleaf pine were the same as those described above for the Virginia pine. Survival, height, and root collar diameter measurements were made annually through the sixth year for the loblolly pine and through the fifth year for the Virginia and shortleaf pine. The plot volume index of Marx et al. (1977), which incorporates both survival and growth, was employed as an indicator of overall seedling performance in response to each combination of treatments. This index is defined as the height (cm) x (root collar diameter [cm])^2 x number of surviving seedlings per plot (for loblolly pine) or per subplot (for Virginia and shortleaf pine). Analyses of variance were done on all data and the differences among means were evaluated with Duncan's New Multiple Range Test.

RESULTS

The examinations of the seedling root systems at lifting from the nursery bed revealed that ectomycorrhizae formed by P. tinctorius were at least moderately abundant on the GA 100 seedlings of the loblolly, Virginia, and shortleaf pine and on the ABB 200 seedlings of the Virginia pine. Thelephora terrestris (Ehrh.) Fr. appeared to be the predominant naturally occurring ectomycorrhizal symbiont on the roots of the inoculated and control seedlings of all three species. The GA 100 loblolly pine seedlings had 15% of their feeder roots infected with P. tinctorius and 17% infected with naturally occurring ectomycorrhizal fungi. Ninety percent of the GA 100 loblolly pine seedlings examined were infected with P. tinctorius. The loblolly pine control seedlings had 35% of their feeder roots infected with naturally occurring ectomycorrhizal symbionts, and none of those examined were infected with P. tinctorius. Twenty percent and 22%, respectively, of the feeder roots of the GA 100 and ABB 200 Virginia pine seedlings were infected with P. tinctorius, and 100% of the seedlings examined of these two treatments were infected with this symbiont. Five percent of the feeder roots of these two treatments were infected with naturally occurring symbionts. The ABB 100 Virginia pine seedlings had only 5% of their feeder roots infected with P. tinctorius and 12% infected with other symbionts, and only 50% of the seedlings examined were infected with P. tinctorius. Twenty percent of the feeder roots of the Virginia pine control seedlings were infected with naturally occurring symbionts, and none of the seedlings examined of this treatment were infected with P. tinctorius. Forty-three percent of the feeder roots of the GA 100 shortleaf pine seedlings were infected with P. tinctorius and 10% were infected with other fungal symbionts. All of the GA 100 seedlings examined of this species were infected with P. tinctorius. None of the shortleaf pine control seedlings were infected with P. tinctorius, but 35% of their feeder roots were infected by other ectomycorrhizal fungi.

The analyses of the soil samples collected at outplanting from the plots of the loblolly pine seedlings revealed that no significant difference existed for any of the parameters tested between the groups of plots of each combination of ectomycorrhizal and fertilization treatment (P=0.05). The means for all of the loblolly pine plots were pH 6.0, 1049 ppm total N, 12 ppm weak bray P, and 120, 340, 136, and 12 ppm of K, Fe, Mn, and Al, respectively. The analyses of the soil samples collected at outplanting from the subplots of the Virginia pine seedlings revealed that no significant difference existed at P=0.05 in pH, total N, weak bray P, K, Mn, or Al between the groups of subplots of each combination of treatments, but that the subplots of the nonfertilized GA 100 seedlings had a significantly higher concentration of Fe than the subplots of the nonfertilized control seedlings. The groups of subplots of the other treatment combinations did not differ significantly from either of these in the concentration of Fe. The means for all of the Virginia pine subplots were pH 5.3, 1265 ppm total N, 10 ppm weak bray P, and 119, 230, 99, and 92 ppm of K, Fe, Mn, and Al, respectively. The analyses of the soil samples collected at outplanting from the subplots of the shortleaf pine seedlings revealed that no significant differences existed at P=0.05 for any of the parameters tested between the groups of subplots of each combination of treatments. The means for all of the shortleaf pine subplots were pH 5.0, 1228 ppm total N, 6 ppm weak bray P, and 105, 89, 44, and 144 ppm of K, Fe, Mn, and Al, respectively. The variability inherent in the chemical properites of minesoils in the southern Appalachian region was much in evidence on this site. Overall, however, this mine site was typical of those found in this region in that it was deficient in P and the levels of Fe and Mn were high (Cummins et al. 1965). With the exception of the portion of the site on which the loblolly pines were planted, the level of Al was also

Table 1. The survival and growth of loblolly pine with and without *Pisolithus tinctorius* ectomycorrhizae and with and without fertilization after six years on a reclaimed surface mine in Tennessee.1/

Treatment	Survival (%)	Mortality: Two Years Following Fertilization Treatment (%)	Height (cm)	Root Collar Diameter (mm)	Plot Volume Index (cm^3)
GA 100 Fertilized	53b	41b	146a	28a	59,939a
GA 100 Nonfertilized	76a	9c	136ab	26ab	55,679a
Control Fertilized	27c	66a	123b	24ab2/	6,615b
Control Nonfertilized	62b	21bc	128ab	24b2/	25,761b

1/ Within a column, means with a common letter do not differ significantly at P=0.1.

2/ Difference in grouping between identical means due to rounding.

typically high. It was atypical in that the level of N was adequate for most of the plant species commonly used in the revegetation of these sites.

The survival of loblolly pine was significantly affected after six years by the infection with *P. tinctorius* and by fertilization (Table 1). *P. tinctorius* ectomycorrhizae promoted enhanced survival of the GA 100 trees, but fertilization at outplanting reduced survival irrespective of the mycorrhizal treatment. The interaction of the two treatments resulted in some moderation of their opposite effects, but the positive result of the *P. tinctorius* infection only partially compensated for the negative result of fertilization. The reduction in survival associated with fertilization was most drastic among the control trees, but within both mycorrhizal treatments, the mortality of fertilized trees during the first two years was significantly higher than that of nonfertilized trees and a disproportionate amount of the mortality of the fertilized trees over the six years of measurement occurred during the first two years. The infection by *P. tinctorius* also significantly increased the growth in both height and root collar diameter of the loblolly pine after six years, but the effect of this treatment on growth was not as dramatic as its effect on survival. The effect of fertilization on the growth of this species was largely negligible. The overall superior performance of the trees with *P. tinctorius* ectomycorrhizae was most apparent when survival and growth were integrated into plot volume index for each of the combinations of treatments. As a whole, the plot volume index of the trees with these mycorrhizae was more than 250% greater than that of the control trees. The exceedingly low plot volume index of the fertilized control trees was primarily the result of their poor survival.

The survival of Virginia pine was not significantly affected by an infection with *P. tinctorius* after five years, but fertilization at outplanting significantly reduced survival within every mycorrhizal treatment except for the control trees (Table 2). Within the control treatment, the trend of reduced survival associated with fertilization noted for the other mycorrhizal treatments was maintained, but the difference between fertilized and nonfertilized trees was not significant. Mortality during the first two years was significantly higher for fertilized than for nonfertilized trees within all but one of the mycorrhizal treatments, the exception again being the control treatment, but here also the prevailing trend was evident. Any effect of either the mycorrhizal or fertilization treatments on the height, root collar diameter, or plot volume index of Virginia pine was nonsignificant after five years, and non discernible trend existed in the variation among treatment combinations of any of these parameters.

The survival of shortleaf pine was also not significantly affected by an infection with *P. tinctorius*, but fertilization during the third year significantly reduced the survival of this species after five years (Table 3). Within both the GA 100 and control mycorrhizal treatments, mortality during the two years following fertilization was significantly higher in fertilized

Table 2. The survival and growth of fertilized and nonfertilized Virginia pine with *Pisolithus tinctorius* ectomycorrhizae from three inoculum formulations and fertilized and nonfertilized control Virginia pine after five years on a reclaimed surface mine in Tennessee.1/

Treatment	Survival (%)	Mortality: Two Years Following Fertilization Treatment (%)	Height (cm)	Root Collar Diameter (mm)	Plot Volume Index (cm^3)
GA 100 Fertilized	67b	23ab	169a	30a	52,648a
GA 100 Nonfertilized	87a	9cd	158a	27a	38,056a
ABB 100 Fertilized	69b	27a	180a	30a	68,380a
ABB 100 Nonfertilized	92a	7cd	190a	34a	72,485a
ABB 200 Fertilized	72b	20a	172a	30a	72,017a
ABB 200 Nonfertilized	95a	1d	172a	30a	58,103a
Control Fertilized	88a	12abc	182a	30a	54,348a
Control Nonfertilized	92a	5bcd	176a	29a	61,710a

1/ Within a column, means with a common letter do not differ significantly at P=0.1.

than in nonfertilized trees, although the application of fertilizer to the shortleaf pine at the onset of the third growing season did not result in the drastic mortality during the ensuing two years exhibited by the loblolly pine, and to a lesser extent the Virginia pine, in response to an identical application at outplanting. Neither the mycorrhizal nor the fertilization treatments had a significant effect on the height or root collar diameters of the GA 100 trees were marginally larger than those of the control trees. Overall, the plot volume index of the GA 100 trees was almost 80% greater than that of the control trees, but the differences in plot volume index between treatment combinations were nonsignificant.

DISCUSSION

It can be concluded that *P. tinctorius* ectomycorrhizae significantly improved the survival and growth of loblolly pine after six years on this site. It is probable that the deficient level of P and the elevated levels of Fe and Mn in this minesoil rendered these mycorrhizae particularly important to this host, as an infection by *P. tinctorius* has been shown to enhance the performance of pine seedlings on sites having deficiencies of essential nutrients and/or elevated levels of potentially toxic metallic ions (Berry 1982, Marx and Artman 1979). It is also possible that the increased capability for the absorption of water and nutrients afforded loblolly pine by the *P. tinctorius* ectomycorrhizae was of added importance in this study due to competition with the ground cover species planted on the site. The desirability of revegetating surface mines simultaneously with both ground cover and woody species is obvious, but the resulting competition for light, water, and nutrients is often intense. The presence of *P. tinctorius* ectomycorrhizae on the roots of the Virginia pine had essentially no effect on the performance of this host species after five years. It is possible that this site was not inadequate for the growth of Virginia pine, a species noted for its hardiness on poor sites, to

Table 3. The survival and growth of shortleaf pine with and without *Pisolithus tinctorius* ectomycorrhizae and with and without fertilization after five years on a reclaimed surface mine in Tennessee.1/

Treatment	Survival (%)	Mortality: Two Years Following Fertilization Treatment (%)	Height (cm)	Root Collar Diameter (mm)	Plot Volume Index (cm^3)
GA 100 Fertilized	40b	10a	132a	31a	18,213a
GA 100 Nonfertilized	72a	0c	150a	35a	40,901a
Control Fertilized	40b	10a	141a	28a	16,337a
Control Nonfertilized	56ab	4b	131a	25a	16,537a

1/ Within a column, means with a common letter do not differ significantly at P=0.1.

the extent that the potential advantage afforded the inoculated trees by *P. tinctorius* did not exceed that provided the control trees by other ectomycorrhizal symbionts. In all probability, a higher initial level of ectomycorrhizal development by *P. tinctorius* on the roots of both the inoculated loblolly and Virginia pine would have resulted in a more substantial improvement in their growth after outplanting, as the initial level of infection of both species by this symbiont could only be considered moderate. The infection of shortleaf pine by *P. tinctorius* resulted in marginal, although usually nonsignificant, improvement in the performance of this species after five years, but inadequate replication necessitated that differences between treatments be exceedingly large to be significant. Throughout this study, the presence of numerous *P. tinctorius* basidiocarps associated with the inoculated trees of all three species provided evidence that this mycorrhizal relationship remained vigorous. The lack of any observed association of these basidiocarps with the control trees of any of the three species indicated that the integrity of the control mycorrhizal treatments remained largely intact.

Fertilization by broadcasting at the rate employed in this study was detrimental to the survival of the loblolly, Virginia, and shortleaf pine. The *P. tinctorius* ectomycorrhizae partially offset this effect in the loblolly pine but not in the other two species. Delaying fertilization until the start of the third growing season resulted in a moderation of this effect in the shortleaf pine, but there was still a significant increase in the mortality of the shortleaf pine associated with this treatment. The effect of fertilization on the growth of all three species was essentially negligible. Czapowskyj (1973) has also noted that the fertilization of forest trees on surface-mined lands was not entirely free from the risk of reducing survival, but the broadcast application of fertilizer at moderate to high rates at outplanting, the method most commonly employed in the southern Appalachian coal fields, may prove to be among the least desirable of the options available when the planting of trees is accompanied by the establishment of a vegetative ground cover. In this study, broadcast fertilization only served to stimulate the growth of the ground cover species, undoubtedly resulting in intense competition for light, water, and nutrients. During the two years following the fertilization of each of the three species, the ground cover species often overtopped the pine seedlings. Jorgensen (1981) has noted that sericea lespedeza competes vigorously with planted trees if control is not exercised on the density of the sericea stand, and this ground cover species appeared to be the primary culprit in a competition-induced increase in mortality of the fertilized trees of all three species in this study. It is also probable that fertilization at outplanting of the loblolly and Virginia pine stimulated excessive shoot growth during the first growing season which the root system was incapable of supporting during the dry periods of late summer and fall. It is likely that any imbalance in the shoot/root ratio of these seedlings contributed to an internal water deficit which was accentuated by the competition with the ground cover species. It is apparent that further research is warranted with respect to the rate, timing, and method of fertilization employed on surface-mined sites when the

establishment of both a ground cover and a tree crop is desired.

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DRY WEIGHT AND ELEMENT CONTENT OF THE HARDWOOD COMPONENT OF MATURE LOBLOLLY PINE FORESTS IN NORTH LOUISIANA[1/]

B. Graeme Lockaby and John C. Adams[2/]

Abstract. Dry weight and nutrient content of understory hardwoods were estimated in mature loblolly pine stands in north central Louisiana. Total understory dry weight was 23.8 t/acre with 4, 19, and 77% of this material distributed among the foliage, branches, and stems respectively. N, P, K, Ca, and Mg contents of 104.6, 9.1, 60.7, 158.8, and 27.1 lb/acre were contained in the understory hardwoods. In relation to the small amount of crown (foliage and branches) biomass, large proportions of all nutrients were contained in the crowns. These results are discussed in terms of the relatively large nutrient removal that would occur for the small gain in low quality biomass obtained by harvesting the crowns.

INTRODUCTION

The increasing cost of traditional sources of energy over the last decade has forced many consumers to adapt to new energy sources and technologies. Many forest industries have adapted the application of a new technology to an old energy source--wood.

In certain areas of the United States forest industries rely to varying degrees on the utilization of non-commercial timber for fuel. This fuelwood often consists of trees of undesirable species and poor form and/or residues left from the logging of commercial species. Hardwood understories in southern pine stands often fall into the former category.

There are several advantages associated with the removal of these understory hardwoods in the southern U.S. First, considerable biomass (and therefore, considerable energy) often is found in this strata (Anonymous, 1983, Ku and Baker, 1980). Second, the removal of these trees may facilitate marking and harvesting operations of commercial species (Cochran, 1984). And, third, the removal of this material can reduce site preparation activities (McMinn, 1983).

However, in comparison with the major commercial species, less research attention has been devoted to nutrient and biomass accumulation in the understory. Knowledge of nutrient accumulation is necessary for the proper assessment of nutrient drain in relation to soil fertility. Information regarding biomass is essential to determine the feasibility of harvesting this material.

The objectives of this study, therefore, were to provide information on both nutrition and biomass of the hardwood understories of mature loblolly pine (*Pinus taeda*) stands on sites of average quality in North Louisiana.

METHODS

Three study areas in north Louisiana were selected and sampled to estimate the biomass and nutrient content of the understory. These areas were located within the Hilly Coastal Plain physiographic province (Evans et al. 1983) in Jackson, Lincoln, and Webster Parishes and were selected as average quality north Louisiana loblolly pine sites 40-50 years old. The Jackson Parish site had been under low intensity forest management while the other two sites had received no formal forest management. There was no indication that fire had been used for understory control on any of the study areas.

The soils of the study areas were the Keithville (Glossaquic Paleudalf), Bowie (Fragic Paleudult), Lucy (Arenic Paleudult), and

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2/ B. Graeme Lockaby and J. C. Adams, are respectively Assist. & Assoc. Professor at the School of Forestry, LA Tech Univ., Ruston, LA 71272.

Frizzel series (Glossaquic Hapludalf). Site index for loblolly pine at 50 years was approximately 80-90 on all sites.

At each study area 12 plots of approximately 10 foot radius were systematically established for a total of 36 plots. Plot centers were 2 chains apart so that approximately 8.5 acres were sampled at each area.

All 2-10 inch DBH understory hardwoods were cut and separated into 3 components: foliage, stems, and branches. A total of 170 stems representing 17 species were sampled over the three study areas.

Green weights of each component for individual trees were obtained in the field. Component materials were composited by species and two samples were taken for each species component from every plot. One composite sample from each species component was used for moisture determinations at 70°C. The remaining sample was dried at the same temperature, ground to pass a 10 mm mesh sieve, and analyzed for N, P, K, Ca, and Mg*. Nitrogen was determined using semi-micro Kjeldahl, P was analyzed colorimetrically, and K, Ca, and Mg were determined by atomic absorption spectroscopy from ashed samples taken up in dilute HCl.

RESULTS AND DISCUSSION

Biomass

Approximately 4, 19, and 77% of the hardwood biomass is associated with the foliage, branches, and stems respectively. These percentages are similar to data reported elsewhere (Phillips and Van Lear, 1984, Johnson and Riser, 1984). The relatively high (23%) proportion of crown material is characteristic of hardwoods which follow a deliquescent pattern of branching according to Phillips and Van Lear (1984). This probably reflects a modification of the branching pattern of normally excurrent species such as sweetgum caused by the adequate growing space but less than optimum light conditions of the understory.

The total aboveground biomass of the understory hardwoods is nearly 24 t/acre (Table 1). This may be compared to the 12.8 t/acre reported by Ku and Baker (1980) in the understories of mature pine stands in southern Arkansas and northern Louisiana. However, these authors sampled only hardwoods < 5.5 inches DBH and, therefore, their values would be expected to be lower.

Table 1. Average dry weight and nutrient content of understory hardwoods at three locations in north Louisiana (standard errors in parentheses).

COMPONENT	DRY WEIGHT	N	P	K	Ca	Mg
	t/Acre	lb/acre				
Foliage	0.9 (0.1)	21.0 (4.3)	1.4 (0.4)	9.6 (1.9)	10.8 (3.3)	4.3 (0.9)
Branches	4.5 (0.9)	31.1 (8.2)	2.1 (0.5)	16.7 (3.3)	51.3 (13.1)	6.2 (1.4)
Stems	18.4 (3.2)	52.5 (9.6)	5.6 (1.3)	34.4 (6.0)	96.7 (19.5)	16.6 (2.8)
Total above-ground	23.8 (4.1)	104.6 (23.0)	9.1 (1.9)	60.7 (13.5)	158.8 (38.1)	27.1 (6.0)

*Analyzed by the Northeast University Soil and Plant Testing Laboratory.

Also, Phillips and Van Lear (1984) have observed that approximately 12 t/acre is a typical amount of biomass for 1-5 inch DBH understory trees in hardwood stands.

Francis (1984), working in an 11 year old bottomland hardwood stand in the Southern Mississippi Floodplain, estimated stand dry weight at 18.8 t/are. It is noteworthy that the biomass of the understories of mature pine stands exceeds that of Francis's study.

Although 17 species of deciduous trees were encountered on sampling plots, nearly 3/4 of the understory biomass was attributable to 4 species (Table 2). Frequency of occurrence of these species was not directly correlated with the amount of biomass associated with each species. Red maple and southern red oak rank 2 and 3 respectively in terms of biomass but rank 3 and 4 respectively in frequency. Blackgum, while ranking second in frequency, had less biomass than any of the other 3 species. This probably indicates numerous small stems in the cases of species ranking high in frequency but low in total biomass.

Nutrients

The hardwood understory contained approximately 105, 9, 61, 158, and 28 lb/acre of N, P, K, Ca, and Mg respectively (Table 1). A ranking of these quantities results in the following: Ca > N > K > Mg > P. This order is identical to that of Ku and Baker (1980) and very similar to that of Rochow (1975).

The amounts of nutrients presented in Table 1 may be compared with the data of Ku and Baker (1980). These authors report that 71.3, 8.7, 50.8, 109.6, and 11.7 lb/acre of the respective elements were contained in the 1-5" DBH hardwood understories of their study.

As would be expected, quantities of nutrients contained in hardwood biomass vary a great deal depending on such factors as the species involved and inherent soil fertility. This is evidenced by the nutrient content data of Francis (1984) which are higher than that of the present study for all 5 elements except Mg. Francis estimated that 176, 22, 115, 240, and 23 lb/acre of N, P, K, Ca, and Mg were contained in 25% less biomass than the 23.8 t/acre of the present study.

Table 2. Average dry weight and nutrient content of four most common understory hardwood species at three locations in north Louisiana (standard errors in parentheses).

FREQUENCY OF OCCURRENCE	SPECIES	DRY WEIGHT	N	P	K	Ca	Mg
		t/acre	lb/acre				
1	Liquidambar styraciflua (Sweetgum)	10.4 (2.5)	38.6 (10.1)	3.7 (1.3)	28.7 (9.1)	62.0 (14.1)	16.6 (5.4)
2	Nyssa sylvatica (Blackgum)	1.3 (0.4)	7.4 (1.9)	0.7 (0.4)	3.8 (1.2)	5.9 (5.8)	2.2 (0.8)
3	Acer rubrum (Red Maple)	3.9 (2.0)	24.4 (12.4)	1.9 (1.0)	12.2 (5.9)	18.8 (11.6)	4.7 (2.4)
4	Quercus falcata (S. red oak)	1.5 (0.8)	19.9 (14.9)	0.3 (0.0)	5.8 (3.0)	11.5 (6.8)	1.0 (0.5)

This is probably due to species differences between the two studies as well as the generally high fertility of the Mississippi alluvium of Francis's study area.

Component element content decreases in the order stem > branches > foliage for all 5 elements (Table 1). This ranking is caused by the biomass differences between these components (i.e. biomass also decreases in the order stem > branches > foliage). The order of component element content is identical to that of Johnson et al. (1982) for N, P, and Ca. Johnson did not report data for Mg and the order of ranking for K was slightly different.

As is generally the case, the majority of all 5 elements is to be found in the stem when compared to the crown (Table 3). N is somewhat of an exception since its content appears to be evenly split between the crown and stem.

Table 3. Percentage of biomass and 5 elements contained in crowns (foliage and branches) vs. stems for understory hardwoods.

Component	Biomass	N	P	K	Ca	Mg
	%					
Crown	23	50	33	44	39	39
Stem	77	50	67	56	61	61

The proportions of all 5 elements in the crown material are higher than the crown proportion of biomass (Table 3). In contrast stem percentages of every element are lower than the stem percentage of biomass. This indicates that for a relatively small increase in biomass gained by harvesting the crowns, large increases would occur in amounts of nutrients removed in the harvest. Also, as pointed out by Phillips and Van Lear (1984), this crown material is lower in quality than stem material due to higher proportions of moisture, bark, and juvenile wood in the former. The result is an even smaller gain in useable material whether the intended use is paper manufacturing or energy production.

Table 2 also provides the nutrient contents of the 4 dominant species. As would be expected, sweetgum, the dominant species in terms of biomass, contains the largest element content. Thirty-seven, 44, 47, 39, and 60% of the N, P, K, Ca, and Mg respectively in the understory are contained in this species alone.

It may be observed that the ranking of the quantities of elements differs among these 4 species (Table 2). However, relatively large standard errors of the mean for certain values (e.g. Ca for blackgum) limit any conclusions that may be drawn from these differences.

CONCLUSIONS

It is apparent that a considerable quantity of understory hardwood biomass may be found in mature southern pine stands in northern Louisiana. This is especially true if, like many pine stands that are not managed as intensively as would be ideal, the stand has had little use of fire.

Associated with this biomass are quantities of nutrients that may or may not be significant in terms of future site productivity. The gain in biomass obtained from harvesting the branches and foliage of this material is offset by the large increase in nutrient losses that will occur if the crowns are removed.

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A METHOD FOR GROUPING SPECIES-FOREST TYPE COMBINATIONS FOR THE DEVELOPMENT OF GROWTH MODELS FOR MIXED SPECIES STANDS [1/,2/]

R.S. Meldahl, M. Eriksson, and C.E. Thomas[3/]

Abstract. -- A method of empirically grouping species within forest types is presented. Forest Service survey data were to be used to develop growth models for Alabama. This required the grouping of the data to obtain a sufficient number of observations by subgroup (e.g., by species within a forest type). Cluster analysis was performed on the coefficients of a periodic diameter growth regression equation. Selection of the independent variable(s) included in the regression was based largely on the standard errors of the regression coefficients and on the reasonableness of the resulting groups.

INTRODUCTION

Recent survey results from both Georgia and Alabama suggest that growth and removals from growing stock have moved precariously toward equality. In some areas removals are already greater than growth. Since approximately 70% of the forest land is in natural stands predominated by mixed species, it is necessary to analyze and evaluate potential yields of these stands. Growth and yield estimates are currently available corresponding to remeasurement cycles, approximately 10 years, but interim estimates and projections would be of value for many purposes. In order to accomplish this task, it is necessary to reduce the complexity of the data that are representative of these stands.

Forest Service survey data provide an opportunity to evaluate a variety of statistical techniques to reduce the complexity of forest type-species interactions as well as a variety of other methodologies which can describe and project the growth and yield of the existing Southern forests. Survey data include tree variables such as DBH, height, and crown class, and stand variables such as forest type, site class, and topography. For a more detailed explanantion, refer to Renewable Resources Inventory Work Plan (Quick, 1980).

Cluster analysis provides a means of subsetting data into homogeneous groups. As described by Turner (1974), the basic premise is to group objects that are in some sense similar so as to minimize the variance within a cluster and maximize variances (or distances) between clusters. Simply stated, one needs to identify the attribute(s) which are important and determine the number of groupings which are desired prior to invoking a clustering procedure. The resulting clusters should provide a reasonable basis for the evaluation of a much less complex system but still remain relevant to the overall system. Using this method, one is able to reduce the complexity but hopefully not lose those elements that do contribute to different growth and development patterns.

METHODS AND PROCEDURES

The data used for this study were the 1982 Forest Service survey data for Alabama. The data cover the entire state and consists of numerous tree and stand characteristics. One of the categorical variables that is collected is forest type. Each location is classified on the basis of species plurality with the local cover type indicated by the key species with the greatest stocking or those species that provide a plurality of the stocking. (An abbreviated list of forest types is given below.) It was assumed

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3/ The authors are Assistant Professor, Research Associate, School of Forestry and Alabama Agricultural Experiment Station, Auburn University, and Research Forester, Forest Inventory and Analysis Unit, Southern Forest Experiment Station.

that this stand level variable captured many attributes that may have an influence on tree growth or stand development pattens. After editing, 12220 survivor growth trees which made up a total of 84 different species and 33 different forest types were available for modeling purposes.

Code	Species or species group
03	White pine
04	White pine-hemlock
05	Hemlock
10	Spruce-fir
21	Longleaf pine
22	Slash pine
31	Loblolly pine
32	Shortleaf pine
33	Virginia pine
34	Sand pine
35	Eastern redcedar
36	Pond pine
37	Spruce pine
38	Pitch pine
39	Table-Mountain pine
41	White pine-northern red oak-white ash
42	Eastern redcedar-hardwood
43	Longleaf pine-scrub oak
44	Shortleaf pine-oak
45	Virginia pine-southern red oak
46	Loblolly pine-hardwood
47	Slash pine-hardwood
49	Other oak-pine
51-59	Oak-hickory types
61-68	Oak-gum-cypress types
73-75	Elm-ash-cottonwood types
80	Sugar maple-beech-birch
99	Nonstocked

The possibility of differential growth response for each species type combination was also assumed. That is to say that a loblolly pine growing in a loblolly pine forest type may grow differently than a loblolly pine of the same size in an oak-gum-cypress forest type with similar stand attributes. Thus, separate models for each of the species-forest type combinations would maximize predictability. However, it was neither desired nor possible to develop separate equations for all of the combinations for two reasons. First of all, applications involving all 2772 (84*33) equations would be unwieldy, and second because many of the cells are either empty or sparsely occupied.

Consequently, some grouping of species and forest types was necessary. This grouping was accomplished in two steps.

The first step involved reducing the number of forest types by species. This was a rather arbitrary methodology, the two primary criteria being (i) sample sizes for each mapped forest type (within species) should, in general, be at least 30, and (ii) a mapped forest type should be comprised of types which are similar based on expected growth response. The reduction was accomplished by first determining, for each species, those forest types which could stand alone as a group; that is, which types had a sufficient number of trees to allow the modeling of that cell separately. Then, to the extent possible (depending on sample sizes), the pine types (20<type<40) were grouped together, the oak-pine types (40<type<50) were grouped together, the oak-hickory types (50<type<60) were grouped together and the oak-gum-cypress types were grouped together. When these groups were not possible (due to the sample sizes), the next choice was to collapse the oak-pine and the oak-hickory types into a single mapped type. Examples of this mapping procedure are given in Table 1. At times it was necessary to form groups across many (or all) forest types. This mapping collapsed the original 84 by 33 matrix into 115 cells.

The second step in reducing the number of species-forest type combinations was to apply a clustering procedure to the coefficients of diameter growth regression equations. The premise here is that any given species-type group (from here on referred to as a cluster) should reflect stand dynamics. That is, a cluster should include species-type combinations which respond to internal (tree) and external (plot) changes in a similar way. Possible alternatives to statistical clustering would be to group together (i) the fastest growers, (ii) the slowest growers and (iii) some classes in between, or to group according to some other classification, e.g. hard hardwoods, soft hardwoods, etc. However, neither of these alternatives considers the dynamics of growth.

Cluster analysis is a multivariate methodology which forms groups of similar elements based on some distance measure. Elements which are close together are, in some sense (i.e., based on the distance measure) more similar and, hence, more likely to belong to the same group than elements which are further apart.

In an ideal situation where growth was a known function of some set of plot and tree variables, species-type combinations with similar coefficients would be expected to respond to environmental factors similarly. Groups of similar coefficients (and therefore, similar growth response) could be found by applying a clustering algorithm. Suppose, for example, it were known that growth is exactly represented

Table 1.--Selected examples of mapped forest type definitions.

Species	Species Code	Forest Type	Mapped Forest Type
Slash pine	111	03-39	1
		40-59	2
		60-99	3
Spruce pine	115	All	1
Longleaf pine	121	21	21
		43	43
		03-39 1/	1
		40-99	2
Loblolly pine	131	31 2/	31
		31 3/	0
		32	32
		46	46
		03-39	1
		40-49	2
		50-59	3
		60-99	4
Hickories	400	53	53
		03-39	1
		40-49	2
		50-59	3
		60-99	4
Sweetgum	611	46	46
		53	53
		62	62
		03-39	1
		40-59	2
		60-99	3
Chinkapin oak	826	All	1
White oak	802	46	46
		53	53
		03-39	1
		40-49	2
		50-59	3
		60-99	4
Other commerical	---	All	1
Noncommercial	---	03-39	1
		40-49	2
		50-59	3
		60-99	4

1/ When forest type includes a single enumerated forest type, that type is excluded from other goupings, e.g., forest type 21 is not included in mapped forest type 1 for longleaf pine.

2/ Loblolly pines occurring in non-plantation stands in the loblolly pine forest type.

3/ Loblolly pines occurring in plantations in the loblolly pine forest type.

by a function with coefficients a and b. Suppose further that two groups are to be formed from four species with coefficients:

Species	a	b
1	0.1	0.1
2	0.2	0.1
3	1.0	1.0
4	1.1	1.2

Clearly, species 1 and 2 would form one group while species 3 and 4 would form another. This principle is easily extended to more than two coefficients.

The above reasoning motivated the use of cluster analysis for forming groups of similar species-type combinations. However, two problems arise which were not present in the above example. First, the form of the "true" growth model is unknown and probably differs for different species and types. Second, when a model is assumed and the coefficients are estimated, there is error associated with the estimates. When the errors are large relative to the values being estimated, poor groupings may result.

For grouping the 115 (mapped) species-forest types found in Alabama, linear models were assumed. It was found that when more than one independent variable was included in the models the errors associated with the resulting coefficients were, in general (i.e., when 115 models were examined), too large for much faith to be put into the resulting cluster groups. Therefore, effort was restricted to simple linear models of the form:

$$PER.D = B0 + B1*X + e$$

where PER.D = periodic diameter increment,
X = independent variable,
B0 and B1 are regression coefficients,
and e is an error term.

Simple correlations between PER.D and a large number of X variables were examined. These variables included tree variables, such as DBH, height, crown ratio, and height*DBH, plot variables, such as average DBH, trees per acre, and basal area, and plot-tree interactions, such as basal area*DBH and trees per acre*DBH. Based largely on these correlations, the above regression was fitted for 22 different specifications of the variable X.

The stability of the resulting coefficients (t-statistics) was examined for each specification of the variable X. Clustering was performed using some of the more promising variables. The final choice among these variables was primarily based on two factors. First, the intuitive appeal of the resulting groupings was assessed. Second, for each of these more promising choices of X and for each of the resulting clusters, a larger, multiparameter, linear function was fitted and the total (across clusters) residual sums of squares evaluated on the assumption that a better clustering would result in better fits by cluster and hence a smaller residual sums of squares.

At this stage the two most promising regressions were for X = BA.BGR (a plot variable, defined as the sum of the basal areas of all trees larger than the current tree, which was significant in 69% of the 115 regressions at the 10% level) and for X = NEW.C.R. (New Crown Ratio a tree based variable significant in 66% of the 115 regressions at the 10% level). It was decided that the final species-type groupings would be based on the coefficients of the regression,

$$PER.D = B0 + B1*BA.BGR + e.$$

The final choice was partly based on good results obtained with this variable in earlier modeling attempts.

The SAS (Statistical Analysis System, SAS Institute, 1982) procedure FASTCLUS was used as the clustering algorithm with the input regression coefficients standardized to mean 0 and standard deviation 1 prior to clustering. In applying this procedure the user has control over a number of options and parameters. The two most noteable being MAXCLUSTERS and WEIGHT. The MAXCLUSTERS option controls the number of clusters to be formed and must be specified. In the above example, the value of MAXCLUSTERS would be 2. For the purposes of this project, it was decided that about 20 would be largest workable number of clusters. This does represent a trade off between the ability to differentiate between variables and have tightly grouped clusters and having a reasonable number of clusters to implement in other applications.

When a WEIGHT is specified, weighted cluster means and variances are computed. This allows the user to increase the importance of those observations in which he has the most confidence. As noted above, many of the regression coefficients were not significant at the 10% level. Thus, some type of weighting scheme, which recognized different significance levels, was desirable. After considering several alternatives, WEIGHT was set to a variable called FREQ:

$$\text{where FREQ} = \begin{cases} 1/(\text{significance level of B1}) \text{ if sig. level} \geq 0.001 \\ 1000 \text{ otherwise.} \end{cases}$$

For the clustering attempts described above, sets of 110[4] regression coefficients were grouped into 20 clusters, but after the final clustering variable, BA.BGR, was chosen, MAXCLUSTERS was set to 15. Selected examples of the group membership for the first 15 clusters is given in Table 2.

Total numbers of survivor growth trees falling into each of these clusters ranged from 33 to 2383. To provide a more even distribution of sample sizes across clusters, the most extreme clusters were removed and the clustering procedure reapplied, again with MAXCLUSTERS = 15. Sample sizes were still rather variable, so some regrouping was done "by hand" to even out sample sizes and the number of clusters was increased to 20. Examples of the final cluster membership is shown in Table 3.

CONCLUSIONS

While the above methodology provided groupings of similar elements, it did not provide a unique solution to the problem. However, it did allow the user to adjust clusters and to impose his knowledge or beliefs on the development of the final clusters. This should not be considered as a final solution, but as a starting point for work with larger regression models and further analyses.

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[4] Loblolly pine on loblolly pine sites had a sufficient number of samples and was important enough to justify a separate cluster. Baldcypress, non-commercial species groups, and species grouped together due to very small sample sizes were also removed prior to using the clustering procedure. Together these account for five mapped forest types (cells) and left a total of 110 cells or mapped types for further grouping.

Table 2.--Selected examples of group membership for first fifteen BA.BGR clusters.

Cluster	Mapped Type	No. Obs.	Coefficients[1/] B0	B1	Prob.[2/] B1	FREQ[3/]
Cluster = 1						
Am. holly	1	23	-2.2543	1.7775	0.0291	34.39
Chinkapin	1	72	-1.4144	1.3641	0.8408	1.19
Hickory	2	124	-1.2451	1.2454	0.9964	1.00
Slash pine	3	27	-1.4862	1.8855	0.5159	1.94
Swamp tupelo	1	31	-1.3580	1.6396	0.5138	1.95
Water tupelo	1	39	-1.3364	1.2241	0.9625	1.04
Cluster = 2						
Scarlet oak	1	42	0.0646	2.2596	0.4281	2.34
Scarlet oak	53	94	0.2837	1.4628	0.7358	1.36
Cluster = 3						
River birch	1	41	0.6790	-1.4699	0.0376	26.61
Virginia pine	1	33	0.5198	-1.0609	0.0001	1000.00
Cluster = 4						
Chestnut oak	1	29	-0.0614	1.3882	0.9210	1.09
Chestnut oak	3	69	-0.3488	1.1284	0.8240	1.21
Hackberry	1	65	-0.5905	1.6221	0.6732	1.49
Slippery elm	1	11	-0.9703	1.8123	0.5437	1.84
White ash	1	58	-0.7384	1.2716	0.9642	1.04
Cluster = 6						
Loblolly pine	2	51	0.7324	0.6532	0.5811	1.72
Yellow-poplar	1	37	1.0982	0.4125	0.3950	2.53
Yellow-poplar	2	62	0.8672	1.1325	0.9244	1.08
Yellow-poplar	53	96	1.0357	0.4514	0.1411	7.09
Cluster = 8						
Shortleaf pine	2	51	0.5888	-2.2970	0.0000	1000.00
Slash pine	2	79	0.2773	-2.0173	0.0037	271.21
Cluster = 10						
Loblolly pine	0	208	1.4167	-1.9646	0.0000	1000.00
Swamp chestnut oak	1	33	1.7475	-2.0992	0.0009	1000.00
Shumard oak	1	28	1.8313	-1.8456	0.1021	9.79
Spruce pine	1	88	1.9876	-2.0401	0.0001	1000.00
Cluster = 14						
Cherrybark oak	1	68	1.9259	-1.0428	0.0150	66.51
Laurel oak	2	56	1.4384	-0.7023	0.0082	121.92
Loblolly pine	32	71	1.4297	-1.3968	0.0024	417.83
Loblolly pine	46	414	1.3129	-1.0929	0.0000	1000.00
Water oak	62	112	1.8573	-0.9785	0.0031	319.54

1/ Regression coefficients from the model PER.D = B0 + B1*BA.BGR.
2/ Significance level of the B1 coefficient.
3/ FREQ= { 1/(significance level of B1) if sig. level $\geq$ 0.001; 1000 otherwise.

Table 3.--Selected examples of group membership for final twenty BA.BGR clusters.

Cluster	Maped Type	No. Obs.	Coefficients[1/] B0	B1	Prob.[2/] B1	FREQ[3/]
Cluster = 2						
Loblolly pine	31	1271	2.7153	-0.0163	0.0000	1000.00
Cluster = 3						
Hickory	53	542	1.0284	-0.0049	0.0000	1000.00
Cluster = 6						
Shortleaf pine	3	111	1.7181	-0.0174	0.0008	1000.00
Shortleaf pine	32	333	1.8507	-0.0159	0.0000	1000.00
Shortleaf pine	44	178	1.6538	-0.0145	0.0000	1000.00
White oak	3	52	1.9786	-0.0152	0.0005	1000.00
White oak	4	18	2.0156	-0.0147	0.2132	4.69
White oak	46	53	2.1390	-0.0149	0.0001	1000.00
Cluster = 7						
River birch	1	41	2.4093	-0.0190	0.0376	26.61
Shortleaf pine	2	51	2.3399	-0.0248	0.0000	1000.00
Slash pine	2	79	2.1004	-0.0229	0.0037	271.21
Virginia pine	1	33	2.2869	-0.0162	0.0001	1000.00
Cluster = 8						
Loblolly pine	2	51	2.4503	-0.0042	0.5811	1.72
Loblolly pine	4	33	2.9611	0.0041	0.6044	1.65
Yellow-poplar	1	37	2.7316	-0.0058	0.3950	2.53
Yellow-poplar	2	62	2.5538	-0.0008	0.9244	1.08
Yellow-poplar	53	96	2.6835	-0.0056	0.1411	7.09
Cluster = 12						
Green ash	63	85	2.1521	-0.0104	0.0152	65.74
Laurel oak	1	39	2.1185	-0.0130	0.0987	10.13
Laurel oak	53	48	2.3791	-0.0092	0.2039	4.90
N. Red oak	1	42	2.3304	-0.0125	0.1047	9.55
S. Red oak	1	85	2.1157	-0.0130	0.0027	374.44
Sycamore	1	35	2.4448	-0.0109	0.2182	4.58
Water oak	2	80	2.5196	-0.0106	0.0672	14.87
Water oak	3	153	2.5061	-0.0117	0.0032	311.24
Cluster = 20						
Black tupelo	1	43	0.8781	-0.0059	0.0450	22.24
Black tupelo	2	92	0.8289	-0.0031	0.2171	4.61
Black tupelo	3	59	1.1759	-0.0063	0.0221	45.23
Black tupelo	53	158	0.8392	-0.0041	0.0010	957.45
Black tupelo	68	115	0.9127	-0.0034	0.0632	15.81
Swamp tupelo	68	151	1.0268	-0.0037	0.0009	1000.00
Water tupelo	67	210	0.9726	-0.0011	0.3873	2.58

1/ Regression coefficients from the model PER.D = B0 + B1*Ba.BGR.
2/ Significance level of the B1 coefficient.
3/ FREQ= { 1/(significance level of B1) if sig. level $\geq$ 0.001; 1000 otherwise.

CROWN RATIO USED AS A SURROGATE FOR FORM IN A VOLUME EQUATION FOR NATURAL LONGLEAF PINE STEMS 1/

Robert M. Farrar, Jr. 2/

Abstract.-- Including an expression of crown ratio as a continuous independent variable significantly reduced the variation in a D^2H stem-volume equation for total cubic feet, inside bark, based on data from felled natural longleaf pines. A volume difference of about 12 percent is predicted between trees with 30 percent and 70 percent crown ratio but with the same D and H. Methods, analysis, and results are discussed along with examples of application of the equation.

INTRODUCTION

The "combined-variable" or "D^2H" volume function has been widely accepted as a model for predicting the volume of tree stems. The usual form is:

(1) $V = b_0 + b_1(D^2H)$ where

V = tree (or stem section) volume

D = tree d.b.h., inches

H = tree height (or stem section length), feet

b_0, b_1 = parameters to be estimated.

This equation is usually fitted via weighted least squares to homogenize the variance in volume with the weight commonly being $1/D^2H$. Often, the r^2 will be > 0.99, which suggests little room for improvement. However, a more general form of equation (1) given by Spurr (1952) is:

(2) $V = b_0 + b_1(f)(D^2H)$ where

f = an expression of bole form (shape).

In fact, equation (1) is also at times called a "constant form factor" equation and in it b_1 defines the constant form. But, shouldn't we consider the possibility of a significant effect of form? If so, what should the form expression be?

BACKGROUND

The historic measures of form such as Girard form class, form quotients, and form point are all likely candidates but have a common fault: all are difficult to use because they either require measurement of an upper-stem diameter, either inside or outside bark, or determination of the height to the estimated crown center of gravity (form point). Also, Girard form class has no utility for trees with height less than about 17 feet. Expensive labor and/or dendrometers are usually required to measure upper-stem diameters and ocular estimation of crown center of gravity seems tacitly undesirable.

Is there some surrogate for form? An obvious candidate is crown ratio or the live crown length expressed as a percentage of total height. Crown ratio percentage is used by silviculturists as an index of the growth or survival potential of a tree since (1) it involves a major dimension of the tree crown (crown length), (2) it is probably well-correlated with crown volume, and, thereby, (3) it represents the photosynthesizing foliage. In general, if the crown ratio

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2/ Principal Mensurationist, Forestry Sciences Laboratory, Monticello, AR, Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Department of Forest Resources and Arkansas Agricultural Experiment Station, University of Arkansas at Monticello.

is 50 percent or greater, the tree is considered capable of maximum growth. Crown length (or height to crown base) is relatively easy and inexpensive to measure along with total height when using a clinometer, Abney level, transit, etc. and a measuring tape or rangefinder.

Developing stem-profile functions for discrete crown-ratio classes has been useful in predicting tree product-volumes in unthinned plantation yield studies for slash pine (Bennett et al. 1978, Dell et al. 1979) and loblolly pine (Feduccia et al. 1979) and for planted (Baldwin and Polmer 1981) and natural (Farrar 1984) longleaf pines. Generally, lower crown ratio indicated larger stem volume for given D and H. Dell (1979) emphasizes the promise of crown ratio in improving tree and stand product-volume estimates and suggests future utility in providing information on biomass, limb-related quality considerations, and potential for certain insect or disease conditions. However, Burton (1980) did not find a significant discriminating effect of crown ratio in an analysis of several stem taper models for planted loblolly pine, although a trend in the coefficients with crown ratio was evident for some models. Also, Lohrey (1983) could find no consistent effect of crown ratio in an analysis of tree volumes in repeatedly thinned planted longleaf pine plots when it was included with D^2H and other independent variables.

The following analysis was performed on a felled-tree data base to see if some expression of crown ratio could be used as a continuous independent variable and surrogate for form in a D^2H volume equation.

METHODS

Data

The data base is described by Farrar (1981). Briefly, it consists of 214 felled natural longleaf pines measured at 1-inch taper steps for d.o.b., d.i.b., and lengths between consecutive taper steps from a 0.2-foot stump to the zero d.o.b. at the tip of the terminal bud. Additionally, diameters, o.b. and i.b., were measured at the stump, breast height, and live crown base along with total height and height to the live crown base. This measurement procedure was used to (1) minimize data errors, to (2) obtain a good description of the shape of the stem, and to (3) facilitate calculation of stem cubic-foot volumes to integer top d.o.b. limits. Cubic-foot volume, i.b., was calculated by assuming a conic section (frustrum) between taper steps and a conical tip section. Section volumes were summed to obtain "observed" total cubic-foot tree volume, i.b., above the 0.2-foot stump. Crown ratio percentage was calculated as [(total height - height to live crown base)/(total height)](100). Height to live crown base was measured from the groundline to the point on the stem where the ventral side of the lowest live limb in the main crown body joined the stem.

These trees were obtained by sampling in a rectangular distribution of d.b.h., total height, and crown ratio percentage. The number of sample trees by d.b.h., total height, and crown ratio classes is shown in Table 1. As illustrated in this table, it was difficult to find the combination of short trees for a given d.b.h. and a low crown ratio.

Analysis

The "observed" tree volumes were used in a conditioned weighted multiple linear regression analysis (SAS 1979) employing the full model:

$$(3)\quad V = b_0 + b_1(100\text{-}CR) + b_2(D^2H) + b_3(100\text{-}CR)(D^2H)$$

where V = tree total cubic-foot volume, i.b., above a 0.2-foot stump

b_0 = 0.00535 (observed V of a longleaf tree with $D^2H = 0$; D = 0 inches and H = 4.5 feet; based on 10 sample trees)

CR = crown ratio, percent

D = d.b.h., inches

H = total height, feet

Weight = $1/D^2H$.

Note that the variable (100-CR) assumes the role of the form variable (f) in equation (2). This particular formulation was used to make the form variable analogous to Girard form class since it was reasoned that a low crown ratio would imply good form and larger volume for a given D and H. Note further that if $D^2H = 0$, equation (3) implies that $V = b_0 + b_1(100\text{-}CR)$. This could present the anomaly of a non-fixed b_0 if CR is < 100 when $D^2H = 0$. It turns out that for the conditioned b_0 chosen (where D = 0 and H = 4.5), such young longleaf pines will generally have a crown ratio of essentially 100 percent and the potential problem is sidestepped.

In the full-model analysis, b_1 was not significant at the 5 percent probability level so a reduced model:

$$(4)\quad V = b_0 + b_2(D^2H) + b_3(100\text{-}CR)(D^2H) \text{ was fitted.}$$

In equation (4) all coefficients were significant. The calculated probability of observing a greater absolute "t" ratio due to chance was 0.0001 for each one. Plottings of residuals on CR and D^2H did not reveal any particular trends with either variable. Adoption of model (4) implies that we accept that the form variable does not affect the regression intercept but does affect the slope.

Table 1. — Number of sample trees by d.b.h., total height, and crown ratio classes.

D.b.h. (in.)	Total Height (ft.)									
	4.6-15	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-105
	≤ 30% Crown Ratio									
0.6 - 1.5	3									
1.6 - 2.5		1								
2.6 - 3.5				1						
3.6 - 4.5					1					
4.6 - 5.5					2	3				
5.6 - 6.5					1	2	1			
6.6 - 7.5							2	1		
7.6 - 8.5							2	1		
8.6 - 9.5						1	2	2		
9.6 -10.5								2		
10.6-11.5									1	
11.6-12.5								1	1	
12.6-13.5								1	1	
13.6-14.5								1	2	
14.6-15.5								1		
15.6-16.5										
16.6-17.5										
17.6-18.5										
18.6-19.5										
19.6-20.5										
20.6-21.5										
21.6-22.5										
										Total = 37

	4.6-15	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-105
	31 - 50% Crown Ratio									
0.6 - 1.5	4									
1.6 - 2.5		3	1							
2.6 - 3.5				2						
3.6 - 4.5		1	1	1	2					
4.6 - 5.5			2	1	2	1				
5.6 - 6.5					1	2	1			
6.6 - 7.5				3	2	4	4			
7.6 - 8.5				1	1	1	3	1		
8.6 - 9.5				1	1		1	2		
9.6 -10.5					1		3	1		
10.6-11.5					1	1	4	1		
11.6-12.5							2	1	1	
12.6-13.5						1	1	4	1	
13.6-14.5							1	1	1	1
14.6-15.5							1		1	
15.6-16.5								2		
16.6-17.5								1		
17.6-18.5						1		1	1	
18.6-19.5										
19.6-20.5										
20.6-21.5										
21.6-22.5										
										Total = 85

Table 1. — (Cont.) Number of sample trees by d.b.h., total height, and crown ratio classes.

D.b.h. (in.)	Total Height (ft.)									
	4.6-15	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-105
	≥ 51% Crown Ratio									
0.6 - 1.5										
1.6 - 2.5	1									
2.6 - 3.5		1		1						
3.6 - 4.5			1	3						
4.6 - 5.5			3	1	1					
5.6 - 6.5			4	1	3	1				
6.6 - 7.5			1		2	2	1			
7.6 - 8.5			1	2	1	1	2			
8.6 - 9.5				1	2			1		
9.6 -10.5				1	2	1	3	2		
10.6-11.5				3		1				
11.6-12.5					2	2	2	1		
12.6-13.5				2	1	1		3		
13.6-14.5					1	2	1	1		
14.6-15.5						2		1	1	
15.6-16.5				1			1	2		
16.6-17.5							2	1		1
17.6-18.5							1	1	1	
18.6-19.5						1	1	2	1	1
19.6-20.5										
20.6-21.5										
21.6-22.5									1	

Total = 92

RESULTS

The fitted form of equation (4) is:

$$(5)\quad V=0.00535 + 0.00186042(D^2H) + 0.00000664898(100-CR)(D^2H).$$

For comparison, a conditioned weighted fit of model (1) was made to obtain the simpler "combined variable" equation:

$$(6)\quad V = 0.00535 + 0.00219706(D^2H) \quad \text{with weight} = 1/D^2H.$$

"Goodness of fit" statistics for equations (5) and (6) are given in Table 2. At first glance, these statistics do not indicate an overwhelming superiority by either equation. Both equations are relatively unbiased as indicated by nearly zero mean deviations (d) and both account for a very large proportion of the variation in tree volume as indicated by the fit indices (FI) of about 0.99 or larger. Both the relative (%d) and absolute relative (RMS%d) deviations are similar for both equations. But, for equation (5) the root mean squared deviation (RMSd) is lower by about 19 percent, indicating that the average absolute size of errors is less with equation (5).

Equation (5) is shown graphically in Figure 1 for three contrasting crown-ratio percentages. Note that, as expected, a low crown ratio results in a larger tree volume for given D and H and implies better stem form for the shorter tree crown. Equation (6), if plotted, would nearly coincide with the line for 50 percent crown ratio in Figure 1 because the mean CR for the data set is also about 50 percent.

To illustrate the effect of CR on tree volume, assume we have a tree with D = 10 inches, H = 70 feet and let CR be 30, 50, or 70 percent. Calculating the volume for these three conditions using equations (5) and (6) we obtain:

For (6), V = 15.385

For (5) and CR = 30%, V = 16.286

" " " " " 50%, V = 15.355

" " " " " 70%, V = 14.425

Compared to equation (6), equation (5) predicts about 1 cubic foot or 5.9 percent more volume for CR = 30% and about 1 cubic foot or 6.2 percent less volume for CR = 70%. The cubic-foot dif-

Table 2. -- "Goodness of fit" statistics for equations (5) and (6).

Equation	Related Statistics						
	n 1/	$\bar{Y}$ 2/	$\bar{d}$ 3/	RMSd 4/	$\overline{\%d}$ 5/	RMS%d 6/	FI 7/
	------ ft.^{3},i.b. ------				------- % --------		
(5)	214	17.331	0.000	1.654	-3.404	15.139	0.991
(6)	214	17.331	0.000	2.042	-2.918	13.912	0.987

1/ n = Number of observations

2/ $\bar{Y}$ = Mean observed total cubic-foot volume, i.b., per tree

3/ $\bar{d}$ = Mean deviation = $(1/n)\Sigma(Y_i - \hat{Y}_i)$ where Y_i = observed volume of the ith tree and $\hat{Y}_i$ = predicted volume of the ith tree

4/ RMSd = Root mean squared deviation = $\sqrt{(1/n)\Sigma(Y_i - \hat{Y}_i)^2}$

5/ $\overline{\%d}$ = Mean percent deviation = $[(1/n)\Sigma((Y_i - \hat{Y}_i)/Y_i)](100)$

6/ RMS%d = Root mean squared percent deviation

$$= \sqrt{(1/n)\Sigma((Y_i - \hat{Y}_i)/Y_i)^2}\ (100)$$

7/ FI = Fit index = $1 - [\Sigma(Y_i - \hat{Y}_i)^2/\Sigma(Y_i - \bar{Y})^2]$

Fit index is analogous to the coefficient of determination in regular regression and takes on values ≤ 1. FI is used to evaluate variation accounted for by conditioned or transformed regressions or systems of equations where the coefficient of determination is not appropriate.

ferences increase as tree size increases, as illustrated in Figure 1, but the percentage differences remain essentially the same. The difference between the volume of two trees having the same D and H but a CR of 30 percent for one and 70 percent for the other is about 11 to 13 percent, depending on the base. This relative difference is on the order of the 10 percent volume difference reported by Dell (1979) between high and low crown-ratio stem-profile functions for planted loblolly pine.

DISCUSSION

Equation (5) shows that an association exists between tree volume and crown ratio in natural longleaf pines, as sampled in this data base, but any cause-effect relationships are interpretive. The trees selected in the rectangular distribution were required only to be naturally regenerated, single-stemmed, visibly undamaged, and to fit into one of the D-H-CR cells. They came from a wide variety of undescribed stand conditions and histories regarding age, site quality, density, and past treatment. Therefore, they are not associated with any particular set of stand conditions or management regimes. The relationship between crown ratio and stem volume observed under specific thinning regimes over a rotation might be somewhat different quantitatively from that herein but should be similar qualitatively if thinning intervals are long enough for crown length and stem form to adjust to the new environment.

Basically, for species exhibiting excurrent or monopodial growth form, a tree stem tends

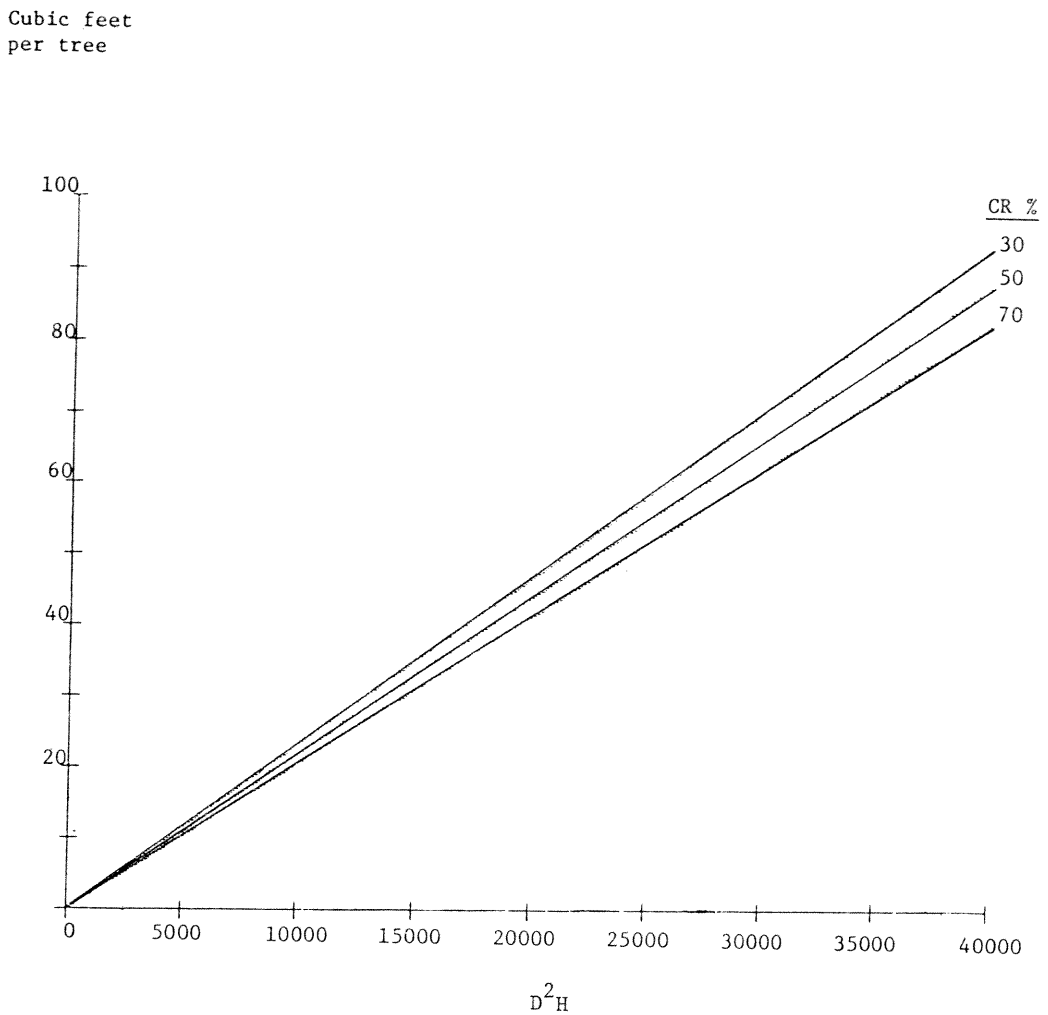

Figure 1. -- Predicted total cubic-foot volume, i.e., by crown-ratio (CR) class, equation (5).

toward a cylinder in shape below the crown base and tapers strongly within the crown. Thus, as crown lengthens, stem form tends to be poorer. Stem shape appears to be modified secondarily by stand density. Open-grown trees generally tend to taper more in the lower stem than trees in a closed stand due apparently to a buttressing response to wind loading. But, also, crown ratio and stand density are co-related since open-grown trees also tend to have high crown ratios while trees in dense stands tend to have low crown ratios. In the normal development of a stand, the trend with time seems toward lower crown ratios and perhaps an approach toward an asymptote. For the most part, it would seem that any treatment that altered the crown ratio would also result, sooner or later, in altered stem form, but how quickly crown ratio changes and stem form adjusts to changed environment in longleaf pine is open to investigation.

Perhaps in Lohrey's (1983) report, where a crown-ratio effect was inconsistent, the crown ratio and stem form never achieved commensurate values or crown ratio never varied consistently among the study treatments due to frequent thinning. Also, possibly the model form or inclusion of other co-related variables prevented detection of an effect of crown ratio. Nevertheless, as Lohrey points out, lateral crown expansion and increased loads on the stem due to wind and increased crown volume after thinning may affect stem form and volume without an appreciable change in crown ratio. The point is also well taken that if we wish best to measure stem form and volume responses to intensive treatments, such as frequent thinnings, live prunings, fertilizations, etc., we should resort to equally intensive measurements. This implies precise dendrometry of the stems in stands, or a sufficient sample thereof, plus establishment of inside- and outside-bark diameter relationships along the stem.

Although crown ratio may not be the most sensitive expression of stem form, it should be adequate in many cases. For applications where the expense of dendrometry is not justified, the added precision of a D^2H volume regression or stem-profile function employing crown ratio should prove useful.

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ESTABLISHMENT OF PERMANENT GROWTH AND YIELD PLOTS IN LOBLOLLY AND SLASH PINE PLANTATIONS IN EAST TEXAS [1/]

J. David Lenhart

Ellis V. Hunt, Jr.

Jock A. Blackard [2/]

Abstract.--Permanent plots have been established in 178 loblolly and 78 slash pine plantations throughout East Texas to study the development of stand structure over time. Analysis of the data will provide methods of estimating growth and yield, mortality, and site productivity to assist managers of these plantations.

In August, 1984, after three years of work, the School of Forestry at Stephen F. Austin State University and participating East Texas forest industries finished installing an array of 178 permanent growth and yield plots in loblolly pine plantations and 78 permanent growth and yield plots in slash pine plantations throughout East Texas.

The need for this comprehensive sample arose because about 15 years ago, many forest landowners started converting mixed pine-hardwood stands to planted pine stands. By 1984, approximately 2 million acres of loblolly and slash pine plantations were established on these non-old-field stands (usually site-prepared) in East Texas. Systems and procedures are needed to predict the future stand structures of these plantations.

In 1981, several participating industrial forest landowners in East Texas and the School of Forestry started a comprehensive long-term study of growth and yield - The East Texas Pine Plantation Research Project.

OBJECTIVES

The basic objectives of the project are:

1) Develop individual tree content prediciton equations.
2) Quantify site productivity.
3) Determine tree survival equations.
4) Develop basal area growth functions.
5) Compute individual tree height growth equations.
6) Develop procedures to recover stand structure parameters.
7) Determine effects of thinning on stand structure.

In addition, several adjunct research projects are being conducted as part of the East Texas study as:

1) Determine the role of non-planted vegetation.
2) Quantify the occurrence of fusiform rust.
3) Characterize the soil.
4) Describe the quality of the planted trees.

Since this is a long-term project, modifications and changes in project goals and objectives will probably occur.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Professor, Associate Professor and Graduate Assistant, respectively, School of Forestry, Stephen F. Austin State University, Nacogdoches Texas, 75962.

DESIGN OF EXPERIMENT

For each of the two species, the permanent plots are distributed over East Texas, so that they comprehensively sampled:

1) Geographic range.
2) Soil classes.
3) Age classes.
4) Site productivity classes.
5) Surviving trees per acre classes.

When a plantation was located that filled a "niche" in the above list, it also had to meet the following sampling criteria:

1) Recognizable as a plantation.
2) Not an old field.
3) Pure species.
4) Not replanted.
5) Unthinned.

When that list of requirements was met, the plot itself was located within the plantation so that:

1) There were no imbedded windrows.
2) There were no "unusually large" openings.
3) It was free of overtopping residual trees.

A plot consists of two adjacent subplots - 60 feet apart. Each subplot was 100 feet square (10,000 square feet). One subplot will remain unthinned throughout the life of the plantation, and the other subplot will eventually receive operational thinnings. A flip of a coin decided which subplot-to-remain-unthinned. A 30-foot buffer will be painted around the subplot-to-remain—unthinned to protect it against inadvertent harvest or disturbance.

Each planted tree within a subplot was tagged with a numbered aluminum tag and evaluated to find:

1) Dbh (tenth of inch).
2) Total tree height (feet).
3) Height to live crown (feet).
4) Crown class.
5) Tree quality characteristics.
6) Incidence of fusiform rust.

For very young plantations, it was not possible to obtain all the values for each tree.

These values were combined with general information about the plantation to obtain:

1) Plantation age (years).
2) Planted trees per acre.
3) Surviving trees per acre.
4) Average total tree height (feet).
5) Site preparation methods.
6) Topography.
7) Drainage.

FUTURE PLANS

In the future, each plot will be remeasured several times to analyze the changing stand structure over time. Beginning in 1985, the plots installed in 1982 will be remeasured. Then, the 1983 plots will be remeasured in 1986 and this sequence will continue until final harvest.

The remeasurement data will be used to classify site productivity and develop stand structure parameters. Moreover, when operational thinnings occur, "before and after" observations will be recorded. A continuous effort will be needed to prevent the premature destruction of these permanent plots.

As the data files become more and more comprehensive due to the collection of remeasurement data, appropriate analyses will be conducted to meet the objecives of the project. To achieve these goals, a long-term commitment by the School of Forestry and the participating forest industries in East Texas must be maintained.

CHERRYBARK OAK DEVELOPMENT IN NATURAL MIXED OAK-SWEETGUM STANDS--PRELIMINARY RESULTS[1/]

Wayne K. Clatterbuck, John D. Hodges

and E. C. Burkhardt[2/]

Abstract.--Development of cherrybark oak was studied over a range of stand densities and ages to determine stand conditions which influence the growth of quality trees. Study was limited to mixed, old-field stands of sweetgum and cherrybark oak in the minor bottoms of central Mississippi. Of 150 total plots, stem analysis was conducted on 153 trees on 31 plots. The results of these analyses indicate that the pattern of development is influenced by spacing and two general patterns are discernible. The first occurs at average spacings greater than 18 feet between dominant and codominant trees, or when the cherrybark oak is older than sweetgum. Since there is little influence from adjacent sweetgum trees, crown spread of the cherrybark oak is accelerated. Under these conditions merchantable lengths of less than 1.5 logs and diameters of 18 to 22 inches are attained in a 40-year rotation. At narrower average spacings the cherrybark oak height curve is sigmoid-shaped. The cherrybark oak is initially shorter than the sweetgum, but is able to surpass the sweetgum in total height within 15 to 25 years of age. With this developmental pattern, one may expect long clear boles of 2.5 to 3.0 logs and diameters of 22 to 24 inches over a rotation of 60 years. A comparison of each pattern of development in terms of log grade is discussed.

INTRODUCTION

There is widespread concern with the future status of oak (Quercus spp.) stands in the eastern United States. Once these stands are cut, they are not regenerating to oak in sufficient numbers. Numerous studies have investigated natural and artificial regeneration techniques and intermediate treatments to ensure oak establishment and growth. However, little is known about the development of southern oaks from seedling to maturity in mixed species stands. A thorough understanding of the development of these stands is needed to prescribe silvicultural treatments which enhance the oak component not only during the rotation but also in initial regeneration efforts.

The objective of this study is to characterize the development of cherrybark oak (Quercus falcata var. pagodifolia Ell.) in mixed oak-sweetgum (Liquidambar styraciflua L.) stands and to use this characterization to determine the conditions which promote the growth of quality cherrybark oak trees. The research is confined to old-field, even-aged stands on the minor bottoms of central Mississippi. Minor bottoms are those floodplains and terraces where the soils are of local origin (Hodges and Switzer 1979). Oaks tend to dominate these stands at maturity even though they are lost among the more numerous sweetgum during the seedling and sapling stages.

[1/] Paper presented at the Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984. Contribution No. 5980 of the Mississippi Agricultural and Forestry Experiment Station.

[2/] The authors are Research Assistant and Professor, Department of Forestry, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Mississippi State, MS 39762 and Consulting Forester, Vicksburg, MS 39180.

PROCEDURES

Stands containing mixtures of cherrybark oak and sweetgum were located at various developmental stages, densities, and ages from 6 to 80 years old. There were 150 plots established with at least ten plots per ten-year age interval. The number of plots was skewed toward the younger age classes because the most rapid changes in stand development occur at these ages. An individual cherrybark oak tree served as the center of the plot. Plot size was variable ranging from 0.02 to 0.20 acre, and irregular because the plots were based on individual cherrybark oak trees. The other plot trees are those that are interacting with or influencing the development of the cherrybark oak subject trees. An interacting tree is defined as any adjacent tree whose crown is touching the crown of the subject tree or whose crown is above or below the drip line or edge of the subject tree crown (Smith and Lamson 1983). At least 75 percent of the trees adjacent to the cherrybark oak had to be sweetgum for the plot to be considered.

The following data were recorded for each tree on the plot:

1. species,
2. DBH,
3. crown class,
4. total height,
5. height to base of live crown or merchantable height,
6. distance and azimuth from the cherrybark oak subject tree, and
7. damage code (lightning, canker, beaver, split, etc.).

On the cherrybark oak subject tree and the dominant and codominant interacting trees additional measurements were taken including:

1. crown width in two directions, north-south and east-west,
2. total age from increment cores at one-foot stump height, and
3. number of 16-foot sawlogs and their grades.

Basal area of each plot was taken six feet due north of the subject tree with a 10-factor prism. Site index (at 50 years) for cherrybark oak on the study areas ranged from 90 to 115 feet according to Broadfoot's (1961) site index curves.

The development of mixed oak-sweetgum stands was evaluated by a combination of the chronosequence and stem analysis techniques. A chronosequence is a series of stands which are of different ages, but are assumed to be similar in appearance when at the same age (Oliver 1982). Its use infers that the measurement of several stands on similar sites, but at different ages, yields results equivalent to successive measurements of one stand over a period of years. Stem analysis reconstructs past tree development by counting and measuring tree rings along the main stem and current branches. By analyzing several adjacent trees, one can assess how a tree develops in height, diameter, and crown dimension in relation to neighboring trees. The stem analysis procedure followed the method of Duff and Nolan (1953). One hundred fifty three trees on 31 plots were stem analyzed. The combination of these two techniques permits stands to be reconstructed as well as projected forward in time.

Regression equations were developed from the plot and stem analysis data to describe height, diameter, and merchantable height relationships for cherrybark oak and adjacent sweetgum trees. Only dominant and codominant trees of both species were used except for the height-age curves which included intermediate and overtopped sweetgum trees. By applying these equations, the respective total heights, merchantable heights, and diameters at particular ages are obtained and the pattern of development of an average tree is constructed (Holsoe 1947). At a given age, log grades were assigned using predicted diameter growth or the amount of clear wood deposited over the knotty core. The knotty core is the wood deposited before the bole becomes clear of branches, i.e., before the branches are shed and additional diameter growth begins to heal over the scars left by lost branches. Diameters outside bark for each merchantable height were determined from taper calculations using form class 80.

RESULTS AND DISCUSSION

Patterns of Diameter Growth

Figure 1 illustrates the cumulative diameter growth patterns for dominant and codominant cherrybark oak and adjacent sweetgum trees. The best equation for each species was a logarithmic function for cherrybark oak and a straight line regression for sweetgum with coefficient of determination (R^2) of 0.88 and 0.70, respectively. Sweetgum has a steady diameter growth pattern of 1.5 inches per decade, while the diameter growth of cherrybark oak is initially slower than sweetgum, but its rate of diameter growth increases with age to 5 inches per decade at age 60. Perhaps one of the most striking differences between diameter growth patterns of these two species is that cherrybark oak has three times the diameter

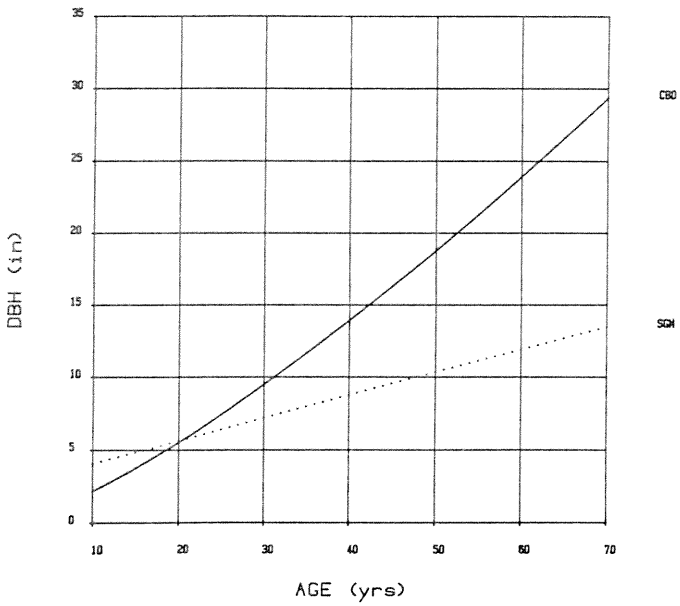

Figure 1.--Cumulative diameter growth patterns of cherrybark oak and sweetgum in the minor bottoms of central Mississippi.

growth rate of sweetgum after age 40. Thus, cherrybark oak has more diameter accumulation than the adjacent sweetgum trees.

Stand density is known to influence the diameter growth of trees, however correlations of cherrybark oak diameter growth to several competition indices (Brown 1965; Gerrard 1969; Hegyi 1973) and to plot basal area were not significant. Two reasons are postulated for this. First, no form of competition index has been able to totally explain mathematically the spacing relationship between adjacent trees and its effect on diameter growth (Johnson 1973). Second, since only dominant and codominant trees were used in the compilation of equations, neither stand density nor basal area had much effect on these trees already in the upper crown classes.

Height Growth Patterns

The height growth patterns of cherrybark oak and sweetgum are shown by crown class in Figures 2A and 2B.[3/] These two figures are the same except for the intermediate sweetgum curve. The intermediate sweetgum in Figure 2A represents a tree that was always below the canopy, even before crown class differentiation of the stand. The intermediate curve in Figure 2B denotes a tree that was a member of the

[3/] There was insufficient data to derive meaningful equations for the intermediate and overtopped crown classes of cherrybark oak.

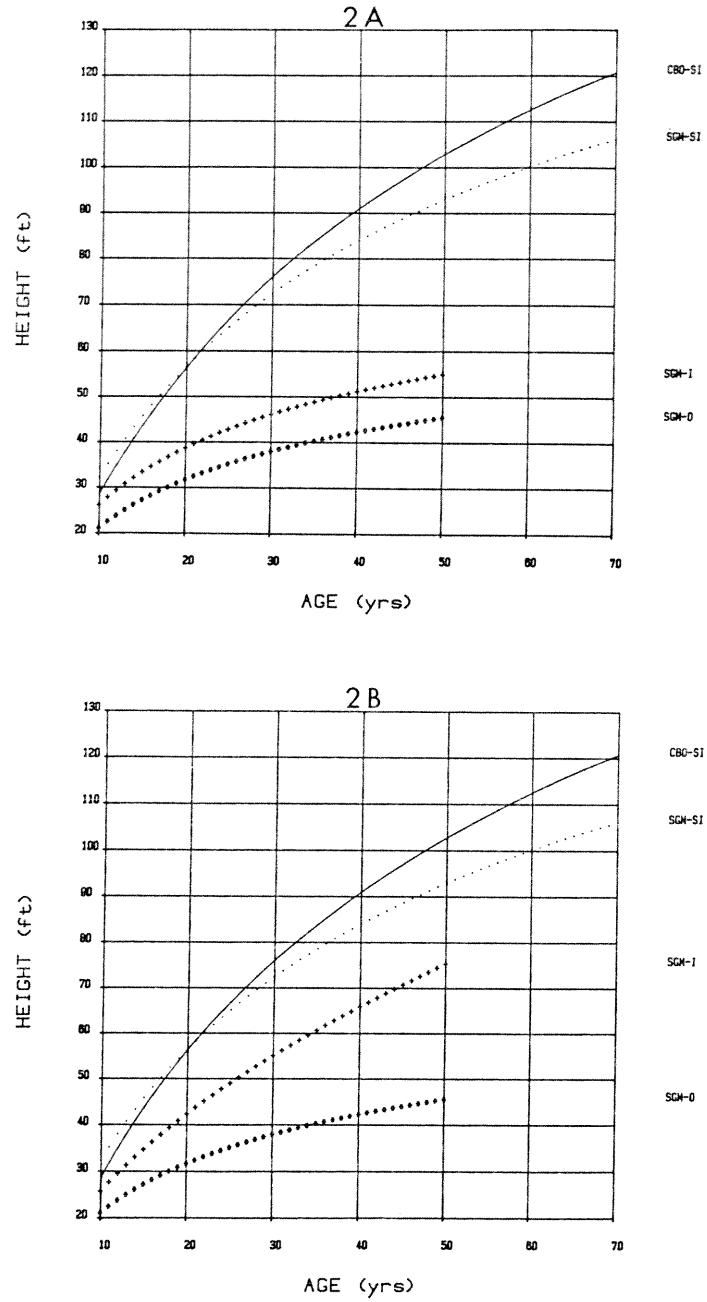

Figure 2.--Height-age curves for different crown classes of cherrybark oak and sweetgum on the minor bottoms of central Mississippi. Figures 2A and 2B show different curves for intermediate sweetgum. Note that SI stands for the site index guide curve which is a composite of the dominant and codominant crown classes.

Legend: ——— Dominant and codominant cherrybark oak (CBO-SI)
..... Dominant and codominant sweetgum (SGM-SI)
+++++ Intermediate sweetgum (SGM-I)
***** Overtopped sweetgum (SGM-O)

canopy before the crowns differentiated, but became intermediate after crown differentiation. The coefficients of determination for each of the curves are 0.95 for the dominant and codominant cherrybark oak, 0.93 for dominant and codominant sweetgum, 0.84 for intermediate sweetgum in Figure 2A and 0.86 in Figure 2B, and 0.83 for overtopped sweetgum.

Height growth of dominant and codominant cherrybark oak is characterized by a sigmoid growth curve representing a period of slow initial growth, followed by a term of rapid growth, and then an extended period of slower but still appreciable growth. Initially, the juvenile growth of sweetgum is greater than that of cherrybark oak. However, by age 23 cherrybark oak is able to catch and surpass the height attained by sweetgum. The intersection of the dominant and codominant curves of cherrybark oak occurs for two reasons: a slowdown in the rate of sweetgum height growth coupled with a rapid increase in the height growth rate of cherrybark oak. After the intersection both species exhibit appreciable height growth, nevertheless the deceleration in the rate of height growth is greater in sweetgum than cherrybark oak. These patterns of height growth generally enable the cherrybark oak to express dominance and form a continuous canopy over the sweetgum in mixed oak-sweetgum stands.

In comparison, the height growth patterns exhibited by cherrybark oak and sweetgum are similar to the previously discussed diameter growth patterns. Sweetgum outgrows cherrybark oak initially, but cherrybark oak is able to catch and surpass sweetgum in both height and diameter by age 23. Once cherrybark oak exceeds the height attained by sweetgum, additional space becomes available for crown expansion. The concommitant increase in cherrybark oak crown volume and leaf surface increases the rate of diameter growth as shown in Figure 1. The crowns of the widely spaced oaks at first appear isolated among the numerous sweetgum stems, but they emerge into the upper canopy and eventually meet to form a continuous overstory. The emergence of oaks into the overstory and the expansion of their crowns create a two-tiered stand with cherrybark oak in the overstory and sweetgum in the mid-canopy. Of course there are a few dominant sweetgum in the overstory, but generally oaks dominate. Sweetgum remains underneath the oak and continues to decline. Holsoe (1948) and Scholz (1948) found similar results with northern red oak (Quercus rubra L.) stands. Northern red oak has the capacity to emerge into the overstory, spread its crown, and consequently crowd out more tolerant species.

Merchantable Height

In this discussion, merchantable height is defined as the height to the base of the live crown or the height to the first live limb in the crown. The merchantable height-total height curves are presented in Figure 3 and the R^2 values are 0.88 for cherrybark oak and 0.65 for sweetgum. A decrease in the rate of merchantable height development might be expected with increases in total height, because merchantable height growth rate would naturally decrease once crown expansion occurs and total height growth rate begins to decline. The more or less straight lines of both species for the merchantable height-total height graph indicate that merchantable height development parallels that of total height, which is a sigmoid curve as explained earlier. Thus, as the total height growth rate declines, so does the merchantable height growth rate.

Cherrybark Oak Development and Log Grade

The development pattern of an average cherrybark oak tree as depicted by the graphs in Figures 1, 2, and 3 is presented in Table 1. The following discussion will refer to the butt log, second log, and third log as successive 16-foot clear bole lengths above a two-foot stump (merchantable height column in Table 1). Each log was evaluated in terms of diameter growth, size of the knotty core, and merchantable height at the time that the log becomes clear of branches. Based on these characteristics, a log grade was assigned following the U.S. Forest Service standard grades for hardwood logs (Rast et al. 1973). Table 1 indicates that the third log (from 34 to 50 feet of merchantable height) becomes clear or free of branches at 58 years old. This will be used as the rotation age for this discussion.

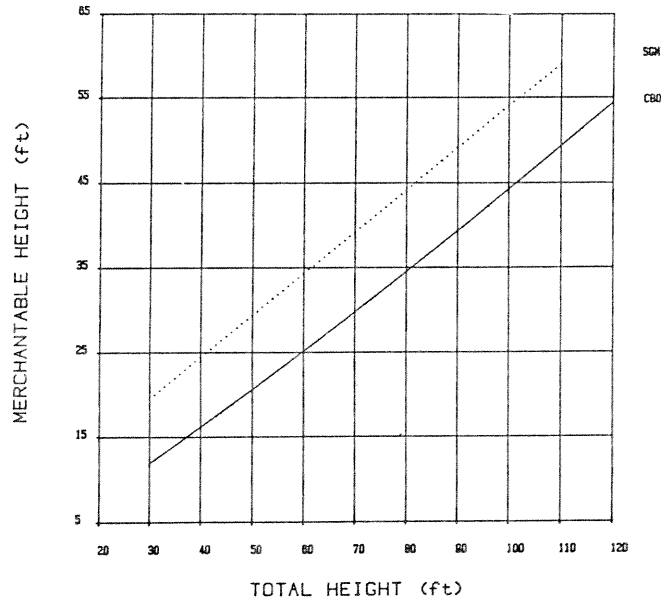

Figure 3.--Merchantable height-total height growth patterns for cherrybark oak and sweetgum on the minor bottoms of central Mississippi.

Table 1.--The development pattern of average dominant and codominant cherrybark oak trees in mixed oak-sweetgum stands in central Mississippi.

Age (yrs)	Height (ft.)		Diameter Outside Bark (in.)			
	Total	Merchantable	4.5 ft.	18 ft.	34 ft.	50 ft.
15	44	18	3.8	3.0		
23	62	26	6.7			
32	79	34	10.4	8.3	6.9	
43	95	42	15.4			
58	111	50	22.9	18.3	16.5	14.5

The butt log would naturally be the best in quality when compared to the other logs because of the smaller knotty core and the greatest accumulation of clear wood on top of the knotty core. The knotty core in the butt log has the shape of an inverted cone with the apex at the ground line and its base at the small end of the log. The DBH at the time the butt log becomes clear is 3.8 inches. After 60 years, the diameter of the tree is almost 23 inches, yielding approximately 20 inches of clear, high-quality wood produced at DBH. With that amount of clear wood accumulation and assuming no major defects, the log grade of the first log would be a grade one.

The second log becomes clear at age 32 when the DBH of the tree is 10.4 inches. The knotty core of the second log is 3.0 inches at the large end of the log and 6.9 inches at the small end. At rotation age the diameters at each end respectively are 18.3 and 16.5 inches. This is still a significant amount of clear wood accumulation, but not as much as in the butt log. If the second log is defect-free, its grade will depend on its final size. The log will be a grade one if the scaling diameter is 16 inches or above. Otherwise it will be a grade two.

The third log becomes clear just at the rotation age of 58 years. Consequently, there is little clear wood deposited on the log, especially on the upper 8 feet, and the dead branch stubs and other defects would still be exposed. Thus, the third log would only be a grade three. Also note that it takes 26 years to develop a clear third log, whereas it took only 17 years to develop the second clear log. This is primarily due to the declining height growth and merchantable height growth rates exhibited during the later stages of development. This suggests that it becomes increasingly difficult to achieve greater merchantable heights and clear diameter growth on the upper logs.

The development of clear bole length in cherrybark oak is a process of crown interactions between cherrybark oak and adjacent trees. When the crowns of adjacent trees meet, the lowest branches eventually die because of the absence of sufficient light to maintain growth. The side branches of adjacent trees continue to grow and meet higher in the tree. These too are shed as light becomes insufficient. This process of meeting and dying of the lower branches of the tree crown forces a highly placed crown of small branches and results in a tall, clear bole. Once the cherrybark oak begins to exceed the height of sweetgum and overtops it, the lower branches of the cherrybark oak crown receive enough side light to grow and become larger in diameter. This crown expansion makes the development of additional clear length less likely because it becomes increasingly difficult for these large, lower branches to be shed and to heal over. The now subordinate and more numerous sweetgum trees serve to keep the cherrybark oak thoroughly pruned.

Number of Trees Per Acre

If the assumption is made that the crown width of a tree is the diameter of a circular zone of growing space of that tree, then the area of that circle can be calculated and the number of trees per acre of that size approximated. Regression equations characterizing crown width and tree diameter were developed for cherrybark oak. When tree diameters average 22 inches these calculations estimate that the ideal stand will contain 40 to 50 cherrybark oak trees of that size per acre. These figures should be used with caution because they assume that there is perfect distribution of stems.

Spacing Between Trees

It is difficult to determine the precise spacing between the cherrybark oak subject tree

and adjacent sweetgum trees and the effect of that spacing on the growth and development of the cherrybark oak. This is due to the variable distribution of stems in natural stands, and because the adjacent sweetgum trees are spaced at different distances around the cherrybark oak stem. As stated earlier, attempts to correlate diameter growth and clear bole length to several expressions of stand density such as plot basal area, number of interacting trees, and several competition indices were unsuccessful. Within the realm of this study, the effects of stand density could not be detected statistically.

However, spacing, or the distance from the cherrybark oak subject tree to adjacent trees, was observed to have some influence on the development pattern of that cherrybark oak tree. To explain these distance relationships, a mean distance or average spacing between the cherrybark oak and interacting trees was calculated by measuring distances between the boles of the cherrybark oak and each interacting tree and taking an average. These mean or average distances reflected two patterns of cherrybark oak development. The first pattern takes place at mean distances of 6 to 18 feet and is the developmental pattern previously described. When average spacing between trees exceeded 18 feet, a second pattern of development was found. This will be discussed in the next section. If mean distance is less than 6 feet, the cherrybark oak is subordinate to and usually overtopped by adjacent sweetgum trees allowing little chance of continued cherrybark oak growth and survival.

The delineations between the patterns of development occurring at 6 and 18 feet are not concrete, but constitute a range of several feet where either pattern may occur. The range of average spacing from 6 to 18 feet in the first pattern of development seems large. This is because average spacing changes over time. When these trees are young, the average spacing is at the small end of the range. As cherrybark oak trees increase in volume, the average spacing increases due to the mortality of the smaller adjacent trees. Thus, the range in spacing exhibited by this pattern of development constitutes a progression of average spacing in the development of cherrybark oak.

A Second Pattern of Development

A second pattern of cherrybark oak development was discovered in 27 of the 150 plots and was found to occur under two situations. These plots had cherrybark oak trees that were 3 to 5 years older than the adjacent sweetgum trees and/or had dominant and codominant trees that were spaced greater than 18 feet from the cherrybark oak subject tree. In either case, there are few, if any adjacent trees that are directly influencing the growth, form, and development of the cherrybark oak. Cherrybark oak either had a head start in growth over adjacent trees so that it had a height and diameter advantage or adjacent trees were spaced so far away that no interacting stems influenced the growth of the subject tree.

When compared to the first pattern of development, these more or less open-grown trees have shorter merchantable lengths, earlier timing of crown expansion and increased diameter growth rates over a shorter period of time. Whereas adjacent interacting stems force a highly placed crown and long merchantable lengths, the lack of these interacting trees allows crown expansion at an earlier age and shorter merchantable heights because the lower crown branches are retained for a longer period of time. Diameter growth rate increases at an earlier stage of development reflecting the earlier timing of crown expansion.

Diameter and height equations and graphs were not formulated because of the small sample size of 27 plots. However, it should be noted that a second pattern of development occurs in these mixed stands and may be a management alternative which bears further investigation. Preliminary results from the 27 plots indicate that these free-to-grow, widely spaced cherrybark oaks attain total heights of 80 to 90 feet, diameters of 18 to 22 inches, and merchantable heights of 16 to 24 feet in 40 years. Observations suggest that the log grade of the only merchantable log in this pattern would be a grade one. Approximately 40 to 50 crop trees per acre, the same number as the first pattern of development, may be grown in 40 years if distribution is adequate.

The pattern of oak development just described is commonly referred to as "butt log forestry" in the United States and "free growth" in Great Britain (Jobling and Pearce 1977). The free growth method is a viable technique used in Europe to stimulate vigorous crown development in order to achieve maximum diameter increment in individual trees. The application of the free growth technique results in a high-quality veneer log in a short period of time.

SUMMARY

Two patterns of cherrybark oak tree development were recognized in mixed oak-sweetgum stands on the minor bottoms of central Mississippi. The first pattern occurs at average spacings of 6 to 18 feet with cherrybark oak averaging 22 to 24 inches in diameter and having merchantable heights of 2.5 to 3.0 logs in 60 years. A majority of the plots in the study followed this pattern of development. This development pattern has been documented in several mixed species stands of both hardwood and coniferous species (Oliver 1978; Scholz 1948; Wierman and Oliver 1979). A second development pattern was found where either the cherrybark oak was a few years older

than the sweetgum or the cherrybark oak was essentially open-grown with adjacent trees being more than 18 feet away. This results in a tree with less than 1.5 logs of clear merchantable length and diameters of 18 to 22 inches in 40 years. The difference between these two patterns of cherrybark oak development is the number of years for the tree to reach a diameter of 22 inches and the clear merchantable height attained. The adjacent interacting sweetgum trees, or the lack thereof, are responsible for these two patterns of growth. Depending on ownership and product objectives, either pattern of development appears to be a viable alternative in growing quality cherrybark oak trees in mixed species stands.

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MODELING EFFECTS OF MID-ROTATION FERTILIZATION ON SLASH PINE PLANTATION DIAMETER DISTRIBUTIONS [1/]

R. O. Lynch, A. V. Mollitor, and N. B. Comerford [2/]

Abstract.--In 1974, The Cooperative Research in Forest Fertilization (CRIFF) program established 11 fertilization experiments in mid-rotation slash pine plantations in Florida, Georgia, and Alabama. Factorial combinations of nitrogen and phosphorus were applied. Trees were measured at 0, 3, 5, and 8 years after treatment. For each study site a fertilizer response model system was developed to predict stand structure changes over time and with fertilizer treatment. The model systems have two major components. Changes in stocking are related to initial stocking and time. Changes in diameter distributions are estimated by predicting changes in Weibull-distribution b and c parameters associated with changing time and fertilizer treatment. The models may be used to predict fertilization effects on stand composition by various tree product classes. Results may be used to conduct economic analyses of responses on sites representative of broad soil groups.

INTRODUCTION

For nearly 20 years, the Cooperative Research in Forest Fertilization (CRIFF) program at the University of Florida has been studying two basic types of pine plantation fertilization: time-of-planting fertilization and mid-rotation fertilization. Many young plantings respond dramatically to phosphorus (P) and should be fertilized as close to planting time as possible. Many sites, however, that would show only moderate response to early P fertilization will respond favorably to nitrogen (N) and/or N + P fertilization when 10 to 20 years old. This mid-rotation fertilization can be attractive in that the time between investment and return is considerably less than an entire rotation.

The primary objective of slash pine (*Pinus elliottii* var. *elliottii*) plantation management on the lower coastal plain of the southeastern U.S. had for many years been production of fiber for use in the manufacture of pulp and paper. More recently, with a large value differential between wood used for fiber and wood used in solid-wood products, there has been increased interest in developing ways to increase production of chip-and-saw logs, sawtimber, and veneer logs from slash pine plantations. The CRIFF program has many mid-rotation fertilization experiments that have been routinely analyzed to determine fertilization effects on total volume (fiber) yields. Data from one series of these experiments were reanalyzed to examine fertilization effects on stand structure and how this might affect yields of trees in various size classes.

This paper describes the stand structure models and provides a few examples of how fertilization affects diameter distributions. The paper in these proceedings by Dippon and Munson illustrates uses of the models in economic analyses.

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[2/] Authors are, respectively, Statistician, Assistant Professor, School of Forest Resources and Conservation, and Assistant Professor, Forest Soils, University of Florida, Gainesville, Florida.

METHODS

Data Base

Eleven mid-rotation fertilization experiments were installed in 1973 and 1974 in slash pine plantations ranging in age from 9 to 16 years. These tests spanned a wide range of soil and site conditions. At each location an N x P factorial was installed in a randomized block design. Three blocks were defined as high, medium, and low basal area strata. Four rates of N and two rates of P were included in the factorial:

N Rate	P Rate
--lb. element/acre--	
0	0
100	100
200	
400	

Three replications of this 4 x 2 factorial occupied 24 plots at each location. Diameters of all trees were measured at 0, 3, 5, and 8 years after treatment.

Four of the 11 study sites were selected to illustrate operation of this diameter distribution model system (Table 1). Test B211 is a poorly drained flatwoods Spodosol. B220 is on a somewhat poorly drained soil with an argillic (clay) horizon at about 30 inches. B227 is on a very poorly drained, heavy-textured, P-deficient flat. Test B230 is on an excessively drained sandhill site.

Table 1.--Four study locations used to illustrate diameter distribution model system.

Test	Location	Soil	Initial Age
B211	Nassau Co. FL	Typic Haplohumod	16
B220	Calhoun Co. FL	Grossarenic Paleaquult	9
B227	Gulf Co. FL	Typic Albaquult	13
B230	Madison Co. FL	Typic Quartzipsamment	13

Survival Model

A separate survival model, of the type suggested by Pienarr and Shiver (1981) was developed for each location. Because no large, consistent effects of fertilization on survival were detected, changes over time in the number of living trees per acre was modeled as a function of initial stocking and time:

$$SPA_n = SPA_0 \cdot [\exp(-\gamma_0 \, TIME_n^{\gamma 1})] + .5 \qquad [1]$$

where: SPA_n = stems per acre at time of interest,

SPA_0 = initial stems per acre,

γ_o and γ_1 are non-linear regression coefficients derived from the data, and

$TIME_n$ = the time of interest, in years, since treatment.

Regressions were conducted on log-transformed time and stocking-change data, so the final regression equation took the form:

$$SPA_n = SPA_0 \left\{\exp(-\exp[(\ln \gamma_0) + \gamma_1 \ln (TIME)_n]\right\} + .5 \quad . \qquad [2]$$

Weibull Distributions

Diameter distributions on each plot for each time were described by using a two-parameter Weibull probability function to calculate the proportion of trees in each diameter class (Bailey and Dell 1973). The probability density function of the Weibull distribution for random variable x is:

$$f(x) = (c/b)(x/b)^{c-1} \exp[-(x/b)^c], \; x \geq 0, \; b > 0, \text{ and } c > 0. \qquad [3]$$

The b (scale) and c (shape) parameters were recovered by maximum likelihood estimation. An average initial diameter distribution was determined for each location by calculating initial (time 0) b and c parameters using combined data from all 24 plots.

For each location, multiple regression was used to model changes in b and c parameters as a function of initial parameter value, time, N fertilization rate, and P fertilization rate:

$$b_n = \gamma_0 + \gamma_1 b_0 + \gamma_2 T + \gamma_3 T^2 + \gamma_4 NT + \gamma_5 PT + \gamma_6 N^2 T + \gamma_7 NPT + \gamma_8 b_0 T, \qquad [4]$$

$$c_n = \beta_0 + \beta_1 c_0 + \beta_2 T + \beta_3 NT + \beta_4 PT + \beta_5 NPT + \beta_6 N^2 T + \beta_7 c_0 T, \qquad [5]$$

where: n = years since fertilization,

b_0 = initial b parameter,

c_0 = initial c parameter,

T = time (years),

N = N fertilization rate,

P = P fertilization rate, and

γ and β are regression coefficients.

For each location, these equations may be used to predict Weibull b and c parameters for any combination of time, N, and P.

Diameter Distributions

By combining predicted b and c parameters with predicted stems per acre from the survival model in an equation derived from equation [3], the number of trees per acre in a diameter class can be predicted using the equation:

$$TPA_d = SPA_n \left[\exp\left(-(d_1/b)^c\right) - \exp\left(-(d_2/b)^c\right)\right] \qquad [6]$$

where:

TPA_d = trees per acre in diameter class d (midpoint in inches),

SPA_n = total stems per acre at time n (years) since fertilization,

d_1 = lower limit of diameter class,

d_2 = upper limit of diameter class,

b = predicted value of b parameter, and

c = predicted value of c paremeter.

Diameter distributions were calculated for the initial conditions, and for eight years after treatment, both without fertilization and with a fertilization treatment of 200 lb. N plus 100 lb. P per acre.

RESULTS

Survival Model

For the eight-year period after fertilization, mortality ranged from 4 to 14 percent in the four examples presented (Table 2). The highest mortality rate was observed on the sandhill site (B230). The initial stocking rates and regression coefficients given in Table 2 can be used in equation [2] to predict stocking at any time up to 8 years after initial measurement.

Table 2.--Initial stocking, regression coefficients, and predicted 8th-year stocking.

Test	SPA_0	$\ln(\gamma_0)$	γ_1	SPA_8
B211	485	-3.828	0.6569	446
B220	509	-3.387	0.1072	488
B227	663	-3.337	0.1460	632
B230	476	-4.630	1.3390	407

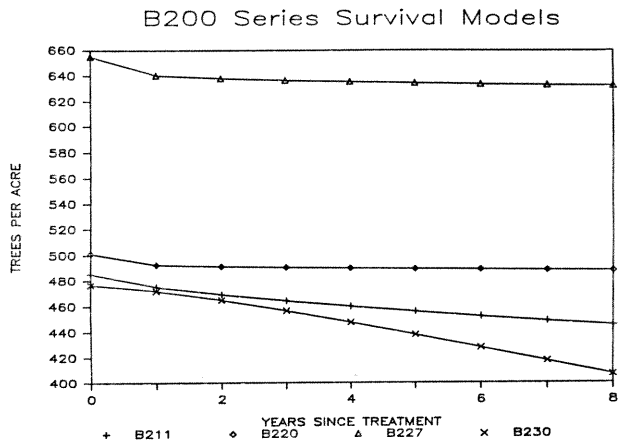

Figure 1.--Predicted survival for the eight-year period after study initiation.

Weibull Distributions

The Weibull parameters for the distributions fit to the diameters at study initiation are presented in Table 3.

Table 3.--Weibull b and c parameters for distributions at study establishment.

	Parameter	
Test	b	c
B211	5.7079	3.9840
B220	3.2340	3.6971
B227	2.5141	2.7586
B230	4.4871	4.9684

These initial parameter values were used along with selected N rates, P rates, and times in equations [4] and [5] to predict changes in b and c parameters. Regression coefficients for equations [4] and [5] for the four examples are provided in Table 4.

Table 4.--Regression coefficients for predicting changes in Weibull b and c parameters.

	Example Number			
Coef.	B211	B220	B227	B230
		Equation [4]		
$\gamma 0$	0.547	-1.539	-0.703	0.910
$\gamma 1$	0.938	1.553	1.362	0.971
$\gamma 2$	4.853E-2	0.452	0.320	-0.171
$\gamma 3$	-1.580E-3	-2.154E-2	-1.351E-2	6.730E-3
$\gamma 4$	1.997E-4	3.725E-4	4.535E-4	1.237E-4
$\gamma 5$	2.289E-4	2.223E-4	2.203E-3	1.605E-4
$\gamma 6$	-2.521E-7	-6.613E-7	-1.159E-6	1.763E-7
$\gamma 7$	-1.118E-9	3.509E-6	9.890E-7	-1.521E-6
$\gamma 8$	1.137E-2	-1.167E-2	-4.230E-2	4.104E-2
		Equation [5]		
$\beta 0$	-0.548	1.145	0.602	0.644
$\beta 1$	1.137	0.833	0.970	0.976
$\beta 2$	7.927E-2	-8.040E-2	0.106	0.154
$\beta 3$	1.719E-4	-1.047E-4	-4.002E-5	-1.980E-4
$\beta 4$	3.600E-5	1.391E-4	1.415E-4	4.088E-4
$\beta 5$	-3.351E-7	-1.870E-6	-7.670E-7	-2.121E-6
$\beta 6$	-3.450E-7	1.143E-7	-1.737E-7	1.010E-6
$\beta 7$	-3.216E-2	1.963E-2	-4.787E-2	-5.671E-2

Predicted values for the b and c parameters eight years after treatment, both with and without 200 lb. N plus 110 lb. P per acre, are illustrated in Figure 2.

In these four examples, predicted values of c parameters show little change with fertilization while b parameters appear more sensitive. Test B227 shows the greatest change in the b parameter while B230 shows very little. Magnitudes of b parameter change for tests B211 and B220 are intermediate.

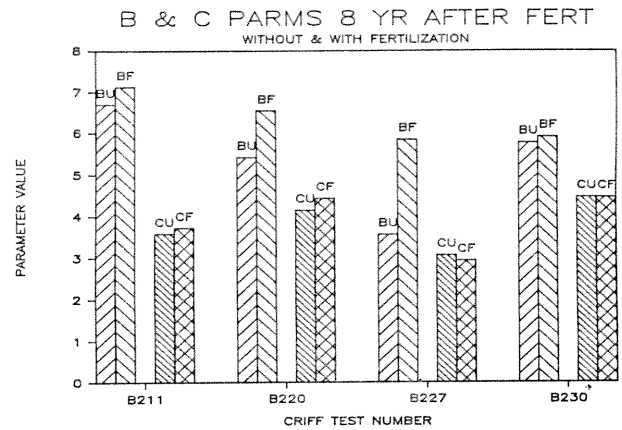

Figure 2.--Predicted values for b and c parameters with and without fertilization at 8 years after treatment.

Diameter Distributions

Combining stocking rates and parameter values for selected times and rates of N and P in equation [6] generates predicted stems per acre in each diameter class (Figs. 3 through 6). Comparison of distributions at establishment with distributions (non-fertilized) after eight years shows that, with stand development over time, distributions tend to flatten and stretch to the right. Comparisons of fertilized and non-fertilized distributions at eight years show similar results with the fertilized distributions having greater maximum diameters but fewer stems in the most heavily stocked diameter class. In accordance with b parameter changes with fertilization, the shift in diameter distribution is dramatic in B227, intermediate in B211 and B220, and minimal in B230.

By selecting specified diameter limits for various product classes, these equation systems can be used to predict treatment effects on product mix. For example, if 7.5 inches is selected as the lower diameter limit for solid wood products, the number of trees in all diameter classes above 7 inches can be summed for selected treatments (Fig. 7). Increase in the number of large-diameter trees is roughly proportional to change in the b parameter. Among these examples, fertilization increases the number of solid wood product trees by as much as 79 trees per acre (B227).

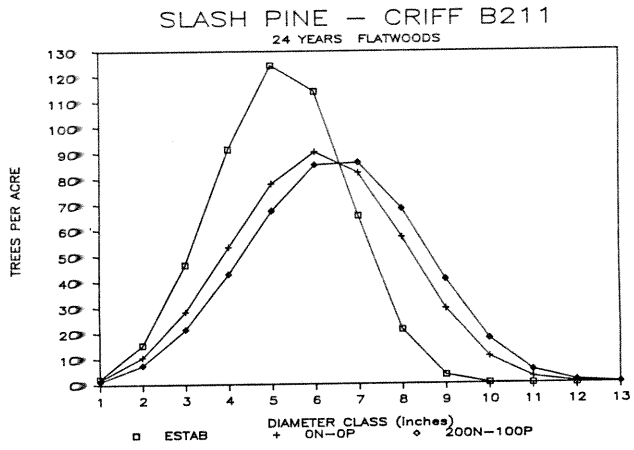

Figure 3.--Predicted diameter distributions on a poorly-drained Spodosol at study establishment, and 8 years after establishment with and without fertilization.

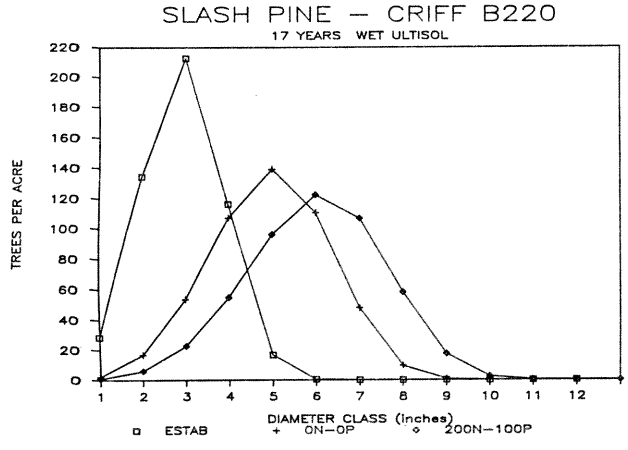

Figure 4.--Predicted diameter distributions on a somewhat poorly-drained coarse-textured Ultisol at study establishment, and 8 years after establishment with and without fertilization.

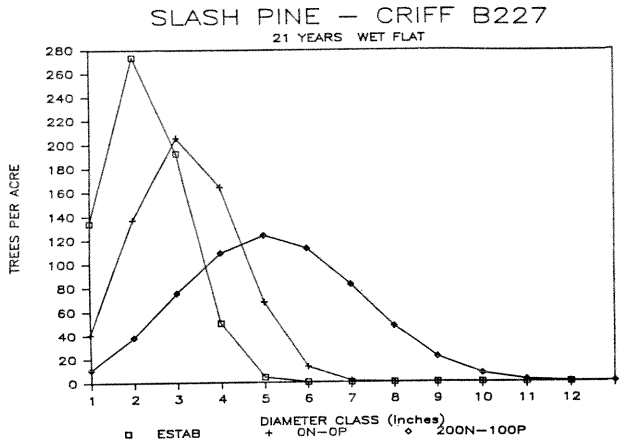

Figure 5.--Predicted diameter distributions on a poorly-drained, fine-textured Ultisol at study establishment, and 8 years after establisment with and without fertilization.

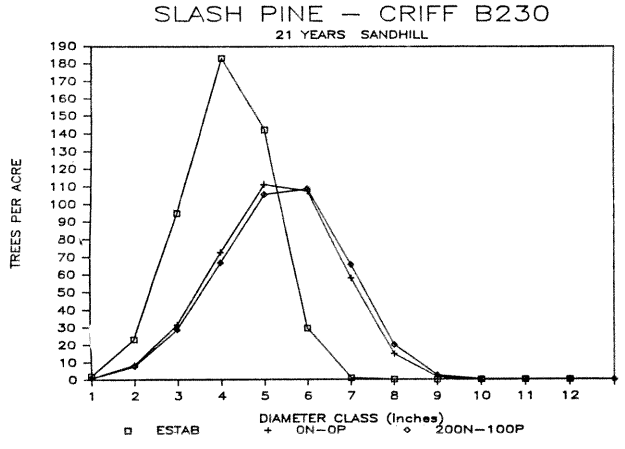

Figure 6.--Predicted diameter distributions on an excessively-drained Psamment at study establishment, and 8 years after establishment with and without fertilization.

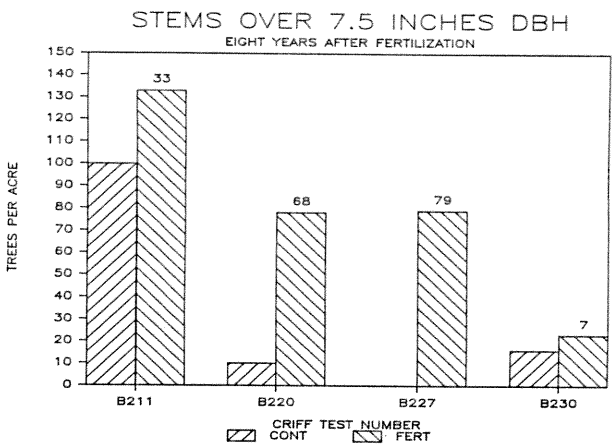

Figure 7.--Difference in trees per acre over 7.5 inches dbh using predicted diameter distributions for fertilized and non-fertilized stands.

DISCUSSION

The CRIFF program has had success in relating total volume response to soil characteristics. While there are only 11 locations in this series of experiments, and the data base is far too small to use for development of a general model of stand structure response to fertilization, by classifying each of these experiments by soil type these stand structure analyses will help to further elucidate the general nature of fertilizer response for broad soil groups.

Of the four examples presented here, test B211 is on a typical coarse-textured flatwoods soil. Total eight-year volume response to 200 lb. N + 100 lb. P per acre was about 500 cubic feet per acre (CRIFF 1984). This response is reflected in an increase of about 5 to 10 trees per acre in each of the 7- to 10-inch diameter classes (Fig. 3).

Total volume response in B220 -- on a coarse-textured savanna soil -- was about 370 cubic feet per acre. Although total volume response was less than in B211, effect on stand structure was greater (Fig. 4) because the stand was younger (9 vs. 16 years) and mean diameter was smaller at time of treatment.

B227 typifies the dramatic P response often observed on wet flats. Eight-year response was about 1400 cubic feet per acre, and diameter distributions show a correspondingly dramatic change (Fig. 5). In contrast, droughty sandhill sites usually show little response to fertilization, and response in test B230 was only about 50 cubic feet per acre after eight years. Stand structure was changed little by fertilization (Fig. 6).

These model systems were developed to evaluate fertilization effects on structure of slash pine plantations growing on identifiable soil types. By quantifying fertilization influences on product mix, more detailed economic analyses of these investment opportunities are possible. The paper in these proceedings by Dippon and Munson provides examples of financial analyses based on these models.

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STEM VOLUME, VOLUME RATIO, AND TAPER EQUATIONS FOR SLASH PINE IN THE WEST GULF REGION[1/]

Richard E. Lohrey[2/]

Abstract.--Equations are presented that estimate: total stem volume inside or outside bark, the ratio of merchantable stem volume between stump height and any upper stem diameter to total volume, and the upper stem diameter at a given height. Separate equations for trees established by planting and those established by direct seeding are compared.

INTRODUCTION

Slash pine (*Pinus elliottii* var. *elliottii* Engelm.) can produce high volumes of wood at an early age, and this wood is an excellent raw material for paper, plywood, and lumber. Consequently, slash pine has been extensively planted and direct-seeded in Louisiana and Texas, west of its natural range. No volume tables are available for trees in direct-seeded stands. Moehring and others (1973) have published tables with volumes from stump height to specific upper stem diameters for planted slash pines in Texas. This paper presents equations to estimate: (1) total stem volume inside bark (i.b.) or outside bark (o.b.), (2) the ratio of merchantable stem volume to total volume, and (3) taper functions to estimate stem diameter i.b. or o.b. at any height for artificially regenerated slash pines.

METHODS

Sample trees were selected from a wide array of sites, ages, stand densities, and silvicultural treatments on National Forest and industrial lands. Only sound trees that did not fork were measured. The oldest direct-seeded stands available were only 26 years old while planted stands ranged up to 48 years. On the average, the planted trees were older, taller, and larger in diameter than direct-seeded ones. Direct-seeded stands had more trees per acre, but the basal area density and site index were similar for stands established by the two methods.

Characteristics of the stands and sampled trees are given in tables 1 and 2. Tables 3 and 4 show the distribution of sampled trees by site index and age classes, and tables 5 and 6 give their distribution by diameter and total height.

Table 1.--Characteristics of sample stands

Item	Unit	Planted stands Mean	Planted stands Range	Direct-seeded stands Mean	Direct-seeded stands Range
Site index (25)	Feet	60	31-78	59	30-70
Age	Years	31	12-48	19	13-26
Trees/ acre	Number	468	51-2,186	1,096	330-3,580
BA/ acre	Feet^2	119	48-217	132	17-204

Table 2.--Characteristics of sample trees

Item	Unit	Planted trees (n=201) Mean	Planted trees (n=201) Range	Direct-seeded trees (n=266) Mean	Direct-seeded trees (n=266) Range
D.b.h.	Inches	8.2	2.2-19.1	5.7	1.3-12.1
Height	Feet	59	20-110	46	12-76
Age	Years	31	12-48	19	13-26
LCR 1/	Percent	33	11-60	36	11-58

1/ LCR = Live crown ratio

1/ Paper presented at the Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Research Forester, USDA Forest Service, Southern Forest Experiment Station, Pineville, Louisiana 71360.

Table 3.--Distribution of planted sample trees by site index and age classes

Age class	Site index (25) ≤49	50-65	≥66	Row total
--Years--	--------Number of trees----------			
≤24	9	18	57	84
25-40	27	27	16	70
≥41	6	28	13	47
Total	42	73	86	201

Table 4.--Distribution of direct-seeded sample trees by site index and age classes

Age class	Site index (25) ≤49	50-65	≥66	Row total
-Years-	--------Number of trees----------			
≤15	21	37	10	68
16-21	17	13	42	72
≥22	7	98	21	126
Total	45	148	73	266

Diameters o.b. and i.b. were measured at heights of 0.5, 2.0, and 4.5 feet and at 5-foot intervals above 4.5 feet. Shorter intervals were used where stem taper was extreme or irregular, such as high in the crown. Total height was also recorded for each tree. Stem volumes, both i.b. and o.b., between measurement points were calculated using Smalian's formula. The tip of the stem was treated as a cone. Volumes for all sections were summed to determine total stem volume.

ANALYSIS OF DATA

Data from the 201 planted and 266 direct-seeded trees were analyzed by linear and nonlinear [modified Gauss-Newton (SAS Institute 1982)] regression methods. Initial use of weighted linear models to estimate stem volume gave unsatisfactory results. They either failed to stabilize the variance, a basic assumption in regression analysis, or left trends in the residuals. Logarithmic transformation of the model suggested by Schumacher and Hall (1933) stabilized the variance and eliminated trends in the residuals. Their model was used to estimate total stem volume in this study.

Table 5.--Distribution of planted sample trees by diameter and height

Diameter at 4.5 feet	Total height (feet) 20	30	40	50	60	70	80	90	100	110	Total
---Inches---	----------Number of trees----------										
2	1	2									3
3	2	6	4								12
4		3	9	2							14
5		5	6	10	3						24
6			4	5	5	2					16
7		1	4	7	9	3					24
8			2	4	13	3	2				24
9			2	4	8	7	1				22
10					6	6	7	1			20
11					3	4	3	1			11
12						3	2	1			6
13						2	2	3	1		8
14						1	1				2
15						1	1	2	1		5
16									1	1	2
17							2	0	1		3
18									1		1
19								2	1	1	4
Total	3	17	31	32	47	32	21	10	6	2	201

Table 6.--Distribution of direct-seeded sample trees by diameter and height

Diameter at 4.5 feet	Total height (feet) 10	20	30	40	50	60	70	80	Total
---Inches---	Number of trees								
1	1								1
2	3	7	10						20
3		7	18	6					31
4		5	7	17	10				39
5			6	18	17	2			43
6				13	16	9			38
7				9	12	14	2		37
8				1	5	17	2		25
9						12	6	1	19
10						4	7		11
11							1		1
12						1			1
Total	4	19	41	64	60	59	18	1	266

A merchantable volume to total volume ratio equation was computed from sample tree data. The predicted ratios may be used to estimate merchantable volume to any desired utilization limit or standard from predicted total stem volume. Several ratio models were considered. Burkhart (1977) described a three-parameter nonlinear model. His model may predict negative volume ratios as the upper stem diameter limit approaches d.b.h. VanDeusen and others (1981) developed a two-parameter exponential model that does not predict negative ratios. Parresol (1983) added a third parameter to VanDeusen's exponential model with good results, and based on these results, Parresol's model was selected for use here.

It is recognized that, logically, total stem volume equations and stem taper functions should be compatible. In fitting data to models, however, volume equations are fitted to optimize volume predictions whereas taper equations are fitted to optimize diameter, or sometimes height, predictions. The equation that is best for estimating upper stem diameters is not necessarily best for estimating stem volume.

Separate sets of coefficients were determined for planted and direct-seeded trees and also for the combined data. Differences between the regression lines for the two stand origins were evaluated by the general linear test procedure described by Neter and Wasserman (1974). Their approach tests the equality of two regression functions but does not compare their slopes or intercepts.

RESULTS

Stem Volume

The Schumacher and Hall (1933) model used to estimate stem volumes is:

$$\hat{V} = b_1 D^{b_2} H^{b_3} \qquad (1)$$

where: $\hat{V}$ = estimated total stem volume (cubic feet) from a 6-inch stump to the tip,

D = d.b.h. (inches) o.b.,

H = total height (feet),

b_1, b_2, b_3 = coefficients estimated from the data.

The model was converted to a linear form by logarithmic transformation:

$$\ln(\hat{V}) = \ln(b_1) + b_2 \ln(D) + b_3 \ln(H) \qquad (2)$$

or

$$\ln(\hat{V}) = b'_1 + b_2 \ln(D) + b_3 \ln(H) \qquad (3)$$

where: ln = natural logarithm,

$b'_1 = \ln(b_1)$ + correction for bias.

The transformed model was solved by linear least-squares techniques (SAS Institute 1982).

When logarithmic estimates are converted back into their original units of measure, the new estimates are biased. The antilogarithm of a logarithmically transformed variable gives the geometric instead of the arithmetic mean (Finney 1941, Flewelling and Pienaar 1981). A correction factor was computed and the b'_1 coefficient includes an adjustment to compensate for this bias. The adjustment followed procedures recommended by Baskerville (1972) and Yandle and Wiant (1982). Other coefficients do not require adjustments.

Coefficients for the stem volume equations are given in table 7.

Merchantable Volume Ratio

The merchantable volume of a tree equals the product of the merchantable volume to total volume ratio and the total stem volume of the tree. Thus, the combination of total stem volume equations and volume ratio equations make it possible to accurately estimate the merchantable volume i.b. or o.b. to any upper stem diameter.

Table 7.--Regression coefficients for total stem volume equations[1/]

Component[2/]	Parameter estimates			Statistics[3/]		
	b'_1	b_2	b_3	F.I.	$S_{y.x}$	C.V.
Planted trees						
TVob	-5.41584	2.08097	0.84544	0.99	1.46	8.86
TVib	-6.93385	2.07195	1.13645	.99	1.83	14.86
Direct-seeded trees						
TVob	-5.16490	2.03533	0.80591	.99	.43	7.56
TVib	-7.00109	1.98146	1.19639	.99	.44	11.21
Combined data						
TVob	-5.23479	2.05779	0.81353	.99	1.13	10.94
TVib	-6.96711	2.02254	1.16941	.99	1.24	16.52

1/The model is: $\ln(\hat{V}) = b'_1 + b_2 \ln(D) + b_3 \ln(H)$

where: $\hat{V}$ = predicted stem volume in ft^3,
D = d.b.h. (inches) o.b.,
H = total height (feet), and
b'_1, b_2, and b_3 = coefficients estimated from the data.

2/TVob = total stem volume (ft^3) from a 6-inch stump to the tip, o.b.

TVib = Total stem volume (ft^3) from a 6-inch stump to the tip, i.b.

3/F.I. = fit index = $\{1-[\Sigma(Y_i-\hat{Y}_i)^2]/[\Sigma(Y_i-\bar{Y})^2]\}$

where: Y is in the original units (ft^3).

$S_{y.x}$ = standard error in the original units (ft^3).

C.V. = coefficient of variation in percent.

Stem volumes (i.b. and o.b.) to various upper stem diameters were used to calculate equation coefficients for the volume ratio model used by Parresol (1983). The model is:

$$\hat{R} = EXP\ [b_1\ (d^{b_2}/D^{b_3})] \qquad (4)$$

where: $\hat{R}$ = estimated ratio of merchantable volume to total stem volume (ft^3),

d = upper stem diameter i.b. or o.b. (inches),

D = d.b.h. (inches) o.b.,

EXP = exponential function, and

b_1, b_2, and b_3 = coefficients estimated from the data.

The data were fitted by nonlinear least squares methods (SAS Institute 1982). Coefficients for the stem volume ratio equations are given in table 8. The MVob/TVob ratio in table 8 can be used to estimate volume o.b. to a given diameter o.b. and the MVib/TVib ratio in the same table can be used to estimate volume i.b. to a given diameter i.b.

Taper Function

A tree stem taper function can be used to estimate the diameter at a given height on the tree. These functions are extremely valuable to forest managers planning to market their timber to maximize product values.

The taper model used was one described by Max and Burkhart (1976). The model is:

$$\frac{\hat{d}^2}{D^2} = b_1(X-1)+b_2(X^2-1)+b_3(a_1-X)^2 I_1 + b_4(a_2-X)^2 I_2 \qquad (5)$$

where: $I_i = \begin{cases} 1, \text{ if } X \leq a_i, \\ 0, \text{ if } X > a_i, \end{cases} \qquad i = 1,2$

d = stem diameter i.b. or o.b. (inches) at any given height, h,
D = d.b.h. (inches) o.b.,
X = h/H,
h = height (feet) at which diameter is to be determined ($\leq$ H),
H = tree total height (feet),
a_i = join points estimated from the data, and
b_i = coefficients estimated from the data.

The data were fitted by nonlinear least squares (SAS Institute 1982). Coefficients for stem taper functions are given in table 9.

COMPARISONS BETWEEN STAND ORIGINS

Regression lines for stem volume, merchantable volume ratios and stem taper were tested, and in each comparison the difference in the regression lines between the two stand origins was statistically significant at the 0.05 level. The differences in predicted volume between planted and direct-seeded trees were small for trees 12 inches or less in diameter. Predictions were higher for planted than direct-seeded trees more than 12 inches d.b.h. Since the largest direct-seeded tree samples was only 12.1 inches d.b.h., important differences in volume per tree occurred beyond the range of data for direct-seeded trees. Readers may use equation coefficients in tables 7, 8, and 9 that apply to their particular situation or those for the combined data that are more universally applicable.

EXAMPLE

The following is an example of how to estimate the total stem volume i.b., merchantable volume o.b. to a 4-inch top o.b., and volume i.b. from a 6-inch stump to a height of 17 feet in a planted tree with a d.b.h. of 12.0 inches and total height of 80 feet. Total stem volume i.b. and o.b. can be estimated from equation 3 and regression coefficients in table 7. Volume i.b. is computed first.

$$\ln(TVib) = b_1' + b_2 \ln(D) + b_3 \ln(H)$$

$$TVib = EXP\ [-6.93385 + 2.07195 \ln(12.0) + 1.13645 \ln(80)]$$

$$TVib = EXP\ [-6.93385 + 2.07195\ (2.48491) + 1.13645\ (4.38203)]$$

$$TVib = EXP\ [3.19470]$$

$$TVib = 24.40\ ft^3.$$

Total volume o.b. would be:

$$\ln(TVob) = b_1' + b_2 \ln(D) + b_3 \ln(H)$$

$$TVob = EXP\ [-5.41584 + 2.08097 \ln(12.0) + 0.8544 \ln(80)]$$

$$TVob = EXP\ [-5.41584 + 2.08097\ (2.48491) + 0.84544\ (4.38203)]$$

$$TVob = EXP\ [3.45992]$$

$$TVob = 31.81\ ft^3.$$

Table 8.--Regression coefficients for volume ratio equations[1/]

Ratio[2/]	Parameter estimates			Statistics[3/]	
	b_1	b_2	b_3	F.I.	$S_{y.x}$
		Planted trees			
MVob/TVob	-1.17608	5.27997	5.14066	0.97	0.05
MVib/TVib	-12.68894	5.96264	6.40722	.95	.07
		Direct-seeded trees			
MVob/TVob	-.88587	5.05297	4.79322	.97	.05
MVib/TVib	-10.54772	5.97395	6.31583	.94	.08
		Combined data			
MVob/TVob	-.99243	5.15647	4.94987	.97	.05
MVib/TVib	-11.56724	5.96343	6.36241	.95	.07

[1/]The volume ratio model is: $\hat{R} = \text{EXP}\ [b_1(d^{b_2}/D^{b_3})]$

where: $\hat{R}$ = ratio of merchantable to total cubic foot volume,
d = upper stem merchantable limit (inches) — o.b. for o.b. ratios, i.b. for i.b. ratios,
D = d.b.h. (inches) o.b., and
b_1, b_2, and b_3 = coefficients estimated from the data.

[2/]MVob = merchantable volume, o.b.
MVib = merchantable volume, i.b.
TVob = total volume, o.b.
TVib = total volume, i.b.

[3/]F.I. = fit index = $\{1-[\Sigma(Y_i-\hat{Y}_i)^2]/[\Sigma(Y_i-\bar{Y})^2]\}$

$S_{y.x}$ = standard error in the original units.

Table 9.--Regression coefficients for stem taper functions[1/]

Dependent variables[2/]	Parameter estimates						Statistics[3/]	
	b_1	b_2	b_3	b_4	a_1	a_2	F.I.	$S_{y.x}$
				Planted trees				
dob^2/D^2	-12.50173	6.17966	-6.04321	200.32062	0.93018	0.06492	0.95	0.10
dib^2/D^2	-4.85915	2.34782	-2.55001	199.97796	.83659	.04855	.95	.06
				Direct-seeded trees				
dob^2/D^2	-2.36460	0.62703	-0.38862	168.50675	1.22788	.07481	.95	.12
dib^2/D^2	-4.16548	1.99603	-2.23061	168.51571	.81647	.05586	.95	.06
				Combined data				
dob^2/D^2	-12.52111	6.16723	-5.97927	172.18416	.93531	.07178	.95	.11
dib^2/D^2	- 4.48947	2.16025	-2.38087	182.85719	.82634	.05231	.95	.06

1/ The model is:

$$\frac{\hat{d}^2}{D^2} = b_1(X-1) + b_2(X^2-1) + b_3(a_1-X)^2 I_1 + b_4(a_2-X)^2 I_2$$

where: $I_i = \begin{cases} 1, \text{ if } X \leq a_i \\ 0, \text{ if } X > a_i \end{cases}$ $\quad i = 1,2$

$\hat{d}$ = stem diameter i.b. or o.b. (inches) at any given height, h,
D = d.b.h. (inches) o.b.,
X = h/H,
h = height (feet) at which diameter is to be determined ($\leq$ H),
H = tree total height (feet),
a_i = join points estimated from the data, and
b_i = coefficients estimated from the data.

2/ dob = diameter o.b. at any given height, h
dib = diameter i.b. at any given height, h
D = d.b.h. (inches) o.b.

3/ F.I. = fit index = $\{1-[\sum(Y_i-\hat{Y}_i)^2]/[\sum(Y_i-\bar{Y})^2]\}$

where: $\hat{Y}_i = \sqrt{D^2(\frac{\hat{d}^2}{D^2})}$ and $y_i = d_i$

$S_{y.x}$ = standard error in original units.

The ratio of merchantable volume o.b. (to a 4-inch top) to total volume o.b. is estimated using equation 4 and regression coefficients from table 8.

$$R = EXP\ [b_1(d^{b_2}/D^{b_3})]$$

$$R = EXP\ \left[-1.17608\ (4.0^{5.27997}/12.0^{5.14066})\right]$$

$$R = EXP\left[-1.17608\ (1{,}509.59559/352{,}942)\right]$$

$$R = EXP\ [-0.00503]$$

$$R = 0.9950.$$

The merchantable volume o.b. is the product of total volume o.b. and the merchantable volume ratio.

$$MVob = R \times TVob$$

$$MVob = 0.9950 \times 31.81\ ft^3.$$

$$MVob = 31.65\ ft^3.$$

Use equation 5 and coefficients from table 9 to determine diameter i.b. 17 feet above the ground.

$$\frac{d^2}{D^2} = b_1(X-1) + b_2(X^2-1) + b_3(a_1-X)^2 I_1 + b_4(a_2-X)^2 I_2$$

$$\frac{d^2}{12.0^2} = -\ 4.85915(\frac{17}{80} - 1) + 2.34782(\frac{17^2}{80^2} - 1)$$

$$-\ 2.55001(0.83659 - \frac{17}{80})^2\ (1)$$

$$+\ 199.97796(.04855 - \frac{17}{80})^2(0)$$

$$\frac{d^2}{144.00} = 3.82658 - 2.24180 - 0.99321 + 0.0$$

$$\frac{d^2}{144.00} = 0.59158$$

$$d^2 = 144.00 \times 0.59158$$
$$d = 9.2.$$

The ratio of merchantable volume i.b. to a 9.2 inch top diameter i.b. to total volume i.b. is determined from equation 4 and regression coefficients from table 8.

$$R = EXP\ \left[b_1(d^{b_2}/D^{b_3})\right]$$

$$R = EXP\ \left[-12.68894\ (9.2^{5.96264}/12.0^{6.40722})\right]$$

$$R = EXP\ [-12.68894\ (558{,}110/8{,}213{,}943)]$$

$$R = EXP\ [-12.68894\ (.06795)]$$

$$R = EXP\ [-0.86216]$$

$$R = 0.4223.$$

Merchantable volume i.b. to the same 9.2-inch top diameter i.b. is the product of this ratio and stem total volume i.b.

$$MVib = R \times TVib$$

$$MVib = 0.4223 \times 24.40\ ft^3$$

$$MVib = 10.30\ ft^3.$$

CONCLUSION

The equations presented here provide the reader with a means to estimate the total or merchantable volume i.b. or o.b. of slash pines established by planting or direct seeding. Readers can also estimate stem diameter i.b. or o.b. at any height on the bole. These results should be applicable throughout the West Gulf Region where slash pine has been extensively planted and direct-seeded.

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SURVIVAL CURVES FOR UNTHINNED AND EARLY-THINNED DIRECT-SEEDED SLASH PINE STANDS[1/]

V.C. Baldwin, Jr.[2/]

Abstract.--Survival data from repeated measurements of 158 unthinned and precommercially-thinned direct-seeded slash pine (Pinus elliotti Engelm.) plots were analyzed for predictable relationships between type of thinning, post-thinning density, and stand age. Types of thinning included select, row, and a combination of the two. These data provided 489 measurements of survival over 2 to 5 year time periods from stand ages 1 through 20 years. Survival equations for use in row-seeded stands, and in unthinned, selectively thinned, and row-thinned broadcast-seeded stands, are presented and discussed.

INTRODUCTION

Thousands of acres of pine stands have been established by direct-seeding throughout the South. Some have been precommercially thinned, but in the many that have received no thinnings, overstocking is common. In general, there is little published quantitative information available about survival patterns in managed direct-seeded pine stands. This study analyzes survival using data from studies in both unthinned and precommercially thinned direct-seeded slash pine (Pinus elliottii Engelm.) stands established on cutover sites in the West Gulf Region. The objective was to develop a survival function that would accurately predict survival in stands similar to those studied.

DATA

Survival data were obtained from remeasurements of eight long term, direct-seeded slash pine studies[3/]. The study plots are located in Natchitoches and Rapides Parishes in central Louisiana and in Washington Parish in southeast Louisiana. The studies were established to provide data for estimating growth and yield of slash pine under various seeding and/or early thinning treatments. The trees were broadcast-seeded or seeded in rows. Many were thinned precommercially using the selection technique, mechanically row-thinned, or row-thinned in combination with immediate or deferred selective thinning. Calculated Site Index (base age 15) for the study plots, using Lohrey's (1984) equation, ranged from 20 to 58 feet overall and averaged 40 feet. Table 1 summarizes basic information about these data. The 158 repeatedly measured plots provided a total of 489 "survival-change" observations ranging from ages 1 to 22 years.

A specific record of rust-associated mortality was not kept. Every effort was made when the studies were installed to avoid heavily rust-infected stands, and in the precommercial thinning studies, rust-infected trees were removed whenever possible. Results of this analysis indicate there was no catastropic mortality on any of the plots and it is reasonable to assume rust infected trees never exceeded 10 percent of the total number of trees in any of the stands measured.

MODELING SURVIVAL

The total data set was divided into nested subsets based on the type of treatment received.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Principal Mensurationist, Southern Forest Experiment Station, Pineville, Louisana 71360

3/ These studies were all installed, remeasured and are currently maintained by Richard E. Lohrey, Silviculturist, with the Southern Forest Experiment Station, Pineville, Louisiana. Utilization of his data for this analysis is gratefully acknowledged.

Table 1.--Direct seeded slash pine studies for the West Gulf Region

Study	When seeded	Measured at ages	Age at thinning	Initial densities	Post thinning density 1/	Treatment(s) 2/	No. of survival re-measurements	No. of plots
	Year			Trees/acre				
1	1962	1,3,10,15,20	-	621-4150	-	S - 0	72	21
2	1962	9,15,20	-	390-650	-	S - 0	7	11
3	1959	3,8,12,17,22	3	5584	500-4200 (5090)	S - 0,1,2,3,4	144	36
4	1964	6,8,11,14,17	-	395-3546	-	R - 0	72	18
5	1966	5,8,11,14	-	608-4263	-	R - 0	54	18
6	1964	4,9,13,18	4	2600-5280	500-2800 (3673)	S - 0,1,2	50	18
7	1968	5,8,11,14	-	588-4249	-	R - 0	54	18
8	1968	3,8,13	3	4290-7270	500-4700 (6327)	S - 0,1,2	36	18

1/ Numbers in parentheses ( ) are average densities of unthinned control plots.
2/ S = broadcast-seeded, R = row-seeded;
0 = no thinning,
1 = selective-thinning,
2 = row-or strip-thinning,
3 = row-thinning followed immediately by selective-thinning of residual trees within the rows,
4 = row-thinning followed by selective-thinning of residual trees within rows five years later.

The schematic below illustrates this allocation:

(A) All data combined (n=489)

(B) Unthinned stand data (n=284) (C) Thinned stand data (n=205)

(D) Unthinned, broadcast seeded(n=104) (E) Unthinned, row-seeded (n=180) (F) Selectively thinned, broadcast-seeded (n=103) (G) Row-thinned, broadcast-seeded (n=102)

where n designates the number of "survival-change" observations in each data set.

For this analysis, all row-thinning data were grouped together, even if there had been partial selective-thinning within the rows of residual trees.

Numerous model forms were then fitted to the data. None of the models tried were clearly superior. However, the model used by Clutter and Jones (1980), fit the data well in most cases. It is:

$$TS_2 = [TS_1^{\beta_0} + \beta_1 (A_2^{\beta_2} - A_1^{\beta_2})]^{1/\beta_0}$$

where

TS_1, TS_2 = Initial and projected trees surviving per acre, respectively,

A_1, A_2 = Initial and projected age, respectively,

β_0, β_1, β_2 = Coefficients estimated from the data.

This model had the desirable mathematical properties that when A_1 equaled A_2, TS_1 equaled TS_2 and, when fitted to the data, β_0 was always negative and both β_1 and β_2 were positive, thus insuring that as A_2 approached infinity, TS_2 approached zero. The fitting was done using the Statistical Analysis System nonlinear regression procedure NLIN with the Marquardt Technique option (SAS Institute 1982). The resulting equations were labeled A to G corresponding to the data sets (A) through (G).

Equation coefficients and some supporting statistics are presented in table 2. In addition, the graphs in figures 1 and 2 visually summarize how well equation D (the worst fitting) and equation E (the best fitting) fit their data. All other fits were between these.

After the equations were developed, they were graphed in two dimensions, by fixing TS_1 at various reasonable values, to look at model trends and differences. Figures 3 and 4 show the survival trends predicted by the various equations, given 1,200 trees per acre surviving at age 5. The trends and relative positions of the curves did not change when TS_1 was varied between 800 and 2,000 trees per acre.

DISCUSSIONS AND CONCLUSIONS

The data for this analysis were taken from studies in which one primary objective was to test hypotheses of equality of growth and yield response with respect to application of various management treatments of direct-seeded slash pine stands. Much variability with respect to treatments, initial and post-treatment density, and site quality was purposefully built into the studies. These equations, nevertheless, did account for at least 87 percent of the variability in all cases, and prediction bias ($\overline{\%\ DIFF}$) did not exceed 6 percent in any case, except for unthinned, broadcast-seeded stands, and averaged 3.7 percent for all seven equations.

Table 2.--Coefficients and supporting statistics for the fitting of the model[1/]

$$TS_2 = [TS_1^{\beta_0} + \beta_1 (A_2^{\beta_2} - A_1^{\beta_2})]^{1/\beta_0}$$ to seven direct-seeded slash pine data sets.

Treatment	Equation	Coefficients			Fit statistics[2/]					
		β_0	β_1	β_2	n	%V	S_e	CV(%)	$\overline{Diff}$	$\overline{\%\ Diff}$
All data combined	A	-0.499580	2.69×10^{-4}	1.142989	489	93	243	19	6	3.2
Unthinned stands	B	-.443062	8.54×10^{-4}	.907085	284	94	252	20	27	5.9
Thinned stands	C	-.596671	5.10×10^{-5}	1.446193	205	92	218	16	-15	.17
Unthinned, broadcast seeded	D	-.597310	5.87×10^{-4}	.747919	104	89	393	28	92	16.2
Unthinned, row-seeded	E	-.402515	1.01×10^{-5}	2.422529	180	99	78	6	10	1.6
Selectively thinned	F	-1.067873	1.85×10^{-11}	5.195985	103	96	174	13	31	1.9
Row-thinned	G	-.492301	3.43×10^{-4}	1.093140	102	87	226	16	22	-.33

1/ TS_1, TS_2 = Initial and projected trees surviving per acre, respectively

A_1, A_2 = Initial and projected age, respectively

β_i = Regression coefficients given in the table

2/ n = Number of plot observations

%V = Percent variation explained by the model = $\{1 - [\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 / \sum_{i=1}^{n}(y_i - \bar{y})^2]\}100$

S_e = Standard error of the estimate in trees per acre units

CV(%) = Coefficent of variation percent

$\overline{Diff} = (1/n)\sum_{i=1}^{n}(\text{predicted}_i - \text{observed}_i)$, in trees per acre units,

$\overline{\%\ Diff} = (100/n)\sum_{i=1}^{n}[(\text{predicted}_i - \text{observed}_i)/\text{observed}_i]$

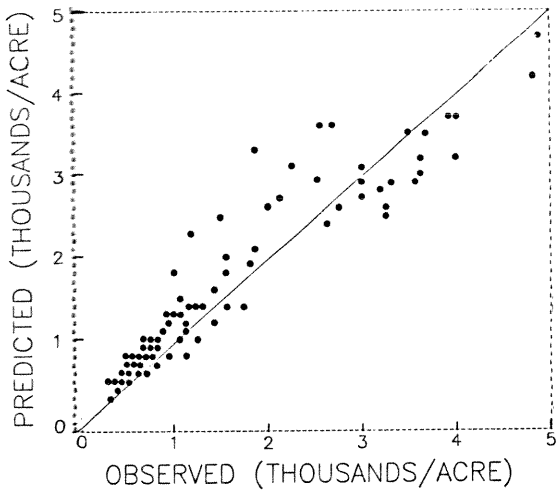

Figure 1.--Comparison of observed versus predicted trees per acre surviving for unthinned broadcast-seeded stands of slash pine in the West Gulf Region, based on equation D.

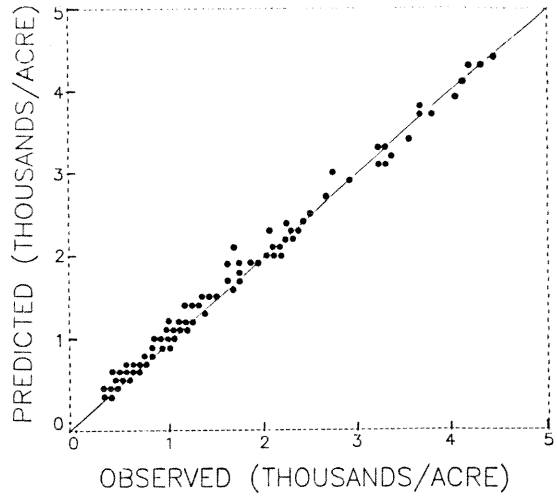

Figure 2.--Comparison of observed versus predicted trees per acre surviving for unthinned row-seeded stands of slash pine in the West Gulf Region, based on equation E.

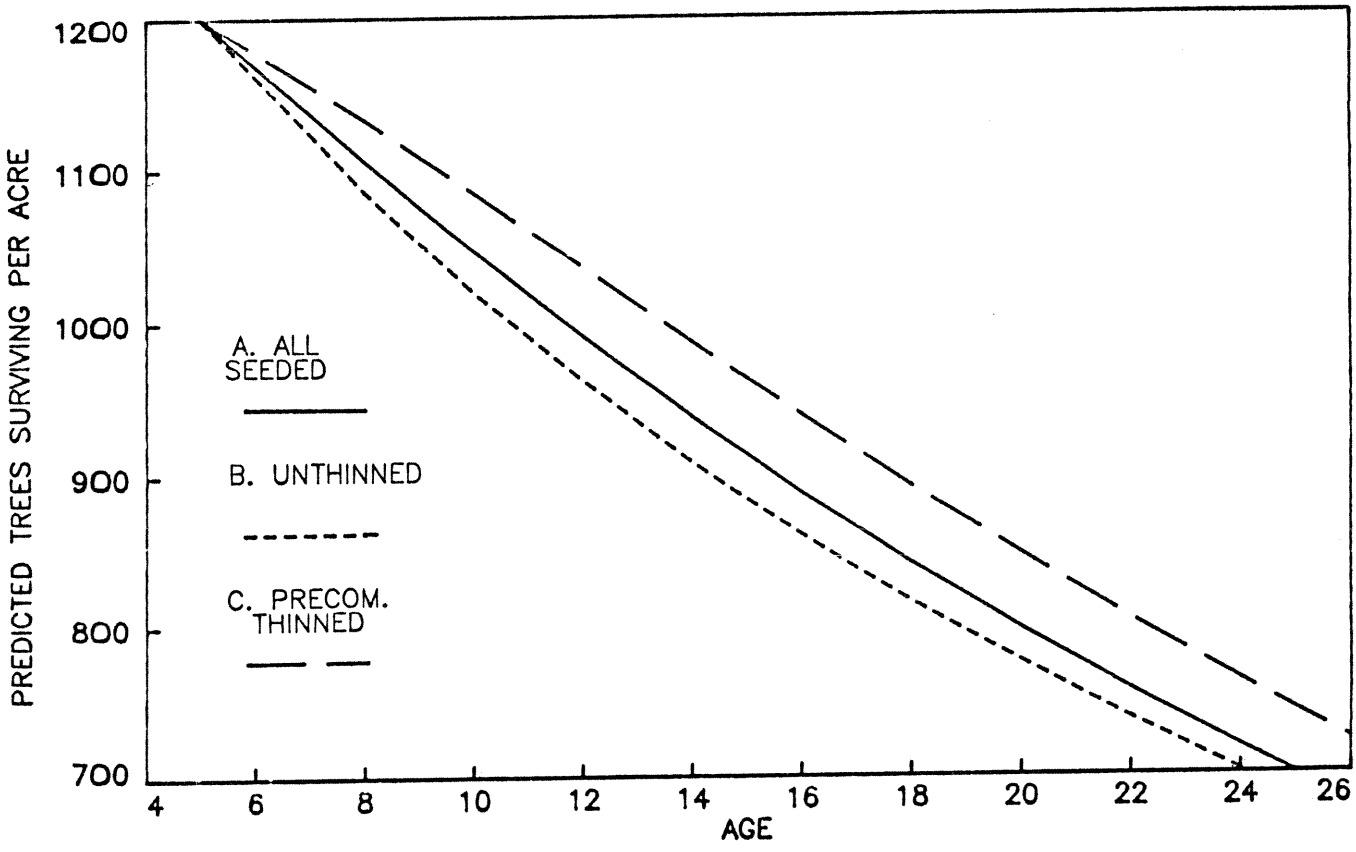

Figure 3.--Predicted survival in direct-seeded slash pine stands according to treatments received for equations A, B, and C.

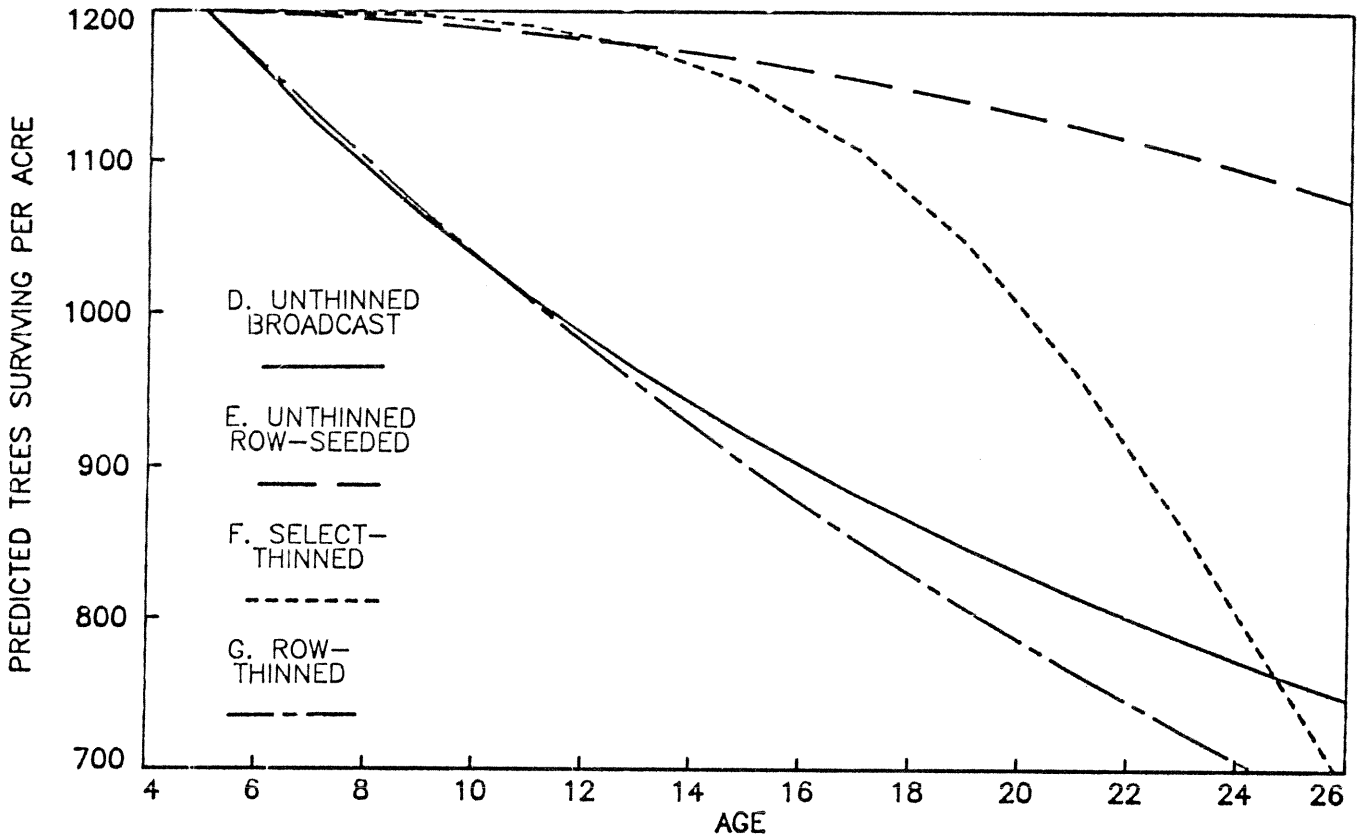

Figure 4.--Predicted survival in direct-seeded slash pine stands according to treatment received for equations D, E, F, and G.

Height of the dominant and codominant trees, which was used as a measure of site quality in some of the model forms tested, was not a consistently significant variable in the regressions. Therefore, to maintain simplicity and model homogeneity over all data groups, it was not used as a predictor in the final model. Site quality, as measured by site index, did vary within each of the data groups (A) through (G), but, interestingly, the overall average site index of 40 feet was also about the average within each group. Therefore, site quality was neither a confounding factor in this analysis nor was it a consistently significant density predictor in these young stands.

Figures 3 and 4 reveal a lot of useful information with respect to this analysis:

(1) The graphs visually justify the initial breakdown of the data into the logical subgroupings based on treatment and/or method of seeding. For example, survival predictions in early-thinned broadcast-seeded slash pine stands using equation F would clearly be different from predictions made using equation G, within the years covered by the data. Predictions using either of the unthinned stand equations, D or E, are also obviously different.

(2) Equations E and F are reverse S shaped --the point of inflection and concave upward portion occur at older ages. If predictions using these curves (particularly equation F) are attempted much beyond age 22, the survival predictions will likely be too low.

(3) These graphs also clearly show the relative magnitude of prediction differences that could occur when using the more general curve rather than a specific curve. For example, at age 13, if the initial number of trees surviving per acre at age 5 was 1,200, the difference between the predicted number of trees surviving using equation B versus using equation E is about 245 trees per acre, and between equations C and F at the same age is about 180 trees per acre. Although these differences are within one standard error of either of the more general curves, the graphs do show that utilization of the more specific curves is best when one is reasonably sure the stand he is dealing with is similar to the stand whose data was used to develop the equation.

(4) Furthermore, the curves clearly exhibit the survival patterns one would logically expect in stands treated similarly. In row-seeding, the combinations of between-row distances and within-

row spacing of seed spots was generally such that the seedlings experienced little competition pressure until about age 11, and then it was slight throughout age 20. Survival in these stands was very much like we would believe survival would be in comparable planted stands.

In selectively thinned stands, the better trees were favored to be left as leave trees, and uniform spacing was a goal, so the trees in these stands did not experience signficant competition until about age 11 either. Survival then began to quickly approach that in unthinned broadcast-seeded or row-thinned stands. However, the delay in mortality and early selection of better leave trees associated with either of these two methods does provide for more trees and perhaps a better selection of leave-tree if a commercial thinning is initiated. There will also be more cut-tree volume in these situations.

One cannot make a management decision based on survival predictions alone, but an accurate survival function is an essential component in any growth and yield prediction system. The functions presented are part of a complete system to predict weight and volume yields in direct seeded slash pine stands in the West Gulf Region that will soon be published and made available. The functions can also be incorporated directly into any system that requires stand survival predictions.

It is recommended that equations D, E, F, and G be used in applicable stands whenever possible. Extrapolation of trees surviving beyond age 25 should not be attempted with equation F. Equations A, B, and C might be used if stands either do not clearly fit into one of the defined treatment categories, are geographically outside of the data range, or are older than age 22.

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TREE FORM EFFECTS ON VOLUME PREDICTION PRECISION FROM TAPER MODELS [1/]

F. Thomas Lloyd [2/]

Abstract.--Preliminary results of comparing observed with predicted total stem volume obtained from a taper model dramatically illustrate how much precision is lost when tree form variables are restricted to diameter at breast height and total height. Specifically, a quadratic-quadratic-quadratic version of a segmnted polynomial fit to diameter-height taper data from 166 loblolly pines produced deviations (i.e., 100 (observed-predicted)/observed) ranging from -26 to 15 percent. The same form of the model fit separately to the taper data for each tree produced deviations of -1.8 to 1.0 percent. The remaining research will study how to incorporate different tree form variables (like form class, form quotient, crown ratio, etc.) into various versions of the segmented polynomial model.)

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Research Forester, USDA Forest Service, Southeastern Station, Charleston, S.C.

CROWN COMPETITION IN YOUNG LOBLOLLY PLANTATIONS: DATA ANALYSIS AND MODELS[1/]

Lynn A. Maguire[2/]

Abstract.--I have developed a growth model for young loblolly plantations that simulates the effects of spacing on crown development and uses crown characteristics to represent the effects of competition on growth and survival. Field data from a spacing trial on the North Carolina coastal plain have been used to test model assumptions and predictions. Live crown ratio declines as crowding occurs, maintaining a constant ratio of crown length to crown width. More of the crown is shaded at closer spacings. The crown projections of trees grown at rectangular spacings deform from circular to fill the available space. These observations are consistent with the model formulation.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Assistant Professor, School of Forestry and Environmental Studies, Duke University, Durham, NC 27706.

A SURVIVAL MODEL FOR THINNED OLD-FIELD SLASH PINE PLANTATIONS[1/]

Bruce E. Borders and Earle P. Jones, Jr.[2/]

Abstract.--Thinning from below in young old-field slash pine stands tended to accelerate mortality; mortality rate was directly related to site index. A difference equation model which expresses the effects of thinning, site index and age on survival was derived and fit.

[1/]Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/]Research Foresters, USDA Forest Service, Southeastern Forest Experiment Station, Athens and Macon, Georgia, respectively.

A GROWTH AND YIELD MODEL FOR UNTHINNED LOBLOLLY PINE PLANTATIONS INFECTED WITH FUSIFORM RUST[1/]

Warren L. Nance, Ronald C. Froelich, Tommy R. Dell, and Eugene Shoulders[2/]

Abstract.--The effect of varying levels of fusiform rust on survival and structure of unthinned loblolly pine plantations was investigated using data from two large, long-term loblolly pine yield studies. The goal of the analysis was to develop a modification to an existing growth and yield prediction system for unthinned loblolly pine plantations which would allow rust level as one of the input variables used to project future yields.

Two-dimensional plots of survival versus age for several hundred test plantations measured over a twenty-year period revealed interesting and unexpected variations among survival curves. Instead of the expected gradual decrease in percent survival over time, many survival curves were relatively flat (little or no mortality) for the entire twenty-year period while others were flat for the first ten to fifteen years and then dropped sharply thereafter. These kinds of patterns are not mimicked by the traditional survival functions that are an integral part of most growth and yield models.

The authors present a possible explanation of these results based on a "law" of natural thinning in even-aged monocultures proposed by Reinecke in 1933. A graphical analysis of survival curves based on Reinecke's concept of natural thinning as a function of stand density and average tree size is presented, and approaches to survival modeling based on Reinecke's concept are discussed. Further efforts to develop yield prediction systems for unthinned loblolly pine plantations infected with fusiform rust hinge on the development of more powerful survival models that can mimic observed patterns of survival in both infected and non-infected stands.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Warren L. Nance is Principal Plant Geneticist, Ronald C. Froelich is Principal Plant Pathologist, Tommy R. Dell is Mathematical Statistician, and Eugene Shoulders is Principal Silviculturist. All are employed by the Southern Forest Experiment Station, Forest Service--USDA.

SITE INDEX CURVES FOR DIRECT-SEEDED SLASH PINES IN THE WEST GULF REGION[1/]

Richard E. Lohrey[2/]

Abstract.--Site index equations were computed for slash pine stands established by direct seeding. The new equations were compared to existing ones for plantations and natural stands.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Silviculturist, Southern Forest Experiment Station, Forest Service--USDA, 2500 Shreveport Highway, Pineville, LA 71360.

EFFECT OF THINNING DAMAGE ON BARK BEETLE SUSCEPTIBILITY INDICATORS IN LOBLOLLY PINE[1/]

C. A. BLANCHE,[2/] T. E. NEBEKER,[2/] J. D. HODGES[3/]

B. L. KARR,[3/] AND J. J. SCHMITT[2/]

Abstract.--Simulated thinning damage in the form of bole scarring and root pruning affected bark beetle susceptibility indicators (total resin flow, initial resin flow rate, resin viscosity, monoterpene levels, and electrical resistance) of residual trees. Root pruning on two sides initially reduced resin flow, whereas bole scarring stimulated it, but these effects disappeared after 7 months. Bole scarring and bole scarring plus root pruning caused lower initial flow rates than occurred in control and root-pruned trees. Total monoterpene and alpha-pinene increased in response to thinning injury. Bole scarring alone caused a decline in stem electrical resistance whereas root pruning on 2 sides caused an increase. These observations indicate that root pruning may increase host susceptibility to bark beetle attack, whereas bole scarring may temporarily reduce it.

INTRODUCTION

Thinning from below is recommended as a means of promoting tree and stand resistance to southern pine beetle attack (Belanger and Malac 1980). Enhancement of resistance is a result of providing an environment conducive to rapid tree growth through a reduction in stress and competition. However, thinning may also cause injuries to the residuals, the extent of which can be very severe.

Since such injuries can have immediate debilitating effect, we suspected that these thinning-related damages could readily predispose the injured residuals to bark beetle attack. Results of an earlier investigation (Nebeker and others, 1983) revealed some interesting patterns in bark beetle susceptibility indicators such as total resin flow, initial resin flow rate, and viscosity. Hence, this study was performed to determine if such patterns are repeatable when treatments are imposed during the fall rather than spring on different stands. Results may find application in the scheduling of thinning of high hazard stands.

MATERIALS AND METHODS

Stand Description

Two loblolly pine plantations, one on an upland ridge site in Winston County and a second on a bottom site in Oktibbeha County in east central Mississippi, were selected to respresent two distinct sites. These 2 stands were established in 1958 from a local seed source. To avoid unnecessary damage to the residuals, both stands were manually thinned to a basal area of 90 sq. ft per acre in May 1983. The ridge site is well-drained, whereas the bottom site is occasionally flooded.

Imposition of Thinning Damage

Prior to the imposition of thinning damage treatments (Sept. 1983), total resin flow (8 hrs), initial resin flow rate (mm/min), relative

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[2/] Assistant Entomologist, Professor and Research Associate, respectively, Department of Entomology, Miss. State Univ., Miss. State, MS 39762.

[3/] Professor and Assistant Professor, respectively, Department of Forestry, Miss. State Univ., Miss. State, MS 39762.

resin viscosity, levels of total and individual monoterpenes, stem electrical resistance (SER), radial growth, and total height were measured. Two weeks later, different thinning damage treatments (Table 1) were imposed on 96 of the residual stems on both sites. Root pruning on one side (R1) was performed by first locating the major lateral root and then severing it with a Ditch Witch about a foot away from the stem. The dimensions of the cut were approximately 0.5 m deep into the soil and 1.5 m long. Root pruning on 2 sides (R2) was done in the same manner with the additional cut made either parallel or perpendicular to the direction of the first cut. Bole scarring (S) was done by removing a portion of the bark plus the associated cambium (one-sixth of the circumference wide and 0.3 m long) at stem base using a hand knife, chisel and fiberglass mallet. Two weeks (Oct. 1983), 7 months (April 1984), and 10 months (July 1984) after treatment imposition, the same measurements and analyses were made except for radial growth and total height.

Table 1.--Treatments imposed to simulate thinning damage.

Treatments	Description	No. of Reps
C	Control	16
R1	1 side root pruned	16
R2	2 sides root pruned	16
S	Scarred	16
SR1	S + R1	16
SR2	S + R2	16

Resin Sampling and Other Measurements

Total resin flow was measured by first drilling a hole (0.95 cm diameter x 2 cm deep) through the bark and into the outer layers of the xylem (at breast height) and driving a glass tubing (10 cm long, 9 mm outside diameter and 2.5 mm inside diameter) into the hole leaving a gap to provide a reservoir for resin to collect. Resin was collected by attaching a 10 ml pipette, with the bottom end cut and stoppered with a cork, to the external end of the glass tubing (flow tube). Total flow for 8 hrs was read directly from the pipette in milliliters. Initial flow rate (mm/min) was determined by timing the resin headflow over a certain distance through the flow tube. Relative resin viscosity was determined by dropping a spherical aluminum ball (0.0625 mm diameter) into a column of collected resin in the pipette and timing the ball as it traveled a constant distance of 20.4 mm. Resin and air temperatures were recorded for each viscosity measurement. After obtaining resin viscosity, an aliquot of the resin was placed in a 1-dram vial and stored in a freezer until analysis. The monoterpene fraction was analyzed using an HP 5830A gas chromatograph equipped with flame ionization detector. A 2.44 m glass column with an internal diameter of 2 mm, packed with 10% Carbowax 20M on 80 to 100 mesh Chromosorb WAW was used. Samples were run isothermally at 115°C using n-heptane as a solvent and p-cymene as the internal standard. Carrier flow rate was 20 ml N_2 per minute. Detector and injection port temperatures were 200°C and 225°C, respectively. Indentity of individual monoterpenes was verified by comparing the relative retention times of suspect compounds with those of authentic monoterpene samples and enrichment chromatography. Quantification was based on the response factor of each monoterpene relative to p-cymene. Monoterpene quantities were expressed in mg per 100 mg resin. Stem electrical resistance (K Ohms) was obtained from the north and south sides of the stem at breast height using a field ohmmeter (Osmose Shigometer Model OZ-67). This was accomplished by inserting the stainless steel probe pins (mean separation was 1.8 cm) through the bark and into the outer xylem. SER readings were obtained from 1:00-2:00 p.m. Total height was measured with a Suunto. Radial growth was measured on increment core samples, using a microcaliper under a dissecting scope.

RESULTS AND DISCUSSION

Total Resin Flow

Root pruning on 2 sides (R2) significantly reduced total resin flow 2 weeks after treatment on both sites (Table 2). However, normal flow was restored 7 months later. On the other hand, bole scarring and bole scarring plus root pruning (SR1) stimulated resin exudation in trees on the bottom site. This stimulation persisted for 10 months. The same treatments (S & SR1) did not affect the ridge-site trees. Bole scarring plus root pruning on 2 sides (SR2) caused a delayed stimulation in total resin flow for the bottom-site trees but did not have any effect on the ridge-site trees.

The depressing effect of root pruning on total resin flow may be attributed to reduced raw material for resin synthesis as a result of increased stomatal resistance and reduced net photosynthesis. Stupendick and Shepherd (1980) demonstrated in Pinus radiata D. Don that root pruning results in a sharp increase in stomatal resistance and a decline in net photosynthesis. They also showed that translocation of C-14 assimilate is restricted by root pruning. On the other hand, the stimulation of resin flow by bole scarring is more of a wound response. It

Table 2.--Mean total resin flow (ml/8 hrs) before and after stress.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	2.1 a	2.5 a	2.5 a	5.9 b
R1	1.1 a	0.7 a	1.9 b	4.1 c
R2	2.7 b	1.9 a	2.6 b	5.6 c
S	2.2 a	3.6 b	4.4 b	7.2 c
SR1	1.1 a	2.4 b	3.1 b	5.1 c
SR2	1.2 a	1.4 ab	2.8 c	2.9 c
RIDGE				
C	1.7 b	1.6 b	0.8 a	4.9 c
R1	1.5 b	1.3 b	1.0 a	4.2 c
R2	1.4 b	1.0 a	1.4 b	4.2 c
S	1.8 b	1.9 b	1.6 a	5.4 c
SR1	1.1 b	1.0 b	0.7 a	3.8 c
SR2	2.3 a	2.7 a	2.6 a	6.8 b

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range: $P < 0.5$).

is known in the naval store industries that an increase in wounding severity increases oleoresin yield, but in progressively declining amounts (Stubbs and others 1984). Apparently bole scarring causes the peripheral area of the wound to become a preferential sink for assimilate. Consequently, oleoresin precursors are concentrated at the zone above the wound.

Total resin flow is a major factor influencing the success of initial southern pine beetle attack (Hodges and others 1979). All things being equal, trees with greater resin flow are more resistant to beetle attack. In the absence of a quantitative relationship between total flow and bark beetle attack, its use as a bark beetle susceptibility indicator is presently confined to relative comparisons. Our results on total flow (Table 2) suggest that root pruning may temporarily increase host susceptibility whereas bole scarring may reduce it, but all these effects exist less than a year. Also, on the basis of total resin flow, host susceptibility should be lowest in July.

Initial Flow Rate

Bole scarring plus root pruning on one side caused an immediate decline in initial flow rate in trees on the bottom, while the same treatment caused an immediate increase in initial flow rate at the ridge (Table 3). Such differential response may be attributed to site differences but genotypic variation cannot be ruled out. The most consistent treatment effect was lower flow rates for scarred and scarred plus root-pruned trees compared to the control and trees root-pruned on both sites. A seasonal pattern of initial flow rates was also evident. Because the time of maximum total flow (July) does not coincide with the time of highest initial flow rate (April), we decided to examine how total resin flow is related to initial flow rate. Correlation analysis revealed that initial flow rate is negatively related to total resin flow ($r = -0.80$). This relationship implies that about 36% of the variation in total flow could not be accounted for by the variation in initial flow rate. Hence, the use of initial flow rate alone as a means for indicating relative susceptibility of trees to bark beetle attack may not be adequate. Anderson and Anderson (1968) pointed out the existence of a definite relationship between oleoresin exudation rate (OER) and incidence and success of *Ips* attacks, while Hodges and others (1979) showed a high positive correlation between total resin flow and resin flow rate. However, their flow rate or exudation rate is basically a reflection of total flow, since rate was determined over an 8-hour period and a very high percentage of the total flow occurs in that period.

Relative Resin Viscosity

Relative resin viscosities of trees on the ridge and bottom sites were combined for purposes of analysis because of inadequate replications. They were unaffected by any of the stress treatments (Table 4). However, a

Table 3.--Initial flow rates (mm/min) before and after stress.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	1.4 a	1.2 a	3.5 b	1.7 a
R1	1.7 a	1.6 a	5.8 b	2.0 a
R2	0.9 a	1.1 a	3.4 c	2.3 b
S	1.0 a	0.7 a	2.2 b	1.2 a
SR1	2.2 c	0.7 a	2.5 c	1.2 b
SR2	1.4 ab	1.1 a	2.8 c	2.2 c
RIDGE				
C	1.3 a	1.4 a	10.4 b	1.9 a
R1	1.3 a	1.1 a	11.2 c	2.4 b
R2	2.0 a	1.8 a	7.8 b	2.0 a
S	1.2 a	1.0 a	4.3 c	2.2 b
SR1	1.4 a	2.5 b	7.2 c	2.8 b
SR2	1.3 ab	0.6 a	4.4 c	1.5 b

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range; $P < 0.05$).

Table 4.--Relative viscosity (mm/sec) for bottom and ridge combined.

Treatment	Sept. 83*	Oct. 83	April 84#	July 84
C	1.7 bc	1.3 b	0.6 a	1.9 c
R1	1.1 b	1.6 bc	0.6 a	2.2 c
R2	1.5 bc	1.4 ab	0.7 a	2.0 c
S	1.3 b	1.1 ab	0.6 a	1.9 c
SR1	1.6 b	1.4 ab	0.9 a	2.0 c
SR2	1.5 b	1.6 bc	0.7 a	2.4 c

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range; $P < 0.05$).
#A drop in temperature from 75°F to 65°F from 12:00 to 1:00 p.m.

seasonal variation was apparent. The lack of significant treatment effect prompted us to analyze viscosity in relation to total flow and total monoterpene level (Table 5). Correlation analysis revealed that the more viscous the resin the less the total flow ($r = 0.76$) for a given duration, and the less the total monoterpene level ($r = 0.63$). Hodges and others (1977), on the other hand, found no significant correlation between viscosity and total flow and between viscosity and total monoterpene level in the same species. Such a discrepancy is difficult to reconcile considering that the monoterpene moiety of the resin acts as solvent (Runkel and Knapp 1946) and an increase in it reduces the viscosity of the resin. In addition, Hodges and others (1977) found significant negative correlations between viscosity and total flow, and between viscosity

Table 5.--Correlation matrix of total flow, viscosity and total monterpene.

Variables	Total Flow	Relative Viscosity	Total Monoterpene
Total Flow	1.00	0.76	0.58
Relative Viscosity		1.00	0.63
Total Monoterpene			1.00

and total monoterpene level for all the major southern pines except loblolly. In spite of this discrepancy, the consensus is that resin viscosity does play an important role in the defensive system of pine trees against bark beetle attack by delaying immediate entry into the inner bark and, therefore, reducing the likelihood of a successful attack.

Monoterpene Components

The effect of the different treatments on alpha-pinene became apparent after 7 months (Table 6). The increase in alpha-pinene in response to these stress treatments parallels that of Hodges and Lorio's (1975) findings with water stress. Also, alpha-pinene increases in lightning-struck loblolly pine trees (Blanche and others, in press). Because alpha-pinene is known to increase attractiveness of the host to bark beetles through its synergistic effect with frontalin, wounding due to thinning can therefore render such trees centers of beetle attraction.

On the ridge site, camphene increased 7 months after root pruning on 2 sides (R2) and bole scarring (S) (Table 7). Bole scarring caused a similar increase in camphene on the bottom site. Whether changes in camphene affect host susceptibility or not, is not known.

Beta-pinene level was unaffected by any of the treatments on the ridge site (Table 8). On the bottom site, bole scarring resulted in an increase in the beta-pinene level 10 months after stress. While this monoterpene is not known to be directly involved in the intriguing chemical communication of the southern pine bark beetles, it has been observed to repel the Douglas-fir beetle (Heikkenen and Hrutfiord 1965). If beta-pinene plays a similar role in repelling southern pine bark beetles, then bole scarring may make pine trees relatively less attractive.

Myrcene and beta-phellandrene levels were unaffected by the treatments on both sites. Limonene increased in response only to bole scarring 10 months after stress imposition (Table 9). Since limonene is known to be the most toxic monoterpene to southern pine beetle (Coyne and Lott 1976) and to 3 other species of Dendroctonus (Smith 1963), its increase in response to bole scarring further supports the resistance-enhancing effect of this type of thinning injury.

There was a general increase in the total monoterpene levels in the wounded trees from the bottom site 7 months after stress imposition (Table 10). The same trend was observed in the ridge site except for SR1 which caused an earlier increase (2 weeks after injury) and an earlier decline (7 months after stress). Evidently, most of these changes were actually due to the changes in the levels of alpha pinene. The implication of these increases in total monoterpene to host susceptibility to bark beetle attack has not been clarified, but the speculation is that total monoterpene enhances host susceptibility through its role in host attractiveness.

Table 6.--Levels of alpha-pinene (mg/10 mg resin) before and after treatment.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	17.0 a	17.6 a	19.4 ab	20.6 b
R1	16.4 a	16.8 ab	19.1 b	19.1 b
R2	17.3 a	17.8 a	20.7 ab	21.5 b
S	16.7 a	19.0 ab	22.0 c	20.6 c
SR1	16.3 a	17.6 ab	21.4 b	19.4 b
SR2	17.1 ab	16.1 a	20.8 b	20.6 b
RIDGE				
C	14.6 a	14.2 a	14.8 a	17.9 b
R1	16.1 a	17.4 a	19.4 a	20.7 a
R2	14.6 ab	11.5 a	19.0 b	18.3 b
S	17.0 ab	14.3 a	20.0 b	19.1 b
SR1	14.9 a	18.3 a	15.7 a	16.5 a
SR2	16.1 ab	16.0 ab	18.5 b	15.0 a

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range; $P < 0.05$).

Table 7.--Levels of camphene (mg/100 mg of resin) before and after stressing.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	0.21 a	0.19 a	0.21 a	0.21 a
R1	0.18 a	0.18 a	0.19 a	0.19 a
R2	0.20 a	0.20 a	0.22 a	0.23 a
S	0.19 a	0.22 ab	0.24 b	0.22 b
SR1	0.18 a	0.20 a	0.22 a	0.20 a
SR2	0.19 a	0.18 a	0.21 a	0.22 a
RIDGE				
C	0.16 ab	0.15 a	0.16 a	0.19 b
R1	0.16 a	0.18 a	0.20 a	0.22 a
R2	0.17 ab	0.13 a	0.20 b	0.19 b
S	0.18 ab	0.14 a	0.20 b	0.20 b
SR1	0.17 a	0.20 a	0.16 a	0.17 a
SR2	0.19 a	0.18 a	0.19 a	0.15 a

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range; $P < 0.05$).

Table 8.--Beta-pinene levels (mg/100 mg resin) before and after stress imposition.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	5.5 a	5.6 a	5.6 a	5.9 a
R1	5.5 a	5.7 a	5.9 a	6.4 a
R2	6.1 a	6.2 a	6.3 a	5.2 a
S	5.7 a	6.4 ab	6.1 ab	7.1 b
SR1	5.3 a	5.6 a	5.7 a	5.6 a
SR2	5.2 a	5.4 a	6.1 a	5.2 a
RIDGE				
C	3.3	3.0	3.1	4.1
R1	2.8	3.7	3.4	4.0
R2	3.1	2.9	4.1	3.5
S	2.7	2.9	4.1	3.6
SR1	4.5	5.3	4.1	4.9
SR2	4.9	4.7	5.5	4.5

*No significant differences.

Table 9.--Levels of limonene (mg/100 mg resin) before and after stress treatments.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	0.9 b	0.7 ab	0.8 ab	0.6 a
R1	0.7 a	0.7 a	0.7 a	0.9 a
R2	1.4 a	0.6 a	0.7 a	0.7 a
S	0.5 a	0.5 a	0.6 a	0.6 a
SR1	0.9 a	0.9 a	1.1 a	0.8 a
SR2	0.5 a	0.6 a	0.8 a	0.7 a
RIDGE				
C	1.2 a	1.1 a	1.2 a	0.8 a
R1	0.6 a	0.6 a	0.7 a	0.7 a
R2	0.3 a	0.4 a	0.4 a	0.5 a
S	0.4 a	0.4 a	0.5 ab	0.6 b
SR1	0.8 a	0.8 a	0.9 a	0.6 a
SR2	0.8 a	0.8 a	0.6 a	0.7 a

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range; $P < 0.05$).

Table 10.--Levels of total monoterpene (mg/100 mg resin) before and after stress imposition.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	24.0 a	24.7 ab	26.3 ab	29.1 b
R1	23.7 a	24.2 ab	26.9 b	27.5 b
R2	25.9 a	25.6 a	28.9 b	29.9 b
S	23.7 a	26.9 a	29.6 b	29.6 b
SR1	23.5 a	25.4 ab	29.5 b	26.9 ab
SR2	23.6 a	23.0 a	28.7 b	27.5 ab
RIDGE				
C	22.3 a	22.0 a	22.4 a	24.8 b
R1	20.2 a	22.5 ab	24.3 ab	26.8 b
R2	18.8 a	15.7 a	24.2 b	24.1 b
S	20.8 a	18.4 a	25.2 b	24.2 b
SR1	20.9 a	25.3 b	21.3 a	23.0 a
SR2	22.9 ab	22.4 a	26.1 b	21.3 a

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range; $P < 0.05$).

Stem Electrical Resistance

Stem electrical resistance (SER) was used in this study as a potential means of indicating stress in, or physiological vigor of, individual trees. Wargo and Skutt (1975) have shown this measure to be an effective indicator of stress in forest trees, and Smith and others (1976) have demonstrated the effectiveness of this measure in detecting differences between nonreleased, released, and released-fertilized paper birch trees.

In interpreting the results on SER (Table 11), it should be pointed out that a higher SER means greater stress or lower physiological vigor. Root pruning on 2 sides caused a significant increase in SER of bottom-site trees two weeks after stress. Bole scarring caused a significant decline in SER of the ridge trees thus further confirming the resistance-enhancing effect of this kind of thinning injury. The earlier recovery of the trees from the ridge than those from the bottom, suggests that the trees from the bottom experienced greater stress than those from the ridge. Improvement in tree resistance to bark beetle attack due to bole scarring and the reduction in it due to root pruning are substantiated by the stem electrical resistance.

CONCLUSIONS

1. The effect of the treatments on total resin flow is similar to what has been found previously (Nebeker and others 1983). The rest of the susceptibility indicators (initial flow rate, resin viscosity, total monoterpene level, and stem electrical resistance) were affected differently by the treatments. More importantly, based on these two studies, the trees injured during the spring recovered much faster than those injured during the fall.

2. Since greater total resin flow indicates higher resistance to beetle attack, bole scarring may temporarily increase resistance whereas root pruning reduces it.

3. Since greater total flow is accompanied by a high level of alpha-pinene, a tree considered resistant may also be attractive to beetles.

4. The greater the resin viscosity, the less the total resin flow and the lower the monoterpene level.

5. Stem electrical resistance can indicate physiological vigor and/or tree susceptibility to bark beetle attack.

Table 11.--Stem electrical resistance (K Ohms) before and after stress treatments.

Treatment	Sept. 83*	Oct. 83	April 84	July 84
BOTTOM				
C	13.3 b	11.4 a	16.3 b	14.0 ab
R1	13.4 a	12.4 a	15.9 a	15.6 a
R2	12.7 a	14.1 b	20.5 c	16.6 b
S	14.4 a	13.1 a	18.1 b	14.8 a
SR1	13.4 ab	11.5 a	17.3 c	15.3 bc
SR2	13.0 a	13.1 a	19.8 b	19.3 b
RIDGE				
C	14.6 a	13.3 a	14.9 a	**
R1	13.6 a	13.1 a	15.3 a	
R2	16.5 a	16.1 a	16.1 a	
S	14.4 b	11.9 a	12.9 ab	
SR1	16.1 a	14.4 a	16.4 a	
SR2	14.4 ab	14.6 a	16.1 a	

*Means within a row followed by the same letter are not significantly different (Duncan's Multiple Range; $P < 0.05$).

**Shigometer malfunctioned.

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HAZARD RATING SYSTEMS AID SOUTHERN PINE BEETLE PREVENTION IN TEXAS[1/]

Charles M. Bryant[2/]

Abstract.--Prevention is the key to successful southern pine beetle (SPB) management. Two primary preventive measures needed for long-term SPB protection are: 1) hazard rating to identify the areas most likely to suffer severe SPB problems and 2) silvicultural treatments to reduce the probability that severe SPB problems will occur. Hazard rating systems can be used on several levels to support integrated SPB management operations. Regional and state managers can use area hazard rating systems to direct SPB management resources to the locations where they will be most effectively utilized. Stand hazard rating can be used to direct attention to individual stands that have a high potential for beetle-caused losses.

Hazard rating systems are being implemented in Texas with considerable success. Commercial pine stands in a 1.1 million acre area were mapped, hazard rated, monitored for treatments to reduce hazard, and monitored for SPB incidence. On a per acre basis, 3 times as many infestations occurred on high and extreme hazard stands as occurred on low and moderate hazard stands. Over 11.8 million acres in Texas were hazard rated using an area-wide system developed by the Texas Forest Service. Although only 5% of the mapped area was rated high hazard, these blocks contained almost 40% of the SPB infestations detected in 1982-1983.

INTRODUCTION

The southern pine beetle (SPB) is recognized as one of the most destructive pests of southern pine forests. However, problems caused by SPB are not entirely due to the insect, but arise from a complexity of insect, host, and environmental factors. Historically, SPB management has been directed at controlling the insect through a crisis response approach to the problem. Today however, the forestry community must recognize that to effectively manage SPB, an integrated approach must be used, incorporating a variety of techniques that are available for managing the problem. This preferred approach to SPB management involves a comprehensive strategy of early detection, prompt evaluation, prompt control, and preventive management. The key element of integrated SPB management; the critical measure needed for long-term SPB protection, is preventive management.

The SPB prevention premise states that the distribution of SPB infestations is not uniform, particular areas (or stands) are more susceptible to SPB than others, specific factors can be evaluated to assess SPB susceptibility, and measures can be taken to modify susceptibility to SPB attack. Specifically, two measures must be taken to protect southern pine forests from SPB infestation. These are:

1) Hazard rate pine stands and forested areas for SPB susceptibility.

2) Manage high hazard stands and forests to promote stand and forest health, growth, vigor, and to reduce SPB hazard.

1/ Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Formerly, Project Forester, Texas Forest Service, Forest Pest Control Section, Lufkin, TX. Currently, Forester, Texas Forest Service, District 12, Rt. 7, Box 151, Conroe, TX, 77384.

There are a number of hazard rating systems available for assessing southern pine susceptibility to SPB (Mason 1984). In Texas, two hazard rating systems are commonly used, one designed for individual stands and the other for large forested areas. These systems are being used to identify potential problem areas, to determine which stands need silvicultural treatments to reduce SPB-caused losses, to evaluate the resource or host potential for SPB outbreak, and to set improved priorities for SPB management actions.

STAND HAZARD RATING

Foresters have observed for many years that SPB infestations occur repeatedly on sites and in stands with similar characteristics. Indeed, some individual stands have been noted for nearly continuous, year-after-year SPB infestation. Typically SPB problem stands were observed to be overstocked or overmature. It was noticed that sites were usually low-lying and poorly drained. Recently these observations have been documented through an extensive research effort.

Following major SPB outbreaks in the early 1970's, the USDA Forest Service embarked on an ambitious effort to gather knowledge for a better understanding of the SPB problem and to develop effective techniques to manage the pest. This project--the Expanded Southern Pine Beetle Research and Applications Program (ESPBRAP)--was charged with the task (among others) of identifying and quantifying site and stand factors associated with SPB infestations. Seven projects in seven states were funded and coordinated by ESPBRAP to collect standardized site and stand data from over 3,300 control (infested) and baseline (uninfested) plots. Site and stand factors included: soil descriptions, slope, landform, tree species, disease, dbh, total height, height to live crown, bark thickness, radial growth, stand basal area, species composition, stand origin, stand age, average diameter, density, disturbance, and size of infestation.

Coster and Searcy (1981) reported in summary, that in the Gulf Coastal Plain region SPB infestations frequently occurred on wet, low-lying sites with high site index. Infested stands often contained higher volume and higher basal area than uninfested stands.

The ESPBRAP site and stand data collected in Texas (Hicks et al. 1981) became the data source for the development of a stand hazard rating system at Stephen F. Austin State University. Six factors (species, composition, percent pine crown closure, average dbh, pine basal area, stand height, and landform) were selected for use in the hazard rating system on the basis of ease of application, ease of data collection, and suitability for photo-interpretation. Original data values were converted into broad classification codes. The simplified values were used as independent variables for a step-wise discriminant analysis process designed to select the most significant variables for discriminating between infested and uninfested stands. The resulting discriminant function is:

$$DS = -5.90 + 1.09\ PBA + 0.65\ SH + 0.56\ LF$$

where:

DS = discriminant score
PBA = pine basal area
SH = stand height
LF = landform

The function was then applied to the original data set to produce a distribution curve of discriminant scores which was subdivided to establish low, moderate, high, and extreme hazard rating classes (Mason et al. 1981).

The SPB stand hazard rating system (the Texas stand hazard rating system) defines two basic types of high hazard stands...dense, overstocked stands, and mature stands. Stands that are both overstocked and overmature are rated extreme hazard. Typically, high hazard overstocked stands are located on side-slope landforms. Pine basal area exceeds 120 sq. ft./acre and stand height is between 50 and 75 feet. The system rates similar stands located on bottomland landforms or with stand height over 75 feet as extreme hazard.

Stands that are not overstocked may be rated high hazard if pine basal area is between 81 and 120 sq. ft./acre, stand height exceeds 75 feet, and the stand is located on a bottomland site.

The Texas system was first implemented on a large scale as a part of a two county (Polk and Tyler) SPB technology demonstration project by the Texas Forest Service (TFS) (funding was provided by the USDA Forest Service Integrated Pest Management Program). Medium scale (1:20,000) 1978 color infrared photographs were used to map the 1.1 million acre area. Stands were delineated on US Geological Survey topographic maps. The resulting maps were superimposed to produce a stand/landform map from which the hazard ratings were calculated. High altitude aerial photography (NASA 1981, scale 1:120,000) was used to update the hazard maps for clearcuts and thinnings. The final hazard map overlays were produced for 7½ minute US Geological Survey orthophotographic-quadrangle maps. Final acreages (1981) for current host, potential host (clearcuts and young pine plantations), and non-host were compiled as follows:

	Acres
Current host	638,000
high and extreme hazard	70,000
moderate hazard	153,000
low hazard	415,000
Potential host	297,000
Non-host	165,000

Copies of the overlays were distributed to TFS offices in the two county area where they are currently available for use by TFS foresters, non-industrial private forest landowners, consulting foresters, and other interested individuals. Non-industrial private landowners with high and extreme hazard stands were notified (via direct mailout) of the potential for SPB infestation in their stands and they were encouraged to thin or harvest when pulp and timber markets are favorable.

Major industrial landowners were provided with copies of the maps showing hazard ratings for their ownerships. In turn, the industrial landowners were asked to provide information on the current status and 5-year plans for their high and extreme hazard stands. Over 50% of the industrial high and extreme hazard stands were harvested or thinned by 1982 and 50% of the remaining stands were scheduled for treatment by 1985.

The reappearance of SPB in Texas during 1982-1984 provided an opportunity to validate the Texas SPB stand hazard rating system. During this period, 254 confirmed SPB infestations were detected in Polk and Tyler counties on low, moderate, high, and extreme hazard stands. Twenty-four percent of the infestations occurred in high and extreme hazard stands. Many of the infestations in low and moderate hazard stands were located in high density or high hazard pockets that were too small (<10 acres) to be mapped as separate stands. Regardless, the concentration of infestations in high and extreme hazard stands was substantially greater than in low and moderate hazard stands, with 3 spots per 10,000 acres of low and moderate hazard stands compared to 9 spots per 10,000 acres of high and extreme hazard stands.

Interestingly, 22 additional infestations were detected in areas mapped as young pine plantations. This indicates one of two possibilities. Either stands previously thought to be too young to be considered host material are in fact susceptible to SPB or stands previously classified as young pine plantations have grown into a current host class (possibly moderate hazard).

In 1984, over 90 SPB infestations detected in the Polk and Tyler counties demonstration area were visited to determine if infested stands had been thinned. Only 2 of 90 infestations occurred in thinned stands. Both stands had been row thinned and both infestations became inactive without control, killing 10 and 25 trees. In several cases, infestations had expanded in unthinned stands until they reached the edge of a thinned stand. At this point, the infestations either became inactive or continued expanding only in the unthinned stand.

AREA HAZARD RATING

As particular pine stands are prone to SPB, so are particular forested areas. During the period 1973 to 1977, 20% of the total susceptible acreage sustained over half of the SPB infestations and ca. 85% of the total volume killed (Billings and Bryant 1983). Recognizing that by defining the site and stand patterns that characterize infestation-prone areas and the occurrence of outbreak populations of SPB, the Texas Forest Service developed a hazard rating system designed to identify areas that have the greatest potential for severe SPB-caused losses.

The area-wide hazard rating system developed by TFS adopted as a rating unit the 5 minute by 5 minute, ca. 18,000 acre grid block system established in Texas for wildfire and SPB operations. Discriminant analysis was used to formulate an equation that separates grid blocks into two SPB incidence severity groups given the abundance and distribution of susceptible pine host type. Grid blocks with 80 or more infestations (>10 infested trees) during a 5-year period (1973-1977) were classified as highly susceptible.

Discriminating variables were obtained by aerial photo-interpretation of site/stand factors from high altitude (scale 1:120,000) color infrared NASA aerial photographs (November 1974) of 90 sample grid blocks. An acetate template, equal in size to a single grid block with 20, ca. 30 acre circular sample plots systematically arranged in 5 rows and 4 columns, was used to provide a 3% sample of each grid block.

Each of the 20 circular plots was classified as follows:

Host type	Classification
Non-host	0
Young pine (less than 15 years)	1
Pine host (15 years or more)	2

For each circular plot classified as pine host (code 2), the following additional data were collected:

Factor	Value	Classification
Percent pine coverage	15-69%	1
	>70%	2
Percent pine crown closure	<80%	1
	≥80%	2
Landform	other terrain	1
	bottomland	2

Discriminating variables (A to J) included each possible combination of the four photo interpreted factors. For each grid block, the input value for a particular variable was equivalent to the frequency of circular plots with that particular factor combination.

The equation formulated by the step-wise discriminant analysis is:

$$DS = -1.35 - 0.108\,(A) + 0.135\,(D) + 0.330\,(E) + 0.404\,(F) + 0.305\,(I) + 0.271\,(J)$$

where:

DS = Discriminant score

A = Non-host

D = Pine host, < 70% pine host coverage, < 80% pine crown closure, bottomland

E = Pine host, < 70% pine host coverage, >80% pine crown closure, other terrain

F = Pine host, < 70% pine host coverage, >80% pine crown closure, bottomland

I = Pine host, >70% pine host coverage, >80% pine crown closure, other terrain

J = Pine host, >70% pine host coverage, >80% pine crown closure, bottomland

A confidence interval of 95% was calculated for the sampling system. This interval was applied to the threshold discriminant score to formulate a hazard classification system as follows:

Discriminant Score	Hazard Classification
<.42	Low
.42 to 1.11	Moderate
>1.11	High

To date, 656 grid blocks covering over 11.8 million acres have been hazard rated using 1980-1983 aerial photography. Currently, 5%, 11%, and 84% of the grid blocks are rated high, moderate, and low hazard, respectively. This distribution represents a dramatic reduction in the abundance of high hazard grid blocks in Texas during the last decade. For example, 17% of the grid blocks were rated as high hazard in 1974, compared to 5% in 1985. Furthermore, most high hazard grid blocks are now located in central eastern Texas and on the western fringe of the pine zone, rather than in southeast Texas as in the 1960's and 1970's. The greatest concentration of highly susceptible host type is currently located in the vicinity of the National Forests in Texas.

Records of SPB infestations during 1982-1983 were compiled and summarized to validate the area hazard rating system. The results indicate that over 40% of the 1407 confirmed infestations detected during the two year period fell in either moderate or high hazard grid blocks. Given the distribution of grid blocks by hazard class, high hazard grid blocks contained an average of 16 infestations, moderate hazard grid blocks contained 5 infestations per grid, and low hazard grid blocks contained approximately 1 infestation per grid block.

APPLICATIONS

The two SPB hazard rating systems used in Texas provide hazard assessments on two levels: individual stands and groups of stands or a forest unit (18,000 acre grid blocks). A third hazard rating level was developed to provide a ranking of counties in order of SPB susceptibility. This system is based on the cumulative rating of grid blocks in each county. Low, moderate, and high hazard grid blocks are assigned weights of 0, 1, and 3, respectively. The weights are multiplied by the number of grid blocks in each class in a given county and the product is divided by the county's acreage in suitable forest type (pine and mixed pine-hardwood). In Texas, this system provides a more accurate basis for predicting SPB population trends than do historical infestation patterns as shown below:

Total Spots 1973 - 1977	Total Spots 1982 - 1983	County SPB Hazard (1983)
1 Hardin	1 Sabine	1 Sabine
2 Montgomery	2 Walker	2 Walker
3 Liberty	3 Houston	3 Houston
4 Jasper	4 San Augustine	4 San Jacinto
5 Polk	5 San Jacinto	5 Montgomery

The hazard rating process can be carried an additional step by complimenting host susceptibility information with current SPB population information. The result is a risk rating system that indicates the potential of a given area for SPB infestations considering both existing stand conditions and the current level of SPB activity in that area. Hazard rating alone provides only an indication of the potential for SPB problems due to existing stand or forest conditions.

This system improves the capability to identify which areas are most likely to suffer severe SPB problems in a specific year. Low, moderate, high and extreme risk ratings are determined for each grid block from cumulative rating points for grid block hazard, previous two-years SPB activity, and proximity to high risk grid blocks.

DISCUSSION

The hazard rating systems described in this paper are extremely useful as tools designed to direct attention to the stands and areas in which SPB management is critically needed and where SPB management can be most effective in terms of losses prevented. However, identification and location of high hazard stands and areas represents only a first step in SPB preventive management. Action must be taken to realize benefits from implementation of these systems.

With the development of an SPB hazard rating hierarchy, actions can be directed at three levels of management: individual stands or management units, districts or groups of stands, and regional or state units. Southern pine beetle management

decisions at the state or regional level can be guided by the county hazard rating system. Management resources can be directed to top ranking counties where SPB problems are expected to be most severe.

The area hazard rating system also provides decision support for state or regional managers as well as individual landowners. State entomologists can use the system to evaluate trends in host availability and the spatial distribution of SPB host type. By utilizing beetle activity level information (SPB risk rating) entomologists can predict which grid blocks may suffer severe SPB problems in a particular year and provide forest landowners and managers with this information. Landowners with tracts in grid blocks identified as high hazard or risk should consider the following:

1) Stand hazard mapping to determine which stands within a grid block have the greatest potential for problems,
2) modification of harvest or thinning schedules to prevent monetary losses by harvesting mature stands before an outbreak occurs and to reduce the potential for outbreaks by reducing the hazard and increasing the health and vigor of stands, and
3) set top priority for SPB detection and control.

Individual stands identified as high hazard (particularly those in high hazard or risk grid blocks) should be considered for:

1) silvicultural treatments
2) top priority for control, and
3) pest monitoring.

As mentioned previously, problem stands are usually characterized as overstocked and/or overmature. Recommended silvicultural treatments to reduce hazard vary depending on stand conditions. Generally however, dense overstocked stands should be thinned to 70 to 90 sq. ft./acre pine basal area. Overmature stands, because they have passed their greatest potential for growth and probably will not respond well to thinning, should be harvested. Market conditions and soil moisture (particularly on bottomland sites) may dictate when harvest or thinning can be scheduled. If high and extreme hazard stands cannot be treated, they should be monitored closely for SPB infestations and when active infestations are detected they should be promptly controlled.

Belanger and Malac (1980) offer a number of recommendations for reducing the susceptibility of pine stands to SPB attack. A synopsis of these recommendations includes: favor resistant species, remove high hazard trees, regulate stocking, mix pine and hardwood, minimize logging damage, regenerate overmature stands, and minimize disease and competition problems. In short, silvicultural treatments that promote healthy growing stands of high quality pine timber at moderate stocking levels will provide long-term protection from SPB. Good sound forest management is good SPB management.

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THEORIES OF INTERACTIONS AMONG BARK BEETLES, ASSOCIATED MICROORGANISMS, AND HOST TREES[1/]

Peter L. Lorio, Jr., and John D. Hodges[2/]

Abstract.--The oleoresin system of southern pines is assumed to be the primary defense mechanism against bark beetle attack and colonization by associated fungi. A general theory based on growth and differentiation balances in plants is used to explain why the oleoresin system's effectiveness will vary considerably with seasons in the absence of any abnormal stresses. A second theory states that resistance to bark beetle attack is a function of the ease of fungal inoculation and establishment.

INTRODUCTION

Foresters and forest entomologists have struggled for years to understand the interactions of the southern pine beetle, Dendroctonus frontalis Zimm., with trees and the basic causes for the onset of outbreaks of this insect (Price and Doggett 1982, Thatcher and others 1980, Thatcher 1960, Dixon and Osgood 1961). In some of the earliest reported work, Hopkins (1892, 1899) proposed that the southern pine beetle swarmed into forests previously not affected by the beetle and caused enormous mortality of healthy, vigorous trees, at least partly because of a lack of natural enemies. Craighead (1925), MacAndrews,[3/] Hetrick (1949), and others subsequently reasoned that some factor or factors such as drought, excessive rainfall, and various disturbances such as lightning strikes, ice storms, and wind adversely affected tree physiology and were precursors of outbreaks.

The prevailing hypothesis states that the physiology of the host trees becomes in some way abnormal, thus causing trees to be especially susceptible to bark beetle attack. Berryman (1972) stresses this idea in an attempt to develop an inclusive hypothesis of conifer resistance to bark beetles. In spite of the speculation in the abundant literature, outbreaks of the southern pine beetle develop and collapse as mysteriously as they did in the early 1900's (Price and Doggett 1982). Although some factors, such as excessive stocking, senescence, and root disease, are recognized as being conducive to outbreaks (Hicks 1980, Belanger 1980), adequate understanding of site, tree, and stand relationships with southern pine beetle activity and population dynamics is lacking. These destructive forest pests have remained puzzling organisms in spite of over 70 years of research.

The general level of knowledge concerning the southern pine beetle was most recently brought together in USDA Technical Bulletin 1631 (Thatcher and others 1980). At this stage in research on this important insect pest of southern pine forests, many gaps in knowledge persist with regard to the beetle, associated microorganisms, and the host trees. For example, researchers continue to question the means by which host trees are killed. A generally proposed hypothesis states that the southern pine beetle kills pines by boring through the outer bark to the cambial layer, excavating egg galleries in the phloem, and effectively girdling the trees over much of the

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2/ Project Leader, Forest Insect Research, Southern Forest Experiment Station, Pineville, LA 71360 and Professor of Silviculture, Forestry Department, Mississippi State University, Mississippi State, MS 39762.

3/ A. H. MacAndrews. 1926. The biology of the southern pine beetle. Unpublished Masters thesis. New York State College of Forestry, Syracuse, NY.

clear bole. However, southern pines are well known to live for long periods following simple girdling. Also, it has not been possible to satisfactorily simulate the type of girdling caused by the beetles and produce the apparent rapid killing associated with beetle attacks. Therefore, some researchers, including the second author of this paper, believe that other factors play a role in the process.

Microorganisms, especially the bluestain fungus, Ceratocystis minor (Hedgcock) Hunt, are generally thought to play important roles in bark beetle biology. Some investigators believe that the bluestain fungus is the primary killing agent and that the beetle is dependent upon fungal colonization for successful attack. However, the mechanism by which the fungus affects the physiology of beetle-attacked trees has not been satisfactorily demonstrated.

Whatever the nature of the process in which beetle-attacked trees are killed, it is clear that the oleoresin system in southern pines must play an important role. Both the primary resin system, most evident in the network of vertical and radial resin ducts in the xylem, and any resin produced in response to wounding or fungal infection influence both beetle activity and fungal growth.

One objective of this paper is to present a general concept that provides a sound basis for conducting and evaluating the results of research on beetle-host or microorganism-host interactions. A second purpose is to elaborate on a theory of beetle-microorganism-tree interactions, to illustrate how current knowledge in this area applies to the general concept, and to propose how this concept can be used to guide future research on these interactions.

We probably should point out that the authors have concurrently, but separately, arrived at their positions and that they are not in total agreement. Individual contributions on the same subject matter are either in the process of publication or have already been published elsewhere.

GROWTH-DIFFERENTIATION BALANCE AND PLANT BEHAVIOR

The concept of growth-differentiation balance (Loomis 1932, 1953) provides a convenient and simplified scheme for predicting or explaining plant behavior. Loomis offered the concept as an improvement over the carbon-nitrogen balance and not as a complete and final statement of developmental processes in plants (Loomis 1932). In current terminology, the concept has to do with source-link relationships and the partitioning of photosynthate in plants, but it also gives a rationale for partitioning. For example, with water not limiting, photosynthates are used primarily in growth, and the new biomass consists largely of proteins and cellulose, with little differentiation. Also, under mild stress, differentiation is favored, and the biomass has a higher content of lignin, wax, and other materials (Loomis 1983). In a nontechnical sense, plants tend to grow when conditions are optimum for growth, and they tend to do other things (differentiate) when conditions for growth are suboptimum.

Loomis (1932), following common practice, divided the development of plants into three more or less distinct but overlapping phases: cell division, cell enlargement, and cell differentiation. The first two are generally considered together as elements of growth involving increase in plant size. The third has to do largely with changes in morphology as a result of pre-existing chemical conditions in the cells or tissue involved. For the purposes of growth-differentiation balance, Loomis defined differentiation as the sum of the chemical changes that occur in maturing cells and of the morphological changes that result from these chemical conditions. Examples of differentiation processes, as provided by Loomis (1953) are: thickening and lignification of secondary cell walls, thickening of leaf cuticle, hardening of protoplasm, formation of specific flowering substances, and production of cellular inclusions such as gum, resin, essential oil, or similar products.

Growth, involving cell division and cell enlargement, is dependent upon an array of internal and external factors, including temperature, water, oxygen, sugar, inorganic nutrients, enzymes, and hormones. As long as all factors are favorable for growth, growth processes predominate over differentiation. Differentiation is dependent primarily upon temperature and sugars and is dominant only when conditions other than temperature and photosynthate supply are below optimum for growth. A shift to differentiation typically produces more cuticle, thicker cell walls, more resistant protoplasm, and more cellular inclusion products (oils, gums, resins, etc.).

EXAMPLES OF GROWTH-DIFFERENTIATION BALANCE

Research on guayule for the production of rubber demonstrated the requirement for some degree of water deficit in order to maximize rubber production (Veihmeyer and Hendrickson 1961). Hevea rubber production is similarly quite dependent on a reduction in growth and an increase in differentiation. Buttery and Boatman (1976), in a review of research on rubber production, point out that the capacity of trees to supply sucrose to laticifers depends on availability of reserve carbohydrates, the photosynthetic capacity of the trees, the transport of sucrose, and the demands of other tissues in the tree for the same material.

The competition between wood formation and the biogenesis of oleoresin in pines is another

example of growth-differentiation balance (Loomis 1953). For southern pines growing in the Southeastern United States, the most common limiting seasonal growth factor is water. And the effects of water deficits on tree growth and development have been a subject of major interest in forest science (Zahner 1968, Kozlowski 1968-1981). However, water deficit has been given little attention in terms of its possible beneficial effects on the formation of differentiation products, such as the oleoresin of pines. Growth-differentiation balance determines when during the growing season and in what tissues resin ducts are formed and oleoresins are produced. Factors that affect tree crown development and radial growth likewise affect the potential synthesis of oleoresin and its flow from wounds.

APPLICATION OF GROWTH-DIFFERENTIATION BALANCE TO THE BARK BEETLE PROBLEM

The seasonal activity of cambial meristems, with earlywood-latewood relationships, and the seasonal production of oleoresin form the basis for understanding tree resistance to attack by the southern pine beetle and to infection by associated fungi. According to the concept of growth-differentiation balance, trees should produce relatively little oleoresin in the spring because conditions are generally favorable for growth. As moderate water deficits develop, growth slows, photosynthates accumulate, and differentiation processes become dominant. Warm temperatures and an abundant supply of sugars, coupled with moderate water deficits that slow growth, permit increased production of oleoresin. And the warm temperatures facilitate resin flow from wounds by lowering resin viscosity.

Because of relationships involving growth-differentiation balance, well-hydrated, fast-growing trees may be quite susceptible to beetle attack from time to time--especially in the spring. Application of the concept eliminates the requirement for some abnormal physiological condition, such as moisture stress, to predispose trees to beetle attack; however, we know that severe water deficit will certainly ensure successful beetle attack (Lorio and Hodges 1977). On the other hand, the concept provides a rationale for understanding why such factors as dense stands, old age, and root disease are commonly associated with the susceptibility of trees to attack.

Growth-differentiation balance applied to bark beetle-microorganism-tree interactions provides a sound basis for developing a real understanding of these interactions and a philosophical basis for the development of future research.

ROLE OF FUNGI IN RESISTANCE OF TREES TO BARK BEETLE ATTACK

Several species of fungi are known to be associated with the southern pine beetle (Francke-Grossman 1965, Barras 1967, Barras and Perry 1972),and a special relationship has evolved between the beetle and the fungi. Spores of the bluestain fungus are almost invariably carried on mites that are phoretic on the southern pine beetle (Bridges and Moser 1983). Other fungi are carried in a special organ or structure called the mycangium, near the head of the female beetle. Apparently, at least some of these fungi are necessary for successful attack or development of the beetle, but the relationship needs further study.

Early investigations implicated the bluestain fungus in the death of the tree (Caird 1935, Craighead and St. George 1938, Bramble and Holst 1940). It was assumed that invasion of vascular elements by the fungi prevented upward movement of water either by blockage or by introduction of air, which would break the water column within the tracheids (Mathre 1964). Anderson (1960) suggested several mechanisms by which the fungi could cause death of the tree; these included: (1) production of a toxin, (2) plugging of the tracheids by fungal mycellia, (3) introduction of air bubbles into the tracheids, and (4) production of particles or compounds that block pit openings by causing tori aspiration. There is evidence, or at least strong suggestion, from the literature that all of the above occur after fungal inoculation, but it has not been proven that they are responsible for death of the tree. Nor does it rule out the possibility that other mechanisms are involved. Also, it is possible that other fungi associated with the southern pine beetle are more important in this respect than is C. minor. For example, several successful infestations of southern pine beetle have been observed that had no evidence of C. minor (Bridges and others 1985).

A theory has been presented (Hodges and others 1984) that may help to explain what is involved in both tree resistance to beetle attack and death of the tree after successful mass attack. The hypothesis states that "The success of beetle attack, and thus death of the tree, is directly related to the successful introduction of fungal inoculum into the living tree, and the subsequent production of toxic substances which in turn alter physiological processes (e.g., water relations) in the tree, and thus make the tree far more susceptible to subsequent attacks. Relative resistance is therefore a function of the ease with which inoculum can be introduced and successfully established."

At least one of the fungi (C. minor) produces substances that could have toxic effects or influence tree functions in some way (McGraw and Hemingway 1977). These are isocoumarin-type compounds (e.g., 6, 8-dihydroxy-3hydroxymethyl isocoumarin) that are very similar to compounds produced by C. ulmi, a fungus carried by Scolytus multistriatus (Marsham) (the smaller European elm bark beetle) and responsible for the Dutch elm disease. The compounds cause increased transpiration rates and foliage wilt in elm (Roberts 1966). Isocoumarin compounds produced by cultures of C. minor will increase transpiration rates in seedlings of loblolly pine. If this happens in trees under attack by the southern pine beetle, the trees should encounter moisture stress, exhibit reduced oleoresin flow and exudation pressure, and have greater susceptibility to beetle attack. Resin flow apparently depends, at least partly, on exudation pressure, but a good relationship has not yet been demonstrated experimentally (Bourdeau and Schopmeyer 1958, Barrett and Bengtson 1964, Hodges and Lorio 1971).

There are other possible ways in which compounds produced by fungi associated with the southern pine beetle could lower resistance to beetle attack. Toxic compounds could cause a rapid decline in oleoresin pressure and flow by disrupting the normal functioning of membranes of epithelial cells that surround the resin ducts. Oleoresin pressure is determined by the turgor pressure of these epithelial cells (Hodges and Lorio 1971), and if the membranes are disrupted, pressure will drop to zero and flow should be drastically reduced. Another possibility is that the fungi may produce compounds of high molecular weight that could block water transport in the xylem cells. Again, this should result in moisture stress and a reduction in oleoresin pressure and flow. Such a phenomenon (blockage) has been observed in elm trees infected with C. ulmi.

The observed and hypothesized sequence of events involving interactions among beetle, fungi, and host tree are presented in figure 1. The hypothesis is best understood by considering the proposed sequence of events that happen when mass attack occurs on a tree having high resistance (high oleoresin flow). The first beetle attacks are usually unsuccessful and no fungal inoculation occurs. With repeated attacks, inoculation occurs, and enough toxin is eventually produced to alter tree physiology, reduce tree resistance, and assure success of subsequent beetle attacks as well as death of the tree and successful brood development. Also illustrated in figure 1 is the relationship between tree resistance and beetle attack density. A relatively resistant tree may be able to sustain light attacks, but under mass attack any tree can be overcome.

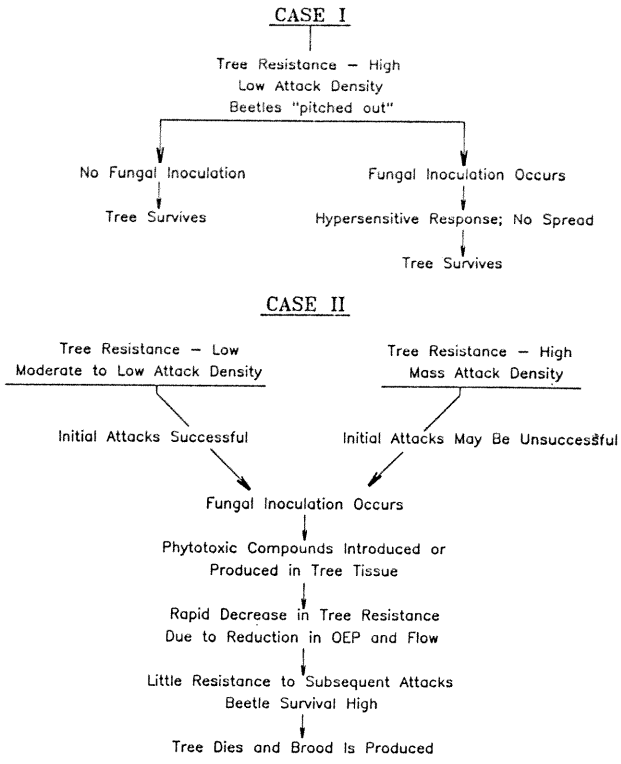

Figure 1.-- Observed and hypothesized sequence of events involving interactions among beetle, fungi, and host tree following bark beetle attack (OEP = oleoresin exudation pressure).

EVIDENCE FOR AND IMPLICATIONS OF THE CONCEPTS

The fundamental idea underlying both concepts is that initial tree resistance is determined by the oleoresin system, principally the amount of flow (Hodges and others 1979). The concept of growth-differentiation balance serves as a basis for explaining changes within the tree that lead to seasonal differences in synthesis and yield (flow) of oleoresin, and the concept of the role of the fungi offers a possible explanation of how the beetles are able to overcome a tree's natural defenses.

Past research indicates strong support for the concept of growth-differentiation balance in terms of radial growth and carbohydrate and nitrogen fractions in inner bark. Data for figures 2 - 5 were collected in connection with a study of tree responses to induced soil water deficits (Hodges and Lorio 1969), and they represent the control (untreated) trees of that study. When cross-sectional growth rates were most rapid (fig. 2, March - May), there was a marked decrease in total carbohydrates of the

inner bark (fig. 3). This decrease was primarily in the form of starch, although reducing sugars also showed a slight decrease (fig. 4). When growth rate slowed in the summer months, sugars, especially non-reducing sugars, showed a rapid accumulation (fig. 4). Amino nitrogen also accumulated during the summer months after the period of most rapid growth (fig. 5).

These findings strongly suggest that in the spring months tree growth places a preferential demand on both current and reserve energy sources. When growth slows in the summer months, photosynthesis continues at a high rate and there is an excess of carbohydrates over that required, or which can be used, for tree growth. This energy source then becomes available for other uses, one of which is the production of oleoresin. Though not a component of the oleoresin, amino compounds are important in the overall synthetic process, and they also increase in the summer months (fig. 5).

Work by Harper and Wyman (1936) with longleaf pine (Pinus palustris Mill.) and Barrett and Bengtson (1964) with slash pine (P. elliottii var. elliottii Engelm.) illustrates clearly that oleoresin yield maximizes in mid to late summer. Although these studies did not examine growth and oleoresin synthesis relationships, flow from wounds was definitely associated with seasonal high temperatures and the usually accompanying water deficits and reduced radial growth. A current study with loblolly pine (P. taeda L.) is producing similar results (R. A. Sommers, personal communication). Such results closely fit the concept of growth-differentiation balance.

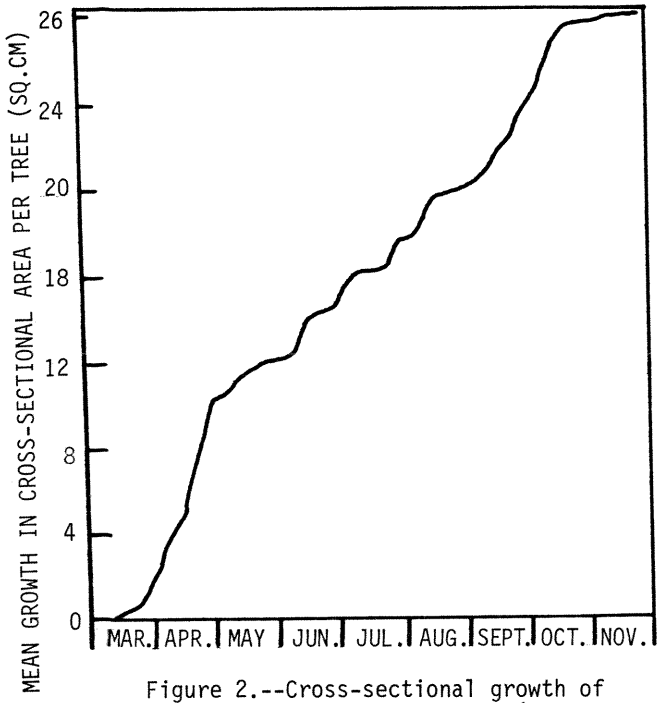

Figure 2.--Cross-sectional growth of 40-year-old loblolly pines (*After Hodges and Lorio, 1969*)

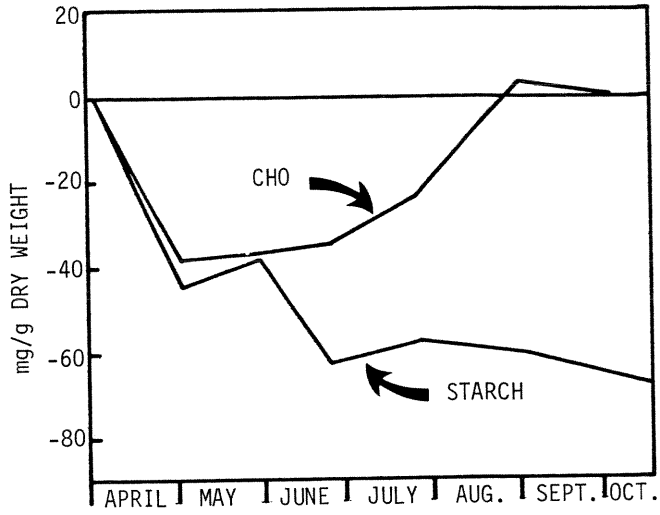

Figure 3.--Changes in total carbohydrates and starch content in inner bark of 40-year-old loblolly pines (*After Hodges and Lorio, 1969*)

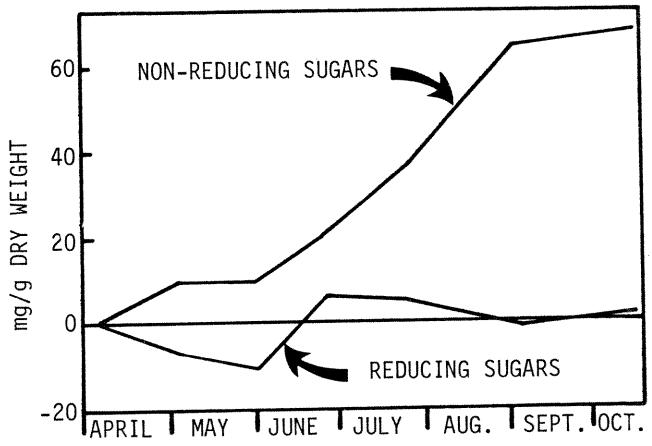

Figure 4.--Changes in sugar content of inner bark of 40-year-old loblolly pines (*After Hodges and Lorio, 1969*)

All of the above discussion suggests that tree resistance to beetle attack should be low in the spring and high in the summer. Conversely, successful attacks should be much higher in the spring than in the summer, and that is what all our experience shows. In essence, it simply means that the lower the amount of resin, the easier it is for beetles to overcome trees. The changes in carbohydrate and nitrogen fractions cited above further indicate

that fungi inoculated by beetles, or by the mites associated with them, would encounter significantly different substrate for growth, depending on the growth stage of the trees.

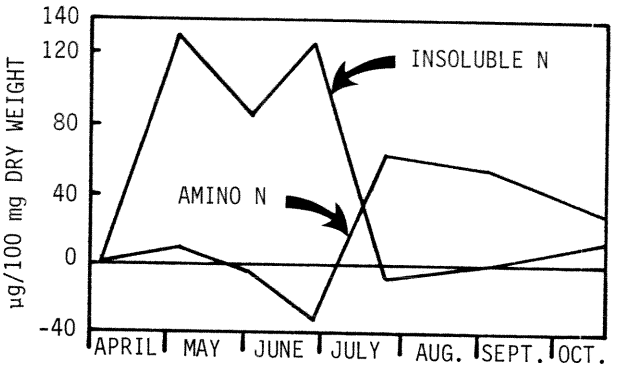

Figure 5.--Changes in nitrogen fractions of inner bark of 40-year-old loblolly pine (*After Hodges and Lorio, 1969*)

It is clear that low oleoresin flow is related to increased susceptibility of trees to attack by the southern pine beetle (Hodges and others 1979). Furthermore, low flow can be the result of several causes, such as moisture stress, reduced oleoresin reservoir (crowded trees → shortened crowns → reduced photosynthate → low oleoresin synthesis), or simply seasonal growth differences as outlined above. However, it is not completely clear how tree resistance (resin flow) is overcome in the attack process. There is certainly evidence to support the hypothesis on the role of beetle-associated fungi in this regard, but it is also possible that early attacking beetles simply "bleed" the tree of oleoresin to the point where subsequent attacks meet little resistance.

A theory of host resistance by Berryman (1972) holds that resistant trees produce a hypersensitive reaction that results in formation of a wound periderm, with resin soaking around the necrotic lesion caused by fungal infection. This reaction supposedly stops the growth of the fungi and prevents successful beetle attack and tree death. This hypersensitive reaction apparently does occur in some cases after attack by the southern pine beetle, but its relation to tree resistance to beetle attack has not been established. However, formation of the reaction zone is dependent on synthesis and/or deposition of oleoresin,which in turn would be greatly influenced by the growth status of the tree. If lesion formation and resinosis is a function of secondary oleoresin synthesis, the carbohydrate and growth relationships cited above must play a major role in the reaction.

CONCLUSIONS

We have presented two concepts, or hypotheses, that we feel will be useful in developing satisfactory understanding of bark beetle-microorganism-host tree interactions. Both assume that tree resistance to bark beetle attack is a function of oleoresin flow. One is a general concept (growth-differentiation balance) that has basis in plant physiology-plant behavior relationships, and its application to the bark beetle problem is supported by experience and past research. It can be further examined through the development of studies specifically designed for that purpose, and, at the same time, be utilized as a guide for testing application of the second concept presented: that a tree's natural resistance to bark beetle attack is overcome by involvement of fungi associated with the beetle. Investigators propose that substances produced by the fungi are responsible for the rapid decrease in oleoresin flow and the ease with which subsequent beetle attacks can occur.

The concepts presented may have to be modified in the future, but for now they serve as rational starting points from which we can design future studies to enhance our understanding of the overall relationships among trees, beetles, and microorganisms. For example, studies are needed of tree growth (earlywood-latewood relationships), resin duct formation and distribution, inner bark carbohydrate status, and oleoresin yield within the same trees over the seasons of the year. One such study is in progress. Although we know something of seasonal changes in bark carbohydrates in loblolly pine, we need to study changes over all seasons of the year and determine the relationships with bark beetle attack, fungal inoculation responses, and beetle brood development. Further work is needed to clarify oleoresin exudation pressure and flow relationships, as well as how these phenomena are related to the growth and water status of trees and their resistance to bark beetle attack. Such studies offer significant challenges to researchers in several complementary disciplines in the coming years.

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CULTURAL TREATMENTS IN LOW-QUALITY HARDWOOD STANDS FOR WILDLIFE AND TIMBER PRODUCTION [1/]

Thomas A. Waldrop, Edward R. Buckner, and Jack A. Muncy [2/]

Abstract. -- Effective management of low-quality hardwood stands in the Interior Uplands of the Southeast is difficult but can yield increases in available deer browse and timber quality. This study tested two methods of clearcutting and prescribed burning of young stands as timber and wildlife management tools in low-quality hardwood stands of the Cumberland Plateau of East Tennessee. Complete and diameter limit clearcutting produced stands of similar composition and structure, both dominated by the species present before harvest. The removal of extra stems by complete clearcutting did not significantly increase browse availability as had been expected. Prescribed burning prolonged the availability of browse but produced few changes in species composition. However, available browse in all clearcuts was underutilized due to lack of forest cover. Pioneer species remained essentially absent after both methods of clearcutting and prescribed burning.

INTRODUCTION

Stands of low-quality hardwoods are widespread throughout the Interior Uplands of Alabama, Tennessee, and Kentucky. The Cumberland Plateau and Highland Rim Regions of Tennessee, for example, are nearly 67 percent forested with 3 million acres of commercial forest land (USDA Forest Service 1982). Less than 10 percent of this area, however, has at least 50 percent stocking with desirable growing stock trees (McGee 1982). Estimates of the precise acreage of low-quality hardwood stands in the Southeast vary, depending on how these stands are defined. In general, stands are considered to be of low-quality due to low stocking and/or a high proportion of trees classified as 'rough or rotten'.

Low-quality hardwood stands are generally the result of a long history of mismanagement or no management at all (TVA 1952, McGee 1982). Many stands are on sites capable of being highly productive. However, production is low due to repeated wildfires and high-grading in addition to a lack of protection from insects and disease. Effective management of these cull-burdened stands presents many problems (Trimble 1963), but also an opportunity for increased production of both wildlife and timber (McGee 1982). For management to be successful, the land manager must have an understanding of how various cultural treatments will affect the composition, quantity, and quality of resulting vegetation.

The Tennessee Wildlife Resources Agency (TWRA) manages the Catoosa Wildlife Management Area, an 80,000 acre block on the Cumberland Plateau of East Tennessee, much of which is forested with low-quality hardwood stands. The primary management objective for these stands is to improve habitat for white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*) and also non-game species when possible (Arney and Pough 1983). Timber management is also of concern since this provides much of the funding for wildlife management. TWRA has tried several management schemes to improve the productivity of their low-quality hardwood stands while main-

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2/ The authors are Research Associate, Department of Forestry, Clemson University, Clemson, SC; Professor, Department of Forestry, Wildlife, and Fisheries, The University of Tennessee, Knoxville; and Project Leader, Division of Land and Economic Resources, Tennessee Valley Authority, Norris, TN.

taining quality habitat for deer and turkey. One such scheme has been to clearcut hardwood stands and allow coppice regeneration. Prescribed fires at 3 to 5 years after clearcutting have been used to keep browse within the reach of deer for longer periods of time.

A study was begun in 1978 to determine how these practices affect the structure and composition of resulting regeneration as well as the quality of deer habitat. This study was one phase of a project to develop a computer model of forest stand dynamics for the Catoosa Wildlife Management Area (Waldrop 1983). Preliminary results (Muncy 1980, Muncy and Buckner 1981) indicated that after one growing season, slightly larger numbers of seedlings and sprouts existed in areas that had been completely clearcut (all stems > 6 feet tall felled) than in areas which had been clearcut to a lower diameter limit of 3 inches (at breast height). Species composition was similar to that of the pre-harvest stand with few pioneer species present. The study was continued to (1) monitor further stand development after complete and diameter limit clearcutting, (2) determine how prescribed burning of young hardwood stands affects the composition and structure of regeneration, and (3) determine how clearcutting and prescribed burning affect the browsing preferences of deer.

STUDY AREA

The study is located on the Catoosa Wildlife Management Area in Cumberland County, Tennessee. The area is characterized as having moderately hot summers and short, mild winters. Mean monthly temperatures range from 35 degrees (Farenheit) in January to 73 degrees in July (USDC 1977). Rainfall averages 57 inches per year with extremes of 3 inches in October and 6 inches in January.

The study area is classified as land type 1 under Smalley's (1982) classification of forest sites on the Mid-Cumberland Plateau. Such areas are gently undulating to slightly rolling. Slopes of greater than 6 percent are uncommon so that aspect is not a dominant factor controlling species occurrences. Elevation ranges from 1,700 to 1,760 feet. Soils of the Hartsells and Lonewood series are dominant. Depth to bedrock is 20 to 40 inches with Hartsells series soils and 40 to 65 inches with Lonewood series soils (USDA 1974, 1975). Both soils are strongly acidic, moderately well drained, and of moderately low fertility (Smalley 1982).

Forests of the study area best fit the Society of American Foresters (SAF 1964) type 41 scarlet oak group which is within the Oak-Hickory Type Group. Mature forest stands were dominated by scarlet oak and post oak with Southern red oak and black oak as common associates (Table 1). (Scientific and common names of all species are included in the appendix). Pignut hickory, Virginia pine, white oak, blackjack oak, blackgum, red maple, and chestnut oak were also present. Major understory species included sourwood and dogwood.

METHODS

The study was established as a split-plot randomized complete block design to study the effects of two harvesting techniques, prescribed fire, and browse on the composition and quantity of regeneration. Each of two replications was divided into three 10-acre plots for the main treatments. Main treatments included (1) diameter limit clearcutting, (2) complete clearcutting, and (3) uncut controls. Each main treatment plot was split into two 5-acre subplots, one of which was burned when regeneration grew out of reach for deer browsing. Nine permanent sampling points were established in each subplot.

Animal exclosures, 1/40 acre in size, were selected around two randomly selected sampling points in each subplot. By using different sized fencing, these exclosures were constructed so that deer were excluded from the entire fenced-in area and rabbits and other small mammals were excluded from one-half of the area.

A buffer strip 100 feet wide was cut around both the diameter limit and complete clearcut plots to eliminate any edge effect. A total of 30 acres was clearcut in one replication and 35 acres in the other. Uncut control plots were located near cut areas but away from any influence of logging operations.

Diameter limit and complete clearcut harvests were completed by the early summer of 1979. Diameter limit cutting was defined as the removal of all stems over 3 inches dbh. This conforms to Tennessee Wildlife Resources Agency policy and was stipulated in contractual agreements with loggers. Complete clear-cutting was defined as the removal of all stems over 6 feet in height. The removal of stems between 6 feet in height and 3 inches dbh was accomplished after the commercial logging operation had been completed. Control plots were established to provide a comparison for other treatment plots.

Prescribed fires were conducted in each replication between the third and fourth growing seasons after harvest (early spring 1982). Burns were conducted on April 12, April 14, and May 2, 1982. Weather predictions called for winds of 10 to 15 miles per hour and low relative humidities of 40 percent. Rain had not fallen on the study areas for 4 days and 6 days, respectively for the first two burn dates. Rain had not fallen for 7 days prior to the third burn date. Due to gusty winds and high fire spread indices, all fires were set to burn into the wind (backing fire). Fires were set at 1:00 pm (Central Standard Time), 10:00 am, and 11:00 am, respectively for the three burn dates.

Table 1.--Pre-harvest stand characteristics

Species	Sawtimber (11.0 in. and >) Av. No. Trees per Ac.	Sawtimber (11.0 in. and >) Basal Area/Ac. sq. ft.	Pulpwood (3.0 to 10.9 in. dbh) Av. No. Trees per Ac.	Pulpwood (3.0 to 10.9 in. dbh) Basal Area/Ac. sq. ft.
Oaks				
Scarlet	13.6 (37%)	18.9 (44%)	18.3 (8%)	3.8 (9%)
Post	10.1 (28%)	9.3 (22%)	46.9 (21%)	13.5 (33%)
Southern Red	4.3 (12%)	4.9 (11%)	38.0 (17%)	6.4 (16%)
Black	3.9 (11%)	4.6 (11%)	24.1 (11%)	4.3 (10%)
White	.6 (2%)	.7 (2%)	16.7 (8%)	2.7 (7%)
Blackjack	.6 (2%)	.6 (1%)	1.7 (.9%)	.4 (1%)
Chestnut	.1 (.4%)	.1 (.3%)	- -	- -
Hickories				
Pignut	1.2 (3%)	1.7 (4%)	3.2 (2%)	.4 (1%)
Mockernut	.2 (.6%)	.2 (.6%)	1.9 (1%)	.3 (1%)
Other Potential Overtstory Hardwoods				
Blackgum	.4 (1%)	.5 (1%)	2.0 (1%)	.4 (1%)
Red Maple	.2 (.6%)	.3 (.8%)	2.2 (1%)	.3 (1%)
Understory Hardwoods				
Sourwood	.2 (.4%)	.1 (.3%)	32.2 (15%)	3.5 (8%)
Dogwood	- -	- -	6.7 (3%)	.6 (1%)
Pines				
Virginia	.9 (2%)	.8 (2%)	23.5 (11%)	4.5 (11%)
Total	36.2 (100%)	42.7 (100%)	217.4 (100%)	41.1 (100%)

Inventories of all study plots were conducted prior to harvest. Each sawtimber-sized tree (11 in. dbh and >) located on each 1/5 acre subplot was mapped in relation to the plot center measured for height and dbh, and recorded by species. The same was done for each pulpwood-sized tree (3 to 10.9 in dbh) on 1/20 acre plots and each sapling-sized tree (6 ft. tall to 2.9 in. dbh) on 1/40 acre plots. Regeneration-sized trees (< 6 ft. tall) on 1/100 acre plots were tallied by species nad by the presence or absence of evidence of browse.

Similar inventories were conducted at the beginning and end of the third and fourth growing seasons after harvest (1 year before and 1 growing season after prescribed burning). Each tree in uncut control areas was tallied as either alive or dead. Uncut trees in clearcut areas were measured for height and dbh. If a tree had been cut, the number of basal, stump, and/or root sprouts produced by the stump was recorded. Regeneration in 1/100 acre plots was again tallied by the number of trees of each species and the number showing evidence of browse.

A factorial arrangement of the analysis of variance was used to test for differences in the number of stems for each of three factors. Factors included two methods of clearcutting (diameter limit and complete), 10 species, and two classes of saplings (seedlings and sprouts). T-tests were used to compare the sprouting characteristics observed in each type of clearcut.

RESULTS

Clearcutting Treatments

Regeneration following the third growing season after clearcutting was similar to the 1-year-old stand as described by Muncy and Buckner (1981). Slightly larger numbers of seedlings and sprouts of most species occurred in the complete clearcut areas than in areas harvested by the diameter limit method. However, this difference was not statistically significant and, therefore, further discussion will characterize a single stand by combining data from both types of clearcuts.

After three growing seasons the total number of stems per acre was 6,168 (Table 2), an increase of 25 percent over the 1-year-old stand. Of this total, 38 percent were seedlings and 62 percent were sprouts. The oak group composed 24 percent of the total regeneration while 38 percent was from other potential overstory hardwoods (including the hickories). Thirty-seven percent of the regeneration consisted of understory hardwood species while only 0.8 percent consisted of pines.

Scarlet oak was the most abundant oak species with 651 seedlings and sprouts per acre. Black oak, Southern red oak, post oak, and white oak were also abundant with 343, 189, 151, and 111 stems per acre, respectively. Two species, blackgum and red maple, predominated in the category of other potential overstory hardwoods. Blackgum was

Table 2.--Regeneration three years after clearcutting (both cutting treatments combined)

Species	Seedlings	Sprouts	Total
	------- Mean Number Per Acre (Percent) -------		
Oaks			
Blackjack	20.8 (0.9)	2.8 (0.1)	23.6 (0.4)
Scarlet	588.9 (24.8)	62.5 (1.6)	651.4 (10.6)
Black	255.6 (10.8)	87.5 (2.3)	343.1 (5.6)
Southern Red	116.7 (4.9)	72.2 (1.9)	188.9 (3.1)
Post	94.4 (4.0)	59.7 (1.6)	154.1 (2.5)
White	84.7 (3.6)	26.4 (0.7)	111.1 (1.8)
Hickories			
Pignut	59.7 (2.5)	88.9 (2.3)	148.6 (2.4)
Mockernut	11.1 (0.5)	9.7 (0.3)	20.8 (0.3)
Other Potential Overstory Hardwoods			
Blackgum	594.4 (25.0)	520.8 (13.7)	1115.2 (18.1)
Red Maple	115.6 (6.6)	831.9 (21.9)	987.5 (16.0)
Persimmon	31.9 (1.3)	6.9 (0.2)	38.8 (0.6)
Black Locust	41.7 (1.8)	- -	41.7 (0.7)
Understory Hardwoods			
Sassafras	111.1 (4.7)	1763.9 (46.5)	1875.0 (30.4)
Dogwood	63.9 (2.7)	165.3 (4.4)	229.2 (3.7)
Sourwood	30.6 (1.3)	77.8 (2.1)	108.4 (1.8)
Serviceberry	54.2 (2.3)	1.4 (0.1)	55.6 (0.9)
Am. Holly	9.7 (0.4)	1.4 (0.1)	11.1 (0.2)
Am. Chestnut	- -	15.3 (0.4)	15.3 (0.2)
Pines			
Virginia	45.8 (1.9)	- -	45.8 (0.7)
White	2.8 (0.1)	- -	2.8 (0.1)
Totals	2373.6 (100)	3794.4 (100)	6168.0 (100)

the most abundant of all overstory species with 1,115 stems per acre. Red maple had 988 stems per acre of which 832 (84 percent) were classified as sprouts.

Sassafras regeneration was the most abundant of the understory hardwoods with 1,875 stems per acre. The majority (94 percent) was of sprout origin. Dogwood and sourwood seedlings and sprouts were common and American holly seedlings were observed occasionally. Sprouts of American chestnut were present but infrequent.

The presence of pioneer species in study plots was smaller than had been expected. Virginia pine seedlings composed 0.7 percent of the total regeneration (46 seedlings per acre) while Eastern white pine accounted for only 0.1 percent (3 per acre). Yellow-poplar and black locust are common in the general area but were essentially absent from study plots. Since larger quantities of pioneer species were observed in the buffer areas around study plots, the distance from a seed source to study plots may partially account for their absence.

Sprouting remained the most common form of regeneration through the third growing season (Table 2). No significant differences were detected between diameter limit and complete clearcuts in the number of sprouts per cut tree or in the height of the dominant sprout from each stump. Although not statistically significant, the total number of stems per acre was slightly larger in complete clearcut areas than in diameter limit clearcuts. This increase was due to the greater number of understory hardwoods harvested in the complete clearcuts and the prolific sprouting characteristic of some of these species, particularly sassafras. The increased sprouting of understory hardwoods in complete clearcut areas is potentially beneficial to wildlife for browse but is of little value to timber management.

Significant differences in sprouting characteristics occurred between the various size classes and species of trees harvested. Seventy-seven percent of the stumps of sapling-sized trees had live sprouts after 3 years. However, this percentage decreased with increased stump size. Thirty-nine percent of the stumps of pulpwood-sized trees had live sprouts while only 4 percent of the stumps of sawtimber-sized trees sprouted. Of all species, red maple was the most prolific sprout producer with 6.2 and 14.8 sprouts per cut stem for sapling- and pulpwood-sized trees, respectively. For most species, basal sprouts were the most abundant of the three types of sprouts observed (basal, stump, and root sprouts). This indicates that stumps should be cut as low as possible for well-formed coppice regeneration.

Prescribed Burning

The prescribed burn conducted on the third burn date (May 2) was blown across plowed fire lines by gusty winds. As a result, all clearcut plots in one replication were burned. Since this left no comparison of regeneration in burned and unburned plots, no statistical tests of the effects of prescribed burning were possible. Many effects were obvious, however, and will be discussed.

One year after burning, sprouts remained more abundant than seedlings. Most stumps that had live sprouts before burning resprouted after the fire (Table 3). This trend varied somewhat by species and diameter class. Seventy-nine percent of the stumps from sapling-sized trees that were alive just prior to burning survived the fire. Survival rates of the oaks in this size class were generally above 60 percent. Black oak, white oak, and Southern red oak had survival rates of 95, 83, and 88 percent, respectively. Other species in the sapling size class with good survival rates included mockernut and pignut hickories, blackgum, red maple, sassafras, and sourwood. Of the survivors in the pulpwood size class, the oaks were the most abundant. Black oak had the best survival rate of all species observed in this size class. Very few sawtimber-sized stumps had sprouts before burning. Of those that did, stumps of scarlet oak and pignut hickory had excellent survival rates.

Prescribed burning produced few changes in species composition. Study plots in both burned and unburned clearcuts had a large component of oaks (Table 4). In both areas, stems of black oak and scarlet oak were the most abundant oak species. The oaks as a group made up 22.6 percent of the stem count in unburned plots and 18.8 percent in burned plots. This difference may be due to the sprouting characteristics of sassafras and blackgum. Burning may have stimulated the sprouting of sassafras and blackgum as shown by the large increase in the stem numbers of these species in burned plots. These two species combined had over 6,600 stems per acre in burned plots which was almost equal to the total number of stems in unburned plots (7,178). The numbers of oak stems remained relatively unchanged after burning. Burned plots had a total of 1,945 oak stems per acre while unburned plots had 1,622. However, with the large increase in the numbers of blackgum and sassafras stems, oak percentages decreased.

An opposite trend after burning was observed with red maple. Even though red maple was a prolific sprouter and had good sruvival rates (Table 3), the average number of stems per acre was much smaller in burned plots than in unburned plots.

Table 3.--Survival of stumps in complete and diameter clearcuts after prescribed fire

Species	Sapling (6' tall-2.9" dbh) No. alive before burning	Sapling No. alive after burning	Pulpwood (3.0"-10.9"dbh) No. alive before burning	Pulpwood No. alive after burning	Sawtimber (11.0" dbh and >) No. alive before burning	Sawtimber No. alive after burning
		(%)		(%)		(%)
Oaks						
Blackjack	2	0 (0)	2	0 (0)	-	- -
Scarlet	14	8 (57)	36	25 (69)	7	5 (71)
Black	56	53 (95)	18	15 (83)	-	- -
White	24	20 (83)	26	15 (58)	-	- -
Southern Red	33	29 (88)	23	15 (65)	-	- -
Post	22	14 (64)	14	10 (71)	3	1 (33)
Hickories						
Mockernut	9	8 (89)	3	3 (100)	-	- -
Pignut	50	41 (82)	-	- -	3	2 (67)
Other Potential Overstory Hardwoods						
Blackgum	79	60 (76)	-	- -	1	0 (0)
Red Maple	7	5 (71)	2	0 (0)	-	- -
Understory Hardwoods						
Am. Chestnut	2	0 (0)	-	- -	-	- -
Am. Holly	2	2 (100)	-	- -	-	- -
Serviceberry	1	0 (0)	-	- -	-	- -
Sassafras	83	67 (81)	-	- -	-	- -
Sourwood	20	15 (75)	65	41 (63)	-	- -
Dogwood	16	10 (63)	7	4 (57)	-	- -
Totals	420	332 (79)	196	128 (65)	11	8 (72)

This difference may be due to the distribution of red maple through the study plots rather than to burning. Before burning, the distribution of red maple was observed to be patchy. Stems of this species appeared to be more abundant in plots that were to be left unburned. Had red maple been more uniformly distributed, it may have shown a different response to fire.

Table 4.--Regeneration one year after prescribed burning (four years after clearcutting)

Species	Burned	Unburned
	----- Stems Per Acre (%) -----	
Oaks		
Scarlet	779.6 (7.5)	500.1 (7.0)
Black	453.7 (4.4)	716.7 (10.0)
Southern Red	359.3 (3.5)	161.1 (2.2)
Post	209.3 (2.0)	138.9 (1.9)
White	138.9 (1.3)	105.6 (1.5)
Chestnut	3.7 (0.1)	- -
Hickories		
Pignut	112.0 (1.1)	249.9 (3.5)
Mockernut	22.2 (0.2)	39.0 (0.5)
Other Potential Overstory Hardwoods		
Blackgum	2,631.5 (23.5)	750.0 (10.4)
Red Maple	296.3	1,105.5 (15.4
Persimmon	14.9	55.5 (0.8)
Black Locust	270.4	166.8 (2.3)
Black Cherry	1.9	5.7 (0.1)
Yellow-poplar	-	11.1 (0.2)
Understory Hardwoods		
Sassafras	4,050.0 (39.2)	2,177.7 (30.3)
Dogwood	187.0 (1.8)	183.3 (2.6)
Sourwood	446.3 (4.3)	583.2 (8.1)
Serviceberry	5.6 (0.1)	50.1 (0.7)
Am. Holly	11.1 (0.1)	16.8 (0.2)
Am. Chestnut	5.6 (0.1)	111.1 (1.5)
Winged Sumac	357.4 (3.5)	5.7 (0.1)
Pines		
Virginia	7.4 (0.1)	44.7 (0.6)
Totals	10,339.0	7,178.4 (100)

The frequency of pines and other pioneer species remained low in both burned and unburned plots. Virginia pine was the only pine species observed, although shortleaf pine and Eastern white pine are native to the region. The average number of Virginia pine seedlings per acre was 44.7 in unburned plots and only 7.4 in burned plots. Yellow-poplar was observed in unburned plots at the rate of only 11.1 seedlings per acre. No seedlings or sprouts of this species were found in burned plots.

The structure of regeneration was also unchanged by prescribed burning. Basal sprouts remained the most common form of regeneration in both burned and unburned plots. A few root sprouts were observed near stumps of pignut hickory, blackgum, and sassafras while an occassional stump sprout of scarlet oak or dogwood was observed.

Browsing

The incidence of browsing in study areas was minimal. During data collection at the end of the fourth growing season (1982), over 7,000 regeneration-sized trees were observed. Of these, only 93 showed evidence of browse. This number was even smaller at the end of the third growing season. Therefore, it was assumed that browsing had no affect on the structure and composition of regeneration. In addition, no comparisons were made on deer preferences to browsing in diameter limit or complete clearcuts as well as burned or unburned clearcuts.

Muncy (1980) noted that browsing occurred most often along haul roads and skid trails within study plots. This trend was repeated during the third and fourth growing seasons. Of those species that were browsed, sassafras and blackgum sprouts were most common. Blackgum is listed as a preferred species for deer browse in Tennessee while sassafras is listed as a common food (Hurd 1980). Occassional browsing of black oak, pignut hickory, and red maple was also observed.

The location of sampling points within clearcut areas may offer an explanation for the small number of browsed stems observed. Sampling points were located near the center of nearly square-shaped 30 and 35 acre clearcuts. Buffer strips, 100 feet wide, were cut around study plots further isolating points near the center of large cuttings. More evidence of browsing was observed in buffer strips than within sampling plots. This may have been due to the proximity of buffer strips to cover provided by the forest edge. Buffer strips were large enough and contained sufficient browse that deer likely remained in these areas rather than entering study plots. Also, study plots were in a heavily hunted area where deer are not likely to wander far from the protective cover of a forest stand.

Observations of browsing may be more valuable in future studies as stands close and much of the regeneration in buffer areas is shaded out. Under these conditions, browsing animals will have to cover a larger area to obtain food, possibly causing a more noticeable impact on species composition and tree growth rates in study plots.

DISCUSSION

Species composition of regeneration after clearcutting a low-quality hardwood stand was largely a function of the sapling-and pulpwood-sized trees harvested. Sprouts from cut stems of these size classes composed a large portion of the regenerated stand since pioneer species and sprouts from sawtimber-sized trees were essentially absent. Seedlings that were a component of the regenerated stand tended to be of the same species as the harvested trees, suggesting that root suckering may be more important than visual observation would indicate.

Regeneration and stand development were relatively unaffected by the choice of either diameter limit or complete clearcutting methods. Both treatments resulted in stands that were approximately 24 percent oak, 3 percent hickory, and 34 percent blackgum and red maple, with the remainder being mostly sassafras (Table 2). Even though large stumps tended not to produce sprouts, the extra expense of harvesting stems between 6 feet in height and 3 inches dbh in a complete clearcut proved to be of little value in terms of improved timber quality and wildlife habitat. A sufficient number of small stems was harvested by the diameter limit method to produce large numbers of sprouts. Seed germination provided an additional quantity of stems resulting in adequate stand regeneration and browse availability. Therefore, diameter limit clearcutting would be recommended over complete clearcutting for stands that have a sufficient quantity of pulpwood-sized trees (3.0 to 10.9 in. dbh) to yield adequate coppice regeneration. Prior to harvest, almost 50 percent of the basal area in the stand used for this study was from pulpwood-sized trees. Complete clearcutting should only be necessary where the pulpwood-sized component of the stand is much smaller.

Prescribed burning of young clearcuts proved to be of little value in terms of controlling species composition. Regeneration observed one year after burning was very similar to that observed the first year after clearcutting. Species composition was similar in burned and unburned plots, both being dominated by oak seedlings and sprouts.

Prescribed burning had a greater affect on browse availability than on species composition or structure. The most obvious differences between burned and unbruned plots were the sizes and ages of the regeneration. Burned clearcuts had small 1-year-old seedlings and sprouts while unburned clearcuts had larger 4-year-old seedlings and sprouts. Although the unburned clearcuts were still young, regeneration was beginning to grow out of the reach of deer. Prescribed burning top-killed most stems resulting in continued sprouting. Therefore, browse should remain within reach for several additional years.

Even though burning created favorable conditions for deer, browsing was minimal in study plots. However, evidence of heavy browsing was observed in buffer strips around study plots. Future recommendations for prescribed burning of young clearcuts should include considerations of the size and shape of the clearcut. In a large or wide clearcuts, such as those used in this study, prescribed burning may be of little actual benefit to deer. Since the majority of the clearcut area is relatively far from cover, particularly after the removal of logging debris by burning, it is not likely to be utilized intensively by deer. Burning may be of greater value to deer in smaller or more narrow clearcuts where a larger percentage of the area is near protective forest cover.

Prescribed burning provided several benefits for timber management including improved accessability to the site, protection from wildifre, and improved sprout quality. Logging debris was abundant in all clearcut areas before burning, creating a physical barrier to travel. Since the slash had cured for almost four years, it also represented a dangerous wildfire hazard. Prescribed burning provided an inexpensive method for slash removal. Sprout quality was improved by burning the tops of stumps. Therefore, resulting sprouts originated from a point closer to the ground which should lower the rate of decay (Roth and Sleeth 1939, Huntley and McGee 1981).

In summary, diameter limit clearcutting followed by natural regeneration proved to be an adequate management technique for timber and deer management considerations in low-quality hardwood stands. Complete clearcutting provided extra expense with few beneficial results. Prescribed burning improved browse availability by keeping it within reach of deer for a longer time period. However, this additional browse was not utilized possibly due to the size and shape of clearcuts. Prescribed burning proved to be more beneficial for timber stand improvement than for enhancing habitat for deer. Stand composition and structure appeared to be affected more by species composition before harvest than by choice of clearcutting method, prescribed burning, or browsing. Most regeneration in burned and unburned areas of both complete and diameter limit clearcuts consisted of sprouts from the stumps of sapling- and pulpwood-sized trees.

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APPENDIX

COMMON AND SCIENTIFIC NAMES OF TREE SPECIES

Common Name	Scientific Name
Red Maple	*Acer rubrum* L.
Sugar Maple	*Acer saccharum* Marsh.
Serviceberry	*Amelanchier arborea* var. *laevis* Wieg.
American Chestnut	*Castenea dentata* Marsh.
Pignut Hickory	*Carya glabra*
Mockernut Hickory	*Carya tomentosa* Nutt.
Dogwood	*Cornus florida* L.
Persimmon	*Diospyros virginiana* L.
American Holly	*Fraxinus americana* L.
Yellow-poplar	*Liriodendron tulipifera* L.
Blackgum	*Nyssa sylvatica* Marsh.
Sourwood	*Oxydendron aroboreum* L.
Shortleaf Pine	*Pinus echinata* Mill.
Eastern White Pine	*Pinus strobus* L.
Virginia Pine	*Pinus virginiana* Mill.
Black Cherry	*Prunus serotina* Ehrh.
White Oak	*Quercus alba* L.
Scarlet Oak	*Quercus coccinea* Muenchh.
Southern Red Oak	*Quercus falcata* Michx.
Blackjack Oak	*Quercus marilandica* Muenchh.
Chestnut Oak	*Quercus prinus* L.
Post Oak	*Quercus stellata* Wangenh.
Black Oak	*Quercus velutina* Lam.
Winged Sumac	*Rhus copallina* L.
Black Locust	*Robinea pseudoacacia* L.
Sassafras	*Sassafras albidum* Nutt.

BIOMASS AND NUTRIENT ACCRETION ON PIEDMONT SITES FOLLOWING CLEARCUTTING AND NATURAL REGENERATION OF LOBLOLLY PINE[1/]

S. K. Cox and D. H. Van Lear[2/]

Abstract.--Vegetative regrowth was sampled on two small watersheds for five years following clearcutting and natural regeneration to loblolly pine (Pinus taeda L.). The primary pathway for biomass and nutrient accretion during the first two growing seasons after harvest was by herbaceous plants. At the end of the fifth growing season, pine seedlings dominated both sites; and accumulation of N, P, and K in standing biomass was nearly equal to or exceeded that of the pre-harvest 41-year-old pine plantation. Calcium accretion in biomass after five growing seasons was about 50 percent of that contained in the pre-harvest biomass on both watersheds. Regrowth is a major mechanism in conserving nutrients on naturally regenerated watersheds following clearcutting of loblolly pine in the Piedmont.

INTRODUCTION

Harvesting timber stands may alter several ecological processes which might be expected to cause large hydrologic losses of essential nutrients. Forest floor decomposition is accelerated, transpiration rates are reduced, storm flow and deep percolation are increased, and nutrient uptake by the former mature stand is interrupted (Witkamp 1971, Likens et al. 1978). However, nutrient losses via hydrologic processes following clearcutting of mature loblolly pine plantations in the South Carolina Piedmont are small when compared to nutrient removals in harvested biomass (Van Lear et al. 1981, Van Lear et al. 1985).

Nutrient accumulation in the biomass of regrowth is a major mechanism in conserving cycled nutrients in northern hardwood ecosystems (Marks and Bormann 1972). Boring et al. (1981) showed that the rapid regrowth and the high nutrient content of sprouts and herbaceous species are major factors minimizing elemental losses following clearcutting of Southern Appalachian hardwoods.

Relatively little is known concerning nutrient accumulation and distribution in regrowth following harvest of southern pines. In this study, biomass and nutrient accumulation in regrowth is quantified following whole-tree and conventional harvesting of mature loblolly pine utilizing natural regeneration in the Piedmont of South Carolina.

STUDY AREA

The study area consisted of two small (2.5 ha) watersheds located on the Clemson University Experimental Forest in the upper Piedmont of South Carolina. These sites were eroded agricultural fields planted to loblolly pine (Pinus taeda L.) in 1939 and clearcut at age 41. Even though both watersheds were similar in slope (10-15%) and aspect (SW), one watershed (WS 66) had a longer and deeper ephemeral stream channel and was more eroded on the lower slopes than the other (WS 64). Surface soil depth on WS 64 averaged about 25 cm as compared to 15 cm for WS 66.

The soils on both areas were Pacolet fine sandy loam (Typic Hapudult). Basal area at the time of clearcutting was 22 m^2/ha for WS 64 and 18 m^2/ha for WS 66. Both watersheds had been thinned twice prior to clearcutting. Major understory species were black cherry (Prunus serotina), black gum (Nyssa sylvatica), eastern red cedar (Juniperus virginiana), dogwood (Cornus florida), oak (Quercus spp.), and hickory (Carya spp.).

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[2/] Research Forester and Professor, Department of Forestry, Clemson University, Clemson, South Carolina 29631.

METHODS

Preharvest treatments for both watersheds included 3 annual burns prior to harvest to reduce the understory hardwood component and prepare a seedbed for natural regeneration. The third burn was applied just prior to seed fall in 1979 and harvest was completed before seed germination the following spring. All above-stump biomass was removed from WS 64 to simulate whole-tree harvesting, while conventional harvesting to a 15-cm top was conducted on WS 66.

To avoid large numbers of destructively sampled plots, prediction equations were developed to relate percent cover and height of vegetation to biomass. Data for the equations were taken during the first two growing seasons from 30 $1m^2$ quadrats, which were selected to cover the range of vegetative conditions on both watersheds. Following development of the equations, 150 $1m^2$ quadrats were randomly located on each watershed during August of 1980 and 1981. Percent cover and height of the dominant vegetation was determined on each of these random plots and biomass predicted for pine seedlings, hardwood sprouts, legumes, and other herbaceous plants.

In August of the fifth growing season, the herbaceous component was estimated by clipping and weighing 40 plots (1/4 by 4 m) randomly located on each watershed. Biomass equations relating ground-line diameter and total height to biomass were developed for loblolly pine and hardwood stems in the fifth growing season from 20 pine seedlings and 20 hardwood stems sampled in late August 1984. These equations were developed for foliage, branches, main stem, and total biomass for both hardwood and pine, and applied to measurements of all stems on five randomly located plots (5 by 5 m) on each watershed.

Samples of vegetative tissue were ground in a Wiley mill to pass through a 20-mesh screen and then analyzed for N, P, K, and Ca by standard procedures at the Coweeta Hydrologic Laboratory. Total nutrient content in above-ground regrowth was obtained by multiplying dry weight biomass by dry weight nutrient concentrations for each vegetation group (legumes, other herbaceous, hardwood sprouts, and pine seedlings) and expanded to an area basis.

RESULTS AND DISCUSSION

The 'seed in place' method of natural regeneration (Lotti 1961) proved effective in establishing abundant loblolly pine seedlings on both WS 64 and WS 66 (Table 1). As is often the case with natural regeneration, more seedlings were established than desired. Logging slash covered 37% of the area on WS 66 after harvest, making pine seedling inventory difficult. As a result, seedling density was probably underestimated on WS 66 during the first growing season. By the second growing season, seedling numbers were about equal on the two watersheds.

Table 1. Pine natural regeneration after clear-cutting two loblolly pine watersheds in the Piedmont of South Carolina.

Harvest Method	Year 1	Year 2	Year 5
	- - -	seedlings/ha	- - -
WS 64 Whole-tree	82,000	75,000	20,500
WS 66 Conventional	33,000	67,000	23,000

First year biomass in above-ground vegetation totaled 3,131 kg/ha on WS 64 and 2,456 kg/ha on WS 66 (Table 2). Despite their large numbers, pine seedlings made up less than 1 percent of total biomass of the regrowth after the first growing season, while hardwood sprouts accounted for 13 to 15 percent of total biomass of the regrowth. About 85 percent of the first year's biomass on both watersheds was herbaceous (including legumes). Total first year biomass of regrowth represented about 2.4 percent of the pre-harvest pine biomass on both watersheds (Table 3).

Nutrient accretion in the first year followed a similar pattern to that of biomass development. Herbaceous biomass contained most of the nutrients and the pine component the least (Table 2). Nutrient accumulation in biomass ranged from 46 kg/ha for K to less than 3 kg/ha for P. Accretion of nutrients in the first year biomass was about 20 percent of the total N, P, and Ca, and about 70 percent of the K as in the pre-harvest plantation (Table 3).

Boring et al. (1981) found net primary production, predominantly in woody plants, was 1,725 kg/ha one growing season after harvest of an Appalachian hardwood forest. First-year regrowth amounted to 1.3% of the biomass of adjacent stands. Regrowth of this hardwood forest contained about half the K content as that found in our study, but amounts of N, P, and Ca were similar. Differences in K accumulation can be attributed to the larger herbaceous component and its high K concentration on our study areas. Siccama and Bormann (1970) also found high K levels in herbaceous tissue in a northern hardwood forest. These studies indicate that regrowth following disturbance rapidly accumulates nutrients made available from decomposing organic matter (forest floor, logging slash, stumps, and roots), N fixation, mineral soil, and atmospheric inputs.

Regrowth on WS 64 was greater than that on WS 66 in all vegetative categories during the second growing season (Table 2). Although herbaceous vegetation still dominated the biomass and nutrient capital of both sites, the

Table 2. Biomass and nutrient accretion in regrowth after harvest of mature loblolly pine on two sites in the South Carolina Piedmont.

Vegetative Component	WS 64 Whole-tree Harvest			WS 66 Conventional Harvest		
	Years after Harvest					
	1	2	5	1	2	5
	kg/ha					
				biomass		
Legumes	130	925	120	92	415	158
Other Herbaceous	2,532	3,986	1,182	2,035	2,663	991
Hardwood	459	753	3,726	324	359	1,804
Pine	9	146	11,037	5	73	17,822
Total	3,130	5,800	16,065	2,456	3,510	20,775
				nitrogen		
Legumes	1.82	12.95	2.75	1.29	5.81	3.62
Other Herbaceous	32.92	51.82	11.12	26.46	34.62	9.33
Hardwood	1.44	6.85	31.82	2.95	3.27	14.81
Pine	0.09	1.46	90.45	0.05	0.73	128.51
Total	36.27	73.08	136.14	30.75	44.43	156.27
				phosphorous		
Legumes	0.09	0.65	0.13	0.06	0.29	0.17
Other Herbaceous	2.03	3.19	1.11	1.63	2.13	0.93
Hardwood	0.42	0.45	3.10	0.19	0.22	1.45
Pine	0.01	0.12	8.04	< .01	0.06	11.78
Total	2.55	4.41	12.38	1.88	2.70	14.33
				potassium		
Legumes	1.25	8.88	0.88	0.88	3.98	1.16
Other Herbaceous	40.15	63.78	10.01	32.56	42.61	8.39
Hardwood	4.04	6.63	16.87	2.85	3.16	7.86
Pine	0.07	1.21	40.14	0.04	0.61	59.21
Total	45.87	80.50	67.90	36.39	50.36	76.62
				calcium		
Legumes	1.26	8.97	0.85	0.89	4.03	1.12
Other Herbaceous	18.23	28.70	7.10	14.65	19.17	5.96
Hardwood	8.86	14.53	44.70	6.25	6.93	21.08
Pine	0.02	0.38	30.16	0.01	0.19	46.41
Total	28.37	52.58	82.81	21.80	30.32	74.57

Table 3. Biomass and nutrient content (above stump) of two mature loblolly pine plantations in the South Carolina Piedmont (Van Lear et al. 1983).

Watershed	Biomass	N	P	K	Ca
	- - - - - - - - -	kg/ha	- - - - - - -		
WS 64	130,000	150	13	71	141
WS 66	100,000	113	10	53	105

pine biomass increased 15 fold. Herbaceous vegetation, including legumes, increased about 85 percent on WS 64 and 45 percent on WS 66 from the first to second growing season, while hardwood sprout biomass doubled on WS 64 and increased only slightly on WS 66. Hardwood sprout and herbaceous growth on WS 66 may have been reduced by shading or physical obstruction from logging slash.

Accumulation of K in biomass at the end of the second growing season was 13 percent greater than that of the pre-harvest pine stand on WS 64 and approached the pre-harvest level on WS 66. Accumulation of N, P, and Ca over the first two growing seasons ranged between 20 and 50 percent of the pre-harvest amounts.

At the end of the fifth growing season, the trend of greater biomass on WS 64 had reversed (Table 2). Total biomass on WS 64 was now less than that on WS 66 (16,000 vs. 21,000 kg/ha). Watershed 66 surpassed WS 64 in biomass accretion because of better growth and survival of pine seedlings. The reduced survival and growth rates of pine seedlings on WS 64 were attributed to a deeper sandy loam surface horizon and more herbaceous competition on WS 64 than on WS 66. Severe summer droughts occurred on these areas during 1980, 1981, and 1983. The deeper surface soil, in combination with droughty summers and more herbaceous competition, probably resulted in moisture stress that affected growth and survival of pine seedlings more on WS 64 than WS 66. Normally, over the course of a rotation, a deeper surface soil in the Piedmont would result in more pine biomass production. However, under severe drought conditions and the intense competition that developed on these naturally regenerated watersheds, growth of small seedlings may be less on sites with deeper, coarse textured surface horizons.

Pine seedlings comprised 69 and 86 percent of the total biomass on watersheds 64 and 66, respectively, after five growing seasons. Hardwood sprout biomass increased on both watersheds, representing about 20 percent of the total biomass on WS 64 and 10 percent on WS 66. Herbaceous plants after five growing seasons contributed less than 10 percent to the total biomass on both watersheds. Switzer and Nelson (1971) in Mississippi found that herbaceous vegetation was still an important component of biomass in the fifth growing season in young loblolly pine plantations. Dominance of pine occurs more quickly in densely stocked naturally regenerated stands than in plantations.

With the exception of Ca, nutrient accretion on the conventionally harvested watershed was generally greater during the fifth growing season than on the whole-tree harvested watershed. The larger component of hardwood sprouts, which has high Ca concentrations, resulted in greater Ca accumulation on that watershed even though it had less total biomass. With the exception of K on WS 64, nutrients in regrowth continued to increase through the fifth growing season. The decline in K content between the second and fifth growing season was caused by the dramatic reduction in K-rich herbaceous biomass. A similar reduction in herbaceous biomass occurred on WS 66, but more growth of the pine component prevented an actual decline in total K content. The intolerant herbaceous component rapidly declined to less than 10 percent of the total biomass as the pine seedlings assumed dominance on both sites.

Accumulation of N, P, and K in standing biomass on WS 64 after five growing seasons amounted to 91-96 percent of the nutrients in the stand prior to harvest while the accretion on WS 66 was about 140 percent greater than that contained in the pre-harvest stand. In contrast, Ca accumulation after five years was only 59 and 71 percent of that in pre-harvest stands on WS 64 and 66, respectively. Foliage comprised about half the pine biomass in the fifth year and contained 60 to 80 percent of the nutrient content (Table 4). Similar trends of biomass and nutrient distribution were found in hardwood sprouts, with the exception of Ca, which was more evenly distributed between foliage, branches, and stems.

Sources of N, P, K, and Ca accumulated in regrowth are the organic reserves left on site after harvest and the exchangeable/extractable soil nutrients (Table 5). The original forest floor decomposes quickly following harvest and contains sufficient nutrients to satisfy much of the nutrient demands of early regrowth (Pritchett and Wells 1978). Little N and P is made available for plant uptake from decomposition of woody logging debris during the regeneration period, although foliage in slash decomposes readily. Potassium, Ca, and Mg in woody slash are released gradually during decomposition (Barber and Van Lear 1984). The rate at which nutrients become available from decomposition of roots of harvested trees is uncertain and deserves further study.

Regrowth following harvest is a major mechanism by which nutrient loss is minimized following ecosystem disturbance. In this study, low intensity prescribed burns were used to prepare the site for natural regeneration. These pre-harvest burns consumed only about 1/3

Table 4. Biomass and nutrient content of loblolly pine after five growing seasons on two harvested watersheds in the South Carolina Piedmont.

	WS 64 Whole-tree Harvest					WS 66 Conventional Harvest				
	Biomass	N	P	K	Ca	Biomass	N	P	K	Ca
	kg/ha									
Foliage	5,981	78	6	31	20	7,981	104	9	41	27
Branches	1,314	5	1	4	3	2,706	10	1	8	7
Stem	3,742	8	1	5	7	7,136	15	2	9	13
Total	11,037	91	8	40	30	17,823	129	12	58	47

Table 5. Potential nutrient sources available for regrowth on clearcut pine watersheds (adapted from Van Lear et al. 1981).

	ORGANIC NUTRIENT RESERVES							
	WS 64 Whole-tree Harvest				WS 66 Conventional Harvest			
	N	P	K	Ca	N	P	K	Ca
	kg/ha							
Forest Floor	176	17	22	164	132	12	17	102
Logging Residue[1/]	0	0	0	0	50	5	16	32
Stumps and Roots	39	7	26	39	29	5	20	29
Total	215	24	48	203	211	22	53	163
	EXTRACTABLE AND EXCHANGEABLE SOIL NUTRIENT RESERVES							
Soil	---	17	213	1,332	---	13	109	501

[1/] Logging residue on WS 64 was assumed to be zero, although a small percentage (< 5%) remained.

of the forest floor each year leaving many viable seeds of herbaceous plants in the residual forest floor. Following harvest, these seeds as well as the recently fallen pine seed, germinated and quickly established a vegetative cover on both watersheds. The rapid development of herbaceous plants and the establishment of large numbers of pine seedlings probably allow for more rapid recovery of nutrient cycling on these naturally regenerated sites than would occur with some commonly used artificial regeneration methods.

CONCLUSIONS

Uptake and accumulation of nutrients in the biomass of regrowth are major ecosystem recovery processes following clearcutting of Piedmont loblolly pine stands. Within five years following clearcutting with seed-in-place regeneration, regrowth had accumulated quantities of most nutrients (except Ca) which equaled or exceeded quantities in the pre-harvest plantation.

The distribution of nutrients in regrowth changes during the regeneration period. During the first and second years, nutrients are primarily accumulating in herbaceous biomass, even though pine seedling density may be extremely high. By the fifth year, pine biomass has become dominant and contains the majority of the nutrients. High proportions of nutrient-rich tissue, as well as the rapid growth rates of early successional vegetation, account for the ability of these sites to restore tight nutrient cycling to the disturbed ecosystem. Regrowth and nutrient accumulation patterns were similar on both the whole-tree and conventionally harvested watersheds.

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BIOMASS AND NUTRIENT DISTRIBUTION IN 3-YEAR-OLD GREEN ASH AND SWAMP CHESTNUT OAK GROWN IN A MINOR STREAM BOTTOM[1/]

Harvey E. Kennedy, Jr., and Bryce E. Schlaegel[2/]

Abstract.--After three growing seasons, green ash had produced 7,342 pounds per acre of above-ground dry matter compared to 3,572 for oak. Of the total biomass, ash had 53% in the bole (wood plus bark), 22% in old branches, 21% in leaves and 4% in new growth; oak had 50%, 21%, 24%, and 5% in the same components. These proportions changed after leaf fall. Concentrations of N, P, K, and Mg followed the general order of: leaves > new growth > bole bark and branch bark > bole wood and branch wood. Calcium concentrations were highest in bole bark and branch bark followed by leaves, new growth, and bole wood and branch wood.

INTRODUCTION

An understanding of biomass and nutrient distribution in forest systems is prerequisite to proper evaluation of the effects of imposed soils and silvicultural treatments. This paper reports biomass and concentrations and distribution of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in leaves, new growth, bole wood and bark, and branch wood and bark of green ash (*Fraxinus pennsylvanica* Marsh.) and swamp chestnut oak (*Quercus michauxii* Nutt.) during the third year of a plantation.

METHODS

This study was superimposed on a larger study being conducted near Monticello, Arkansas.[3/] The study occupies about 55 acres in a minor stream bottom that transects pine uplands. The site was cleared of a mixed hardwood-pine stand and prepared for planting by shearing, root raking, and disking. The soil is classified Arkabutla, a member of the fine-silty, mixed, acid, thermic family of Aeric Fluvaquents. These somewhat poorly-drained soils formed in silty alluvium. Estimated site indices (Broadfoot 1976) range from 85-105 feet for green ash and 80-100 feet for swamp chestnut oak, both at age 50 years.

The larger study site was planted with eight species at five different spacings. Species were green ash, swamp chestnut oak, sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), cottonwood (*Populus deltoides* Bartr. ex Marsh.), water oak (*Quercus nigra* L.), cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.), and Nuttall oak (*Q. nuttallii* Palmer).

The five spacings in feet were 2 x 8, 3 x 8, 4 x 8, 8 x 8, and 12 x 12. Spacings were chosen to span from the narrow coppice spacings to the more usual pulpwood and saw log spacings. The 8-foot distance between rows was chosen to allow tending by standard farm equipment.

Each plot consists of 169 trees of one species planted in a rectangular grid of 13 by 13 rows. The interior 5 by 5 rows were designated as permanent remeasurement rows with the exterior four rows as a buffer.

The minor stream floodplains, such as represented in this study, typically consist of flats, slopes, and small ridges. Two species, green ash and swamp chestnut oak, were chosen for sampling. These represent one of the faster and one of the slower growing species in the initial study. One plot for each species on a ridge and flat was chosen for sampling. The study was limited to these

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[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Harvey E. Kennedy, Jr., is Principal Silviculturist and Bryce E. Schlaegel is Principal Mensurationist at the Southern Hardwoods Laboratory, maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

[3/] Schlaegel, Bryce E., and Harvey E. Kennedy, Jr. 1976. Effects of spacing on species yields in minor bottoms. Study Plan FS-SO-1110-29, on file at Southern Hardwoods Laboratory, Stoneville, Miss.

two species on two sites because of the tremendous amount of sampling time required. Sampling was done on the second Monday of each month starting in April 1979 and continuing through March 1980.

The present study was set up in plots with 4- x 8-foot spacing. Three trees, representative of those on the whole plot, were selected from the second and third border rows around each sample plot. In the field, all leaves were removed from a tree before cutting and stored in plastic bags in an ice-chest. Tall trees were pulled over to remove the upper leaves. New growth, defined as woody growth that occurred during the third growing season, was separated, bagged, and labeled. Old branches were clipped into small segments, bagged, and labeled. Main stem was severed at groundline, diameter outside bark measured at 0.5 and 4.5 feet, and total height recorded. The bole was then cut into 0.5-foot sections, bagged, and labeled. Components of each tree on a plot were kept separate for subsequent weighing and nutrient determinations.

Green weights of all materials were recorded upon returning to the Southern Hardwoods Laboratory. A representative sample of branches was randomly selected and the bark separated from the wood. Each third section of the bole was selected and bark removed from the wood. The bark samples included cambium and phloem tissues. Green weights of each sample were then recorded. Samples and the remainder of each tree were dried to a constant weight at 70°C and dry weights obtained.

Leaves and samples of woody material and bark were ground to pass a 2-mm mesh in preparation for chemical analyses. Nitrogen was determined by standard Kjeldahl procedure, P by colorimetry with molybdenum-blue color development, and K, Ca, and Mg by atomic absorption spectrophotometry after samples had been dry-ashed and taken up in dilute HCl.

Differences in nutrient concentrations between sites for each species and monthly concentrations in each tree component for each nutrient were tested using a split-plot analysis of variance. Species were tested separately because of inherent growth differences and possible differences in nutrient uptake. Comparisons among means were made using Duncan's New Multiple Range Test. All comparisons were made at the 0.05 level of confidence.

RESULTS

Biomass

Averaged across both sites at the end of the third growing season, green ash was 1.2 inches dbh and 13.0 feet tall compared to 0.6 inches and 6.8 feet for swamp chestnut oak. Green ash had produced 7,342 pounds per acre of above-ground biomass, whereas the oaks had produced 3,572 pounds per acre.

The proportion of above-ground biomass in the tree components measured was very similar during the growing season regardless of species (table 1). Green ash, during the growing season, averaged 21 percent of its biomass in the leaves, 53 percent in the bole (wood plus bark), 22 percent in branches (wood plus bark), and 4 percent in new growth. Swamp chestnut oak had 24, 50, 21, and 5 percent in the same components. The proportions of the various components are shown during the dormant season for each species in table 1. Each component makes up a larger part of the total without the leaves, but again ratios are very similar for both species. The proportions of biomass contained in the various components remained relatively constant throughout the sampling period.

Nitrogen

Leaves of both species were at their highest N concentration in May. During the other months, green ash had lower concentrations[4/] in October than June (fig. 1). Concentrations for oak were higher in May than the last three months of the growing season. Sites did not differ. Averaged across sites, green ash contained 1.85% and oak 1.75% N in May. These values had declined to 1.16% and 1.29% respectively in October. All leaves had fallen by the November sampling date. During the growing season 21% of the green ash biomass and 55% of the N was in leaves. Swamp chestnut oak had 24% of its biomass and 58% of the N in leaves.

Bole wood and bark in both species started out with high N concentrations at the beginning of the growing season, decreased to their minimum value late in the growing season, and then increased during the dormant season (figs. 2 and 3). Branch wood for green ash on the ridge contained higher N concentrations than trees on the flat site. April concentration for green ash branch wood was greater than all other months. No trends were really discernible, with some growing season months not different from some dormant season months. Oaks had higher N concentrations in branch wood on the flat than on the ridge site. Months and the site by months interaction were significant. The trend appeared to be to start high in April, decrease to low values during the growing season and increase again during the dormant season. Branch bark for both species started with high N concentrations at the beginning of the growing season, decreased during the growing season, then increased during the dormant season--a trend similar to bole bark. Nitrogen concentrations

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4/ All differences discussed are significant at the 0.05 level.

Table 1.--Biomass and nutrient proportions in components of green ash and swamp chestnut oak trees

Component and species		Dry weight	N	P	K	Ca	Mg
			Percent with leaves (May-Oct.)				
Leaves	Green ash	21	55	46	49	34	47
	Oak	24	58	44	40	30	40
Bole wood	Green ash	43	16	24	18	8	14
	Oak	39	13	21	21	9	17
Bole bark	Green ash	10	14	10	16	31	20
	Oak	11	11	13	14	29	14
Branch wood	Green ash	14	5	7	5	5	4
	Oak	14	5	6	7	5	6
Branch bark	Green ash	8	7	6	7	15	10
	Oak	7	9	10	9	23	15
New growth	Green ash	4	4	8	6	6	6
	Oak	5	4	6	8	5	7
			Percent without leaves (Oct.-Apr.)				
Bole wood	Green ash	56	42	55	43	20	31
	Oak	52	33	38	30	15	21
Bole bark	Green ash	12	22	15	24	41	36
	Oak	16	26	21	27	42	30
Branch wood	Green ash	17	13	14	13	8	8
	Oak	18	13	14	12	6	9
Branch bark	Green ash	8	13	8	13	22	17
	Oak	9	21	17	23	28	30
New growth	Green ash	8	11	8	7	10	9
	Oak	6	7	11	11	7	10

were about two to three times higher in bark than wood (figs. 2 and 3). New growth in both species started with its highest N concentration in May, decreased in June, then decreased again but did not differ the remaining 9 months. Nitrogen was higher in oak on the flat than on the ridge site.

Because of space limitations and similar trends among many elements in the various tree components, only N, K, and Ca for leaves, bole wood, and bole bark are shown in the graphs. Other nutrients will be discussed and the similarities pointed out when appropriate.

Proportions of N contained in the various tree components are shown in table 1. Even though branches and boles accounted for a large proportion of the biomass, they contained small amounts of N compared to the leaves. These proportions changed after leaf fall.

Phosphorus

Foliar P levels for green ash did not differ during the growing season. For oak, May had higher concentrations than all other months, which did not differ among themselves. Trends in P for green ash bole wood were similar to that of N. Oak bole wood had significant differences between sites and months, as well as the site by months interaction. Trees on the flat site were higher in P than those on the ridge. Fluctuations from month to month made any trends hard to discern. Both green ash and oak had higher P concentrations in bole bark on the flat than ridge site. Green

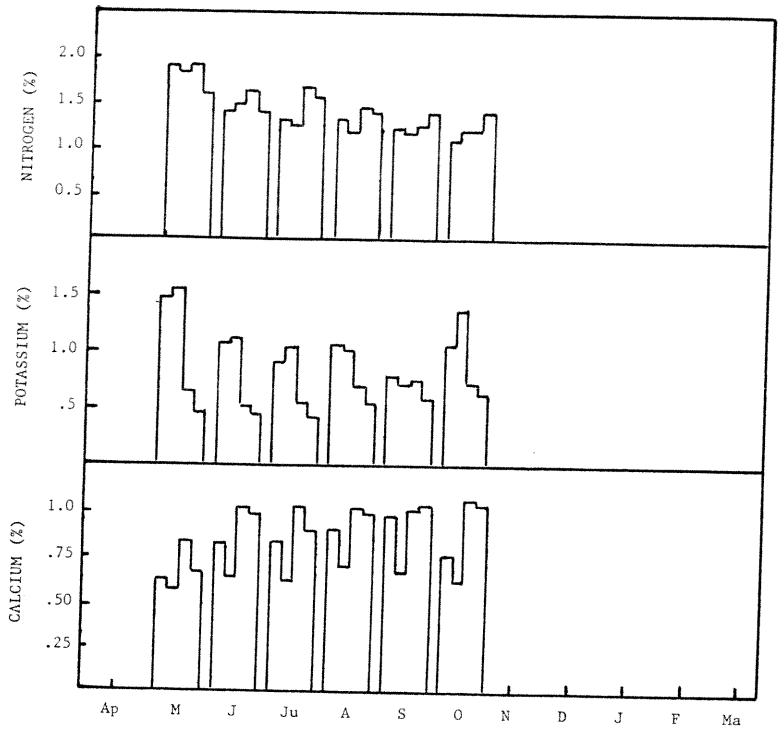

Figure 1.--Nitrogen, potassium, and calcium concentrations in green ash and oak leaves during the third year. First bar is GA ridge; second, GA flat; third, oak ridge; and fourth, oak flat.

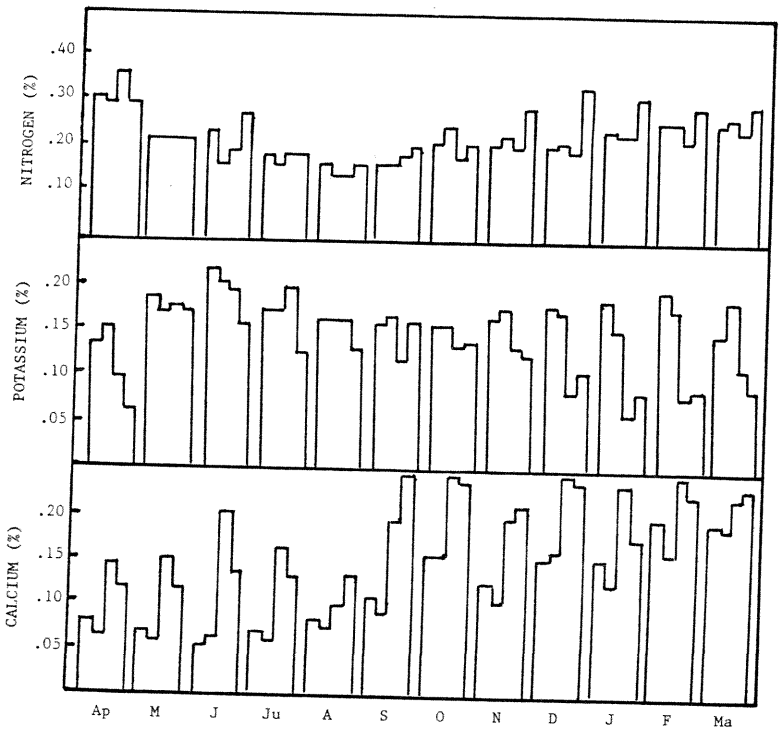

Figure 2.--Nitrogen, potassium, and calcium concentrations in green ash and oak bole wood during the third year. First bar is GA ridge; second, GA flat; third, oak ridge; and fourth, oak flat.

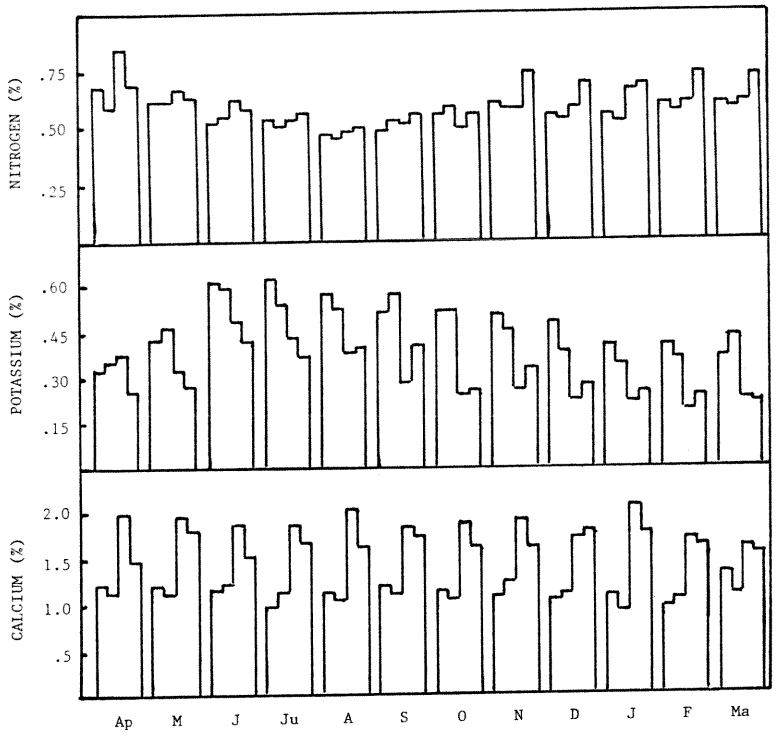

Figure 3.--Nitrogen, potassium, and calcium concentrations in green ash and oak bole bark during the third growing season. First bar is GA ridge; second, GA flat; third, oak ridge; and fourth, oak flat.

ash had higher P in April and June compared to January, but no trends could be discerned because of monthly variations. There was a significant site by months interaction for P in oak bole bark. The apparent trend was low P during the growing season followed by increased P during the dormant season.

P was also highest in branch wood of both species on the flat site. Monthly trends showed P in branch wood started high at the beginning of the growing season in green ash, decreased during the summer, then increased during the dormant season. Oaks had a significant site by months interaction. Trends appeared to be that oak on the ridge started out high in April, dropped rapidly in May and remained relatively stable the remainder of the year. On the flat, however, P concentrations were low during the growing season and increased during the dormant season.

Concentrations in branch bark in green ash started out high at the beginning of the growing season, then decreased through July, with a low from July into most of the dormant season. Again, there was a significant site by months interaction for P in oak branch bark. The trend, however, appeared to be that trees on the ridge and flat started out high at the beginning of the growing season, decreased in the growing season, and increased in the dormant season. The interaction appeared to be mainly from an extremely high value for the oak ridge site in April. There were no differences in P concentrations in new growth.

Leaves again contained the highest P levels, but in contrast to N, bole and branch wood and bark had similar P concentrations.

Leaves also contained a high proportion of the P found in trees (table 1), with other components having a much lower proportion.

Potassium

Foliar K levels for green ash were higher in May than all other months, which did not differ from each other (fig. 1). Oak on the other hand, had higher concentrations the last 2 months of the growing season than the first 3 months (fig. 1).

Concentrations in new growth of green ash decreased each month from May through August, with the remaining months having lower, but stable concentrations. Oak was maximum in May, decreased the next 2 months, then decreased again and remained stable the remainder of the year.

There were no differences in K concentrations in green ash bole wood (fig. 2). However, oak started low early in the growing season, maximized from May through October, then decreased during the dormant season (fig. 2). Ash and oak bole bark concentrations started out low, maximized during the mid- and late-growing season, then decreased during the dormant season (fig. 3). There were no differences in concentrations in ash and oak branch wood. Potassium in branch bark in green ash was greatest in June with no real trend

discernible during the year. Oak was similar to the green ash. Proportions of K in the various components with and without leaves are shown in table 1.

Calcium

Calcium concentrations in green ash foliage started at a low level in May, peaked in August and September, then decreased in October (fig. 1). Oak leaves, however, started low in May and increased during the summer to a high in October. Green ash and oak trees had higher Ca concentrations in new growth on the ridge than flat sites. No other differences occurred.

Calcium concentrations in ash bole wood on both sites started low at the beginning of the growing season, then increased in the late growing season until a maximum was reached during the dormant season (fig. 2). Calcium in bole wood of oak was low during the growing season, increased rapidly in September and October, then remained relatively stable during the dormant season. Branch wood of both species started out low, then increased in the late growing season and dormant period. Oak branch wood had higher concentrations on the ridge site. There were no significant differences in bole bark for either species (fig. 3), and branch bark for oaks during the sampling period. There were monthly differences in green ash branch bark, but no trend was discernible since 11 of the 12 months did not differ. Calcium in oak bole bark and branch bark was higher on the ridge site.

Proportions of Ca in the various components are shown in table 1. Leaves and bole bark contained a high proportion of Ca. After leaf fall, bole and branch bark and bole wood appeared to be major storage areas for this element. Calcium concentrations (fig. 2) indicate possible absorption through the roots and consequent storage in bole wood during the dormant season.

Magnesium

Magnesium levels in most components remained relatively stable throughout the sampling periods. Exceptions were in monthly Mg concentrations in ash new growth, bole bark, branch wood and bark, and oak branch bark. However, even in these components there were variations up and down, and definite trends were not discernible. Leaves again contained a high proportion of Mg when they were present (table 1). As with Ca, bole and branch bark and bole wood seemed to be the major storage components during the dormant season.

SUMMARY AND CONCLUSIONS

These data characterize biomass and nutrient concentrations and distribution in two hardwood species grown at 4- x 8-foot spacing over a 1-year period in the life of the plantation. Site, age, species, and stand density affect proportions of nutrients in individual parts by altering the distribution of the total biomass among tissues and perhaps affecting concentrations of nutrients in individual segments (Shoulders 1981).

After three growing seasons, green ash had produced 7,342 pounds per acre of above-ground dry matter compared to only 3,572 for swamp chestnut oak. Of the total biomass, ash averaged 53% in the bole (wood plus bark), 21% in leaves, 22% in old branches (wood plus bark), and 4% in new or current-year growth. Swamp chestnut oak had 50, 24, 21, and 5% in the same components. These proportions changed after leaf fall. Concentrations of N, P, K, and Mg followed the general order of leaves > current-year growth > bole and branch bark > bole and branch wood. Calcium was highest in bole and branch bark followed by leaves, current-year growth, and bole and branch wood. Foliage of ash accounted for 21% of the total biomass and contained 34-55% of the individual nutrients, while oak foliage comprised 24% of the biomass and contained 30-58% of the individual nutrients. Fifty-three percent of the total biomass and 47-51% of individual nutrients were in the bole of ash, while in oak the bole accounted for 50% of the biomass and 41-47% of the nutrients. These results are similar in trends and concentrations to those reported for different species by other researchers (Baker and Blackmon 1977, Carter and White 1971, Shoulders 1981, Shelton *et al.* 1981, Francis 1984).

Some elements, as shown by higher concentrations, probably were absorbed by roots and stored in stems and branches even when trees were in dormancy.

Because of the high concentration of individual elements contained in the leaves, any harvesting system that returns the leaves to the site would return a large proportion of the nutrients to the soil and thus contribute to maintenance of site quality.

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IS AERIAL IGNITION A PANACEA TO THE SOUTHERN PRESCRIBED BURNER?[1/]

R.W. JOHANSEN[2/]

Abstract.--Igniting prescribed burns from aircraft permits the forest manager to ignite large areas expeditiously and allows for rapid burnout. Because aircraft rentals, ferrying, and standby costs are high, these machines must be used efficiently to make their use economically feasible. Burning areas in excess of 500 acres usually allows per acre amortization of costs to a reasonable level, but smaller areas can be affordably burned only if several neighboring areas are done successively. Helitorches filled with gelled gasoline are best used for site preparation burning while the aerial ignition device (AID) system allows for better spot fire placement when underburning existing stands.

INTRODUCTION

Prescribed fire continues to play an important role in the management of many Southern forests, primarily for purposes of hazard reduction and undesirable species control. But one of the endemic problems of an extensive burning programs has been the limited number of suitable days for burning when winds remain steady, but not too high, for extended periods and temperatures remain below 60°F.

Before the use of aircraft in prescribed burnes, areas were usually ignited by men walking and stringing fire from drip torches. The rate of ignition was limited by the rate at which men could travel on foot and the number of internal lines constructed beforehand. Special care had to be exercised in the ignition patterns used so the torchmen would not be endangered by their own fires. The recent use of aircraft to ignite prescribed burns has had two effects:

1. The ignition process has been greatly accelerated, and
2. The type of ignition pattern used is not governed by considerations of personnel safety within the fired area. No one need be there.

Two types of aerial ignition systems are currently available for use: (1) the aerial ignition device (AID) that is a machine-dispensed plastic capsule containing an igniter chemical, and (2) the helitorch, which is a giant version of a hand-carried drip torch from which a flaming petroleum liquid is dispensed.

AERIAL IGNITION DEVICES

In the mid 1960's Australian foresters developed the first AID prototype by using powdered potassium permanganate in a cylindrical plastic capsule that would ignite upon the introduction of ethylene glycol solution (Packham and Peet 1967). The system

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2/Ragner W. Johansen, Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, Southern Forest Fire Laboratory, Macon Georgia

allowed for machine injection and dispensing of the activated capsules from fixed-wing aircraft and was used to prescribe burn thousands of acres of forest land daily.

Canadian foresters adopted the use of AIDs in the 1970's but changed the design of the igniter to a ping-pong ball-like capsule and redesigned the dispensing machine to handle this new capsule. These new AIDs are available to the public for purchases3/. Use of the AIDs requires no ground support to supply or operate the equipment, but a dispensing machine operator is needed in the aircraft. The system should only be used when the ground litter is entirely continuous because the plastic ball ignition area is not much greater than the ball itself. The main advantages to using AIDs are the complete control that is possible in placement of spot fires within an area and the lack of need for ground support personnel to service the machine. This ignition system is not recommended for igniting piled logging debris or broadcast debris areas where considerable fuel discontinuity exists.

The AID system is being used extensively throughout the South. The North Carolina Forest Service uses excess property military helicopters and AID machines, and offers a prescribed burning service at cost to forest landowners in the State. Landowners must make early application for prescribed burning services so the State personnel can plan the most efficient use of the proximate to each other. The Georgia Forestry commission also owns a machine they use to prescribe burn State Forest lands. The machine has also been used to burn Federal lands within Georgia. Weyerhaeuser Co. and Union Camp Corp., among others, also use AIDs to underburn their pine forests in the South.

HELITORCHES

Several prototypes of helitorches are being used operationally to ignite accumulations of natural undisturbed forest litter and logging debris, but only the Simplex torch, certified for use on National Forests, is commercially available to the public4/. The simplex torch is suspended below the helicopter on two cables, 13 and 16 feet long, that are attached to the craft's cargo hook. This allows for the immediate jettison of the torch in emergencies. A ground crew of four men is usually used with this operation. Only a two man crew is needed if a cart, recently designed by USDA Forest Service personnel, is used to move the fuel drums. Aircraft servicing is somewhat cumbersome because either the pilot must hover while fuel tanks are exchanged or the helitorch must be landed before the craft can land beside it.

The ignition fuel now used in all torches is gelled gasoline, made by mixing a proprietary product, Alumagel powder, with gasoline. The recommended proportions of powder to gasoline are 5 to 6 pounds per 25 gallons, but one operator uses only 3 to 4 pounds by mixing a day's supply several hours before use. Gasoline containing tetraethyl lead such as regular gasoline, thickens more quickly and uniformly than the unleaded product. A newer product called Surefire, available from Western Equipment Co. at about $4.00 per gallon, will thicken gasoline more rapidly at a concentration of only 2 pounds per 30 gallons.

The owner of Summerville Aviation, Inc., Summerville, South Carolina, has designed a helitorch that is mounted on his own helicopters for contract prescribed burning work. The aircraft is serviced by one ground-crew member who carries all needed supplies in a long-bed pickup truck. These aircraft operate from forest openings and woods road intersections. Replenishing torch fuel mix usually takes less than 2 minutes as a result of the pilot being able to land and take off in a normal configuration. Emergency landings, such as by autorotation, are also in normal configuration with the torch fuel igniter turned off.

Another aircraft leasing firm, Rotor Wing, Inc. Birmingham, Alabama; has designed and constructed a steel tubing frame in which the helitorch and torch fuel tank are fastened. The helicopter skids fit into metal channels on top of the frame which is held to the helicopter

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3/ Premo Plastics Engineering, Ltd., 863 Viewfield Road, Victoria, B.C., Canada.

4/Simplex Manufacturing Co., Portland, Oregon.

by cables attached to the plane's cargo hook. In case of in-flight emergencies, the frame can be immediately jettisoned from the aircraft by releasing the hook. In the operational mode, the bottom of the frame contacts the ground and supports the weight of the aircraft. The frame would not support the helicopter in an emergency autorotation landing. Currently one ground crewman is used to mix the gelled gasoline and service the aircraft from a pickup. The operation runs smoothly, although the gasoline is not always properly gelled by the time the helicopter returns for refueling... a not uncommon occurrence in mix-as-needed operations.

BURNING COSTS

Using helicopters to deliver ignitions from either AID machines or helitorches is expensive. The charge for leasing a four to five passenger helicopter such as the Bell 206 currently costs about $550 per day for standby plus $150 per hour for flying time. Smaller helicopters, such as the two place Hughes 500, cost approximately $350 for standby plus $100 per hour when flying. Fortunately, the smaller aircraft are adequate for performing the prescribed burning tasks. Per acre burning costs are minimized if the operation takes place on areas 1,000 acres or greater. Reasonable costs, averaging under $3 per acre, can also be realized on smaller areas (tracts) if several are proximately located to minimize ferry time and which can be burned during the same day.

There would be a definite advantage for the landowner to deal with aircraft operators who have had previous experience with aerial ignition, but in all cases there should be adequate ground control such that the operation can be halted if fire behavior becomes more intense than desired.

FIRE BEHAVIOR DIFFERENCES RESULTING FROM SPOT AND LINE IGNITIONS

That fire fronts behave differently depending on whether they are moving with, against, or flanking the prevailing wind direction is common knowledge among wildland fire fighters. There also is evidence that the spread rate of fires moving with the wind is greatly influenced by the length of the fire front.

Preliminary results from a fire behavior study involving, among others, simultaneous ignitions of a 4-chain line of heading fire proximate to a single spot fire indicate that within the first 10-min burning period the line of fire will have travel a distance 1.7 to 13.5 times farther downwind than the spot fire (table 1). This means that a series of spot fires ignited along a line would be expected to develope lower fire intensities along the ignition line than would an equal line of fire in the same, continuous understory fuel. Such information should be useful to prescribed burners who are considering using either a helitorch or AID machine.

INFLUENCES OF TREE SIZE AND BURNING SEASON

Young trees, frequently up to 3 inches d.b.h., are often stem girdled by heat when burned in wildfires. Most native pine species will not survive such treatment while the hardwoods will usually resprout from adventitious buds in the root collar or lateral roots. Young plantations have been successfully prescribed burned, but extreme care was exercised. Fuel loading must be light weight, and backing fire is usually used to minimize fireline intensity.

Trees with stems more than 5 inches d.b.h. are usually not damaged by heat exposure to the stem. Most mortality is due to heat kill at the cambium and buds in the tree crown. The taller the tree, the greater the fireline intensity the crown can with stand before damage occurs because heat dissipates with height (Davis and Martin 1960). Thus, prescription burns in the understory of a 30-foot stand must be undertaken with considerably more care and finesse than if the stand were double that height. The decision whether aerial ignition can be safely used to underburn depends not only on stand size but also on available fuel loading in the flaming front. The amount of fuel and rate at which it burns determines heat release rate, which is the key to judging the probable success of a burn.

In all cases where natural stands are being prescribed burned, aerial ignitions will result in higher fire intensities than if backing fires are

Table 1.--Spot fire and line fire downwind distances traveled during January 1984 for equivalent time periods in a 2-year palmentto-gallberry rough in Coastal Plain Georgia

Fire replication	Hour	Surface litter fuel moisture	Travel distance			
			Spot fire		Line fire	
			5 min	10 min	5 min	10 min
		Percent	Feet			
1	11:35 a.m.	37	--	14	34	105
2	2:50 p.m.	30	--	12	61	162
3	3:45 p.m.	32	58	139	89	242

used. The forest manager, therefore must first decide whether the understory in need of burning can tolerate anything other than a backing fire because of too young an overstory, too much fuel accumulation, or both. Only if crop trees can withstand the expected fireline intensity without excessive damage of aerial ignition.

LITTER MOISTURE EFFECTS ON FIRE SPREAD RATE

Estimates of changes in rate of fire spread due to changes in litter moisture in palmetto-gallberry fuel under a slash pine stand have been published by Hough, where he suggests that halving the litter moisture will cause an approximate 25 percent increase in fire spread rate at the head (Hough and Albini 1973).

Preliminary study information (table 1) shows that a line of fire burning across surface litter of 37 percent moisture content moves only at an average rate of 10.5 feet per minute. The author observed a backing fire would not sustain itself at this moisture content. When the surface litter moisture content was lowered to 30-32 percent, heading fire spread rate increased to 16-24 feet per minute and backing fires would progress in a continuous line. Spot fires ignited in the palmetto-gallberry type on a 2-chain square grid also respond differently to changes in litter moisture content. When surface litter moisture content was approximately 24 percent, the mean time needed to travel to its downwind neighbor was 13 minutes, but at a 30 percent moisture content the time increased to 20 minutes.

The prescribed burner should keep in mind that on days when dry air moves into an area and relative humidity drops to below 30 percent, the surface litter can change from a moisture content above 35 percent in the morning to well below 30 percent in the afternoon. As a result, fire behavior will also change sharply during the course of the day. The prescribed burner must remain cognizant of these changes and conduct burning in accordance with them.

SITE PREPARATION BURNING

In clearcut logged areas where debris has been either piled or allowed to remain broadcast before burning, the helitorch is ideally suited to do the job. The globs of burning gelled gasoline released from the torch are long-burning and adhere well to anything they touch. The penetration quality of this burning fuel is especially useful when dropped into debris that has been piled for it brings about rapid ignition. Rapid ignition allows for rapid burnout of an area, and any desired firing pattern can be used because no personnel need be inside the fire control lines.

CONCLUSIONS

There is no doubt, that the use of aerial ignition can, in many instances, be a panacea to the forest landowner who burns large tracts. This is especially true if logging debris is in need of disposal before regeneration can take place. Gelled gasoline dispensed from a helitorch is the best system conceived to date for the ignition of logging debris.

There is some question, however, whether aerial ignition techniques should even be used for the first burn in young pine stands or where heavy litter and fuel continuity into the overstory is evident. Very high fireline intensity buildups can

occur under these circumstances if extreme care is not used in selecting the proper burning conditions. The safest approach would be to use backing fire for the first burn and aerial ignition thereafter on a 2-to 3-year burning cycle.

Aerial ignition would not ordinarily be a panacea to the small forest landowner because standby aircraft costs could not be amortized over a large area, thus making per acre costs excessive. Only if State Forestry Commissions offered an aerial ignition prescribed burning service (thus, eliminating stand-by costs), or burning could be done in conjunction with a neighboring large landowner operation, could a small land-owner afford to use aerial ignition techniques.

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OAK REGENERATION BEGINS GROWTH EARLIER UNDER FOREST CANOPIES THAN IN CLEARCUTS[1/]

Charles E. McGee[2/]

Abstract.--Budbreak and leaf development were monitored on seedlings and saplings of northern red oak, white oak, black oak, post oak, scarlet oak, and chestnut oak growing under forest canopies and in open clearcuts. Oaks growing under canopies consistently broke bud and initiated leaf development earlier than those growing in clearcuts. The observed phenological patterns suggest that early leaf development, particularly for advance oak regeneration recently released by harvest, exposes saplings to adverse weather and may cause regeneration problems.

Problems with oak regeneration are widespread. Following harvest, oak stands are often replaced by stands containing fewer oaks or, occasionally, no oaks. While oak regeneration problems are not new, the current reporting of difficulties across a wide array of conditions and regions brings urgency to solving the problems. Unfortunately, there seems to be no immediate relief in sight. Since the reported difficulties cover a range of oak species and site conditions, it seems likely that there is no one cause and probably no common solution to the problems.

One source of regeneration problems may be the pheonological habits of oaks. Previous work has shown that potted northern red oak and scarlet oak growing in the shade will break buds and initiate leaf development sooner than those growing in the open (McGee 1975). When these potted oaks are removed from the shade during the dormant season, they will still begin growth earlier than those grown continually in the open. It made no difference if potted oaks were outplanted in the shade or in the open--those that had been grown in the shade began growth ahead of those that had been grown in the open (McGee 1976). A year later, during the second growing season, the oaks outplanted under a canopy began growth 17 days ahead of those outplanted in the open. Evidently, the annual initiation of growth in oaks is controlled by the presence or absence of a canopy the previous growing season rather than by the current condition. Seedlings that were released after growing for a year or more under a canopy began growth earlier than open-grown seedlings and were exposed to damage from cold weather. In these studies, temperatures in the open were found to be colder and the likelihood of frost substantially greater than under a canopy.

The purpose of the present study was to determine if naturally growing seedlings and saplings of six species of oaks had different patterns of budbreak and leaf development under canopies or in the open. This study also documents the effect of relatively small differences in topographic position on the time of budbreak.

METHODS

Four locations in Franklin County, Tennessee, within two miles of each other, were selected for study. Each location included a clearcut area and an adjacent mature hardwood forest. Plateau I and Plateau II were located on the Cumberland Plateau top at elevations of 1,950 feet, and Cove I and Cove II were located in sidehill coves on the Plateau escarpment at elevations of about 1,500 and 1,600 feet.

The clearcuts ranged in age from 3 to 7 years and contained a wide variety of species. The adjacent hardwood forests contained 70 to 110 square feet per acre basal area and provided a full canopy. Oak species in the understory of these forests varied by location

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Principal Silviculturist, USDA, Forest Service, Silviculture Laboratory, Sewanee, Tennessee, maintained by the Southern Forest Experiment Station, in cooperation with the University of the South.

As many as 10 healthy seedlings or saplings of each oak species available at each location under both canopy conditions were described, measured, and tagged. Periodic observation of the budbreak and leaf development of sample seedlings and saplings began in early March. After March 15, observations were made at least three times a week.

Observations made on each sapling included:

1. Date of bud elongation.
2. Date of first budbreak.
3. Date budbreak one-half completed.
4. Date budbreak completed.
5. Date leaves first visible.
6. Date leaf first fully expanded.

All observations on budbreak and leaf development were made with the unaided eye. Budbreak of oaks is easy to observe because breaking is characterized by the appearance of greenish or reddish material between the bud scales. Exact determination of the date of first leaf appearance and leaf expansion is somewhat more subjective, but errors in these observations are thought to be small.

The sample included 64 white oaks, 35 northern red oaks, 45 black oaks, 33 scarlet oaks, 34 chestnut oaks, and 22 post oaks. Of the total, 118 were in clearcuts and 115 were under the forest canopies. White oak was the only oak occurring in the open and in the shade at all locations. Northern red oak occurred only in the cove sites, and scarlet oak and post oak occurred only in the sites on top of the Plateau.

Most of the observed oaks were between 2 and 5 feet tall, but a few growing in the open exceeded 5 feet, and a few in the shade were less than 2 feet.

RESULTS

The presence or absence of a canopy and topographic position were found to be important factors in the initiation of spring growth (Table 1, Fig. 1). Shaded oaks began growth earlier and developed faster than those in the open. Similarly, oaks growing in the two cove sites began growth earlier than those on the two Plateau sites.

The first observed budbreak was on a white oak in the shaded portion of Cove II on March 28, and the last to show budbreak were a white oak and a black oak growing in the open on Plateau I on May 7. Thus the budbreak period covered 40 days.

Average dates of budbreak were calculated from the individual dates of budbreak by species and location for shade vs. open conditions (Fig. 1). In all cases where a comparison was possible, the average date of budbreak for shaded oaks preceded the average date for oaks in the open, ranging from 16 days for white oak in Cove II to 4 days for black oak in Plateau sites I and II. A few trees contradicted the trend when the first individuals to break bud in the open preceded the last individuals to break them in the shade (Table 1). The only extensive example of nonconformity was in Cove I where one open-grown northern red oak preceded by 5 days the last northern red oak to break bud in the shade.

In the shaded sites of Cove I and Cove II, the leaves of chestnut, white, and northern red oaks first appeared on April 15, 16, and 18, respectively, and in the open on April 22, 24, and 26, respectively. On the two Plateau sites, the pattern of leaf emergence was about the same but occurred 8 to 12 days later than in the coves.

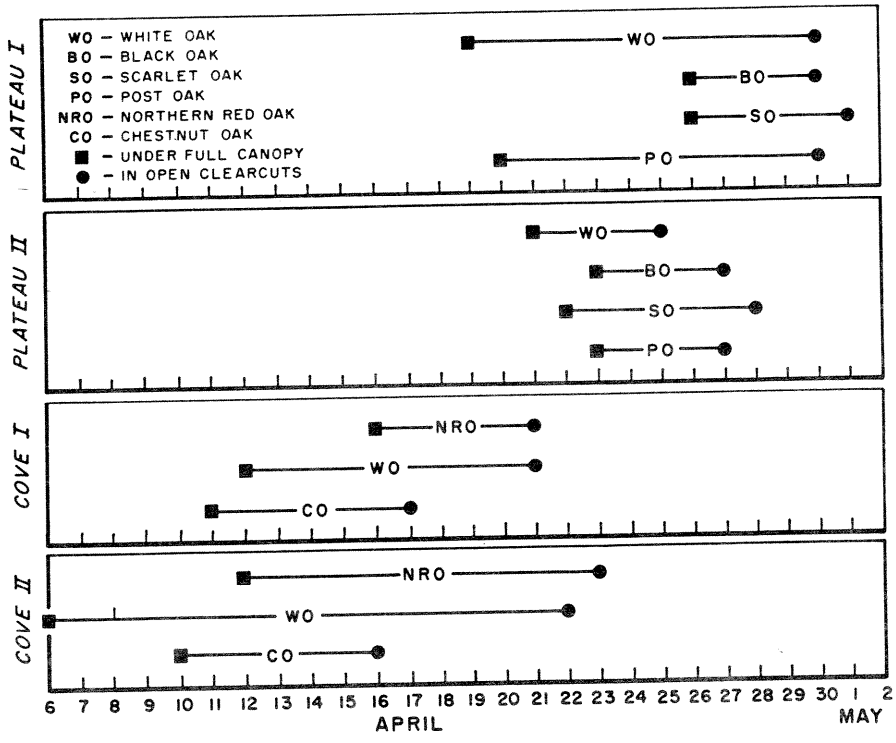
A light, scattered, and very late frost that occurred on May 31 had a visibly adverse effect on the open-grown oaks on the Plateau I site. Of the 38 sample oaks in this area, 18 were lightly damaged and 7 were moderately damaged. None received heavy frost damage, but neighboring hickory, blackgum, and sumac saplings were heavily damaged. None of the oaks or other species growing under the nearby hardwood forest were damaged. Usually, plants that leaf out the earliest are damaged most by frost and cold weather, but in the case of this very late frost, damage was greatest on those plants that leafed out last and had very young leaves.

DISCUSSION

This study provides further documentation that shaded oak seedlings and saplings begin budbreak substantially ahead of those growing in the open. Budbreak data also showed that oaks growing in sidehill coves on the Cumberland Plateau escarpment (Cove sites I and II) began growth earlier than those on Plateau sites I and II. The variable pattern of budbreak and leaf initiation helps to explain why some individual oaks as well as other plants are sometimes damaged by weather, while others growing nearby are not. Open-grown plants are exposed to warmer daytime temperatures and colder nighttime temperatures than shaded plants. Open-grown plants are also more likely to receive frost than those growing in an understory. Fortunately for tree growers, open-grown oak saplings begin growth later than shaded oaks, normally after temperatures have increased and danger from frost has diminished. However, if oaks that had been shaded by a canopy the previous year begin growth the growing season following canopy removal as though they were still in the shade, there is increased likelihood of weather damage to new growth. The average dates of first budbreak for shaded oaks were earlier than open-grown oaks by as much as 16 days. For example, shaded white oak in Cove II began growth on April 6. The average date of the last spring freeze is April 9, and 4 out of 5 years temperatures as low as 38°F occur after April 29. If the canopy is removed from the oaks in Cove II, and white oak budbreak occurs the following year about April 6, then exposed and tender buds will be subjected to a freeze 1 in every 2 years and to temperatures conducive to frost about 4 in every 5 years.

Table 1.--Range of dates of budbreak for oak seedlings and saplings

Species	Shade		Open	
	No. of samples	Dates of budbreak	No. of samples	Dates of budbreak
Plateau I				
White oak (*Quercus alba* L.)	10	4/13-4/23	10	4/27-5/7
Black oak (*Q. velutina* Lam.)	10	4/23-4/27	10	4/27-5/7
Scarlet oak (*Q. coccinea* Muenchh.)	9	4/20-4/27	10	4/30-5/4
Post oak (*Q. stellata* Wangenh.)	2	4/18-4/23	8	4/30
Plateau II				
White oak	10	4/18-4/23	8	4/23-4/27
Black oak	10	4/20-4/25	10	4/23-4/30
Scarlet oak	4	4/18-4/25	10	4/23-5/2
Post oak	7	4/18-4/25	5	4/23-5/4
Chestnut oak (*Q. prinus* L.)	None	---	4	4/18-4/23
Cove I				
White oak	10	4/9-4/16	10	4/16-4/23
Black oak	None	---	2	4/23-4/27
Chestnut oak	10	4/5-4/13	9	4/13-4/23
Northern red oak (*Q. rubra* L.)	10	4/13-4/23	10	4/18-4/25
Cove II				
White oak	3	3/28-4/11	3	4/20-4/23
Black oak	None	---	3	4/23
Chestnut oak	10	4/5-4/16	1	4/16
Northern red oak	10	4/11-4/16	5	4/20-4/27



These findings strongly suggest that phenological patterns are involved in the growth and development of oak regeneration and may in some cases be the partial cause of oak regeneration failure. Over the years, a number of studies of precommercial thinning in oak stands have reported failure of the oaks to increase in height immediately following release. The effect of shade and shade removal on the timing of budbreak may have played a role in the lack of height growth in released trees. Obviously, more study is needed to fully evaluate the theories and conclusions offered in this paper.

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RESPONSE OF SLASH PINES TO GRAZING FROM REGENERATION TO THE FIRST PULPWOOD THINNING[1/]

H. E. Grelen, H. A. Pearson, and R. E. Thill[2/]

Abstract.--Survival and growth of planted and seeded slash pine (*Pinus elliottii* Engelm.) on grazed forest range was compared with that of trees in ungrazed fenced exclosures. Measurements at age 18 indicated that height of planted trees was not affected by grazing, but heavily grazed plots had fewer trees/acre with larger d.b.h. than the ungrazed. Consequently, differences in volume were not significant. Seeded trees showed no significant effects of grazing.

INTRODUCTION

Millions of acres in the South had remained essentially treeless following clearcutting of old-growth longleaf pine (*Pinus palustris* Mill.) during the early 1900's. Annual burning kept upland hardwoods in check, favoring the growth of grasses and other forage plants. Much of the cutover land was abandoned by the timber companies, and open-range grazing became a way of life. Later attempts by companies to restore pines to these lands failed because of the frequent fires.

After World War II, the booming postwar economy demanded more lumber from southern pine lands, and forest management--including fire prevention--became more intensive. As pines regained dominance, forage production declined and cattlemen realized that they must fit their operations into timber management.

To help provide guidelines for this new era in southern forest grazing, a study was begun in 1960 on cutover land in Louisiana to evaluate the long-term reciprocal effects of managed yearlong grazing and slash pine regeneration. The study was recently concluded with the first pulpwood thinning at stand age 18. Survival and heights at age 5 were reported by Pearson and others (1971).

METHODS

Study Area

The study was on the Palustris Experimental Forest in central Louisiana. Annual precipitation averages 58 inches, and most of the soils are deep, medium textured, and moderately permeable. Topography varies from flat to rolling, with slopes of up to 10 percent.

When the study began in 1960, trees were mainly scattered pines (*Pinus* spp.) and oaks (*Quercus* spp.). Slender bluestem (*Schizachyrium tenerum* Nees), and pinehill bluestem (*S. scoparium* var. *divergens* (Hack.)) Gould, were the dominant herbaceous plant species. Cattle had grazed the clear-cut study area for many years, and frequent fires had maintained a prairielike landscape. In 1960, two range units averaging approximately 600 acres each were stocked with Brahman-crossbred range cattle at 26 and 13 acres per cow to attain light and heavy forage utilization.[3/] Forage production averaged about 2,000 lb/acre for the first 8 years, but began to decline in year 9 as the pine canopy closed. During the first 10 years of the study, stocking rates were constant and utilization averaged 35 percent in the lightly grazed unit and 57 percent in the heavily grazed unit (Pearson and Whitaker 1974). By tree age 15, forage production averaged about 500 pounds/acre.

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2/ Authors are Range Scientists, Southern Forest Experiment Station, Pineville, LA. 71360

3/ A third range unit stocked to provide moderate utilization was included, but the unit was thinned before final measurements were made. All three units were included in comparisons made at age 5 (Pearson and others 1971).

Beginning in year 11, and continuing through year 15, cattle numbers were decreased about 10 percent each year to maintain the desired utilization intensities.

Slash Pine Regeneration

In early 1960, 25 percent of each range unit was burned in preparation for regeneration. These burned areas were regenerated in 1961, two-thirds by planting and one-third by seeding. This burning and delayed regeneration were repeated through 1964, when pine regeneration was completed. The fresh burns attracted cattle, keeping them away from recently planted and seeded pines. This reduced damage to new pine seedlings while removing the herbaceous rough from the next year's regeneration areas.

On planted areas, 1-year-old nursery stock seedlings were planted 6 feet apart in 8-foot rows (908/acre). For seeding, 1 pound/acre of repellent-coated seed was sown with cyclone-type seeders.

After the final planting and seeding in 1964, burning was discontinued until 1966. From 1966 through 1969, each regenerated area was carefully burned using late-winter backfires, with planted pines being burned initially at age 5 and seeded stands at age 6. In 1970, each range unit was divided into three unfenced burning compartments and burned during late winter on a 3-year rotation throughout the remainder of the study.

Pine Stand Measurements

Immediately after the pines were seeded and planted, 0.1-acre plots were randomly established and fenced to determine seedling survival and growth without grazing. Three of the exclosures were located in the planted area and two in the seeded area of each range unit. Each exclosure was paired with a 0.1-acre plot open to grazing. Thus, five pairs of plots were established on each range unit in each of 4 years--a total of 20 pairs in each unit.

Pine survival was first tallied in May following planting or seeding, then in October of the same year, and again at the end of the second and fifth growing seasons. On planted plots, a 100-percent inventory was made; on seeded plots, pines were counted on 18 milacre quadrats on each plot until the fifth growing season, when trees per acre and heights were measured in a 100-percent inventory on all plots.

Final measurements of trees per acre, heights, and d.b.h. were made prior to thinning, when plot tree ages ranged from 16 to 22 years, with an average of 18 years. The 7-year span in prethinning measurements resulted from delays in the harvesting schedule. All prethinning-measurement tree ages are noted as 18 years.

Diameters were measured on all trees of each plot, and actual heights were determined for a representative number of trees within each diameter class; heights of the remainder were then estimated by regression. From trees per acre, height, and d.b.h. measurements, an expression of total stem volume[4/] was computed for final comparisons of grazing effects.

Differences in trees per acre, mortality, heights, d.b.h., and volume between grazed and ungrazed plots of the lightly and heavily grazed pastures were compared using a paired-plot "t" test at the 0.05 level of significance.

RESULTS AND DISCUSSION

Slash pine survival

At the first measurement, 4 months after planting, significantly fewer planted trees had survived on heavily grazed plots compared to paired ungrazed exclosures. Survival averaged 73 percent on heavily grazed planted plots and 84 percent on ungrazed plots (Table 1). However, survival on heavily grazed planted plots between May and October of the first year was not significantly different from that on ungrazed plots, nor were the differences significant for the intervals between subsequent measurements. Survival on lightly grazed planted plots was not significantly different from that on ungrazed plots at any time.

Initial densities on seeded plots averaged over 900 trees/acre on both grazed and ungrazed plots of both range units. At no time during the study did grazed and ungrazed seeded plots differ significantly in any measurement. Seeded grazed plots averaged 631 trees/acre and ungrazed plots averaged 676 trees/acre at the prethinning measurement. In 6 of the 15 seeded plot-pairs, the grazed plot actually exceeded the ungrazed in trees per acre.

Tree heights

Planted pines averaged 3.5 ft taller than seeded pines at age 5 and 3.0 ft taller at age 18 (Fig. 1). Thus, height growth of seeded trees between ages 5 and 18 was essentially equal to that of planted trees, both averaging about 37 feet for the 13 years. Differences between lightly or heavily grazed plots and ungrazed plots, either seeded or planted, were not significant at age 5 or at age 18.

[4/] Total stem volume is an estimate of the cubic-foot volume of stems from 6 inches above ground to the tip, outside bark; model from unpublished data of R. E. Lohrey, Southern Forest Experiment Station, Pineville, LA. 71360

Table 1.--Survival of planted slash pine under light and heavy grazing[1/]

Tree age	Paired plots: Ungrazed	Paired plots: Lightly graze	Paired plots: Ungrazed	Paired plots: Heavily graze
	--------Trees/acre (% survival in parentheses)---------			
At planting (1-year-old nursery stock)	908	908	908	908
4 months	821 (90)	811 (89)	761 (84)	660 (73)[2/]
1 year	741 (90)	714 (88)	711 (93)	615 (93)
2 years	725 (98)	653 (91)	691 (97)	565 (92)
5 years	697 (96)	618 (95)	683 (99)	559 (99)
18 years[3/]	464 (67)	459 (74)	427 (63)	325 (58)
Overall survival	(51)	(51)	(47)	(36)

1/ Percent survival (in parentheses) is based on live trees at the previous measurement.
2/ Survival on heavily grazed plots was significantly lower (P >0.05) than on paired ungrazed plots.
3/ Tree ages at final measurement ranged from 16 to 22 years and averaged 18 years.

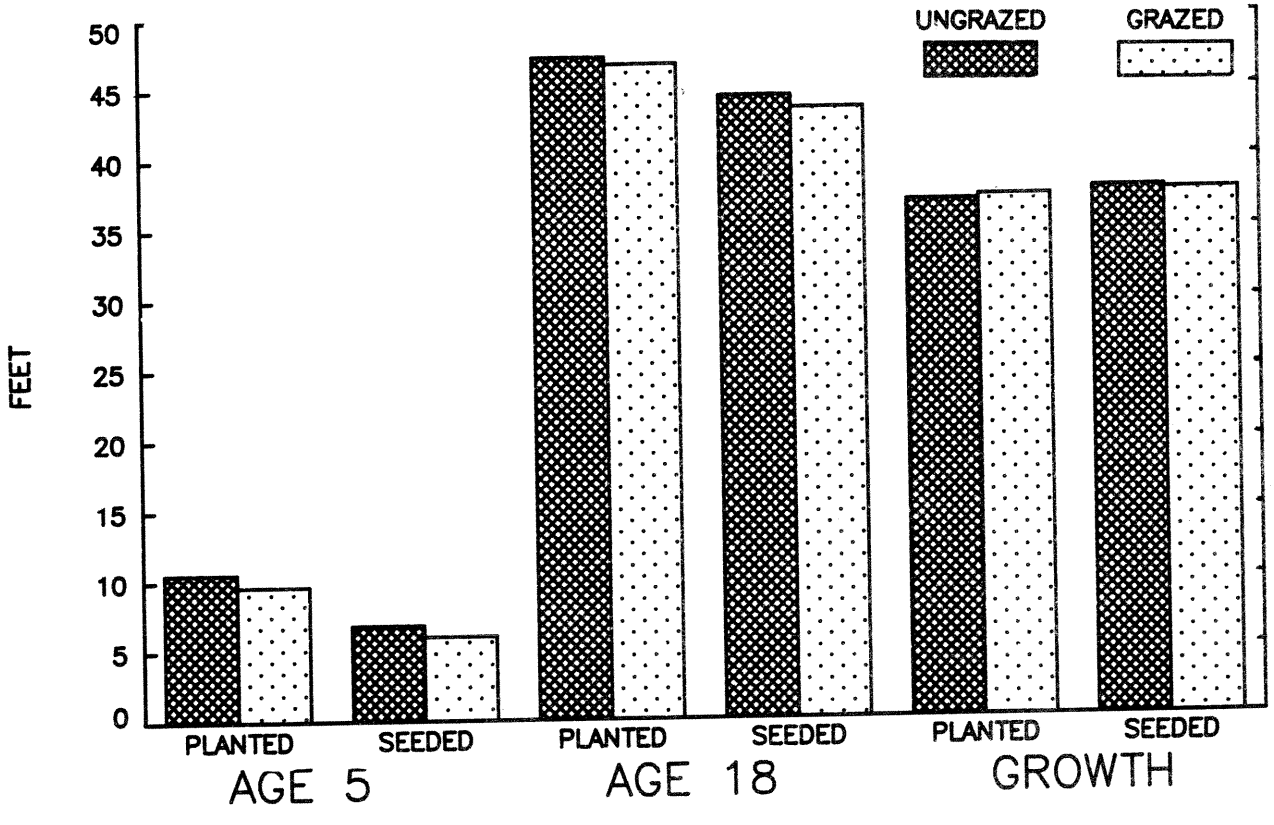

Figure 1.--Heights of slash pines at ages 5 and 18, and age-5 to -18 height growth.

Diameter and volume

Heavily grazed planted plots had significantly fewer trees per acre than ungrazed plots at the final measurement, but the trees that survived on these grazed plots were significantly larger in diameter than trees on ungrazed plots (Table 2). As commonly occurs following precommercial thinning (Bennett and Jones 1983), the larger diameters apparently compensated for the loss of trees. Differences in volume were not significant (Table 2).

CONCLUSIONS

Heavy grazing significantly reduced the density of planted seedlings by May of the first year following regeneration. However, subsequent mortality on grazed units was not significantly different from that on ungrazed units.

More than one-third of the heavily grazed seeded plots contained higher tree densities at age 18 than their matching ungrazed plots. Some of this variation was probably due to hotter fires in the heavier herbaceous fuel accumulations within the exclosures.

By age 5, average tree densities on heavily grazed planted plots exceeded 500 trees/acre, well above the minimum stocking for slash pine stands scheduled for sawtimber rotations (Bennett 1969). The lack of a significant difference in volume between heavily grazed and ungrazed plots at age 18, accompanied by significantly larger diameters on grazed plots, indicates that faster growth of the surviving trees compensated for the trees initially lost to heavy grazing.

Although the average height of seeded trees was about 3 feet less than planted trees, actual height growth was about the same. Likewise, total volume was similar for seeded and planted plots even though a greater number of stems occurred on seeded plots.

Table 2.--Measurements on paired grazed and ungrazed plots in planted and seeded slash pine at age 18 1/

Treatment	Density	Height	D.b.h.	Volume
	trees/acre	feet	inches	ft^3/acre
Planted				
Ungrazed	464	47.0	6.4	2917
Lightly graze	459	45.7	6.2	2900
Ungrazed	427* 2/	47.5	6.7*	2718
Heavily graze	325*	47.7	7.5*	2453
Average	419	47.0	6.7	2747
Seeded				
Ungrazed	567	43.6	5.7	2189
Lightly graze	580	42.9	5.5	2492
Ungrazed	786	45.3	5.5	3382
Heavily graze	682	44.1	5.4	2951
Average	654	44.0	5.5	2754

1/ Average age prior to thinning; ages ranged from 16 to 22 years.
2/ Within-columns differences between values marked with asterisks were significant at the 0.05 level.

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ENVIRONMENTAL EFFECTS OF SILVICULTURE IN PINE FLATWOODS

H. RIEKERK and L. V. KORHNAK [1/]

Abstract. A series of watersheds and plots were established to evaluate the environmental effects of a range of silvicultural practices in the Lower Coastal Plain of Florida. The results showed significant, but short term, changes in stormflow, water yield, and water quality even after highly intensive harvesting and site preparation. Soil moisture in high-density fuelwood plantations was reduced some because of rainfall interception. Suspended sediments, pH, and cation levels increased in association with stormflow. Nutrient losses were proportional to harvesting intensity suggesting longterm site degradation. Soil amendment with coal-ash, for fuelwood production neutralized the normally acid soil and runoff.

INTRODUCTION

Management of the southeastern pine forest is rapidly developing toward the intensity of agricultural land use. Harvesting of relatively young plantations for pulpwood and for fuelwood chips has increased the nutrient drain from forest lands (Neary el al., 1984). Site preparation is intensive and includes the removal or burning of slash, disking or bedding of surface soil, fertilizer and herbicide use, and relatively close spacing of genetically improved seedlings. Utilization of waste materials to supplement fertilizers for soil amendment is becoming an attractive alternative to waste disposal (Sopper et al., 1982). All of these operations have significant environmental effects on the water regime, water quality, and nutrient balance of a forested tract.

Little quantitative information about the environmental effects of these intensive silvicultural practices is available for the poorly-drained landscape of the Lower Coastal Plain. Concern about the lack of such data resulted in a cooperative and discipline-integrated study at the University of Florida that began in 1976 (Swindel et al., 1983). This study in combination with other research focused on the environmental effects of silvicultural practices was described in the first Biennial Southern Silvicultural Research Conference (Riekerk et al., 1984). The present paper updates the research information from these combined studies through 1983.

PROCEDURES

The focus of the research effort was a set of five watersheds constructed in the pine flatwoods of north-central Florida (Riekerk et al., 1982). The watersheds were isolated by roads and ditches and were instrumented with recording flumes, water table recorders, and a weather station and raingauge network. Rain was sampled by a wet/dry fall collector and analyzed by the National Atmospheric Deposition Program (NADP). Runoff was automatically sampled every four hours for weekly collection, and analyzed by standard laboratory procedures at the University of Florida (Riekerk et al., 1979). Soil and vegetation mapping, sampling, and analysis were performed by other researchers of the interdisciplinary team (Swindel et al., 1982; Morris and Pritchett, 1982).

The watersheds were harvested, site prepared, and planted after one year of pre-treatment calibration according to the following research design. One watershed, containing a 66 ha cypress (Taxodium distichum) pond (WS 3, 140 ha), remained as an undisturbed control. One

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Associate Professor and Forester III, respectively, School of Forest Resources and Conservation, University of Florida, Gainesville, FL.

Table 1. Bradford Forest Watershed precipitation and runoff

	Precip.	Control	Pulpwood Min.Prep.	Pulpwood Max.Prep.	Whole-tree Med.Prep.	Whole-tree Max.Prep.
	cm/yr					
1978	154.2	58.3	61.7	65.2		
1979	126.2	5.4	10.7	20.6		
Predicted[1]	---	---	4.3	5.0		
% Change	---	---	149	312		
1980	126.1	19.3	16.7	17.5		
Predicted[1]	---	---	19.1	20.6		
% Change	---	---	-13	-15		
1981	86.6	0.1	0.9	3.1	1.4	0.6
Predicted[1]	---	---	0	0	---	---
% Change	---	---	---	---	---	---
1982	183.6	19.2	13.4	8.7	18.7	14.3
Predicted[1]	---	---	18.3	20.2	---	---
% Change	---	---	-27	-57	---	---
1983	163.6	45.3	34.7	55.4	35.7	25.0
Predicted[1]	---	---	47.1	50.1	---	---
% Change	---	---	-26	11	---	---

[1]Predicted from pre-treatment calibration regressions with the control.

study described above. The groundwater seepage rates of Table 2 were calculated for watersheds WS 4 and WS 5 since, lacking pond storage, they best approximated the conditions of the lysimeter. The average recharge rate thus calculated was about 18% of incoming precipitation. The higher values found for 1982 may reflect soil moisture recharge after the drought period. The average recharge rate was much more than the 3% calculated earlier for the large watersheds (WS 1, WS 2 and WS 3) based on analyses of hydraulic gradients across the underlying clay layer (Riekerk et al., 1979).

Table 2. Water balances for WS 4 and WS 5.

		Rain fall	Run off	Evap trans	Ground water	GW
		cm/yr				%
1981	WS 4	90	1.4	77	11.6	13
	WS 5	90	0.6	77	12.4	14
1982	WS 4	184	18.7	111	54.3	30
	WS 5	184	14.3	111	58.7	32
1983	WS 4	162	35.7	118	8.3	5
	WS 5	162	25.0	118	19.0	12

High-density fuelwood plantations reach crown closure sooner than standard pulpwood plantations of the same age, and may intercept more rainfall. However, the data from the plot studies of several tree species throughout Florida did not clearly show different moisture regimes due to the plantting density at early stages of growth (Table 3). Soil moisture under the very high density plantations was less in the subsoil of all plots but only significantly so for slash pine in north-central Florida and Eucalyptus grandis in south-west Florida. The pre-dawn moisture potential measured in foliage of the very high density plantation of slash pine during the summer of 1981 also showed significantly more stress at -0.21 mPa as compared to -0.15 mPa in foliage of the adjacent Eucalyptus viminalis. The moisture stress of both species was significantly less in the lower density plantations at -0.15 mPa for slash pine and -0.10 mPa for Eucalyptus viminalis (Hendrickson, 1983). Rainfall interception by the two high-density slash pine canopies did not differ and averaged 38% of rainfall during the summer of 1983 while that of a nearby 17-year old pulpwood plantation was about 15% (unpublished data). Interception by the dense foliage of the nearby Casuarina plantation on ash-treated soil was 34% of rainfall.

watershed with a shallow 27 ha cypress pond (WS 1, 67 ha) was harvested for pulpwood and site prepared with little disturbance, and one watershed with two small 6 ha cypress ponds (WS 2, 49 ha) was harvested for pulpwood and site prepared with high disturbance. Two years later a new, smaller watershed (WS 4, 3.8 ha) was harvested for whole-tree utilization and site prepared with little disturbance, and another watershed (WS 5, 4.2 ha) was harvested for total-tree utilization (including stumps) and site prepared with high disturbance (Riekerk and Gain, 1982). All units were planted to slash pine (Pinus elliottii) except for WS 5, which was planted to Eucalyptus viminalis. The treatment effects on runoff have been evaluated comparing annual regressions of runoff data from paired watersheds (Swindel and Douglass, 1984). Unfortunately, similar regressions for the water quality data showed very poor correlations and annual t-tests of paired data sets were used instead.

Additional studies were focused on 10x10 m plots to evaluate the environmental effects of high-density fuelwood plantations and of waste recycling. Sand pine (Pinus clausa), in northwest, slash pine and Eucalyptus viminalis in north-central, and Eucalyptus grandis in southwest Florida were planted in high density (1.0x1.5 m) and very high density (1.0x0.5 m) plots to evaluate water regimes (Hendrickson, 1983). A small watershed (WS 7, 0.28 ha) in north-central Florida was treated with 127 Mg/ha of unweathered coal-ash and planted to Australian pine (Casuarina cunninghamiana) and Eucalyptus viminalis at (1.0x2.0 m) spacing. Comparisons were made with the untreated control (WS 8, 0.06 ha) with respect to growth response and runoff water quality (Riekerk and Korhnak, 1984). A 3.0 m diameter and 1.2 m deep weighing lysimeter was constructed in a young slash pine plantation next to a weather station in north-central Florida to measure the ratio of actual evapotranspiration to potential evapotranspiration during stand development (Riekerk, 1984).

RESULTS and DISCUSSION

Water regimes

The effects of silvicultural practices on the water regimes of the three large watersheds (WS 1, WS 2, WS 3) depended on the severity of the silvicultural treatments. Pulpwood harvest of the forest stand resulted immediately in a significant rise of the water table, even without much rainfall during the fall season (Figure 1). The treatment effect was due to the removal of transpiring and intercepting tree canopies and was more pronounced when water tables were low.

Increased soil moisture and rising water tables caused excess water to run off in proportion to harvesting intensity (Table 1). The

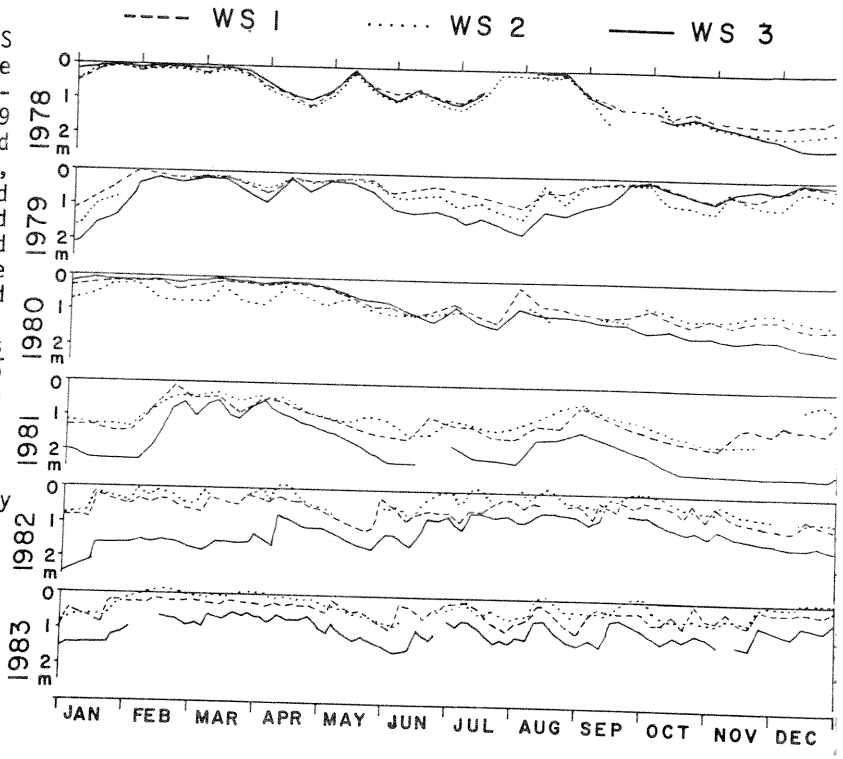

Figure 1. Groundwater table fluctuations.

low disturbance pulpwood treatment (WS 1) had 59% of the forest cover removed (excluding the cypress pond), which increased runoff 0.11 cm for each percent of forest cover removed. The high disturbance pulpwood treatment (WS 2) had 74% of the forest removed and showed a runoff increase of 0.21 cm for each percent of forest cover removed. These increases were similar to those reported for south-facing upland hardwood forests in the eastern United States, but did not last as long (Douglass, 1983). The ground vegetation recovered very rapidly, especially when disturbance was minimal, and quickly established normal evapotranspiration. Analyses of stormflow and peakflow data after these treatments suggested that windrowing on the highly disturbed watershed facilitated more rapid surface runoff (Neary et al., 1982). The treatment effects on water yield and stormflow from the smaller watersheds (WS 4 and WS 5) were not evaluated because the drought produced poor pre-treatment calibration data and caused the plantations to fail.

The groundwater recharge rate in these pine flatwoods, underlain by a discontinuous clay layer, was estimated by difference from the water balance equation:
Rainfall = Runoff + Evapotranspiration + Seepage.
Rainfall and runoff were measured, and actual evapotranspiration (ET) was estimated from potential evapotranspiration (PET) with monthly "ET/PET crop coefficients" (Gray, 1970). These monthly coefficients were derived from the evapotranspiration data of the weighing lysimeter

Table 3. Average volumetric soil moisture content in high-density tree plantations in Florida (Hendrickson, 1983).

	Soil depth m	Spacing 1x1.5 m	Spacing 1x0.5 m	Spacing 1x1.5 m	Spacing 1x0.5 m
		percent			
Northwest Florida					
Pinus clausa		2/27/80 - 3/20/81		3/20/81 - 10/22/82	
	0.3	4.2	4.3	4.4	4.3
	1.0	4.4	4.4	4.5	4.4
North central Florida					
Pinus elliottii				5/12/81 - 9/3/81	
	0.2	---	---	11.4	10.2
	0.4	---	---	21.3	18.2
	0.6	---	---	28.0	25.0 [1]
Eucalyptus viminalis				5/12/81 - 9/3/81	
	0.2	---	---	10.9	---
	0.4	---	---	17.3	16.5
	0.6	---	---	26.7	25.4
Southwest Florida					
Eucalyptus grandis		4/24/80 - 3/3/81		3/3/81 - 3/25/82	
	0.3	10.8	9.9	6.1	7.0
	0.6	17.8	16.5 [2]	9.4	7.2 [1]
	0.9	26.7	25.9	18.8	14.2

[1] Significant at 5% level; [2] significant at 1% level.

In summary, the effects of the various silvicultural treatments on the water regimes were predictable in that increases of first-year runoff, here induced by higher water tables, were in portion to the degree of forest removal. The short duration of these effects reflected the rapid recovery of ground vegetation. Stormflow and peakflow increases were associated with more overland flow across smoother soil surfaces after windrowing. Soil moisture at deeper depths and foliar moisture potentials reflected drier soils due to more rainfall interception by the canopies of high-density plantations.

Water quality

The drought that occurred during the study period also affected the reference water quality regime of the watersheds. The data from the undisturbed control watershed (WS 3) in Figure 2 show large variations in suspended sediments, nitrate nitrogen, and calcium in association with the drought cycle beginning in 1979 and ending in 1982. The extreme case was the very high nitrate nitrogen recorded for a few of the samples during 1981. This effect was probably due to rapid aerobic decomposition of bottom muck exposed in the large cypress pond during the drought period (Tate and Terry, 1981).

The high disturbance pulpwood treatment caused a significant pH increase in runoff during the treatment year of 1979. Such pH increases after harvesting and site preparation in poorly drained sites have been noted by others (e. g. Fisher, 1981). The mechanisms may have been a simple dilution of a fixed hydrogen-ion pool in the watershed by the excess water, and/or hydrogen-ion exchange with cations. A similar effect in the high disturbance total-tree treatment watershed (WS 5) was not apparent during the drought year of 1981, but showed up after rewetting of the site during the following year. Suspended sediment production during the pretreatment calibration year was high mostly because of boundary road grading. This effect was alleviated by sloping the road surfaces outward and leaving the interior boundary ditches undisturbed. The treatment effects on suspended sediment levels appeared to be proportional to site disturbance with the high disturbance pulpwood treatment becoming significantly different from the control. The relatively high sediment levels during the drought year were due to some very turbid samples that probably were stirred up by wildlife in standing water of the sediment traps.

High variability of the generally low levels of nitrate nitrogen precluded any statistical significance due to treatments in these poorly-drained flatwoods. However, soil solution data collected simultaneously showed significant increases due to more mineralization after treatment, suggesting rapid uptake and/or denitrification (Morris and Prichett, 1982). Ammonium nitrogen showed similar patterns in soil solutions and runoff from these watersheds (unpublished data). Low level, but significant, increases of nitrate nitrogen in runoff from a wet savanna site after standard silvicultural treatment in Florida

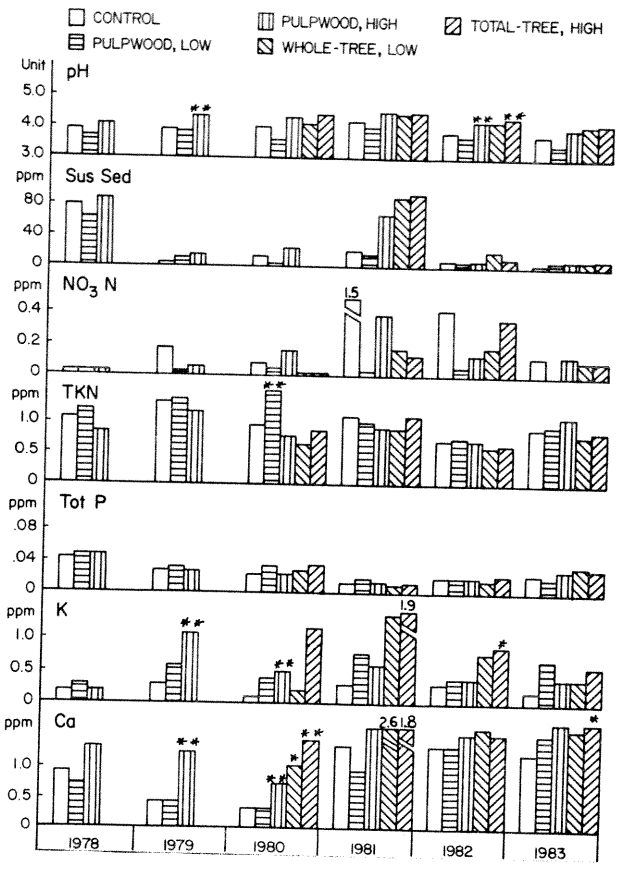

Figure 2. Runoff water quality.

in Florida was reported by Fisher (1981). Total nitrogen in runoff as determined by the Kjeldahl method showed little variation. Significantly higher levels were found in runoff from the low disturbance pulpwood watershed during the pre-treatment calibration year and the year after treatment. It is not clear why the total nitrogen concentration from this watershed was initially different and its response to treatment was delayed.

Total phosphorus and ortho-phosphate (unpublished data) concentrations in runoff were not affected by the treatments or drought conditions. Soil solution monitoring also showed no treatment effects on ortho-phosphate concentrations (Morris and Pritchett, 1982). These observations suggest that ortho-phosphate release into runoff was regulated by soil moisture content.

A significant effect was found for potassium concentrations in runoff in proportion to applied treatment intensity. Furthermore, the high levels of potassium in runoff from the smaller watersheds after whole-tree (WS 4) and total-tree (WS 5) harvests suggested a large contribution due to more intensive harvesting in addition to the effect of soil disturbance by site preparation. The effect of the treatments on calcium levels in runoff was different from those of potassium in that only the high disturbance site preparation treatment, which included windrowing, showed a significant increase. The high calcium levels in runoff from the two smaller whole-tree and total-tree watersheds during the 1980 calibration year were probably a carry-over from the boundary ditches of installation.

From these observations of soil solution and runoff water quality responses it may be concluded that the treatment effects for nitrogen species were mostly associated with biological soil decomposition and uptake processes, and those for phosphorus were associated with soil moisture content. In contrast, the suspended sediment, pH, potassium, and calcium data suggested more of a washout of surface materials by the overland portion of the significantly increased stormflow runoff. In addition, potassium and calcium cations in runoff may have been exchanged from the soil complex by hydrogen ions. All effects were of relatively short duration.

Nutrient balances

Estimates of annual watershed nutrient input and export can be calculated from the rainfall, runoff, and water quality data (Figure 3). The apparent association with the drought cycle showed that the magnitude of these fluxes was mainly dependent on the annual water flows. It was impossible to assign statistical significance but it appears that the only real treatment effects were for potassium and calcium export during the first year. Whether the relatively high nitrogen export after the high disturbance pulpwood treatment was significant is not clear without good pre-treatment calibration. Similarly, the treatment effects of the whole- tree and total-tree harvested water-sheds cannot be demonstrated conclusively.

Comparison of the annual export by runoff with input by rainfall (wet only) showed a conservation of nitrogen and phosphorus also documented for many other watershed nutrient budgets (Likens and Bormann, 1975). However, in contrast to data from most upland watershed studies, the input and output of potassium and calcium from the flatwoods watersheds were nearly bal-anced. This confirmed earlier observations of low nutrient input by mineral weathering in these acid-leached sandy surface soils (Pritchett, 1980).

Therefore, any additional export from the watersheds in the form of whole-tree biomass chips could create a negative nutrient balance, resulting in some longterm loss of site productivity (Riekerk, 1984; Neary et al., 1984).

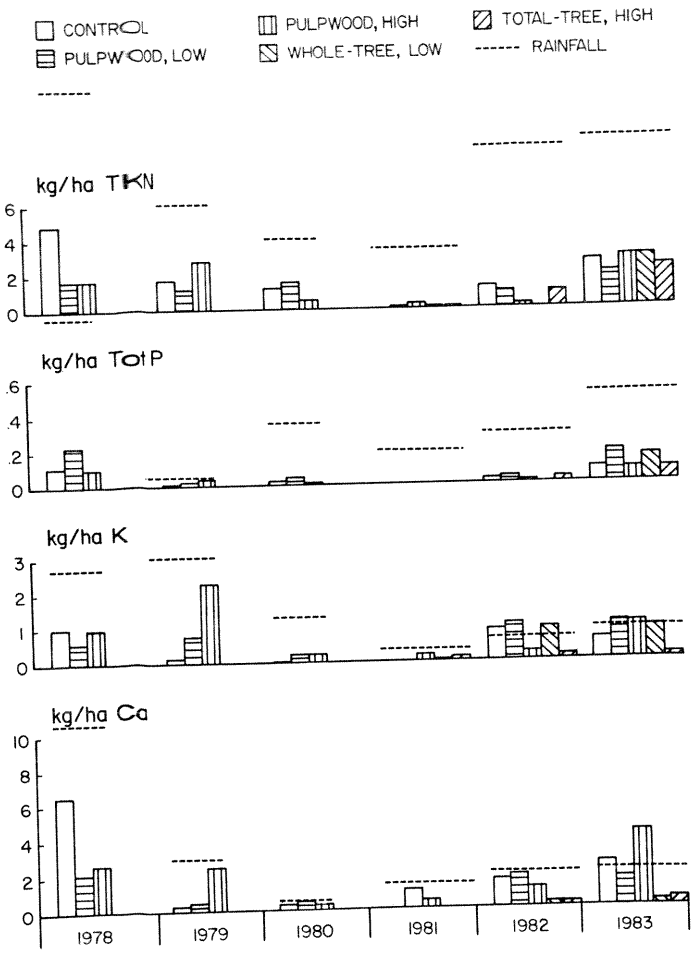

Figure 3. Rainfall input and runoff export of nutrients.

Waste utilization

Longterm reduction of site productivity from excessive nutrient drain could be reduced or even reversed by soil amelioration with commercial fertilizers or waste products (Smith and Evans, 1979). Watershed studies of the environmental effects of forest fertilization have been initiated in a new slash pine plantation on flatwoods soil in north-central Florida, but no data are yet available. Plot studies of the environmental effects of municipal garbage, sewage, and industrial pulpmill sludge utilization in pine flatwoods of Florida have shown increased nutrient and heavy metal levels in the surface soil and its solutions, but little deep loss from the study sites (Fiskell and Pritchett, 1979; Comerford and Fiskell, 1983; Neary and Comerford, 1984). No watershed studies have been conducted to evaluate the overall environmental effects of sewage utilization in pine flatwoods. Utilization of coal-ash as a soil amendment for woody biomass production on acid flatwoods soil was evaluated on a pair of very small water-sheds (Riekerk and Korhnak, 1984). The Australian pine plantation responded well with a seven-fold yield increase to the coal-ash treatment after three years, while the Eucalyptus viminalis showed no improvement. However, a severe freeze terminated the experiment prematurely. Runoff water monitoring showed a significant increase of base cation levels, causing the pH to rise by about two units during the three years of observation (Table 4). Ammonium-nitrogen levels in runoff were decreased during the first year, suggesting rapid uptake by the vigorously growing trees. The ortho-phosphate levels in runoff increased after the ash treatment, which may be of concern for downstream eutrophication. None of the heavy metal levels increased significantly, but zinc showed somewhat higher levels in runoff from the treated watershed.

CONCLUSIONS

The information from the range of experimental treatments showed short term changes in runoff flow and water quality by low and high disturbance pulpwood silviculture, but suggested long-term site changes for high disturbance whole-tree harvesting and for waste utilization.

Canopy removal raised water tables and increased first-year runoff at rates similar to those for more northern upland forests on south facing slopes, which reflected the high solar input in Florida. Increased stand density only slightly reduced subsoil moisture and increased foliar moisture stress during the early growth stages of some species in north-central Florida. This may have resulted from significantly greater rainfall interception by the dense canopies.

It appeared that suspended sediments, pH, and cation nutrients in runoff were increased proportional to site disturbance. Increased surface stormflow from the windrowed pine lands accounted for most of this. Increased biomass removal by whole-tree chipping could create significant nutrient depletion requiring periodic soil amendments to maintain site productivity. Soil amendment with coal-ash neutralized the acid flatwoods soil and runoff, and released more phosphorus.

Table 4. Average annual runoff water quality from coal-ash treated flatwoods soil (Riekerk and Korhnak, 1984).

		Time and treatment					
		1981		1982		1983	
		Ash	Control	Ash	Control	Ash	Control
Acidity	pH:	6.1	4.3	6.4[2]	4.3	5.2[2]	3.8
Ammonium-N	ppm:	0.12	0.20[1]	0.09	0.20	0.07	0.05
Nitrate-N	ppm:	0.10	0.06	0.05	0.03	0.02	0.02
Kjeldahl-N	ppm:	0.72	0.69	0.72	0.71	1.00	0.95
Phosphate-P	ppm:	0.014[2]	0.010	0.020	0.017	0.014[2]	0.006
Total-P	ppm:	0.024[2]	0.014	0.030	0.025	0.050	0.024
Potassium	ppm:	3.0	1.0	3.2[2]	0.7	2.2[2]	1.0
Calcium	ppm:	26.1[1]	1.8	27.4[2]	1.1	18.1[2]	2.0
Magnesium	ppm:	2.4	1.4	4.2[2]	1.7	3.9[2]	1.9
Iron	ppm:	0.22	0.16	0.15	0.14	0.24	0.14
Aluminum	ppm:	0.17	0.50	0.01	0.06	0.13	0.12
Copper	ppm:	0.005	0.003	0.003	0.002	0.004	0.005
Zinc	ppm:	0.035	0.014	0.130	----	0.292	0.077
Susp. Sed	ppm:	----	----	29.2	30.2	11.1	9.7

[1] Significant at 5% level; [2] Significant at 1% level.

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WATER QUALITY CHANGES ASSOCIATED WITH FOREST DRAINAGE AND PINE PLANTATION ESTABLISHMENT[1/]

by

Thomas M. Williams and George R. Askew[2/]

Abstract.--Concentrations of several dissolved constituents were measured in stormflow water draining from a 2,300 ha interstream divide in coastal South Carolina. This area contained several subwatersheds which represented phases of drainage and pine plantation establishment from an untreated hardwood area to a 15 year-old pine plantation. Samples were collected from the rising and falling stages of one stormflow event of each month between January 1981 and December 1982. One liter grab samples were taken for pH, O_2, NO_3-N, SO_4, Ca, Mg, K and suspended sediment. Intalllation of new drainage produced significant increases in suspended sediment, NO_3-N, SO_4, Ca, and Mg concentrations. A young pine plantation, however, produced waters with concentration of hydrogen ion, NO_3-N, SO_4 and Mg significantly less than the untreated hardwood stand.

INTRODUCTION

Much of the commercial forest land of the Atlantic coastal plain is on soils with high water tables. One major class of high water table soils is located near the center of broad interstream divides. Buol (1978) showed that soils near the center of such divides have very poor drainage. Surface drainage systems have not developed in these young marine sediments and groundwater flow is insufficient to remove rainfall. Campbell and Hughes (1981) outlined drainage methods which have increased pine growth rates on these sites.

Water quality impact of forest drainage and intensive management has been addressed by only Hollis et al. (1978) in western Florida. Often forest drainage has been lumped into a broad category with agricultural drainage which has resulted in concerns that may be inappropriate to forestry. For example, pesticide and fertilizer runoff are viable concerns of agriculture but are of minor importance in forestry. This study was intended to determine which aspects of the drainage and site preparation sequence had direct impacts on water quality.

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[2/] Associate and Assistant Professors of Forestry respectively, Belle W. Baruch Forest Science Institute of Clemson University, P. O. Box 596, Georgetown, SC 29442.

Study Area

The cooperative study was conducted in a 2,300 ha watershed located in southeastern Georgetown County, South Carolina. The area is being converted by the owner from a Bald-cypress-Tupelo forest type (Eyre 1980) to a drained loblolly pine plantation. Soils are primarily of the Cape Fear series. Cape Fear soils are a member of the clayey, mixed thermic family of Typic Umbraquults. They have black loam A horizons up to 41 cm thick and dark gray to gray, clay to clay loam, B horizons from 90 cm to over 150 cm thick. They are very poorly drained, have ponded or slow runoff and slow permeability. Water table was at or near the surface during wet seasons. Prior to drainage, water moved northerly through the area in a diffuse manner to a small natural stream near the northern edge.

The general conversion sequence was: (1) install drainage ditches and build access roads using ditch spoil; (2) log the stand after one year of drainage; (3) push down culls and other non-merchantable timber; (4) crush residual material with large-bladed drums; (5) leave fallow for a year and then plow beds about 1 m wide and 50-80 cm high on a spacing of about 3 m, incorporating triple superphosphate into the beds; (6) plant loblolly pine seedlings. Burning was used either prior to or after chopping when necessary.

Sections of the study area have received this treatment during the past 20 years. A main drainage ditch was installed from the natural outlet at

the north end of the bay to the sandy ridge forming the southern border of the area. This main ditch is roughly a rectangular channel 2.5-4m wide and 2-2.5m deep. Secondary ditches (triangular channels 2-2.5m wide and 1.5-2m deep) were then installed to drain areas scheduled for conversion. Installation of these secondary ditches and roads has divided the area into several subwatersheds. Since the conversion process began in the north end of the study area these subwatersheds ranged from undisturbed cypress-hardwood swamp to 15 year-old loblolly pine plantations.

METHODS

Twenty sample points were established in the study area in July 1980 (Figure 1). These sample points included subwatershed outlets and points in the main channel downstream from each subwatershed outlet. Subwatershed samples were collected from several areas, each of which were undergoing a different phase of establishment process; undisturbed cypress-tupelo forest (#3), active logging (#5); site preparation areas (#6), 1-3 year-old pine plantation (#8), 3-15 year-old plantations (#18), and several subwatersheds with combinations of treatments (#9, 12, 14, and 16). Eleven sample points in the main ditch (#1, 2, 4, 7, 10, 11, 13, 15, 17, 19 and 20) were installed to determine the influence of the addition of drainage from each subwatershed. In August 1980 a new ditch was installed intersecting the main drainage ditch between sample point #2 and #4. This created a new subwatershed which was labelled #2A. Each of the sample points were sampled once during the rising phase and twice during the falling phase of the first storm flow event of each month. Storm flow events were defined as that runoff which occurred after at least 3 cm of rain. Sampling began in January 1981 and continued through November 1982. Thirteen events during this period met the criteria. Temperature and dissolved oxygen content (DO) of the drainage water were measured on site with a YSI Model 51B Dissolved Oxygen meter. One liter of water was collected at each sample point on each of the three collection days for each storm flow. Water samples were filtered through Whatman GF/F glass micro fiber filters with an effective retention of 0.7 µm. Filters were weighed to the nearest 0.00001 gram before and after filtering and the suspended sediment content was expressed in milligrams per liter.

Chemical analyses on each sample consisted of:

Analysis	Technique	
(NO_3)	Brucine	(Taras, M. J. et al., 1975)
(SO_4)	Turbidimetric	"

Ca, Mg and K were assayed by atomic absorption. All measurements were recorded to the nearest 0.001 mg/l.

RESULTS AND DISCUSSION

Results of the study are presented in figures 2-9 for the water quality parameters considered: dissolved oxygen (Fig. 2), suspended sediment (Fig. 3), pH (Fig. 4), nitrate nitrogen (Fig. 5), sulfate (Fig. 6), calcium (Fig. 7), magnesium (Fig. 8), and potassium (Fig. 9). Results (with 95% confidence limits) from the subwatersheds that represent only one silvicultural activity are presented in section A of each figure. All subwatersheds and the main ditch means (dotted lines) are presented in section B.

Natural Hardwood Stand

Runoff concentrations from the natural hardwood stand were similar to these found in slash pine flatwoods in Florida (Table 1).

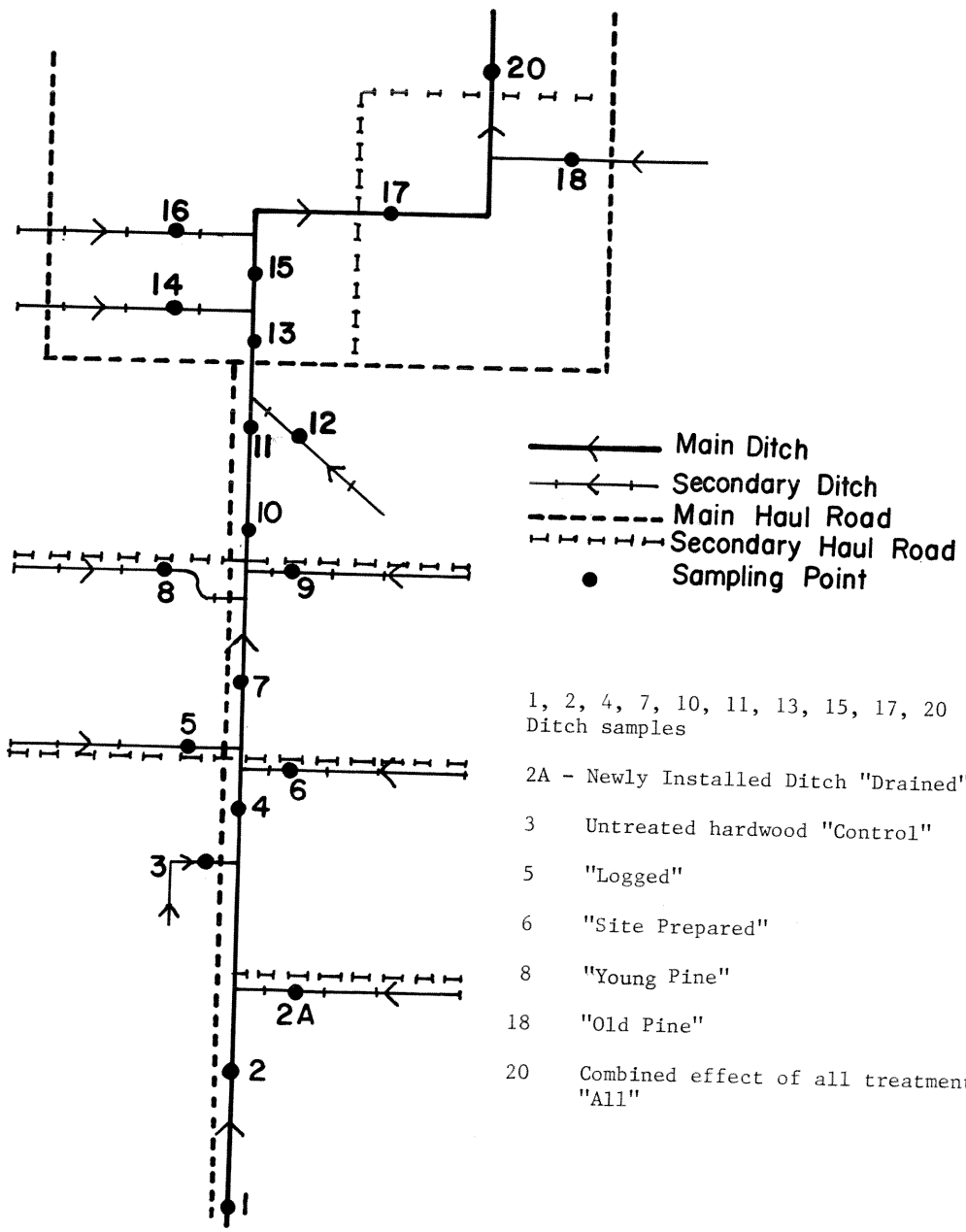
Table 1. Comparison of constituents in water from undisturbed watersheds in this study and central Florida IMPAC study (Riekerk 1982).

Constituent		This Study	IMPAC study watershed 3
pH		4.39	3.79
NO_3-N	mg/l	.47	.03
NH_4-N	mg/l	.05	.10
Total P	mg/l	.01	.03
K	mg/l	.80	.13
Ca	mg/l	5.49	1.16
Mg	mg/l	2.70	.70
Suspended sediment	mg/l	4.08	2.7
SO_4	mg/l	32.8	

Water from these watersheds is stained with organic acids derived from incomplete decomposition of organic matter. Flat slopes of the coastal plain have little erosive potential so most of the material leaving the watershed is in the dissolved state. In this study total suspended sediments were only 4 mg/l while the dissolved sulfate alone was 33 mg/l. There are several differences in the data collected from our study and the one in Florida. Calcium and magnesium concentrations were much higher in this study. This may be due to younger soils near the coast which may have a greater supply of weatherable bases.

Nitrate-nitrogen concentrations are much higher in this study than those reported in most other published data from the Southeast. This may be due to the sampling technique. We sampled only stormflows and some of these stormflow events occurred after dry periods. The high mean concentration was due to high nitrate concentrations in these samples (as indicated by

FIGURE I. SCHEMATIC OUTLINE OF SAMPLING POINTS AND SUBWATERSHED LOCATIONS



1, 2, 4, 7, 10, 11, 13, 15, 17, 20 Ditch samples

2A - Newly Installed Ditch "Drained"

3 Untreated hardwood "Control"

5 "Logged"

6 "Site Prepared"

8 "Young Pine"

18 "Old Pine"

20 Combined effect of all treatments "All"

the wide confidence limits). Apparently nitrate was produced in these areas when the water table fell during an extended dry period and was then exported during a subsequent stormflow.

Newly Installed Drainage

Installation of new drainage ditches proved to have the most significant impact on water quality. Suspended sediment, pH, nitrate-nitrogen, sulfate, calcium, and magnesium concentrations all showed significant changes from the control. These changes ranged from a 50% increase in magnesium concentration to a 50 fold increase in suspended sediment.

The large increase in suspended sediment was due to runoff from ditch spoil, ditch banks, and the adjacent road. Highest concentrations occurred in rising limb samples with a concentrations decreasing on the falling limb of the hydrograph. Turbid water from the adjacent road was seen entering the ditch during the first day but elevated concentrations during the subsequent days probably were derived from material from the banks that had slumped into the ditch.

Concentrations of several dissolved constituents were also significantly higher in the new ditch. Concentrations of both nitrate and sulfate showed large increases in the newly installed ditch. Chemistry of both nitrogen and sulfur are similar. Both are incorporated into biological materials which accumulate on the forest floor. Both are released during decomposition and are mineralized to end products that undergo similar oxidation-reduction reactions. Prior to drainage, decomposition on these soils had been slow due to saturated conditions and the upper soil horizons contained a great deal of organic matter. As drainage reduced the degree of saturation decomposition was likely to have increased. Increased nitrate and sulfate originated as either a result of increased mineralization or as oxidation of reduced forms of previously mineralized material.

The higher concentrations of calcium and magnesium are more easily explained. Calcium plus magnesium are in ionic balance with the concentration of sulfate. Magnesium was well correlated to sulfate concentration ($r^2 = 0.78$) even when measured across all treatments. Oxidation of sulfur compounds to sulfate also releases hydrogen ions which are then available to displace cations from the exchange complex. Nitrification would have resulted in the same reaction but in this system sulfate is several fold more abundant.

Hydrogen ion concentration was slightly reduced on the drained area. This conflicts with the explantation of calcium and magnesium chemistry. However, the major source of hydrogen ion in these streams is organic acids. By reducing the period of standing water the concentrations of these acids may have been reduced.

Each treatment (logging, site preparation, pine establishment) which reduced the amount of decomposing organic matter resulted in a decrease in hydrogen ion concentration.

Logging

Concentrations of most constituents from the logged area were similar to those of the natural hardwoods. Only potassium and hydrogen ion were greatly different. Potassium concentrations appear to vary with the degree of disturbance to living vegetation. All of the subwatersheds on which vegetation was disturbed had significantly higher potassium concentrations.

Nitrate, sulfate, calcium, and magnesium all showed values smaller than the newly drained subwatersheds, with all but calcium being as low as the natural hardwood. These results tend to support the hypothesis that drainage causes the oxidation of reduced forms of N and S rather than as a result of increases mineralization. Logging has been assumed to increase the rate of mineralization (Likens et al. 1970). However, logging also causes a rise in the water table due to reduced transpiration (Trousdell and Hoover 1955). In this study the higher water table associated with logging seems to have resulted in oxidation-reduction reactions similar to the undrained stand.

Site Preparation

Shearing, drum chopping, burning, and bedding associated with site preparation were the most severe mechanical treatments applied during the establishment process. Yet, these treatments had a relatively minor impact on water quality. Suspended sediment concentrations were no higher than other treatments with drainage ditches. On the level land of the lower coastal plain exposure of mineral soil does not result in erosion unless equipment creates channels into drainage ditches or streams. Nitrate concentrations were slightly higher than in the logged area but were still significantly less than in the natural hardwood. Sulfate, magnesium, and hydrogen ion concentrations were all significantly lower than in natural hardwood, while calcium was lower than the logged area. After cull trees were sheared and chopped they were burned with a very hot fire in late summer. The intensity of these fires could have volatilized sulfur from litter and perhaps from the soil. Sulfate concentrations of all subwatersheds on which such a fire had occurred were significantly less than those without such a fire. Decreased calcium and magnesium concentrations may have been due to ash in convection columns (Lewis 1974, Grier 1975). However, the ionic balance between sulfate and these cations would suggest a cation exchange explanation is more likely.

FIGURE 2. DISSOLVED OXYGEN

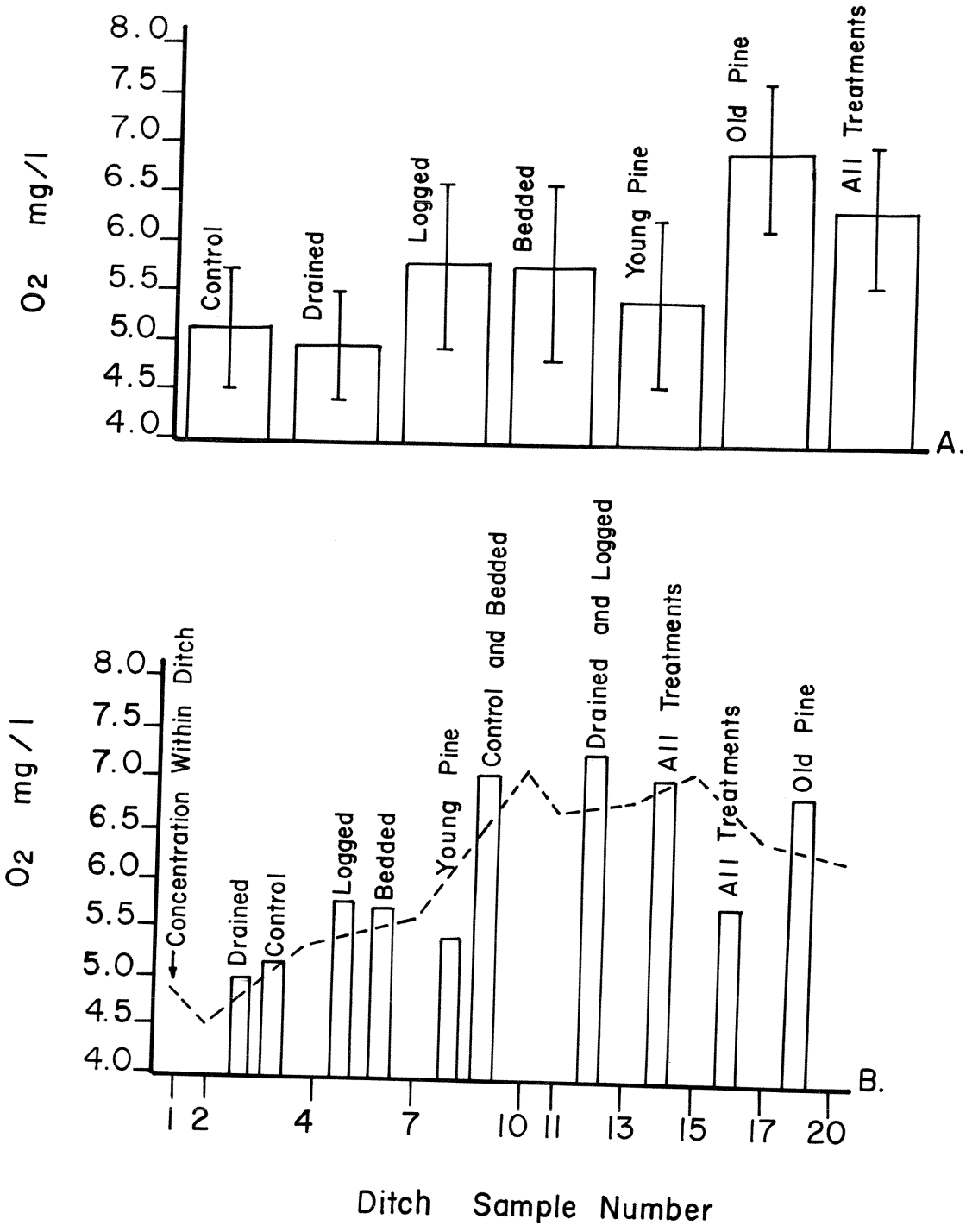


FIGURE 3. SUSPENDED-SEDIMENT

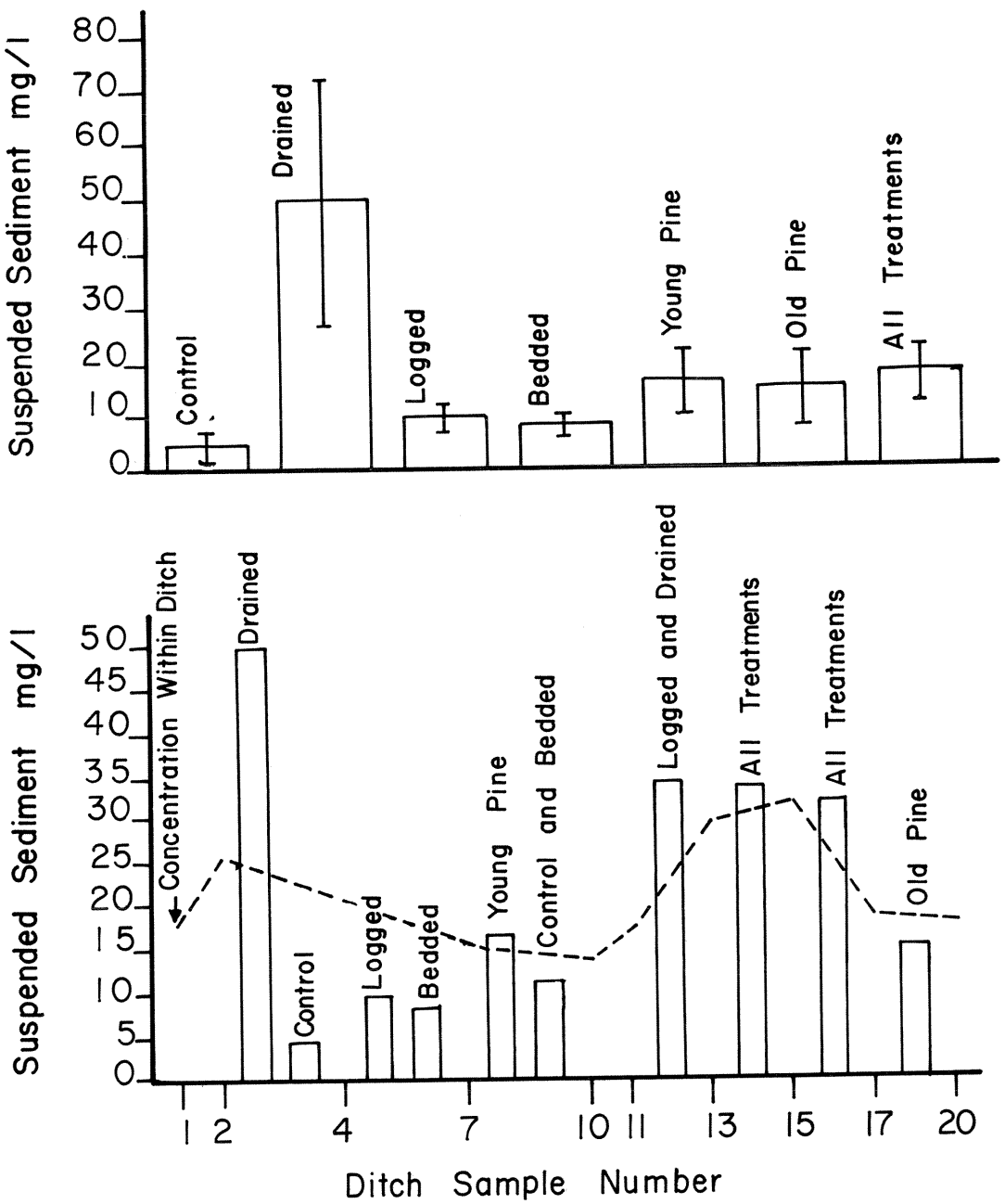


FIGURE 4. HYDROGEN ION

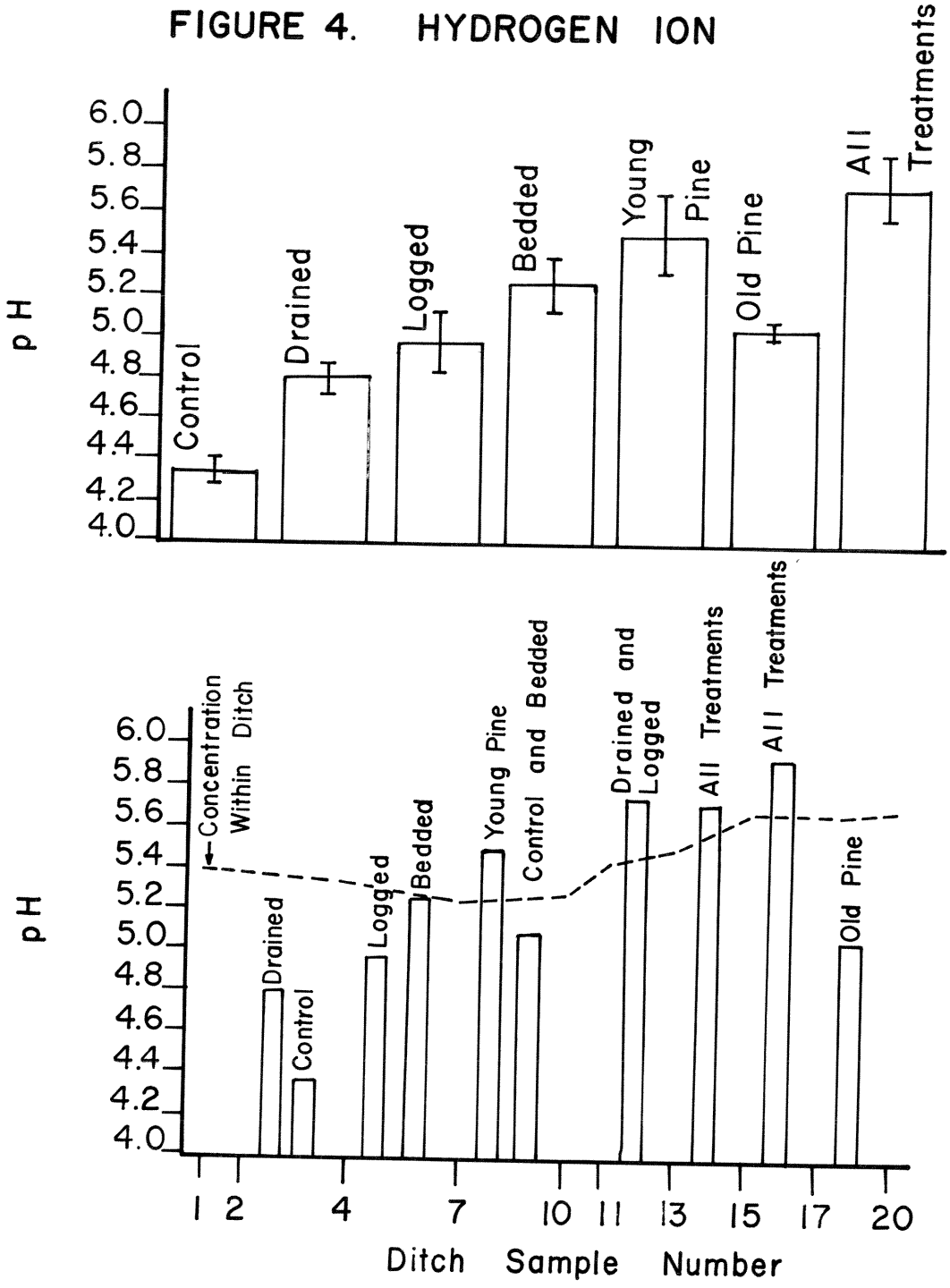


FIGURE 5. NITRATE - NITROGEN

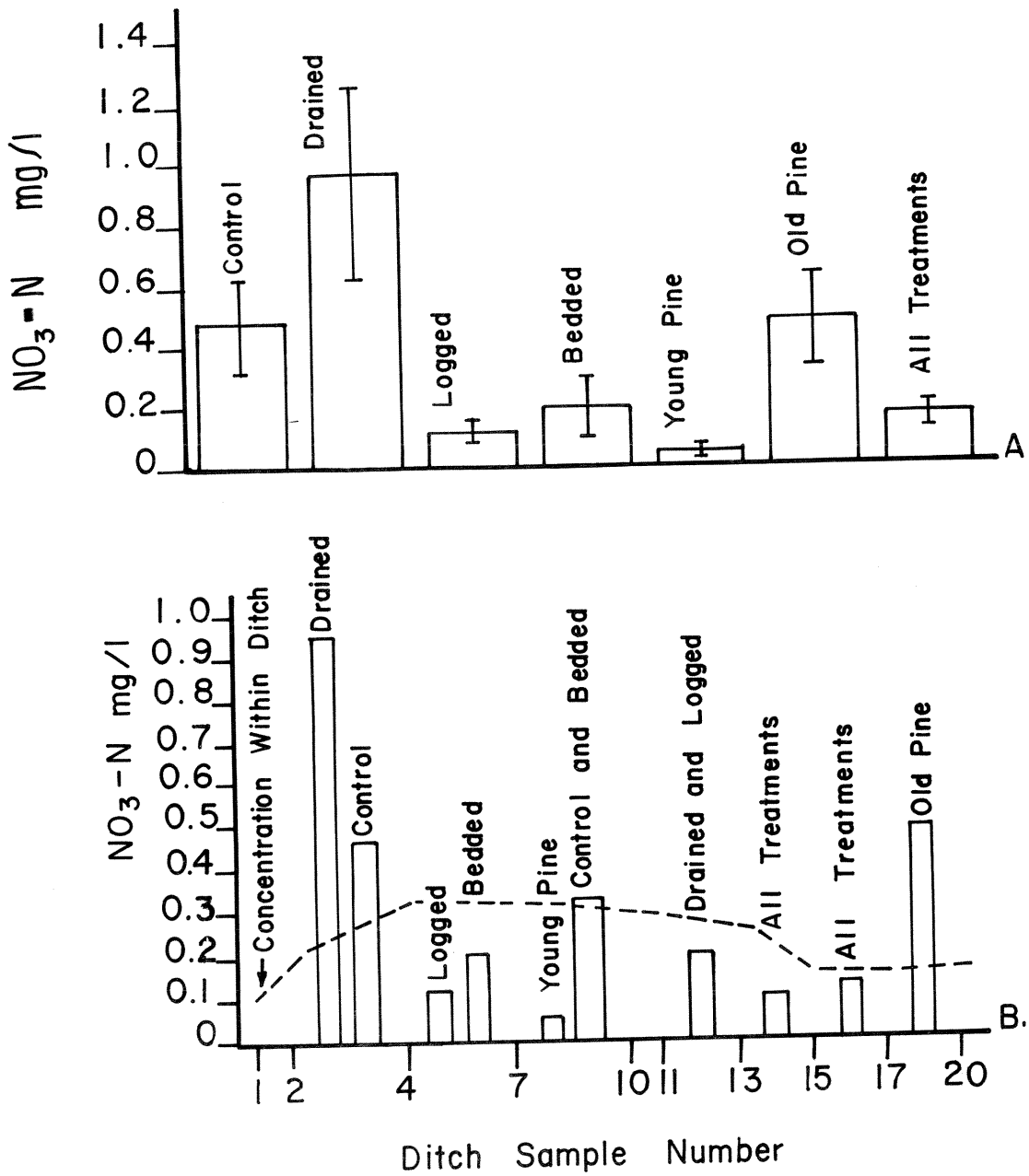
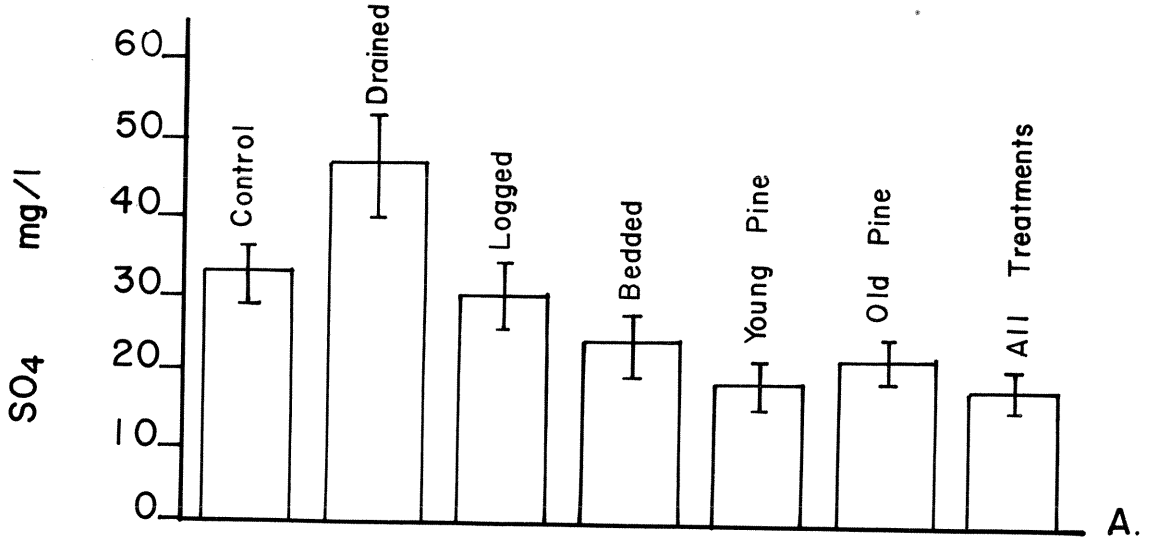


FIGURE 6. SULFATE



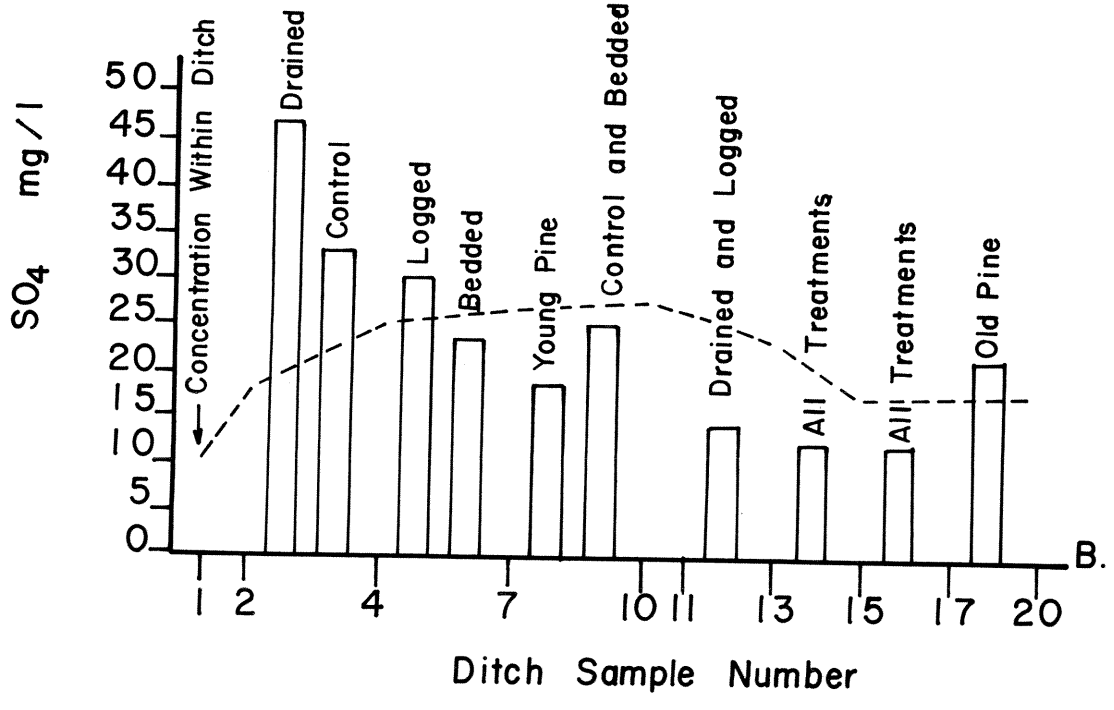


FIGURE 7. CALCIUM

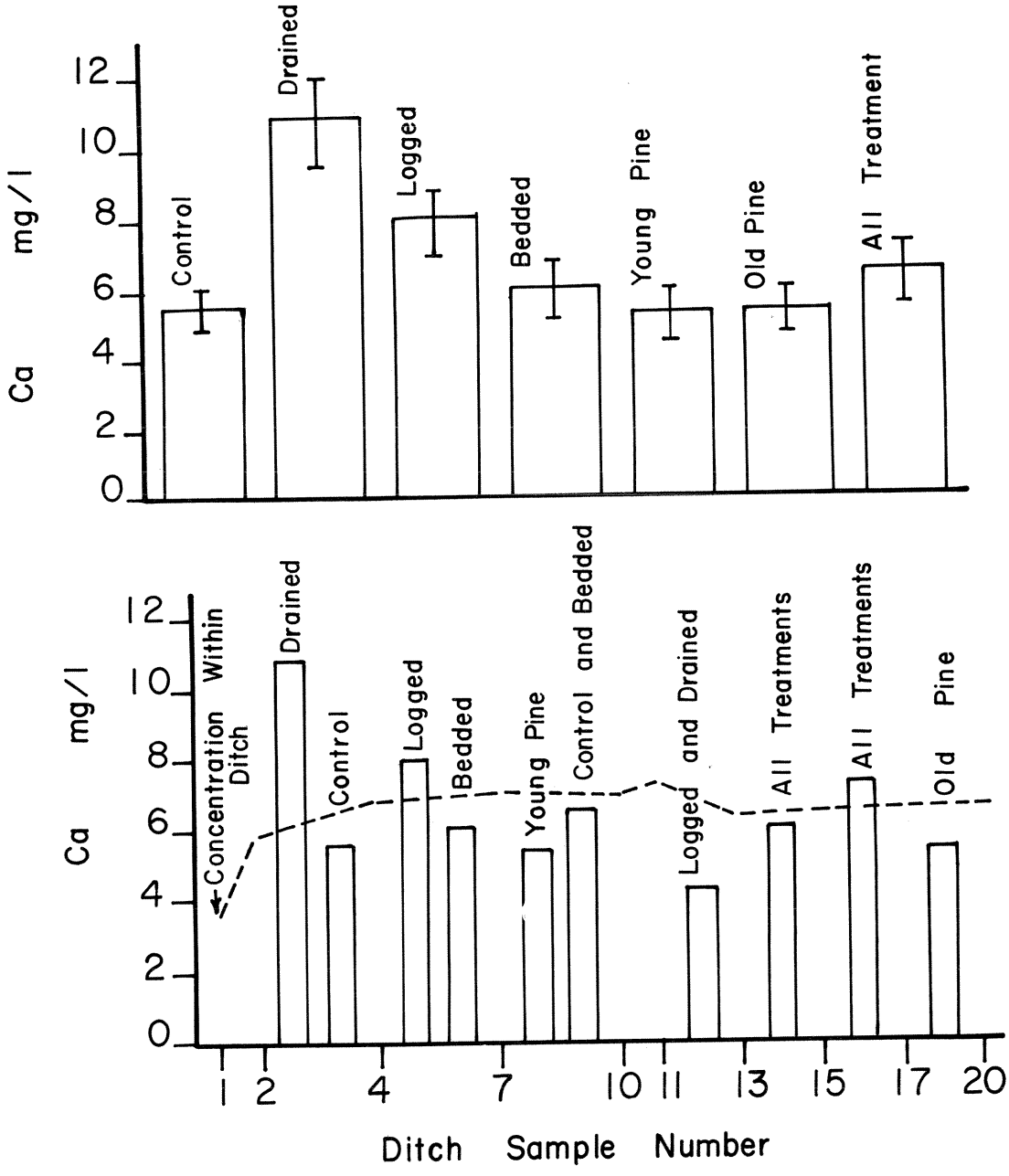


FIGURE 8. MAGNESIUM

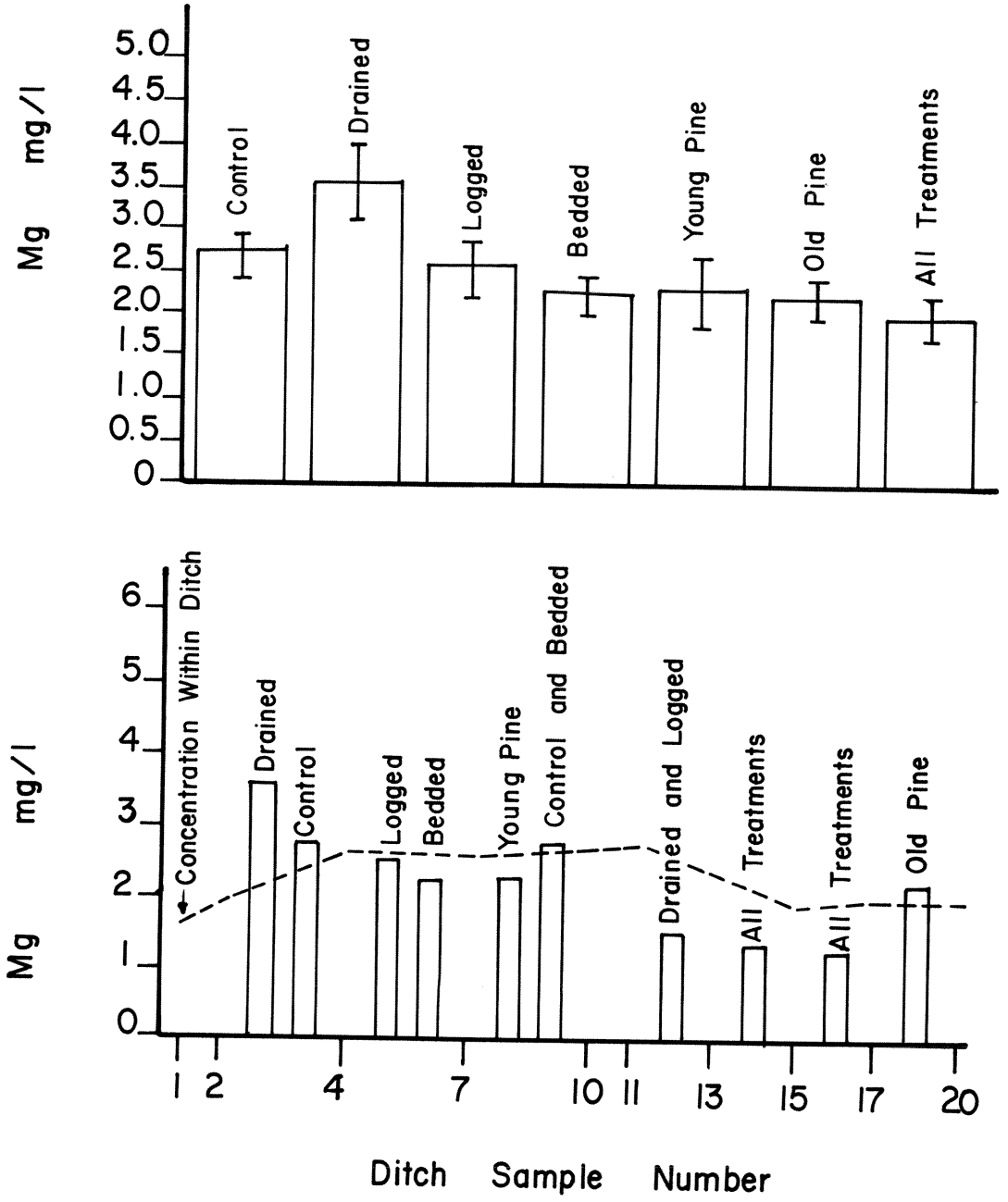
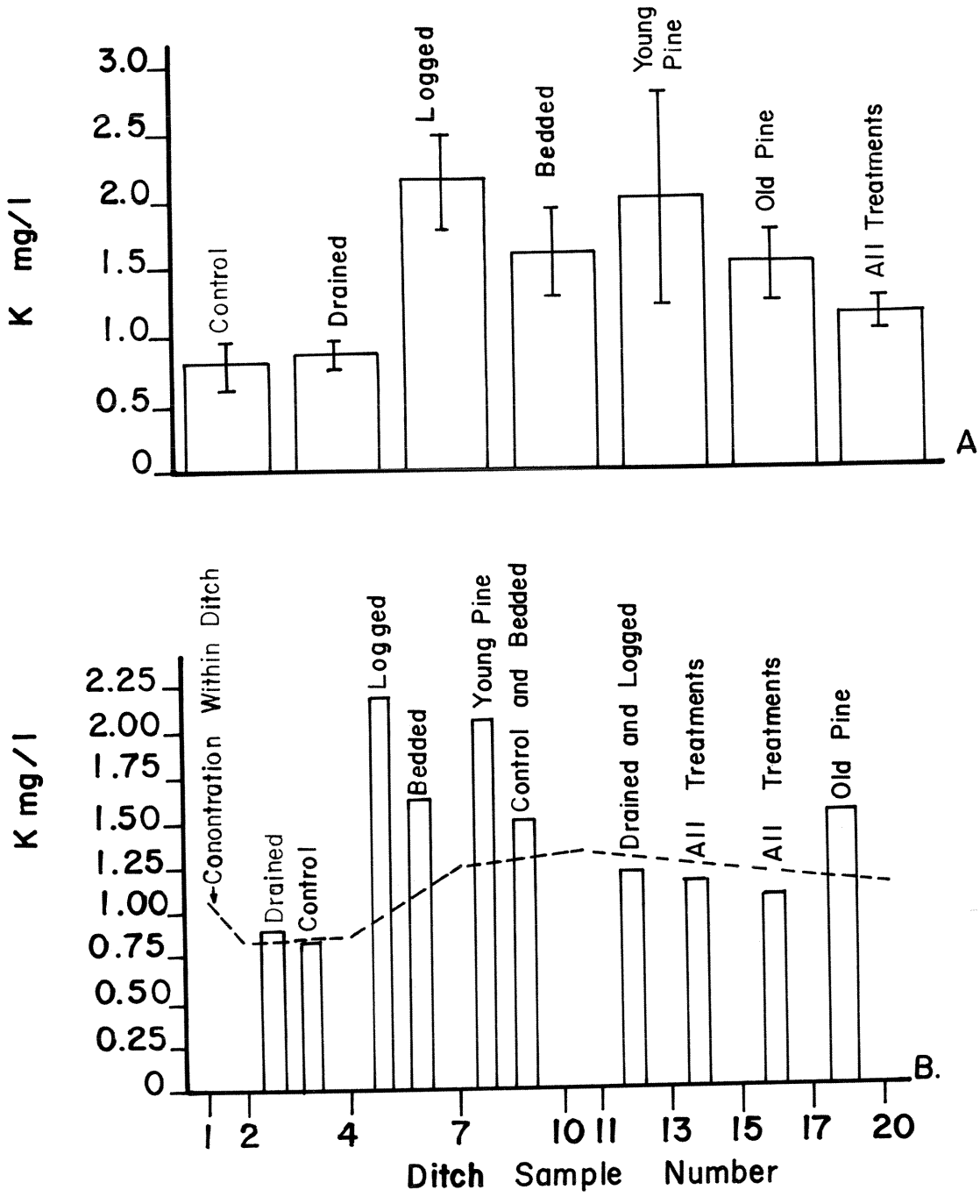


FIGURE 9. POTASSIUM



Young Pine Plantation

The young pine plantation had the highest quality water of any subwatershed in the study. Concentrations of nitrate, sulfate, calcium, and hydrogen ion were the smallest of any of the subwatershed values. Pine growth rates were relatively rapid on this area and the pine trees were the dominant vegetation on the site by the end of the study. It seems that with the addition of phosphorus fertilizer the young pines were able to utilize the other nutrients on this site more effectively than the natural stand. The consistently low nitrate concentrations are consistent with results from other well drained pine sites (Hewlett 1979, Richter et al. 1982). Control of nitrate concentration on this site may have no longer been due to oxidation-reduction reactions but due to the more common mineralization reactions.

Only two constituents of runoff from the young pine stand failed to show consistently high quality. Suspended sediment was significantly higher than in the site-prepared area and dissolved oxygen was lower, although more variable. Both of these values seemed to be due to heavy growth of aquatic macrophytes and epiphitic algae in the drainage ditch. When this vegetation was alive it contributed to the oxygen in the stream but when it died it consumed oxygen and contributed a large amount of suspended organic matter. This subwatershed was the only subwatershed in which the suspended material contained visible quantities of organic matter.

Older Pine Plantation

Concentrations from the older pine plantation were similar to those of the young pine except for nitrate nitrogen and hydrogen ion. The higher and more consistent hydrogen ion concentration may have been a result of the build up of a stable forest floor. The concentration was similar to the watershed of the IMPAC study (Riekerk 1982) which contained mostly slash pine. Nitrate concentrations were not significantly different from the control. This may have been due to a return of transpiration and the large fluctuations of the water table characteristic of the lower coastal plain (Trousdell and Hoover 1955, Tainter et al. 1982). Another explanation may be that the stand had exhausted the phosphorus added at planting and could no longer effectively utilize nitrogen.

Integration of all Treatments

The constituent concentrations at sample point 20 were a reflection of all the subwatershed outputs and any processes which operated within the main drainage ditch. For all of the dissolved constituents, except oxygen, there seemed to be little processing within the main ditch. Changes in concentration were as would be expected if dilution was the only process active. Dissolved oxygen appears to have been dominated by channel processes. On the subwatersheds that were well channelized dissolved oxygen averaged near 7 mg/l while those with flow over the surface had significantly lower averages near 5 mg/l. Likewise, in the main stream where water stayed within the channel and had turbulent mixing the values were near 7 mg/l. In the region between sample points 15 and 20 the main channel was not large enough to contain the flow and the dissolved oxygen dropped from 7 to 6 mg/l.

Suspended sediment measurements showed that both sediment additions and sedimentation occurred in the main channel (Askew and Williams 1984). Suspended sediment concentrations declined sharply between point 2 and point 7 and between point 15 and 17. The decline between points 2 and 7 may have resulted from dilution by relatively clean water. However, the decline between points 15 and 17 occurred despite the addition of water with higher sediment concentrations. Suspended sediment was also added to the main ditch in quantities rivaling those of several subwatersheds. Between points 11 and 13 the concentration increased from 16 to 29 mg/l. The concentration of subwatershed 12 was 33 mg/l but it drained an area of less than 200 acres while the main ditch drained an area of nearly 2000 acres. The only other source of sediment between points 11 and 13 was the crossing of the main haul road. The main haul road also crossed the ditches in subwatersheds 14 and 16, which had suspended sediment concentrations of 33 and 31 mg/l respectively.

CONCLUSIONS

The overall effect of drainage and pine plantation establishment in this case was to improve runoff water quality. The drained area was a broad interstream divide which received excess water by rainfall. The natural stand was a hardwood stand which had been selectively (selection for profit) logged during the 1940's. In this case the runoff water was dominated by high concentrations of organic acid, low levels of dissolved oxygen, occasionally high concentrations of nitrate, and high concentrations of sulfate and associated cations. Overall conversion decreased the acidity level, increased the oxygen level, and lowered the concentrations of nitrate, sulfate, and magnesium.

Aspects of the conversion process which had the largest impacts on water quality were installation of new drainage ditches and establishment of the pine plantation. Installation of drainage produced an increase in suspended sediment from ditch bank, spoil, and an adjacent road. Increased drainage also appears to have increased the rate of oxidation of the forest floor and soil. This resulted in a pulse of dissolved nutrients (NO_3-N, SO_4, Ca, and Mg).

These losses were large enough to be statistically significant even with the limited sampling of this study and could be of concern from a productivity standpoint. Establishment of a vigorously growing pine stand had the greatest positive impact on water quality. The stand in this study produced water similar in quality to other pine forests. On this site the incorporation of phosphorus into the beds resulted in a stand that seemed able to more completely utilize the site. Not only did phosphorus concentrations remain below our 0.01 mg/l detection limit but other nutrient concentrations in runoff also declined.

There appears to be only two areas of potential water quality concern in the practice of pine plantation establishment on these sites. The sediment and dissolved nutrients from the initial eatablishment of drainage ditches presented a problem for at least two years. Slow development of a tract as practiced here solves these concerns with dilution. If a tract is developed over a period of twenty years then no more than ten percent would have new ditches. Suspended sediments from the new ditches and from main haul roads does settle from the stream which will improve water quality but the sediment in the stream impedes flow. This problem may be alleviated by installing settling basins in the drainage system to accumulate sediment (Gregory per. com.). These basins can also be used to provide water for fire protection.

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EFFECT OF THINNING YOUNG LOBLOLLY PINE ON SOIL MOISTURE IN SOUTHEASTERN LOUISIANA [1/]

R.J. Lilieholm and S.C. Hu [2/]

Abstract.--Stand growth and soils under three thinning treatments were studied for one year. Plots heaviest thinned contained more water during the growing season than controls. Daily water use was equal among treatments. Moisture in upper soil horizons reduced water use periodically from March to November while depths below 2.5 feet remained near field capacity. Tree diameter growth increased with increased thinning intensity.

INTRODUCTION

Current projections show increasing demands for wood and wood products while forestland in the U.S. decreases (Hall 1983). To meet increased demands from a declining resource base, forests are becoming more productive through shorter rotations and intensive management (DeBell et al. 1977). Greater utilization, genetically improved planting stock, fertilization, and thinning are more common each year on many acres of forestland.

Thinning has been widely used to improve tree growth and quality by alleviating competition for a number of growth factors including solar radiation, nutrient elements, and soil moisture (Daniel et al. 1979). While all of these factors are important, Black (1957) identified soil moisture as the single most limiting factor to plant growth on most sites.

Loblolly pine (*Pinus taeda* L.) is the major timber species of the southeast United States and each year thousands of acres are thinned to improve tree growth and quality. While many studies have examined the effect of thinning loblolly pine on growth, few if any have focused on the underlying cause of improved growth--increased soil moisture.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Graduate Research Assistant and Associate Professor of Forestry respectively, School of Forestry, Wildlife, and Fisheries, Louisiana Agricultural Experiment Station, LSU Agricultural Center, Baton Rouge, LA 70803.

METHODS AND PROCEDURE

Study Area

The study was conducted on LSU's Lee Memorial Forest located in southeastern Louisiana. The area falls in the forest habitat subregion identified by Evans et al. (1983) as the Middle Coastal Plain, Southern Loam Hills, gentle topography unit. The site is occupied by a young loblolly pine stand naturally regenerated in 1964-65. Site index for loblolly pine within this habitat subregion is normally from 84 to 91 feet at base age 50 years. While loblolly pine dominates the site, scattered longleaf (*Pinus palustris* Mill.) and shortleaf pines (*P. echinata* Mill.) are present. Common hardwoods include sweetgum (*Liquidambar styraciflua* L.), yaupon (*Ilex vomitoria* Ait.), yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), and various oaks (*Quercus* spp.).

Ruston and Savannah fine sandy loams underlie the site. The well-drained Ruston soil series is found extensively throughout Louisiana and covers over one million acres in the South. Most of this land supports stands of southern pine, of which loblolly pine is a major component. The moderately well-drained Savannah series has a fragipan at 16 to 38 inches, creating a perched water table at 1.5 to 3.0 feet from January to March. Rainfall, collected nearby at the Sheridan fire tower, averaged 75 inches per year over the past 13 years.

Plot Establishment

Twelve 0.5-acre square plots were established across the stand in the spring of 1980. One nine-foot aluminum access tube was installed in each plot center to allow soil

moisture measurement with a neutron probe. The 12 plots were then divided into four blocks of three plots each and every plot within each block was randomly assigned one of three treatments:

1) hardwood removal, thinning to 200 trees per acre (TPA), prescribe-burn,
2) hardwood removal, thinning to 400 TPA, prescribe-burn, and
3) control.

Hardwood trees and shrubs on plots to be thinned were cut in December and January 1982-83. Loblolly pines were marked for thinning in January of 1983. At this time other pine species were removed. Loblolly pines thinned from the plots were selected by the following criteria: first, dying trees; second, diseased and broken trees; third, trees making negligible growth compared with the average; fourth, excessively limby dominants whose removal would release better trees; and lastly, trees whose removal would improve the spacing of remaining trees. Thinning began in early January and continued through February. Thinned plots were prescribe-burned in February to discourage hardwood sprouting and reduce slash.

Measurements

Pine diameter at breast height was recorded in March 1983. Pine basal area averaged 52.5 ft^2/ac on 200 TPA plots, 72.1 ft^2/ac on 400 TPA plots, and 63.4 ft^2/ac on controls. Hardwood basal area on control plots averaged 17.2 ft^2/ac with 2,350 stems per acre. In addition, 15 pines nearest the plot center on all plots were measured for total height and live crown ratio. Measurements were repeated after one growing season.

Hardwood understory sprouting was sampled in November of 1983, one growing season after thinning. Two 0.0125-acre subplots were established in each thinned plot and the number of sprouts and height of the dominant sprout for each root collar was recorded.

Volumetric soil moisture was measured with a Troxler Model 2655 scaler-ratemeter and Model 1255 depth moisture probe approximately every two weeks from March 6, 1983 to February 26, 1984. Soil moisture was measured from depths of 0.5 to 7.5 feet at one-foot intervals. A field calibration for the neutron probe was made at the study site.

Two rain gages were installed on the study area to measure biweekly rainfall. Measurements were recorded in conjunction with neutron probe readings to aid in interpreting soil moisture fluctuations. In addition, daily rainfall data from a nearby fire tower were obtained.

Soil moisture retention curves for both the Ruston and Savannah soil series were constructed for depths of 0.5, 1.5, 2.5, 3.5, and 4.5 feet. For each soil series and depth, volumetric moisture content was determined for soil water potentials of 1/3, 1, 4, 8, and 15 bars.

RESULTS AND DISCUSSION

Effect of Thinning on Tree and Understory Growth

Diameter growth increased with increased thinning intensity. Trees on plots thinned to 200 TPA grew the most, adding an average of 0.27 inch to their diameters (table 1). Plots thinned to 400 TPA had the next greatest radial increment growth with 0.19 inch, and trees on the control plots grew the least, averaging only 0.15 inch. No significant differences were found in height growth, change in live crown ratio, or per-acre basal area growth at the 0.05 probability level.

Table 1.--Diameter growth at breast height, height growth, change in live crown ratio, and basal area growth after one year among three thinning treatments

Treatment	Diameter growth	Height growth	Change in live crown ratio	Basal area
	in.	ft.	percent	ft^2/ac
Thin to 200 TPA	0.27 A	1.2 A	0.006 A	3.40 A
Thin to 400 TPA	0.19 B	1.6 A	0.015 A	4.79 A
Control	0.15 C	1.1 A	-0.100 A	4.76 A

Column means with similar letters are not statistically different at the 0.05 probability level. Diameter growth means differ at the 0.01 probability level.

Early in the spring of 1983, hardwood stumps on the thinned plots began vigorous sprouting which continued throughout the growing season. Sweetgum, yaupon, red maple (*Acer rubrum* L.), and yellow-poplar sprouts were dominant. No significant differences were found in hardwood understory growth among the thinning treatments. Dominant hardwood sprouts averaged 51.5 inches in height, with approximately 3,500 sprouting root collars per acre.

Effect of Thinning on Soil Moisture

Volumetric Moisture Content

Average moisture content for each treatment at three soil depths during the study is shown in Figure 1. No statistically significant differences were found in soil moisture among the treatments at any depth. Despite this, some general trends in volumetric soil moisture content were observed. First, soil moisture depletion was already in progress when measure-

ments began in March, coinciding with increased evapotranspiration from warming temperatures and initiation of vegetative growth.

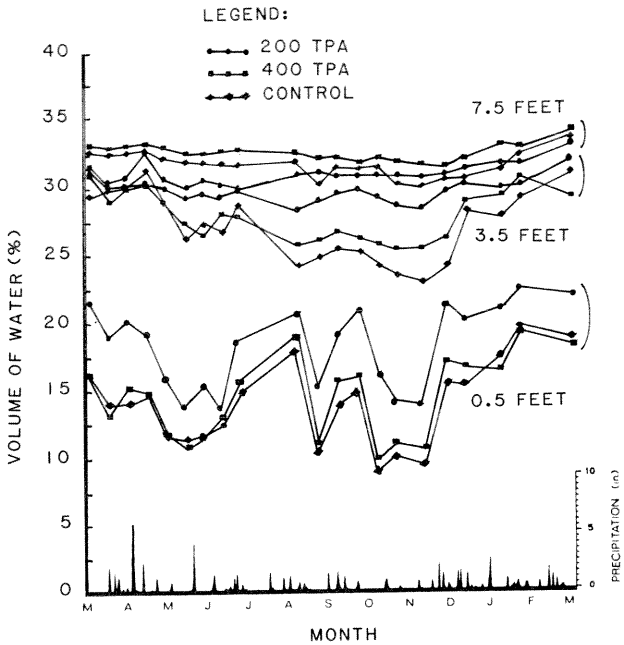

Figure 1.-- Daily precipitation and average soil moisture content under three thinning treatments at three depths from March 6, 1983 through February 26, 1984.

Soil moisture recharge began in November and continued through February in conjunction with decreased evapotranspirational demands. Soil moisture recharge was abrupt, with the soil going from the lowest moisture content measured to near field capacity in 17 days. Field capacity, assumed to be the maximum moisture content observed in the soil (Bay and Boelter 1963), was reached in January regardless of treatment.

Seasonal fluctuations decreased with increasing depth in the soil, indicating that evapotranspirational demands and effects of precipitation were greatest in the upper soil horizons, where most roots are concentrated. Correspondingly, soil moisture increased with increasing depth in the soil during the growing season. Seasonal changes in soil moisture were found to a depth of 7.5 feet.

Throughout the growing season, the close correlation between rainfall and soil moisture status diminished as soil depth increased. It was also observed that heavy rains during the growing season could dramatically recharge the soil. Three heavy rains in mid-September recharged upper soil horizons to near field capacity.

Inches of Water in the Soil

While no differences were found in volumetric moisture content at one-foot intervals in the soil profile, differences were found in the total amount of water in the profile to a depth of eight feet (figure 2). Soils under plots thinned to 200 TPA contained more water than controls during the growing season; control plots had significantly less. All treatments recharged to approximately the same levels in the winter. At field capacity, these soils hold about 29 inches of water in the upper 8 feet.

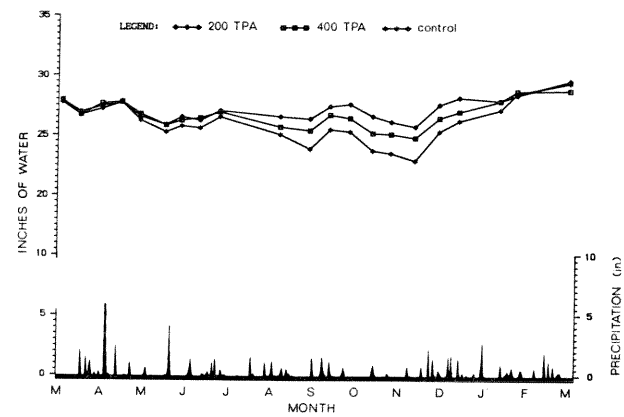

Figure 2.-- Daily precipitation and average total inches of water in the soil to a depth of 8 feet for each treatment from March 6, 1983 through Feburary 26, 1984.

Daily Water Use

Daily water use from the upper 8 feet of soil is illustrated in figure 3. Water use was calculated by finding the difference in total inches of water between two successive measurement dates and adding to this the amount of precipitation received on the plots between the two measurements. The loss of water was then divided by the number of days between measurements to give a daily average of soil water use.

Several assumptions must be made when calculating water use in this fashion. First, rainfall received at the rain gages accurately describes the rainfall falling over the entire study area and that all this water enters the soil (i.e. no runoff, stemflow, or evaporation). Secondly, there is no lateral movement of soil water and no vertical movement, up or down, at a depth of 8 feet. A final assumption is that the moisture gradient between soil depths measured changes in a linear fashion, allowing the averaging of the measured soil moistures found throughout the soil profile.

How well these assumptions are met is unknown; however, heavy rains in April violated the first assumption of no runoff. Runoff from

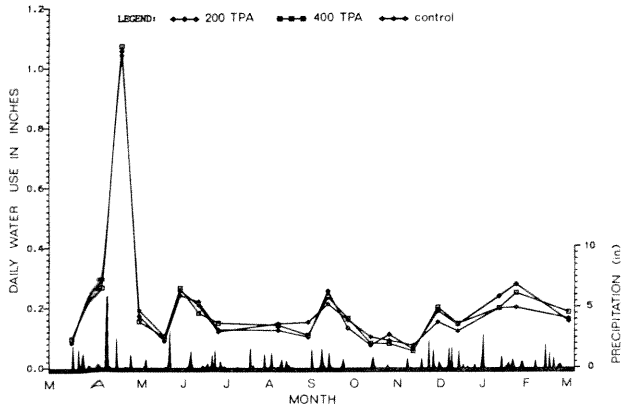

Figure 3.-- Daily precipitation and average daily water use for each treatment from March 19, 1983 through February 26, 1984.

these large storms caused widespread flooding and resulted in excessive water use estimates of 1.00 inch per day. Another questionable period is during December, January, and February. Much precipitation was received during this time and soils were already recharged to field capacity. In addition, tree growth had ceased, making daily water-use estimates of 0.14 to 0.28 inch too high, especially since the estimated maximum potential water use during the winter for loblolly pine is 0.01 inch per day (Zahner 1960). Most likely surface runoff and subsurface drainage were taking place.

Ruling out these two periods, maximum water use fluctuated between 0.23 and 0.26 inch per day. This estimate is close to two published estimates for loblolly pine of 0.24 and 0.25 inch by Bassett (1964) and Zahner (1960), respectively. Periods of low water use (0.07 to 0.09 inch per day) in March, May, August, October, and November coincide with periods of low soil moisture. Average daily water use observed in this study during the growing season was 0.15 inch per day or 4.5 inches per month.

While no differences were found between daily soil water use and treatment, plots heaviest thinned had a greater water-use to tree ratio. This suggests that increased moisture in the soil due to thinning further impacted tree growth since there was more soil water available on a per-tree basis.

Converting inches to volume, the study area lost 7,060 gallons of water per acre on days averaging losses of 0.26 inch. Making assumptions of negligible water loss by evaporation and hardwood sprouts and uniform moisture loss over plots by all trees, this would equal 35 and 18 gallons of water per tree per day on plots thinned to 200 and 400 TPA respectively.

On days of low water use (i.e. 0.07 inch per day), losses dropped to 1900 gallons per acre per day, or 9.5 and 4.8 gallons per tree per day for 200 and 400 TPA plots respectively. Since most water is lost during the midday hours, peak water use per hour would be greater. Zahner's (1960) estimate of 100 gallons per hour for a sawlog size loblolly pine during peak water use is probably realistic. While this seems like a large quantity of water, soils under the study area contain more than 3/4 of a million gallons of water per acre in the upper eight feet of soil at field capacity.

Soil Water Potential

In both Ruston and Savannah soils, clays eluviate downward and accumulate at lower depths, leaving high percentages of sand in the upper horizons. Thus, there is a sharp drop in moisture retained with increasing suction at a depth of 0.5 foot. As depth in the soil profile increased to 2.5 and 3.5 feet, the greater accumulation of clay allowed more moisture to be retained against suction.

Along with evapotranspirational demands, this explains some of the temporal variability in moisture observed at soil depths of 0.5 and 1.5 feet and why lower horizons remained more constant. In addition, it helps illustrate the rapid recharge capacity of these soils. Since the surface horizons tend to be sandy, incoming precipitation can readily infiltrate the soil. While the clays below the sandy horizons are less permeable, the precipitation, once in the soil, is held and allowed to slowly percolate downward instead of being lost as runoff.

Figure 1 shows maximum moisture contents of about 18 to 22 percent at depths of 0.5 foot. This corresponds with a suction of about 1/3 to 1 bar for Savannah soils and 1/3 bar for Ruston soils. Minimum values for moisture at a depth of 0.5 foot are about 10 percent, which could represent a suction of anywhere between 1 and 15 bars due to textural variability of soil samples used to construct the moisture retention curves. Minimum moisture contents at 1.5 feet were about 20 percent, or approximately 1/3 to 1 bar. Moisture contents at depths below 2.5 feet were near field capacity year-round.

Moehring (1966) found that loblolly pine growth slows considerably as soil water potential gets below 0.5 bar, stopping growth for most trees at 3 to 4 bars. But while soils at depths of 0.5 foot dried to the point of water stress during this study, loblolly pine has been shown to remove large quantities of water to depths of six feet during drought (Hoover et al. 1953). It would seem that although trees were stressed in the upper foot of soil, the abundant supply of moisture at greater depths would indicate that soil moisture was not limiting. However, during these periods of low soil moisture, water use also decreased, meaning tree growth was not being maximized even

though soils below 2.5 feet were near field capacity.

CONCLUSIONS

Plots heaviest thinned had significantly more water in the upper eight feet of the soil profile than controls. Correspondingly, loblolly pine diameter growth was greatest. No differences were found in height growth, live crown ratio change, or hardwood understory sprout growth on thinned plots.

Several soil moisture patterns were observed. Soil moisture depletion was in progress when measurements began in March and generally declined during the growing season, reaching its lowest levels in mid-November. During the growing season, large storms could recharge upper soil horizons to near field capacity. Annual soil moisture recharge began at the end of November and was rapid. Soils under all treatments recharged to approximately the same level in the winter.

Biweekly soil moisture fluctuations were greatest in the surface foot of soil and decreased with increasing depth in the soil profile. In addition, soil moisture generally increased with increasing soil depth.

No differences were found in water use among treatments. Maximum water use averaged between 0.23 and 0.26 inch per day. Plots heaviest thinned used more water per tree than lightly thinned plots.

Soil moisture throughout much of the year was favorable to tree growth, particularly below 2.5 feet. However, moisture in the upper foot of soil dropped low enough to be limiting to tree growth several times during the growing season, illustrating the importance of an even distribution of rain for soil moisture recharge.

This research identifies the importance of soil water to tree growth and in doing so has important implications for thinning. While thinning to 200 TPA was excessive by conventional standards, water use was equal to that of heavier stocked plots. In addition, soil water dropped low enough to be limiting to tree growth as early in the growing season as March. Problems of water stress were predominantly in the upper foot of soil. Since this is the area of greatest root concentration for both pine and competing hardwoods, thinning would be more effective if conducted in conjuction with hardwood control and manipulative measures aimed at improving water infiltration and retention in the upper soil horizons.

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IS PRECIPITATION A USEFUL VARIABLE IN MODELING DIAMETER GROWTH OF YELLOW-POPLAR?[1/]

Donald E. Beck[2/]

Abstract.--Diameter growth of yellow-poplar (Liriodendron tulipifera L.) was highly correlated with precipitation during portions of the growing season. Rainfall for July, measured on site, accounted for up to 98 percent of year-to-year variation in mean radial increment at five locations in the Southern Appalachians. However, correlations of increment with published records of rainfall measured at the closest National Weather Service climatological station were weak and not statistically significant. The sparse network of weather stations and highly variable rainfall patterns limit the usefulness of published weather records in growth modeling.

Annual diameter growth of trees frequently varies widely from year to year and place to place in ways that appear unrelated to stand and site conditions. Efforts at modeling radial growth with stand and site factors often account for half or less of the total variation. It has been shown for a number of species that ring width varies with several weather-related variables, particularly growing season rainfall. In the Southern Appalachians, rainfall is extremely variable and could account for some of the observed variations in growth. Adjustment of growth data for weather conditions could improve growth projections as well as models of the real effects of site, stand, and treatment variables.

The objectives of the study described here were (1) to quantify the relationship of radial growth of yellow-poplar to growing season rainfall measured on-site, and (2) to determine the suitability of published records from the closest National Weather Service (NWS) climatological station as a substitute for on-site measurements.

METHODS

The study was conducted in the Southern Appalachians south of Asheville, N.C. Standard rain gauges were installed in five yellow-poplar stands that contained long-term growth plots (Beck and Della-Bianca 1970). Precipitation was measured weekly for 5 years, except for some periods in December and January when access was limited due to ice and snow. Elevation of the study locations ranged from 2,750 to 2,800 feet. Soils were deep colluvials, mostly of the Tusquitee series with concave surface shape on slopes of 20 to 30 percent. Soils were deep (in excess of 55") with A horizons of 10 or more inches. Textures were predominantly loams with some light clay-loams in B horizons. Available water in the top 20 inches of soil ranged from 3.2 to 4.2 inches.

Increment cores were taken from 635 trees on the permanent growth plots at the five locations in order to measure annual growth during the 5 years in which precipitation was observed. In addition, dendrometer bands were installed on 20 trees at each location and read weekly during two growing seasons to establish seasonal growth patterns.

Additional rainfall records were obtained from the permanent NWS station at the Bent Creek Experimental Forest headquarters (BCHQ). This station's elevation is 2,200 feet. The five growth locations are 2.1 to 8.4 miles southwest of the NWS station.

Correlation and regression analysis, together with extensive plotting of the data, were used to examine the relationships between annual radial growth and various expressions of precipitation.

1/ Paper presented at Third Biennial Southern Silvicultural Research Conference, Atlanta, GA, November 7-8, 1984.

2/ Principal Silviculturist, USDA Forest Service, Southeastern Forest Experiment Station, Asheville, NC.

RESULTS AND DISCUSSION

On-Site Analysis

Seasonal growth trends for all trees combined are shown in figure 1. Growth began in very late April and was completed in early September. Two-thirds of total growth occurred in June and July, and 80 percent of annual growth was completed by the end of July. Based on these observations it seems logical that moisture relationships from late spring through midsummer would be most important.

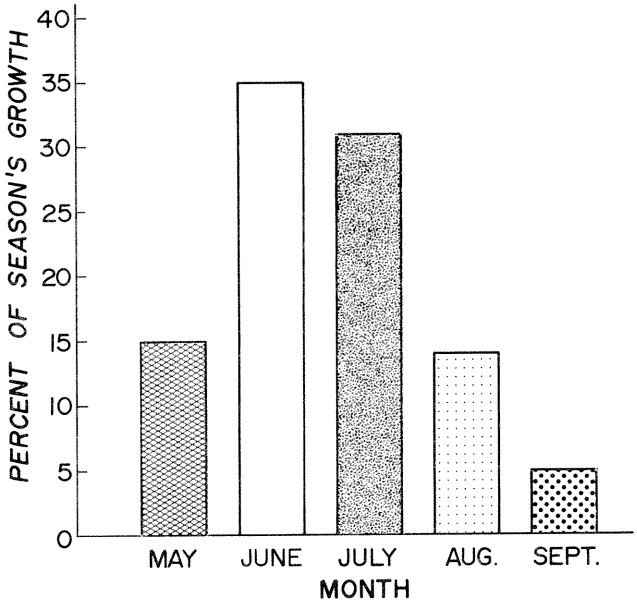

Figure 1.--Distribution of seasonal growth.

Simple correlations were determined between mean radial increment at each location and precipitation by individual months and combinations of months preceding and during the growing season. Seasonal totals of precipitation and partial seasonal totals that have been isolated in other studies were surprisingly nonsignificant. The only consistently significant correlation was for July rainfall. The linear model

$$\text{Increment} = b_0 + b_1 \text{ (July rainfall)} \quad \text{(equation 1)}$$

was fit to the data by station. With the exception of location 1, July rainfall accounted for a majority of year-to-year variation in mean radial increment (table 1). Examination of residuals for location 1 showed that deviations from the regression could be explained by the pattern of June rainfall. Apparently June rainfall becomes important when high June rainfall is coupled with low rainfall in July. If, however, July rainfall was normal or above, June rainfall had little effect on growth. Incorporation of this information into the model

$$\text{Increment} = b_0 + b_1 \text{ (July rainfall)} + b_2 \left[\frac{\text{June rain}}{\text{July rain}}\right] \quad \text{(equation 2)}$$

resulted in dramatic improvement in the fit for location 1 (table 1). There was slight, but nonsignificant, improvements at the other four locations.

Table 1.--Coefficients of determination (R^2), mean square error (MSE), and coefficient of variation (CV), for increment regressions

Location and statistic	Model 1	Model 2	Model 3
Station 1			
R^2	0.3115	0.9782	0.4015
MSE	.0080	.0017	.0091
CV	10.51	2.29	12.00
Station 2			
R^2	.8851	.8144	.4729
MSE	.0028	.0055	.0075
CV	2.96	5.64	7.77
Station 3			
R^2	.9769	.9868	.4735
MSE	.0011	.0010	.0054
CV	1.46	1.35	6.96
Station 4			
R^2	.8221	.9566	.6020
MSE	.0086	.0053	.0131
CV	8.23	5.10	12.60
Station 5			
R^2	.7912	.8813	.4982
MSE	.0065	.0062	.0103
CV	6.71	6.34	10.64

The demonstrated relationship between increment and rainfall can be logically explained in terms of available moisture during the period of growth. Consider figure 2, which compares Thornthwaite's (Thornthwaite and Mather 1955) monthly Potential Evapotranspiration (PE) to precipitation under normal conditions in the study area. Under normal circumstances, precipitation substantially exceeds PE until the month of June. Even under the driest condition during the 5-year study period, rainfall exceeded normal PE in late spring so that soils were fully charged going into the period of rapid growth in June. Given the relatively large water-holding capacity of the deep soils involved, level of rain in June had little effect on growth during June. If July rainfall was adequate, the amount of June rainfall had little effect on seasonal growth. On the other hand, high June rainfall resulted in fully charged soils going into July and was able to compensate somewhat for low rainfall in July.

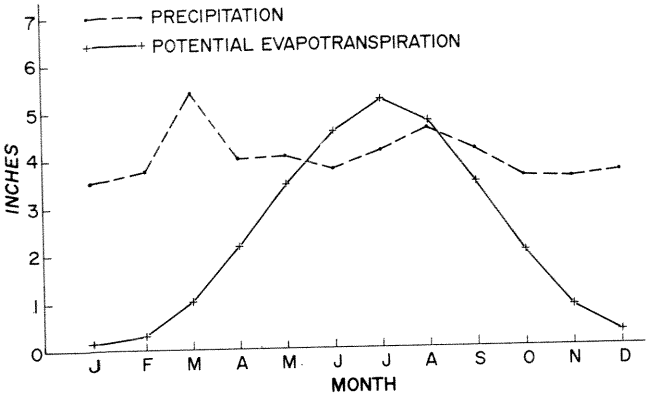

Figure 2.--Normal precipitation and evapotranspiration for the general study area.

August rainfall was of little consequence. In fact, the highest August rainfall occurred in the year of minimum increment. By August, water demands have slackened and the proportion of seasonal growth occurring in August is small.

Total precipitation for the growing season--May through August, was very poorly correlated with increment. High seasonal totals inflated by high rainfall in June or August occurred in years when increment was lowest. This finding is contrary to that reported by Tryon et al. (1957) for yellow-poplar in West Virginia; they found that seasonal totals which included both June and August were highly correlated with radial increment.

Nearest NWS Station Analysis

In growth model development, are records from the nearest NWS station a reasonable substitute for on-site records? In table 1, model 3 was obtained by substituting NWS records from BCHQ for on-site measurements. In all cases, the equations are substantially poorer than those developed from on-site measurements.

As can be seen from table 2, July rainfall at BCHQ is poorly related to rainfall at the five study locations. It is evident that BCHQ is not a good index of rainfall trends at any one location from year to year. It can also be seen that the axiom that rainfall increases by a set amount for each increment in elevation is not tenable for these data. All five locations were at about the same elevation, but their rainfall differed considerably. Relationships developed on broad averages by year and place apparently apply poorly to short time periods and specific locations.

Table 2.--July rainfall for study locations and weather station (BCHQ)

Location	Year 1	2	3	4	5
	Inches				
1	6.09	4.78	2.46	2.45	1.31
2	9.15	5.91	3.90	1.84	2.27
3	7.96	5.10	3.52	2.46	2.01
4	9.46	6.28	6.12	5.89	1.97
5	9.65	6.19	6.39	5.97	1.47
BCHQ	4.28	4.13	4.87	1.36	1.34

SUMMARY AND CONCLUSIONS

Annual radial increment of yellow-poplar at five locations in the Southern Appalachians was highly correlated with July rainfall and the quotient of June to July rainfall. The demonstrated relationship is biologically reasonable in terms of moisture balance during periods of growth accumulation. The caveat is that rainfall was measured on-site. Incorporation of this increment-rainfall relationship in growth modeling should improve parameter estimates and growth projections. One should be aware, however, that the relationship developed is time-, place-, and species-specific. Other situations may well require vastly different models. This conclusion is evident from the range of models that have been developed in the past.

Rainfall at a nearby NWS climatological station proved to be a poor substitute for on-site measurements. Rainfall at the NWS station was not indicative of that at the five study locations, and correlations with radial increment were not significant. Highly variable rainfall patterns and the thin network of permanent weather stations limit the usefulness of published records in growth analyses. If the demonstrated relationships between increment and rainfall are to be used in growth modeling, there will have to be better algorithms developed to estimate rainfall distribution or stations will have to be established at study locations.

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NUTRIENTS IN STORM RUNOFF FROM HARDWOOD-FORESTED WATERSHEDS IN THE OZARK HIGHLANDS[1/]

Edwin R. Lawson

Thomas L. Rogerson

and

Leslie H. Hileman[2/]

Abstract.--Nutrients in storm runoff from five forested watersheds in the Ozark Highlands of Arkansas were monitored. One watershed was lightly thinned, one was moderately thinned, and three were left undisturbed. Nutrients or chemical properties monitored included: P, K, Ca, Fe, Na, NH_3-N, Mg, Mn, NO_3^-, COD, and HCO_3^-. Turbidity, pH, and specific conductance were also evaluated. Thinning treatments did not generally influence nutrient levels in runoff.

INTRODUCTION

Forested areas are generally the sources of the nation's highest quality water (Corbett, et al 1978; Douglass 1974; Stone 1977). The chemical and physical properties of water coming from these areas are the result of natural and man-made factors. Even without man's interference, variations in water quality occur largely as a result of variations in precipitation, vegetation, and soils. Man's activities in a watershed may affect all three of these factors (Douglass and Swank 1975; Stone 1977).

Nutrient levels in surface waters are becoming an increasingly important water-quality consideration in managing streams and lakes. Excesses of certain nutrients can greatly decrease the productivity of streams and lakes for aquatic organisms and/or create problems when water is used for municipal, industrial, or agricultural purposes. Excessive losses of nutrients in runoff from watersheds reduce the productive potential of soils for growing crops.

The objectives of this report are to present baseline data on nutrient levels in runoff from relatively undisturbed hardwood forests and from areas subjected to light and medium thinning treatments.

STUDY AREAS

The 5 watersheds used in this study are located in north-central Arkansas on the Henry R. Koen Experimental Forest south of Harrison, AR. They have aspects ranging from northeast to south and west. Three of the watersheds, WS-1, WS-2, and WS-3, are adjacent and are 5.17, 5.76, and 4.29 acres in size, respectively. The other two, WS-5 and WS-6, are 16.20 and 18.54 acres in size and are within 3/4 mile of the three smaller catchments. Hydrologic characteristics of WS-1, WS-2, and WS-3 were previously reported by Rogerson (1976). Elevations of the 5 watersheds range from approximately 1,000 to 1,525 feet and slopes are about 25 to 30 percent.

Summers are warm in the study area, with July temperatures averaging 78.6°F. Winters are moderately cold, with a January average temperature of 38.6°F. Mean annual temperature for the area is 58.3°F. The average growing season is about 190 days long, lasting from about April 15 to October 22. Long-term average annual precipitation for the region is about 45 inches (U.S. Department of Commerce 1982). Almost all of the precipitation is rain, but light

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1/ Paper presented at Third Biennial Southern Silviculture Research Conference, Atlanta, GA, November 7-8, 1984.

2/ The authors are, respectively, Supervisory Research Forester, Research Forester, Southern Forest Experiment Station, 830 Fairview Street, Fayetteville, AR, and Assistant Professor, University of Arkansas, Department of Agronomy, Fayetteville, AR.

snow usually falls a few times each winter. Precipitation is distributed fairly evenly throughout the year, although May and June have slightly greater amounts and December and January slightly lesser amounts than other months.

Soils in the watersheds were principally formed from limestone and cherty-limestone parent materials. Major soils include the Noark, Clarksville, Moko, and Arkana series (Fowlkes, et al 1985). Noark soils are classified as clayey-skeletal, mixed, mesic Typic Paleudults and have moderately permeable, well-drained, cherty silt loam surface soils. Clarksville soils are loamy-skeletal, siliceous, mesic Typic Paleudults and are deep, very cherty, somewhat excessively drained, and moderately permeable. They commonly occur on steep side slopes and ridges. Soils classified as Moko are loamy-skeletal, mixed, mesic Lithic Hapludolls and are well-drained, moderately permeable with very stony surface layers. Arkana soils are classified as very fine, mixed, mesic Mollic Hapludalfs. These soils are moderately deep and very slowly permeable soils that formed from cherty limestone parent material. The Noark and Clarksville series are the most common series on all 5 watersheds. The pH of the surface layers of the Noark and Clarksville soils ranges from 4.5 to 6.5. In the Moko and Arkana soils, the pH ranges from 6.6 to 7.8. Vegetative cover on these soils is usually trees or grasses, which may influence pH levels.

Overstory vegetation on the watersheds can be classified as mixed hardwoods and consists principally of white oak (Quercus alba L.), red oak (Q. Rubra L.), southern red oak (Q. falcata Michx.), black oak (Q. velutina Lam.), white ash (Fraxinus americana L.), various hickories (Carya spp.), and less frequently encountered black walnut (Juglans nigra L.), eastern redcedar (Juniperius virginiana L.), shortleaf pine (Pinus echinata Mill.), and black cherry (Prunus serotina Ehrh.). Primary understory species include dogwood (Cornus florida L.), ironwood (Ostrya virginiana Mill.), and various elms (Ulmus spp.).

Stems greater than 2.5 inches d.b.h. averaged 338 per acre on the three smaller catchments. About 50 percent of these stems were saplings (2.5 to 4.5 inches d.b.h.), 38 percent were pole timber (4.5 to 10.5 inches d.b.h.), and 12 percent were sawtimber (greater than 10.5 inches d.b.h.). Basal area averaged 91.0 ft^2/acre. Saplings accounted for 12 percent of the basal area, pole timber for 37 percent, and sawtimber for 51 percent. More than half the stems were oaks and they accounted for two-thirds of the basal area.

Two of the small catchments, WS-1 and WS-3, were thinned in May of 1979 to 60 percent and 40 percent relative stocking density (Gingrich 1967), respectively. Residual basal areas were approximately 60 square feet on WS-1 and 40 square feet on WS-3. Thinning was done favoring the higher-quality oaks as residual stems in both the over- and understories. Also, small, undesirable species were deadened with herbicide to reduce competition for the more desirable species. Smaller oaks were severed near the ground to provide sprout regeneration. Vegetation on WS-2, WS-5, and WS-6 was not disturbed.

STUDY METHODS

Field Measurements

Runoff from the 3 smaller watersheds (WS-1, WS-2, and WS-3) was measured using 2-foot H-flumes, while 3-foot H-flumes were used on WS-5 and WS-6. Depth of flow in the flumes was measured with FW-1 water level recorders and converted to volume. Nearly all of the runoff in these ephemeral flowing streams originates as subsurface flow.

One-liter water samples were automatically collected at stage heights of 0.05, 0.10, 0.20, 0.30, 0.50, 0.75, and 1.00 feet in the flumes. These stages represent, respectively, discharge rates of 0.01, 0.03, 0.11, 0.23, 0.62, 1.40, and 2.57 cubic feet per second for the 3-foot flumes and 0.007, 0.02, 0.08, 0.18, 0.51, 1.20 and 2.25 cubic feet per second for the 2-foot flumes. The technique developed by Sartz and Curtis (1967) allows sampling during the rising stages only and prevents purging after collection. Samples were usually, but not always, collected at the same stage heights in a given runoff-producing storm. Date of storm was recorded for each sample. Samples were picked up as soon as possible after each runoff-producing storm and were stored in a refrigerator or freezer until analyses could be performed.

Laboratory Analyses

All laboratory analyses and measurements were performed by the University of Arkansas Soil Testing Laboratory, using standard methods (U.S. Environmental Protection Agency 1976; American Public Health Association 1980). Analyses of all individual elements were not made throughout the entire study period due to lack of available analytical equipment or to insufficient quantity of water collected. Analyses were made on unfiltered samples.

The following determinations were made for each sample, except where sample quantities were insufficient: pH, iron (Fe), manganese (Mn), total phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), chemical oxygen demand (COD), hardness, ammonia nitrogen (NH_3-N), nitrate (NO_3^-), carbonate (CO_3^-), bicarbonate (HCO_3^-), specific conductance, and turbidity, All data are given in milligrams per liter (mg/l). Specific conductance is reported in µmhos/cm at 25°C, and turbidity is reported in nephelometric turbidity units (NTU).

Statistical Analyses

The water sample data were summarized in two groups relating to time periods, the first of which extended from 1973 to early 1979 (the pretreatment

period) and the second of which extended from 1979 into 1982 (the posttreatment period). These groups were analyzed separately because they represented the break point between the pretreatment data and that collected following the 1979 treatments being evaluated in this study. Data sets from both groups were combined to provide overall means if there were no significant differences attributable to variations among watersheds and seasons (months). There were laboratory analyses in the second group that could not be performed earlier due to lack of equipment.

The experimental design called for a split-plot in-time analysis, but an alternative analysis was used because of unbalanced data. Thus, statistical analyses should be regarded as approximate. The statistical analyses were performed using the General Linear Models Procedure provided by Statistical Analysis System Institute, Inc. (1979). Each of the measured factors was considered to be the dependent variable in the analyses. The model included watershed; month that samples were collected, which are fixed factors; and the watershed-month interaction. Data from each storm runoff event provided replication. The analysis of variance provided "F" values and significance probability for the model and its sources of variation. Only statistical probabilities of 0.01 or less were considered significant in all tests. Differences between means were tested using a least significant difference procedure for unequal replication (Steel and Torrie 1960).

RESULTS AND DISCUSSION

Several factors affecting interpretation of results should be kept in mind. First, due to precipitation patterns, there may be little or no runoff from these ephemeral streams in a given month compared with the same month in another year. A similar variation among seasons and years is characteristic of runoff patterns. Second, there are some inherent differences in runoff response among watersheds that affect sampling frequency. Watersheds WS-3 and WS-5 provided the largest number of runoff samples. Third, antecedent soil moisture affects the amount of runoff and therefore the amount of leaching that takes place in response to a storm. Thus, previous leaching may cause changes in nutrient concentrations or other chemical and physical properties of storm runoff. Nutrient release is known to be affected by soil moisture and soil temperature (Pritchett and Wells 1978).

The rather high variations in data, due to previously mentioned factors, tended to mask any potential changes in nutrient levels associated with the thinning treatments. Analyses of pretreatment data often showed significant differences among watersheds, seasons (months), and the watershed-month interaction. Where there were no differences among watershed means, or where pretreatment means were significantly different, averages of all data were calculated for the 1973-1982 or other applicable time period (Table 1).

Table 1.--Average nutrient concentrations in runoff from Ozark watersheds (1973-1982)

Nutrient	WS-1	WS-2	WS-3	WS-5	WS-6
Fe	0.32	0.25	0.38	0.40	0.23
Hardness	75.33	74.81	111.66	89.41	100.13
Mn	0.05	0.05	0.06	0.05	0.04
P	0.26	0.26	0.17	0.24	0.25
K	2.93	1.89	1.51	1.69	1.61
Ca	18.40	17.48	31.75	16.48	32.16
Mg	0.15	0.18	0.13	0.20	0.16
Na	0.79	0.54	0.72	0.76	0.77
COD[1/]	5.88	12.10	8.66	7.89	6.68
NH_3-N[2/]	0.81	1.03	0.81	0.69	0.53
NO_3^-[3/]	2.50	2.16	1.82	2.14	2.06
HCO_3^-[3/]	49.46	40.58	82.31	53.45	99.18

[1/] Based on 1973-1975 data.
[2/] Based on 1975-1982 data.
[3/] Based on 1977-1982 data.

Most of the nutrient values were relatively low and were similar to those from the Ouachita Mountain Region of Arkansas (Lawson and Hileman 1982). Considerable variation in mean nutrient levels occurred among watersheds (figs. 1, 2, and 3).

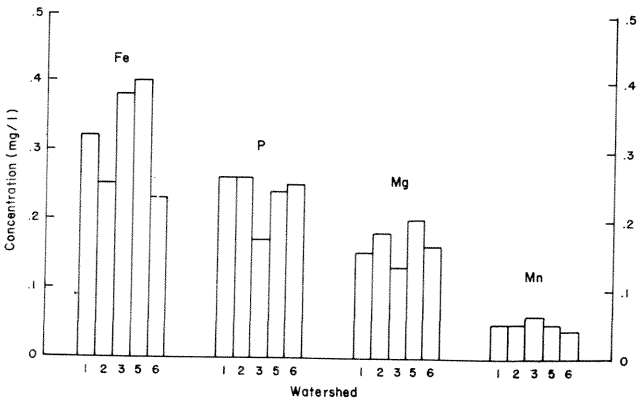

Figure 1.--Average concentrations of Fe, P, Mg, and Mn in runoff from Ozark watersheds

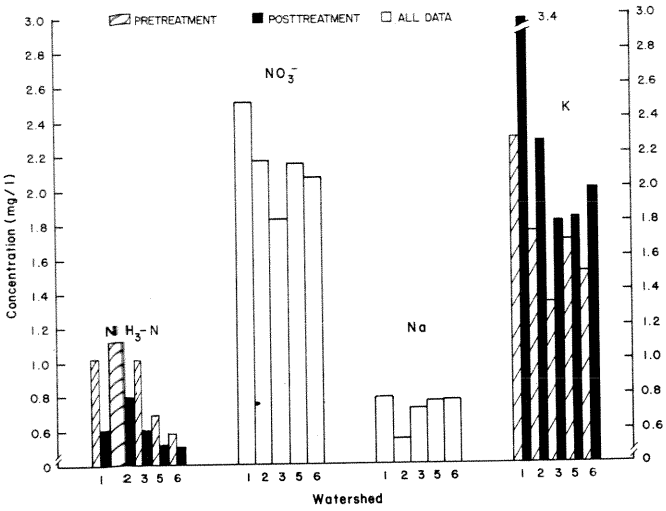

Figure 2.--Average concentrations of NH_3-N, NO_3^-, Na, and K in runoff from Ozark watersheds

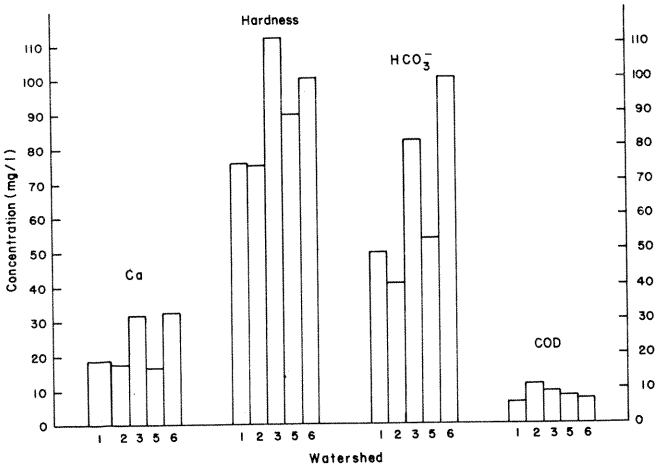

Figure 3.--Average concentrations of Ca, hardness, HCO_3^-, and COD in runoff from Ozark watersheds

Watershed WS-3 tended to have lower Mg and P levels, while WS-3 and WS-5 had higher Fe levels. Manganese and Na concentrations were similar among watersheds. Watersheds WS-3 and WS-6 had the highest levels of Ca, bicarbonate (HCO_3^-), and total hardness. These differences are believed to reflect variations in soil parent materials in the watersheds. Watershed WS-6 especially has a substantial area of Moko soils in the lower part of the watershed with some outcrops of limestone. These soils are known to have higher pH levels in the upper horizons (Fowlkes, et al 1985). High bicarbonate levels are consistent with the mineralization of limestone. The more unstable CO_3^{--} was not detected in analysis of numerous samples. The levels of HCO_3^- found in this study are higher than those reported by Lawson and Hileman (1982) and Lewis and Grant (1979). Nitrate (NO_3^-) levels were significantly different among watersheds and months, with a significant interaction between the two factors. Watershed WS-3 (heavy thinning) had the lowest level while WS-1 (moderate thinning) had the highest level of NO_3^-. These concentrations were slightly lower than those found in the runoff in the Ouachita Mountains (Lawson and Hileman 1982).

Ammonia nitrogen (NH_3-N) varied significantly among watersheds during the posttreatment period, with WS-2 having the highest level at 0.78 mg/l. Differences before treatment were larger and not significant, but were based on fewer samples. The posttreatment differences among watersheds appear to be due to inherent characteristics of runoff rather than to the effects of thinning. Organic matter and vegetation differences could be influencing nitrogen and COD levels. The COD levels were somewhat higher on WS-2 than on the other watersheds.

Potassium showed significant differences among watersheds during the posttreatment period, but not during the pretreatment period (fig. 2). However, the response does not appear to be the result of thinning since the lightest thinning had the highest level of all watersheds. A significant difference among months was also found, but it was judged to be more the result of sample frequency differences rather than true seasonal effects.

Some nutrients in runoff were found to vary significantly among months of the year, thus showing seasonal trends. Iron concentrations in runoff were highest in February, decreasing to a low in summer and increasing in early winter (fig.4).

Figure 4.--Seasonal changes in average Fe concentration in runoff from five Ozark watersheds (1973-1982)

Manganese varied significantly among months with the highest levels in March and October and the lowest levels in July and January (fig. 5). The lower summer levels may be the result of lower solubility during periods of low soil moisture.

The pH of runoff varied significantly among watersheds during the pretreatment period (1973-1979), but not during the posttreatment period.

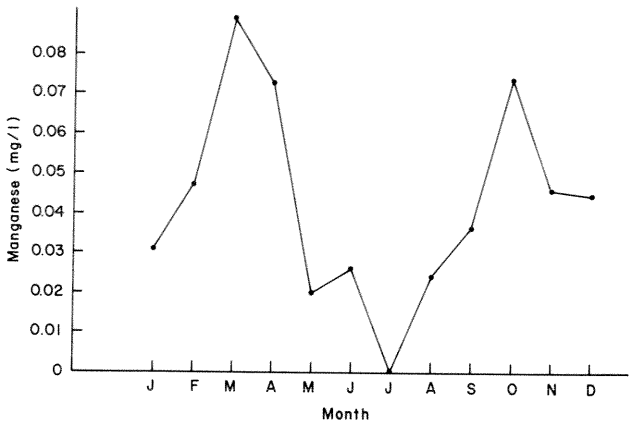

Figure 5.--Seasonal changes in average Mn concentrations in runoff from five Ozark watersheds (1973-1982)

Watersheds WS-1 and WS-2 had the lowest mean pH while WS-3 and WS-6 had the highest levels. The highest pH levels on WS-3 and WS-6 are consistent with the greater Ca, hardness, and HCO_3^- concentrations previously discussed. The higher pH levels in runoff from WS-3 and WS-6 also reflect differences in soils on the watersheds. Significant differences among months were found to occur in both periods. Combined data showed that the highest pH levels occurred in late winter and the lowest levels in late summer (fig. 6).

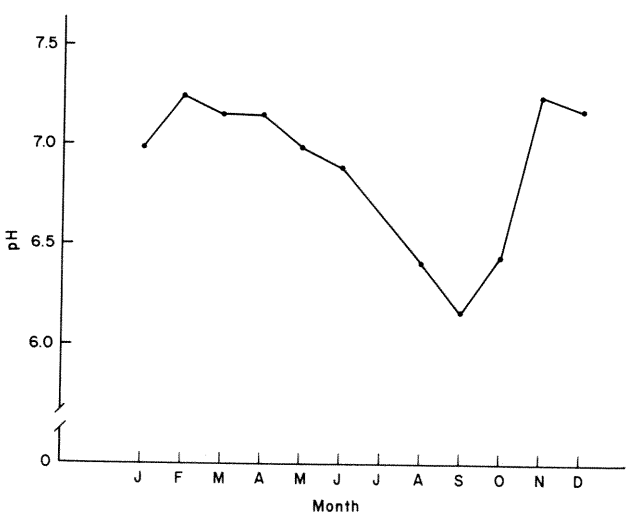

Figure 6.--Seasonal changes in average pH of runoff from five Ozark watersheds (1973-1982)

Soil pH levels are known to show seasonal trends (Keogh and Maples 1972). Runoff from forested areas generally occurs as lateral flow in the upper porous soil layers and rarely as overland flow. Thus, changes in soil chemical properties are likely to be reflected in corresponding changes in the properties of runoff water. The number of storm events, especially runoff events, is usually lower during the late summer and early fall, resulting in less leaching of soils. Organic matter in soils would likely be lowest in late summer and early fall, with accumulation beginning in the fall followed by increased weathering as soil moisture levels increase.

Specific conductance values from the 5 watersheds showed large variation during the pre- and posttreatment periods (Table 2).

Table 2.--Average pH, specific conductance and turbidity of runoff from Ozark watersheds

Item	WS-1	WS-2	WS-3	WS-5	WS-6
pH[1/]	6.81	6.78	7.11	7.01	7.16
Conductance[2/] (µmhos/cm)	114.9	83.5	166.1	110.0	187.6
Turbidity[3/] (NTU)	17.5	23.2	20.4	36.5	12.7

1/ Based on 1973-1982 data.
2/ Based on 1975-1982 data.
3/ Based on 1977-1982 data.

Watersheds WS-3 and WS-6 had the highest specific conductance levels and WS-2 the lowest. The differences are apparently not related to the thinning treatments since watershed means were found to follow the same pattern during both periods. Specific conductance is probably reflecting the greater mineral content, particularly Ca, HCO_3^-, and total hardness, in runoff. The specific conductance values from these watersheds are much higher than those found in the Ouachita Mountains, where sandstone and shale parent materials prevail.

Data on turbidity of runoff was too limited during the posttreatment period to show valid treatment effects. Analyses of the data for the 1977-1982 period showed significant differences among watersheds and months. Turbidities from undisturbed WS-5 were highest while those from WS-6 were lowest (Table 2). Turbidity levels in runoff showed significant seasonal trends (fig. 7). The January NTU value of 9.0 was based on only four samples and was not included on the graph. The highest turbidity levels were reached in early winter and declined from late winter to late summer. These seasonal trends are believed to reflect the increased storm runoff patterns in late fall and early winter which would tend to erode loose materials, especially in stream channels. The fact that turbidities are affected by other impurities, such as organic matter, should be kept in mind when assessing results.

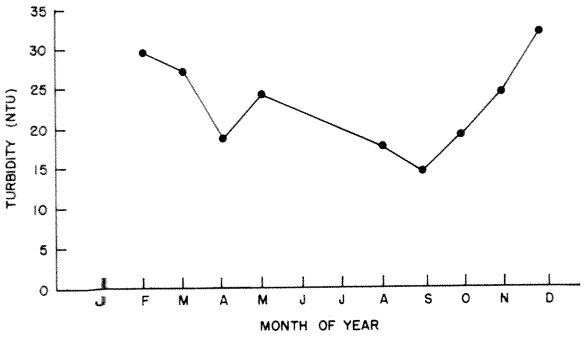

Figure 7.--Seasonal changes in average turbidity of runoff from five Ozark watersheds (1977-1982)

SUMMARY

Much of the nutrient data tended to be highly variable, thus requiring greater differences or more samples to be significant. Nutrient levels in runoff are naturally highly variable, due to the complex interactions affecting their presence. In this study, differences in nutrient levels due to the thinning treatments were not discernible because of natural differences in watersheds or because of strong interactions between watersheds and seasonal effects. Only K and NH_3-N showed significant differences among watersheds during the posttreatment period, but these were judged to be the result of catchment characteristics rather than treatment effects because undistrubed areas or the lightly thinned watershed had the greater levels. In New England, Martin, et al (1984) found that even clearcutting generally resulted in small differences in stream chemistry when compared to uncut watersheds representing a wide variety of soils and forest types.

Iron, Mn, pH, and turbidity in this study showed seasonal differences, with levels generally being lowest during late summer and early fall and highest during winter and spring months.

Overall levels for most nutrients in runoff from the 5 watersheds were generally within the range of those reported in other areas (Douglass and Swank 1975; Hewlett 1979; Lawson and Hileman 1982; Peterson and Rolfe 1982). However, some nutrient levels and chemical characteristics such as Ca, HCO_3^-, and specific conductance reflected geologic conditions in the area.

The baseline data provided in this study will be useful for estimating nutrient yields and other chemical and physical properties of runoff from similar watersheds within the geologic region.

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HYDROLOGIC EFFECTS OF COMPLETE AND CONVENTIONAL HARVEST OF LOBLOLLY PINE BIOMASS[1/]

S. J. Ursic[2/]

Abstract.--Loblolly pine plantations were established on four small calibrated catchments to determine their effect on stormflow volumes and sediment yields. They were clearfelled with minimum site disturbance during their 16th field-growing season. Harvesting treatments included two replicates of removing the above-ground biomass and of removing only the merchantable stems. Statistical comparisons of stormflow volumes as the pine developed and after harvest were based on calibrations developed with control catchments before the pine was planted. Stormflow volumes for two catchments of pine formerly in depleted hardwoods were decreased an average of 83 percent after plantation ages 12 or 13. As much as half of the decreases were retained during the 2-year postharvest period. For two catchments of pine established on more severely-eroded old-fields, decreases of stormflow volumes, averaging about 50 percent after pine age 8, were largely attributed to increased interception of rainfall by the pine. After harvesting, stormflow volumes for these catchments returned to, or exceeded, preplanting levels. The erosion-history of the catchments overshadowed any differences due to the harvesting options. The developing pine on all catchments reduced sediment concentrations and yields to base levels, and postharvest increases of sediment concentrations at the gaging points were short-lived. However, with increases of rates and volumes of flow after harvesting, part or all of the improvement of water quality in downstream sand channels achieved by the pine was probably nullified. Except for a slight increase in potassium export in stormflows, chemical water quality was unaffected. Pole-size loblolly plantations established on eroded hilly Coastal Plain sites can be harvested with minimum impact on chemical water quality and site productivity. But such plantations, especially those planted on severely-eroded old-fields, are not candidates for early clearfelling where reductions of downstream sediment concentrations to improve water quality and decreases in stormflow volumes to reduce small-area floods are important.

INTRODUCTION

Three developments of national concern prompted the research reported in this paper. The energy crisis focused attention on forest biomass as an energy source. The National Forest Management Act mandated that national forests would be managed to maintain and improve site productivity. A corollary legislated

1/ Paper presented at Third Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

2/ Principal Research Hydrologist, USDA Forest Service, Southern Forest Experiment Station, Forest Hydrology Laboratory, Box 947, Oxford, MS 38655.

concern was the protection and improvement of the quality of the Nation's waters (Public Law 92-500).

The research sought to determine the effects of total harvest of the above-ground tree biomass of southern pine (hereafter, complete harvest), and of conventional clearcut harvest or removal only of merchantable stems (conventional harvest). Hydrologic behavior including stormflow volumes, sediment concentrations and yields, and chemical water quality was evaluated during the development of the pine and after harvest. Effects on site productivity were surmised.

STUDY AREA

Three small contiguous catchments with poor-quality hardwoods and three abandoned-field catchments with a grass-forb cover were instrumented in 1958, planted to pine in 1964, and harvested in 1979. Pertinent characteristics of these northern Mississippi, Coastal Plain sites are summarized in table 1.

The silt-loam soils, mapped primarily in the Providence series (fine, silty, mixed thermic, Typic Fragiudalfs), were developed in loess deposits on ridge tops and upper slopes. The loessial soils grade into Ruston sandy loam (fine, loamy, silicious, thermic, Typic Paleudults) on the mid-to-lower slopes.

Providence soils have a fragipan that perches water during the dormant wet season. Due to past erosion of the catchments, the pan is closer to the soil surface than its original depth of 18 to 24 inches. Water-storage opportunity in the soil profile above the pan is a major factor in determining the occurrence and magnitude of stormflows, especially for the more severely-eroded old-field catchments.

Prior to treatment, vegetative cover on the abandoned fields consisted primarily of bluestem grasses (Andropogon spp.), whose ground-level basal area covered an average of 14.5 percent of the three catchment areas.

The hardwood cover at the time of initial treatment consisted largely of post oak (Quercus stellata Wangenh.), hickories (Carya spp.), and blackjack oak (Quercus marilandica Muenchh.). The completely inventoried stands contained an average of 215 trees per acre larger than 0.5 inch d.b.h.; half the trees were cull. Basal area per acre averaged 52 square feet, 23 square feet of which were cull.

TREATMENT

Two of the three catchments in each cover type--hardwood and abandoned-field--were initially treated in December 1963. Treatment of the two hardwood units consisted of a slow backfire followed by under-planting loblolly pine (Pinus taeda L.) at a 6x6-foot spacing. The hardwood overstory was treated in May 1964 by injecting undiluted 2,4-D amine into the bases of all stems 1 inch d.b.h. and larger. Remaining stems were cut and the stumps mopped with a mixture of 2,4-D and 2,4,5-T in diesel fuel in early June 1964. Treatment of the two old-field catchments consisted of a hot backfire in December 1963. Loblolly seedlings were planted on the four treated catchments in March 1964.

Burning in these studies was an ancillary treatment. The burning effects could be isolated because the planted pine had negligible hydrologic influence during the first few years. The hypothesis was that burning would increase stormflow volumes while the postulated long-term effects of planting pine would be decreased flows. Instrumentation, the details of the stormflow analyses, and results of the initial treatments have been reported (Ursic 1969, 1970). Stand descriptions of the plantations after 15 field-growing seasons are given in table 2.

Table 1.--Physical characteristics of study catchments

Original cover type	Treatment	Drainage area	Soils: Loessial	Soils: Coastal Plain	Range in elevation
		Acres	Percent	Percent	Feet
Grass	None (Control)	2.62	64	36	44
	Complete harvest	2.65	100	0	37
	Partial harvest	2.43	25	75	49
Hardwoods	None (Control)	2.56	65	35	49
	Complete harvest	2.12	34	66	58
	Partial harvest	2.13	100	0	44

Table 2.--Descriptions of the 15-year-old loblolly pine plantations

Catchment	Height	d.b.h.	Trees per acre	Basal area[1/]	Volumes
	Feet	Inches	Number	Ft^2/acre	Rough cords
History--Old fields					
Sandy loam	41	5.4	1,077	171 (148)	30
Silt loam	42	5.3	1,044	163 (147)	30
History--Hardwoods					
Sandy loam	42	5.4	1,037	163 (148)	30
Silt loam	43	5.6	906	147 (129)	26

1/Five-inch d.b.h. class and larger in parentheses.

The pine stands were harvested during their 16th growing season. The four catchments were clearcut and the slash treated between mid-June and the end of October. All stems were cut with a chain saw, delimbed, cut into bolts, and loaded on bob-tailed trucks. On the conventional-harvest catchments, the slash was chipped using an electric power company chipper and was uniformly distributed. Slash on the complete-harvest catchments was removed. The objective was to include the extremes of removing all slash and of leaving all slash; but, because of rapid drying and breakage, some of the foliage and small branches were left onsite so that the complete-harvest treatment was not as complete as intended.

The harvested catchments were replanted with loblolly pine without further site preparation and hydrologic measurements continued for about 2 years when 4 of the 6 catchments, including the old-field and hardwood controls, were destroyed by road construction.

ANALYSES

The paired catchment approach was used for analyses of individual stormflow volumes and their characteristics (Ursic and Popham 1967). The performance of each of the two treated catchments in each study was compared to that of a common undisturbed control catchment by covariance analyses. Details of the stormflow, interception, and other analyses for the first 15 years after pine was established on the hardwood-history catchments have been reported (Ursic 1982). Results for these catchments reported here are slightly revised due to the addition of data collected during part of the 16th year before harvest.

An initial objective of the research was to determine the effects of establishing pine on stormflow volumes. Reduction of flood flows was and still is an important problem in northern Mississippi as it is over much of the hilly Coastal Plains. While it is possible to compare the postharvest results with calibrations developed for the last discrete periods before harvesting the pine, I chose to make all comparisons with the original calibrations, i.e., when the respective catchments had hardwood or grass cover. This approach will allow me to address three questions. First, "What were the effects of establishing pine?"; second, "What were the effects of the clearfelling treatments?"; and lastly, "How did the postharvest performances compare to those of the original hardwood and grass covers?".

Although replication of the two harvesting treatments is implied, i.e., biomass on the four catchments was similar, treatments were confounded by soil differences and, as will be shown, especially by the prestudy history.

Chemical-water-quality and sediment-nutrient data were subjected to analysis of variance and t-tests. All statistical comparisons in the study were at the 0.05 level of confidence. Changes in sediment concentrations and yields during the full course of the study were generally distinct, and comparisons were of ratios and means. Site and vegetation variables were measured periodically.

RESULTS AND DISCUSSION

Stormflow Volumes

Old-Field History Catchments

Complete-Harvest, Silt-Loam Catchment.--Stormflow volumes during plantation ages 9.5-15.5 decreased an average of 0.14 area-inch (AI) per storm (table 3). The reduction was best expressed as a constant for all events regardless of size. The reduction of 20.2 AI during this 6-year period was 42 percent of the flow predicted.

Stormflow volumes during the 2-year postharvest period increased 4.1 AI and represented a 23-percent increase when compared to the original grass cover. Nine of 39 storms had significant increases averaging 0.55 AI and ranging up to 1.0 AI. These results, as for all catchments, are for what is probably minimum disturbance of the site during harvesting operations.

Conventional-Harvest, Sandy-Loam Catchment. Stormflow volumes decreased 7.0 AI during pine -- ages 9.5-15.5 for a reduction of 55.3 percent (table 3). Flow volumes were significantly less than expected for all events predicted to yield 0.25 AI or more with the reductions trending directly with stormflow size (fig. 1).

Stormflow behavior in the postharvest period reverted to levels measured during the time the catchment had a grass cover. The 1960-63 calibration and 1979-81 postharvest equations were almost identical. Clearly, all the flood prevention benefits achieved by the pine were lost during the 2-year postharvest period for both catchments with the old-field history.

Hardwood History Catchments

Conventional-Harvest, Silt-Loam Catchment.- Stormflow volumes gradually declined as the pine developed and decreased 20.4 AI during pine ages- 13-15.5 years, a 79-percent reduction from predicted (table 3). Volumes were significantly decreased for all events predicted to yield 0.25 AI or more. The reductions varied directly and positively with stormflow size and ranged up to 1.7 AI (fig. 2).

Compared to the original hardwood cover, stormflow decreases continued after harvest but were not as large. Volumes decreased 4.8 AI for a 41-percent reduction. Flows were significantly less than expected for all events predicted to yield more than 0.5 AI with decreases ranging up to 1.1 AI.

Complete-Harvest, Sandy-Loam Catchment.-- Total stormflow decreased 14.0 AI during pine ages 12-15.5, an 87-percent reduction from that predicted (table 3). Here, too, flows were significantly less than expected for all events predicted to yield 0.25 AI or more. Decreases varied directly with stormflow size and ranged up to 1.0 AI (fig. 2).

Stormflow reductions continued during the postharvest period. A total decrease of 3.9 AI represented a 58-percent reduction. All flows predicted to yield 0.25 AI or more were significantly decreased. The decreases continued to trend directly with stormflow size and measured up to 0.8 AI.

Overall, the erosion-history of the catchments had a greater influence than differences between the harvesting treatments. The maximum absolute reductions in annual and individual stormflow volumes were obtained by replacing hardwoods with pine on moderately eroded, silt-loam soils. Of importance to management for flood prevention is that maximum reductions of individual flows for moderately-eroded soils were twice as great as for similar but more severely-eroded soils.

Table 3.--Total changes of stormflow volumes

History--Hardwoods		History--Old Fields	
Pine age / Treatment	Changes $\sum(Y-\hat{Y})$ as percent of predicted 1/	Pine age / Treatment	Changes $\sum(Y-\hat{Y})$ as percent of predicted 2/
	SILT LOAMS		
13-15.5	-79	9-15.5	-42 3/
Conventional harvest	-41	Complete harvest	+23
	SANDY LOAMS		
12-15.5	-87	9-15.5	-55
Complete harvest	-58	Conventional harvest	+ 8 n.s.

1/Comparisons with 1958-63 calibrations.
2/Comparisons with 1960-63 calibrations.
3/Change in level. Adjusted difference 0.14 area-inch per event.

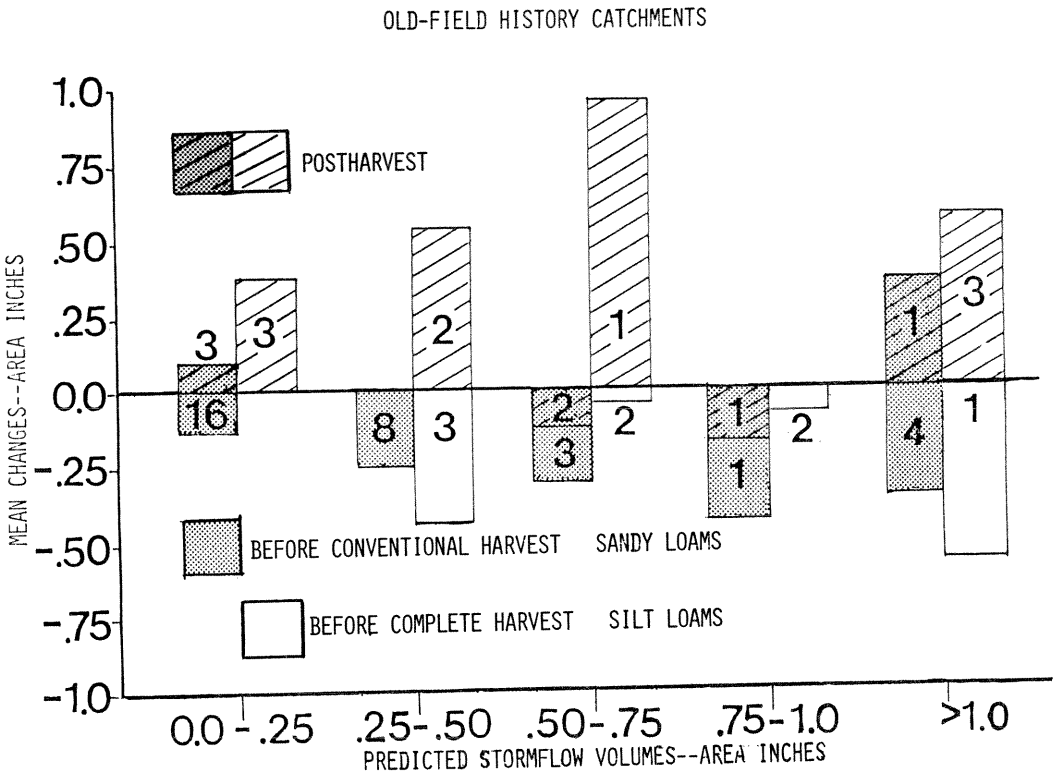

Figure 1.--Significant changes of stormflow volumes by size-class for pine plantations established on old-field catchments. Numerals on histograms indicate number of events.

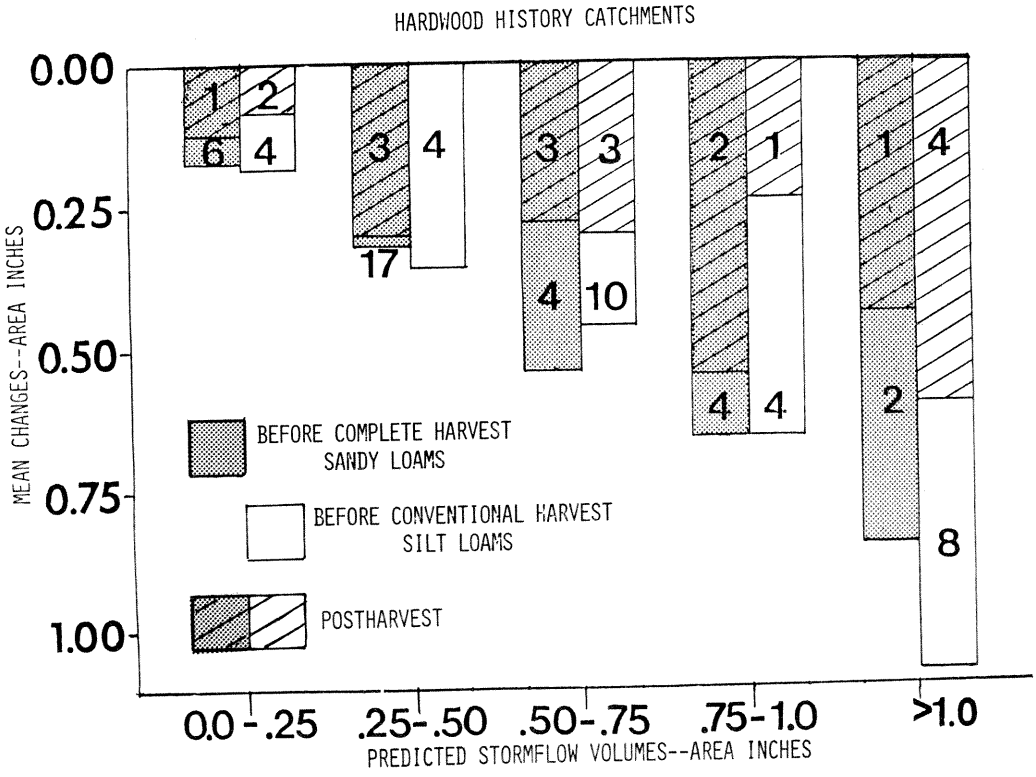

Figure 2.--Significant changes of stormflow volumes by size-class for pine plantations established to replace depleted upland hardwoods. Numerals on histograms indicate number of events.

Stormflow behavior of the hardwood-history catchments during the 2 years after harvest was comparable to that at pine ages 9 to 12 years during which total stormflow volumes were decreased about 60 percent. In contrast, stormflow behavior on the grass-history catchments reverted to the behavior before the catchments were planted to pine; i.e., all benefits were lost.

Interception Effects on Stormflow Changes

Old-Field History Catchments

During pine ages 9-15.5, increased interception of rainfall by the developing pine plantations could account for all the significant decreases of stormflow volumes from the sandy-loam catchment, and with a few exceptions those from the catchment of silt-loam soils. In the postharvest period, hydrologic behavior of the sandy-loam, conventional-harvest catchment reverted to old-field conditions. For the silt-loam, complete-harvest catchment, significant postharvest increases of stormflow volumes exceeded decreases of interception, indicating the additional effect of harvesting disturbance. Clearly this worst-case example of severely-eroded, silt-loam soils with restricted soil drainage emphasizes such sites are not candidates for early clearfelling where stormflow reductions are important.

Hardwood History Catchments

All significant decreases in stormflow volumes after plantation age 9 years for the sandy-loam catchment and age 12 for the silt-loam catchment were greater than the estimated increases in interception. During pine ages 12-15.5 years for the sandy-loam catchment and 13-15.5 years for the silt-loam catchment, decreases of stormflow volumes not attributed to interception accounted for 29 and 51 percent of the respective significant decreases totaling 13 and 18 area-inches. The latter figures represent 93 and 88 percent of the total stormflow volumes during these intervals.

During the postharvest period significant increases of stormflow volumes for the sandy-loam, complete-harvest catchment were all less than the decreases in interception. For the silt-loam, conventional-harvest catchment, three stormflow events in the first few months after harvest had increases in excess of interception decreases despite much of the slash remaining onsite. However, for all eight events with significantly increased flows totaling 3.5 AI, during the postharvest period, the decrease in interception could account for 3.3 AI. Thus, stormflow reductions not attributable to interception changes in the preharvest period were largely retained for both of the hardwood-history catchments during the postharvest period.

Sediment

Sediment is the most important threat to pollution of Coastal Plain waters. A liability in itself, sediment also accounted for about two-thirds of the phosphorus and nitrogen exported from the study catchments by water. Similar results were obtained from previous studies in the area (Duffy et al. 1978, Schreiber et al. 1980). In the context of water quality, sediment concentration is the most appropriate expression. Comparisons of concentrations and sediment yields were limited to complete data sets for the three catchments of each history.

Sediment Concentrations

Hardwood History Catchments.--Following moderate increases after burning, maximum reductions of sediment concentrations were achieved during the first 5 years after pine was established. Annual discharge-weighted concentrations for the two treated catchments averaged 0.006 and 0.007 ton/AI of flow during pine ages 5-15. These values conform to the 0.007 ton/AI previously postulated as the base-line level for small catchments of not-recently-disturbed southern pine types (Ursic 1977). The concentrations represent contributions from the forested slopes and channels. They do not include sediment which may come from roads or other sources.

Harvesting did not increase sediment concentrations from the complete-harvest, sandy-loam catchment. Postharvest concentrations for the conventional-harvest, silt-loam catchment increased 4-fold from the base-level, but much of the increase occurred during the first 2 months after harvesting was completed. Concentrations during the next year (calendar year 1980) fell to 0.009 ton/AI. Thus harvesting had only a slight and temporary effect on sediment concentrations for this catchment and none for the complete-harvest, sandy-loam catchment where the highest concentration for an event was only 0.008 ton/AI. Annual concentrations for the hardwood-control catchment during the full duration of the study averaged 0.018 ton/AI.

Old-Field History Catchments.--Compared to the calibration period, sediment concentrations for the old-field history catchments increased considerably during the first year after the hot burn. Concentrations for the silt-loam catchment increased from 0.004 to 0.063 ton/AI. A 44-fold increase from 0.01 ton/AI for the sandy-loam catchment was due to the reactivation of an old gully. The concentrations returned to calibration levels in 1 to 3 years. Concentrations averaged 0.001 and 0.002 ton/AI during pine ages 10-15, these very low rates being fostered by the healing of the channels and dense growth of honeysuckle in sections of the channels.

Sediment concentrations increased to calibration levels during the 2-year postharvest period with most of the increase due to higher concentrations during the first 4 months after cutting. Concentrations 4 months after harvesting fell to below 0.007 ton/AI. However, with rates and volumes of flow reverting to calibration levels, decreases of sediment concentrations in downstream sand channels achieved by the pine were probably nullified. Annual concentrations for the old-field control catchment during the entire course of the study averaged 0.032 ton/AI.

Sediment Yields

Sediment yields are the product of sediment concentrations and volumes of flow plus any sediment deposited in the approach section above the measuring flume.

Hardwood History Catchments.--The relationship of annual sediment production among watersheds was fairly consistent during the calibration years. Mean yields from the sandy-loam catchment (0.15 ton/acre) were approximately twice those from the control, while the yields from the silt-loam unit approximated those from the control. These ratios were applied to predict yields in the posttreatment years, and the increases were calculated as measured minus predicted values. Sediment yields from the complete-harvest, sandy-loam catchment increased for 2 years and then decreased about 90 percent during pine ages 4-15. Yields from the conventional-harvest, silt-loam catchment relative to the control roughly doubled for 3 years and then decreased about 70 percent during pine ages 4-15.

Harvesting did not increase yields from the complete-harvest, sandy-loam catchment. Due both to higher sediment concentrations and flow increases, it slightly increased yields from the conventional-harvest, silt-loam catchment. Considering the two catchments as part of the general landscape of sandy-and silt-loam soils, sediment yields during the approximate 2-year postharvest period averaged less than 0.1 ton/acre/year.

Old-Field History Catchments.--After yields of 0.8 ton/acre for the silt-loam catchment and, due to reactivation of a gully, 2.9 tons/acre for the sandy-loam unit during the first year after burning, sediment yields dropped drastically during pine ages 3-15 to averages of about 0.01 ton/acre.

The complete-harvest, silt-loam catchment produced 0.14 ton/acre during the first 4 months after harvesting was completed in August 1979; but the rate decreased to the calibration mean of 0.05 ton/acre during the next year (1980). Yields were not increased from the sandy-loam catchments. Annual yields for the control catchment during the full duration of the study averaged 0.13 ton/acre. Compared to the calibration period, yields from the untreated control catchment decreased during the course of the study, while yields from the hardwood control did not show this trend. However, annual yields for the entire course of the studies averaged 0.14 ton/acre for the hardwood control and 0.13 ton/acre for the old-field control.

Chemical Water Quality

Chemical water quality was determined from stormflow samples, and from samples of the soil solution collected in 16 pairs of tensionless lysimeters set 6 inches below the soil surface and installed to sample the combinations of two replicates, two soils and four treatments. The fourth treatment consisted of unharvested 15-year-old pine adjacent to the catchments.

Stormflows were analyzed for solution phase total Kjeldahl nitrogen (TKN), total phosphorus (TP), and potassium (K), organic matter concentrations and, where quantities of sediment permitted, sediment phase TKN and TP. Soil solution samples were analyzed for TKN, TP and K. Analyses of stormflow samples were available for about 2 years prior to harvesting.

Results indicated no significant differences, due either to harvesting treatment or soils, in concentrations of TKN, TP or K among the samples of soil solutions. Average postharvest concentrations over all plots were as follows:

Year	TKN	TP	K
	-----Lb/acre-inch-----		
1980	0.14	0.01	0.44
1981	0.18	0.01	0.41

For Coastal Plain conditions these concentrations represent the nutrient quality of seepage potentially available for ground water accretion.

Analyses of the proportional-to-flow stormflow samples indicated no significant changes of solution concentrations of TKN, TP or of organic matter compared to the controls and harvested plots either before or after harvesting.

Concentrations of K increased significantly in stormflows from the conventionally harvested plots when compared to the controls. Preharvest comparisons showed no significant differences. The increase of solution K of about 0.22 lb/AI does not portend a loss of site productivity on the sites studied. Too, the annual input from atmospheric deposition exceeds the additional loss of K. Similar nutrient relationships were found in a study of eight clearcut catchments

of 27-and 37-year-old loblolly pine in west Tennessee (McClurkin et al., unpublished)[3/].

Far more important than stormflow and soil solution losses are the nutrient exports in the sediment phase. Averaging all plots before and after treatment for the 4.5 years of sampling, about three-quarters of the TKN and TP losses in stormflows were via sediment. Mean sediment TKN concentration was 1.58 percent by weight of sediment, and mean TP concentration was 0.04 percent by weight. Thus, while a 4-inch increase in stormflow volumes would result in a loss of about 0.4 lb/acre of TKN in solution, the very low base-rate of sediment concentrations (0.007 ton/AI) would result in twice this loss. Similarly, a 4-inch increase in stormflow volumes would export about the same amount of TP in solution as would the base-rate of sediment concentrations. The loss of nutrients from the catchments in this study was largely that in the biomass removed. Additional nutrient losses on similar sites would be almost wholly a function of higher sediment yields.

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SPECIES AND CULTURAL EFFECTS ON SOIL CHEMISTRY IN A SOUTHERN PINE PLANTATION AFTER 24 YEARS[1/]

R. C. Schmidtling[2/]

Abstract.--Soils and foliage were analyzed from a 24-year-old study that tested the effects of early cultivation and three levels of N, P, and K fertilization on long-term growth of loblolly and longleaf pines (Pinus taeda and P. palustris).

Organic matter content, K, Zn, Fe, Cu, and B of the soils all varied with each treatment. Cultivation alone decreased these nutrients below the controls, but cultivation plus moderate to high amounts of fertilizers restored levels to the levels of the controls, and sometimes even exceeded them. Oxidation of organic matter resulting from cultivation apparently mobilized these elements, allowing leaching on the cultivated-only plots. Tree growth was much greater on the fertilized plots, which probably enabled these nutrients to be incorporated into the biomass before leaching occurred.

The chemical composition of soils under the two tree species also differed. Soils in the loblolly plots were higher in P, K, Mg, Zn, and organic matter, but lower in S and Cu than those of longleaf plots. The amount of litter produced in a 1-year period from 1983 to 1984 also differed with tree species. Longleaf plots averaged 1,921 kg per ha, whereas loblolly plots averaged only 507 kg per ha.

INTRODUCTION

Intensive cultural methods--such as site preparation, cultivation, and fertilization--have generally increased growth when applied to southern pines (Gilmore and Livingston 1958, Hughes and Jackson 1962, Schmidtling 1973). Long-term site productivity can also be altered by site preparation and cultivation. In some cases this leads to increased nutrient mobilization and subsequent losses due to leaching (Pritchett and Wells 1978). This report describes the soils and foliage of longleaf and loblolly pines (Pinus palustris Mill. and P. taeda L.) 24 years after site preparation, cultivation, and fertilization treatments.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 7-8, 1984.

[2/] Principal Plant Geneticist, Southern Forest Experiment Station, P. O. Box 2008, GMF, Gulfport, MS 39505

MATERIALS AND METHODS

The study area, about 32 km north of Gulfport, Mississippi, had been stocked with second-growth longleaf pines before it was clearcut in 1958-59. The soils are well-drained upland, fine sandy loams in the Poarch series and the Saucier-Susquehanna complex. Slope varies from 0 to 8 percent on the gently rolling land.

One-year-old seedlings of longleaf and loblolly pines (P. taeda L.) were bar-planted at 3.05- by 3.05-m spacings in February and March of 1960. The design was a split plot, randomized complete block with four replications. Each block consisted of 10 plots, 5 plots were of longleaf pine and 5 plots were of loblolly pine. Each plot consisted of 100 trees (10 rows by 10 trees) surrounded by two rows of border trees. Total size of the plots, including border rows, was 0.21 ha. A different cultural treatment was applied to each of the five plots of each species. The five cultural treatments were:

C--Control, no cultivation or fertilizer.

F-0--Cultivated, but not fertilized.

F-1--Cultivated, with a single application of 112 kg N, 24 kg P, and 47 kg K per ha.

F-2--Cultivated, with a single application of 224 kg N, 49 kg P, and 93 kg K per ha.

F-4--Cultivated, with a single application of 448 kg N, 98 kg P, and 186 kg K per ha.

On control plots, stumps, soil, and competing vegetation were not disturbed. Cultivated plots were cleared of all stumps and slash, then plowed, disked, and planted. Cultivation consisted of disking three times each season for 3 years after planting and mowing in the fourth and fifth seasons. Fertilizer was applied with an agricultural spreader and disked into the soil in May 1961, 1 year after planting.

In January 1983, the entire planting was prescribe burned to reduce wildfire hazard. In April 1983, soil samples were taken from each plot. Samples were taken from the top 25 cm of soil from three different locations within the plot, then dried and mixed thoroughly for analysis. Analyses of organic matter (OM), P, K, Mg, Ca, S, Zn, Mn, Fe, B, Cu, and pH of the soil were done by a commercial laboratory. In March 1984, all the litter within a 9-m^2 area in the center of each plot was collected, ovendried, and weighed. These samples represented 1 year's litter accumulation, since the plots had been burned the previous year. Means were compared by analysis of variance. Statistical significance was tested at the 0.05 level of probability.

Foliage samples were collected from both tree species in January 1984 on two of the cultivated-only plots and four of the cultivated plots that had received the highest level of fertilization. Needles from the upper crown of four trees near the center of each plot were collected and combined for each plot sampled. The foliage samples, plus samples of litter from each of these sample plots were analyzed for N, P, K, Mg, Ca, S, Zn, Mn, Fe, B, Cu, and Al (table 2). Differences between the two treatments for each nutrient were compared using a "t" test (species were combined).

RESULTS AND DISCUSSION

Figure 1 shows the OM and Cu contents of the soils 24 years after cultivation and fertilization treatments. Cultivation alone decreased OM for both species, but fertilization combined with cultivation returned OM levels to the OM level of the controls. The OM level on some plots even exceeded that of the controls.

There was a significant difference in percentage of OM by species--OM was higher under loblolly pines than under longleaf pines (fig. 1).

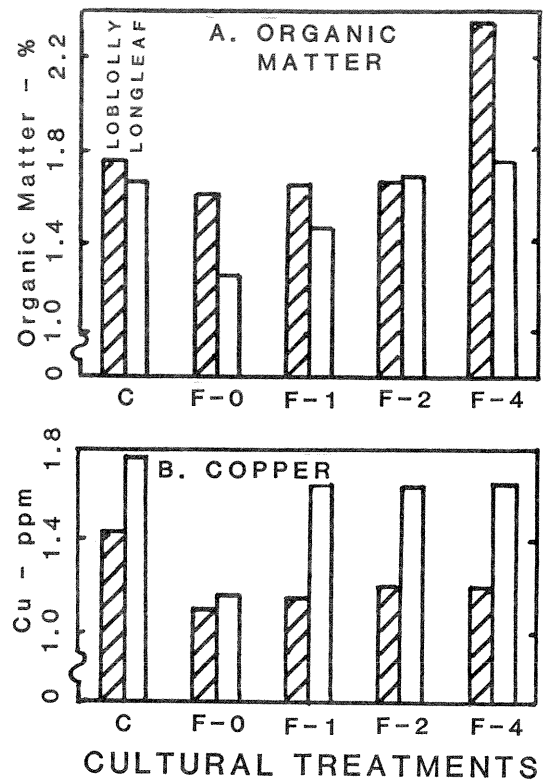

Figure 1.--Effects of cultivation and fertilization on organic matter and copper content of soils 24 years after treatment. See table 1 footnote for definitions of C, F-0, F-1, F-2, and F-4.

Table 1 shows the levels of micronutrients, macronutrients, OM, and soil pH, by cultural treatment after 24 years. Copper content of the soils shows a decrease with cultivation and increase with the addition of fertilizer, although the level never reached that of the control (fig. 1B). Total Cu was greater under longleaf pine than under loblolly pines, the opposite of the variation in OM (fig. 1).

Variation in soil K, Zn, manganese Mn, Fe, and B by cultural treatment was similar to the variation in Cu, although the differences were not always statistically significant (table 1).

Pritchett and Wells (1978) concluded that soil disturbances associated with site preparation can result in nutrient losses if a suitable nutrient "sink" is unavailable to absorb mobilized nutrients. This is apparently what has happened in the present study. Cultivation alone improved growth, but not enough to capture the mobilized nutrients. Growth of trees on the fertilized plots, however, was rapid enough to capture these nutrients and then OM was replaced by increased rates of litter fall.

Levels of soil P, Mg, Ca, and S did not follow any consistent pattern, although statistical significance was obtained in the analysis of S content (table 1).

There was a correlation of pH with OM (r = -0.66). Soils were less acid under cultivated-only treatments, reflecting the lower OM content and therefore less organic acids.

Present differences in soil chemistry are insufficient to explain the continued growth responses in this planting. At 22 years, basal area in the loblolly plots that had received the highest rate of fertilization averaged 23 m^2/ha, versus only 9 m^2/ha on the control plots (Schmidtling 1984). Similarly, dominant/codominant height was 21 m on these fertilized plots versus only 12 m on the control plots, and the differences seemed to be increasing. The growth differences between control and cultivated-only loblolly pine plots were not statistically significant at age 22. Longleaf pine plots were not measured in this study (Schmidtling 1984). At age 9, however, cultivation alone had increased growth of both species over the controls (Schmidtling 1973). The early control of competition apparently outweighed the decrease in quality of the soil due to cultivation.

The amount of litter deposited on all plots, as shown in figure 2, follows a trend similar to the basal area differences noted above by Schmidtling (1984) for loblolly pine plots. There is more than a four-fold difference among treatments for a single year's litter accumulation for both tree species, and much greater amounts were accumulated on the longleaf plots (table 1, fig. 2). One would have expected soil OM to be greater on longleaf plots because

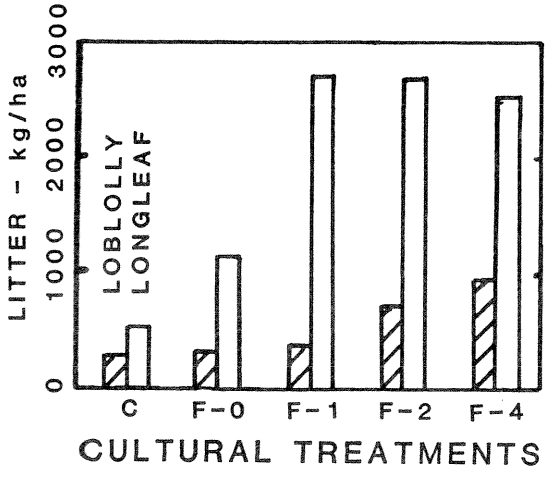

Figure 2.--One-year accumulation of litter for five different cultural treatments. See table 1 footnote for definitions.

of the greater amounts of litter being deposited, but the opposite was observed (fig. 1A). This is undoubtedly due to the fact that initial growth rates for longleaf pine were much less than for loblolly (Schmidtling 1973). The present high rates of litter deposition on longleaf pine plots is of recent origin.

Chemical analysis of foliar and litter samples indicated no significant differences in either macronutrients or micronutrients among treatments, although the differences in P approached significance in foliar samples (p = 0.08) (table 2). Foliage from the plots fertilized at the highest level averaged 0.068 percent P, compared to 0.055 percent P on the cultivated-only plots. This is similar to differences observed by Tiarks (1983). Differences in both foliar N and P might have been statistically significant if a larger sample size had been used. The same trends of higher N and P on fertilized plots is also evident in the analyses of litter samples (table 2).

The differences in foliar nutrients are helpful in explaining some anomalies in soil nutrient contents among species. Soil OM, P, K, Mg, and Zn were all higher in loblolly plots, reflecting the greater initial growth of loblolly compared to longleaf, and therefore greater "capture" of mobilized nutrients. Soil S and Cu, however, were significantly higher on longleaf plots than on loblolly plots. The higher relative levels of S and Cu in foliage of longleaf pines compared to loblolly pines indicates (table 2) that longleaf may have a greater ability to absorb these nutrients from the soil, capturing and recycling them at a higher rate.

CONCLUSIONS

Differences in growth among cultural treatments cannot be accounted for by differences in soil chemistry. It is clear, however, that much larger total quantities of nutrients are contained in the more intensively cultured plots, both within the trees and re-circulating through litter fall. It is these differences that account for the continued response to fertilization.

The long-term effects of cultivation plus fertilization in this study have been to actually enhance productivity. It appears that proper management could benefit the long-term prospects of the site. Cultivation alone, however, may cause a significant deterioration of site productivity in the long-term. The use of herbicides rather than mechanical site preparation and cultivation could perhaps overcome these problems.

Table 1.--Various soil properties 24 years after five different cultural treatments[1/]

Treatment	P (Bray)	P ($NaHCO_3$)	K	Mg	Ca	S	Zn	Mn	Fe	B	Cu	Organic matter	pH
	ppm											percent	
Control (C)	1.00	3.88	37.0*[3/]	35.1	48.8	9.0*	1.25	3.63	34.0	0.33	1.60*	1.71*	4.78*
Cultivated (F-0)[2/]	1.63	4.00	33.6*	39.3	60.0	24.5*	0.75	2.38	18.8	0.25	1.14*	1.41*	4.84*
Fertilized (F-1)	1.13	4.88	45.1*	32.9	56.2	28.1*	1.45	5.88	31.3	0.31	1.40*	1.54*	4.79*
Fertilizer (F-2)	1.50	6.13	43.0*	40.5	62.5	18.4*	0.78	1.88	27.6	0.31	1.41*	1.66*	4.66*
Fertilized (F-4)	1.00	3.88	37.0*	35.1	48.8	10.1*	1.16	2.63	26.1	0.31	1.43*	2.03*	4.78*

[1/]Averages for both longleaf and loblolly pine.

[2/]F-0 = cultivated only; F-1 = cultivated plus 112 kg N, 24 kg P, and 93 kg K per ha; F-2 = cultivated plus 224 kg N, 49 kg K and 93 kg K per ha; F-4 = cultivated plus 448 kg N, 98 kg P and 186 kg K per ha.

[3/]*Indicates treatment values within a column were significantly different at the 0.05 level of probability.

Table 2.--Nutrient content of foliage and litter (fallen needles) of loblolly and longleaf pine plots 24 years after initial treatment[1/]

Material and treatments analyzed	N	P	K	Mg	Ca	S	Zn	Mn	Fe	B	Cu	Al
	percent						ppm					
Loblolly foliage												
cultivated only (F-0)[2/]	1.23	0.050	0.57	0.13	0.21	0.050	19	506	48	13	3.0	430
cult. + fertilized (F-4)	1.26	0.070	0.57	0.13	0.19	0.073	13	353	53	11	2.7	393
Longleaf foliage												
cultivated only (F-0)	1.25	0.060	0.62	0.11	0.13	0.080	19	286	86	10	10.0	360
cult. + fertilized (F-4)	1.28	0.065	0.64	0.14	0.16	0.075	14	219	49	15	3.5	490
Loblolly litter												
cultivated only (F-0)	0.39	0.085	0.21	0.13	0.35	0.025	8	710	70	14	2.0	425
cult. + fertilized (F-4)	0.41	0.093	0.20	0.13	0.37	0.023	7	695	80	13	2.0	507
Longleaf litter												
cultivated only (F-0)	0.30	0.090	0.17	0.10	0.30	0.040	13	328	104	10	2.0	480
cult. + fertilized (F-4)	0.32	0.095	0.20	0.10	0.27	0.040	8	290	80	10	2.0	470

[1/]Litter samples were taken in March 1984, following a prescribed burn in January 1983.

[2/]See table 1 for definition of F-0 and F-4.

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A P P E N D I X E S

APPENDIX I--REGISTRATION LIST

William Abernathy
International Paper Co.
P. O. Box 249
Camden, AR 71701

B. D. Achterman
Dow Chemical
4852 Truesdale Place
Matthews, NC 28105

John C. Adams
Louisiana Tech University
School of Forestry
Ruston, LA 71270

Mary Beth Adams
NCSU School of Forestry
Box 8002
Raleigh, NC 27695-8002

H. Lee Allen
North Carolina State
Box 8002
Raleigh, NC 27695

Steven Anderson
NC State University
2807-B Conifer Drive
Raleigh, NC 27606

Walter C. Anderson
U.S. Forest Service
701 Loyola Avenue
New Orleans, LA 70113

Jack Arthur
Champion International Corp.
P. O. Box 191
Huntsville, TX 77340

Mark K. Augspurger
Clemson University
School of Forestry
Clemson, SC 29631

Mike Aust
Mississippi State University
P.O. Drawer FR
Mississippi State, MS 39762

Roger P. Balenger
Forestry Sciences Laboratory
Carlton Street
Athens, GA 30602

Olen Aycock
U.S. Forst Service
1070 Amelia Drive
Marietta, GA 30060

Doug Back
NEALA Forestry Services
309 Lenlock Drive
Anniston, AL 36206

Catherine Bacon
VA Polytechnic Institute
228 Cheatham Hall
Blackburg, VA 24061

James B. Baker
U.S. Forest Service
P. O. Box 3516
Monticello, AR 71655

V. C. Baldwin, Jr.
U.S. Forest Service
2500 Shreveport Highway
Pineville, LA 71360

William Balmer
Consultant Forester
3682 Sexton Woods Drive
Chamblee, GA 30341

James Barnett
U.S. Forest Service
2500 Shreveport Highway
Pineville, LA 71360

Stanley J. Barras
South. For. Exp. Station
701 Loyola, Rm. T-10210
New Orleans, LA 70113

Rick Batillo
The Buckeye Cellulose Corp.
P. O. Box 238
Oglethorpe, GA 31068

Don Beck
SE Forest Experiment Station
200 Weaver Boulevard
Asheville, NC 28804

Barry Beers
F & W Forestry Services
P. O. Box 3610
Albany, GA 31706

Victor Bilan
Stephen F. Austin St. Univ.
Forestry Department
Nacogdoches, TX 75962

George M. Blakeslee
University of Florida
School of Forest Resources
Gainesville, FL 32611

John Blanton
Cherokee National Forest
1401 S. Tennessee Avenue
Etowah, TN 37331

Bruce Borders
University of Georgia
School of Forest Resources
Athens, GA 30602

Lindsay Boring
University of Georgia
School of Forest Resources
Athens, GA 30602

Doug Bowling
International Paper
Southlands Experimental Forest
Bainbridge, GA 31717

William D. Boyer
South. For. Experiment Station
G. W. Andrews Forestry Sciences Lab
Auburn University, AL 36849

David L. Bramlett
Southeastern Forest Experiment Station
Box 182A
Dry Branch, GA 31020

John C. Brissette
South. For. Experiment Station
2500 Shreveport Highway
Pineville, LA 71360

Charles Bryant
Texas Forest Service
Route 7, Box 151
Conroe, TX 77304

James A. Burger
VPI & SU
228 Cheatham Hall
Blacksburg, VA 24061

James D. Burton
U.S. Forest Service
2500 Shreveport Highway
Pineville, LA 71360

Michael D. Cain
U.S. Forest Service
Route 1, Box 174T
Crossett, AR 71635

James R. Caldwell
USDA, Vernon Ranger District
3362 Lake Charles Highway
Leesville, LA 71446

R. L. Campbell
Georgia Kraft
P. O. Box 108
Coosa, GA 30129

Quang V. Cao
Louisiana State University
School of Forestry
Baton Rouge, LA 70803

William C. Carlson
Weyerhaeuser Co.
P. O. Box 1060
Hot Springs, AR 71901

Jessie B. Casey
U.S. Forest Service
601 Broad Street, S.E.
Gainesville, GA 30501

Tom Cathey
Champion International Corp.
37 Villa Road, Suite 319
Greenville, SC 29615

Jim Chambers
Louisiana State University
School of Forestry
Baton Rogue, LA 70803

Robert Chambers
First National Bank of Atlanta
P. O. Box 4148
Atlanta, GA 30302

Terry R. Clason
LA. Experiment Station
Route 1, Box 10
Homer, LA 71040

Robert T. Colona
Jefferson National Forest
210 Franklin Road, S.W.
Roanoke, VA 24001

Gordon R. Condit
Boise Cascade Corp.
P. O. Box 1000
DeRidder, LA 70634

John Conn
Champion International Corp.
Route 1, Box 97 A-1
Swansea, SC 29161

Rick Cooper
The Buckeye Cellulose Corp.
P. O. Box 238
Oglethorpe, GA 31068

Cosimo Cotrufo
Forestry Sciences Laboratory
P. O. Box 12254
Research Triangle Park, NC 27709

Knight Cox
Clemson University
School of Forestry
Clemson, SC 29631

Lee Cromley
U.S. Forest Service
4467 Allgood Springs Drive
Stone Mountain, GA 30083

George S. Crum
Hammermill Paper Co.
417 Medical Center Parkway
Selma, AL 36701

Richard F. Daniels
Westvaco
P. O. Box 1950
Summerville, SC 29484

Charles E. Davis
Cooperative Forest Research
Savannah River Plant
Aiken, SC 29801

William C. Davis
Duke University
School of Forestry
Durham, NC 27706

Tommy R. Dell
South. For. Experiment Station
701 Loyola Avenue
New Orleans, LA 70113

Roger W. Dennington
U.S. Forest Service
1720 Peachtree Street, NW
Atlanta, GA 30360

Laura E. DeWald
VPI & SU, c/o P. P. Feret
228 Cheatham Hall
Blacksburg, VA 24061

Duane R. Dippon
University of Florida
118 Newins Ziegler Hall
Gainesville, FL 32611

Kevin Donnelly
Deleware Forest Service
Drawer D
Dover, DE 19903

Joe Paul Downs
Monsanto Company
321 Interstate North Parkway
Atlanta, GA 30367

Brad Dreyer
International Paper Co.
P. O. Box 249
Camden, AR 71701

Stuart Duba
Auburn University
Department of Forestry
Auburn University, AL 36849

Anthony P. Durkas
U.S. Forest Service
601 Broad Street, S.E.
Gainesville, GA 30501

Lou Ebling
U.S. Forest Service
P. O. Box 1008
Russellville, AR 72801

M. Boyd Edwards
Georgia Forestry Center
Route 1, Box 182A
Dry Branch, GA 31020

Thomas H. Ellis
South. For. Experiment Station
701 Loyola Avenue
New Orleans, LA 70113

Robert M. Farrar
U.S. Forest Service
P. O. Box 3516
Monticello, AR 71655

Don Feduccia
Louisiana Office of Forestry
TMR-1102, 2500 Shreveport Hwy.
Pineville, LA 71360

Peter P. Feret
Virginia Tech
Dept. of Forestry
Blacksburg, VA 24061

Richard O. Fitzgerald
U.S. Forest Service
P. O. Box 2417
Washington, DC 20013

Ed Flowers
Union Camp Corp.
P. O. Box 410
Waycross, GA 31501

Thomas R. Fox
NC State University
Box 8002
Raleigh, NC 27695

John K. Francis
U.S. Forest Service
P. O. Box 227
Stoneville, MS 38776

George A. Freeland
Jefferson National Forest
210 Franklin Road, S.W.
Roanoke, VA 24001

Conner Fristoe
Clemson University
School of Forestry
Clemson, SC 29631

Ron Froelich
U.S. Forest Service
P. O. Box 2008, GMF
Gulport, MS 39503

Harry Gibson
Purdue University
Dept. of Agric. Engineering
W. Lafayette, IN 47907

Samuel F. Gingrich
U.S. Forest Service
2730 Savannah Highway
Charleston, SC 29407

Dean Gjerstad
Auburn University
School of Forestry
Auburn University, AL 36849

Mike Golden
Auburn University
School of Forestry
Auburn University, AL 36849

F. Eugene Gonzalez
Dupont Company
8995 Martin Road
Roswell, GA 30076

Sandy Gorse
ITT Rayonier, Inc.
Box 437
Yulee, FL 32097

David Graney
U.S. Forest Service
830 Fairview Street
Fayetteville, AR 72701

Dale Greene
Auburn University
School of Forestry
Auburn University, AL 36849

Harold E. Grelen
South. For. Experiment Station
2500 Shreveport Highway
Pineville, LA 71360

Charles Gresham
Clemson University
P. O. Box 596
Georgetown, SC 29442

Jimmy Groton
University of Tennessee
Department of Forestry
Knoxville, TN 37901-1071

James Guldin
University of Arkansas
Dept. of Forest Resources
Monticello, AR 71655

Richard W. Guldin
South. For. Experiment Station
T-10210 Postal Service Bldg.
New Orleans, LA 70113

M. Elizabeth Haines
NC State University
P. O. Box 8002
Raleigh, NC 27695-8002

Don Ham
Clemson University
School of Forestry
Clemson, SC 29631

Mark Hammer
Clemson University
School of Forestry
Clemson, SC 29631

William J. Hammond
Westvaco
Box 1950
Summerville, SC 29484

Howard Hanna
Container Corp. of America
P. O. Box "T"
Fernandina Beach, FL 32034

William R. Harms
SE For. Experiment Station
2730 Savannah Highway
Charleston, SC 29407

Constance Harrington
South. For. Experiment Station
Box 3516
Monticello, AR 71655

James Harrison
Forshaw Chemicals
650 State Street
Charlotte, NC 28208

Glyndon Hatchell
Forestry Sciences Laboratory
Carlton Street
Athens, GA 30602

Ron Hay
University of Tennessee
P. O. Box 1071
Knoxville, TN 37901

Ms. Jackie Haymond
Clemson University
School of Forestry
Clemson, SC 29631

Tom Hennessee
Oklahoma State University
Department of Forestry
Stillwater, OK 74074

Clifford E. Henry
The Buckeye Cellulose Corp.
Route 3, Box 260
Perry, FL 32347

Keith Hern
Dow Chemical
20 Perimeter Center East
Atlanta, GA 30346

Joe Hockman
Virginia Tech
623 Jackson Street
Blacksburg, VA 24060

John D. Hodges
Mississippi State University
P. O. Drawer FR
Mississippi State, MS 39762

Charles A. Hollis
International Paper Co.
Route 1, Box 571
Bainbridge, GA 31717

W. L. Hood
International Paper Co.
6600 LBJ Freeway
Dallas, TX 75240

Walter A. Hough
South. For. Experiment Station
701 Loyola Avenue
New Orleans, LA 70113

Tony S. C. Hu
Louisiana State Univerity
School of Forestry
Baton Rouge, LA 70803

Joe Huff
Champion International Corp.
37 Villa Road, Suite 319
Greenville, SC 29615

Greg Janzen
Mississippi State University
P. O. Drawer FR
Mississippi State, MS 39762

Bill Johansen
U.S. Forest Service
SEFES, Rt. 1, Box 182A
Dry Branch, GA 31020

Jon Johnson
University of Florida
Dept. of Forestry, 320 N-Z Hall
Gainesville, FL 32611

Rhett Johnson
Auburn University
Route 7, Box 131
Andalusia, AL 36420

Earle P. Jones, Jr.
SE Forest Experiment Station
Route 1, Box 182A
Dry Branch, GA 31020

Jacques R. Jorgenson
Forestry Sciences Laboratory
P. O. Box 12254
Research Triangle Park, NC 27709

Kayananda Kariyawasam
School of Forest Resources
University of Georgia
Athens, GA 30602

Chet Karpinski
Clemson University
School of Forestry

Jonathan S. Kays
Virginia Tech
228 Cheatham Hall
Blacksburg, VA 24061

Harvey E. Kennedy, Jr.
Southern Hardwoods Laboratory
P.O. Box 227
Stoneville, MS 38776

Frank Kidd
Dow Chemical, U.S.A.
6055 Primacy Parkway, Suite 330
Memphis, TN 38119

W. N. Kline
Dow Chemical U.S.A.
20 Perimeter Center East
Atlanta, GA 30346

John F. Kraus
SE Forest Experiment Station
Route 1, Box 182A
Dry Branch, GA 31020

Richard E. Kreh
Virginia Tech
Route 1, Box 21
Critz, VA 24082

Erich H. Krumm, Jr.
Champion International Corp.
P. O. Box 91
Huntsville, TX 77340

Timothy T. Ku
University of Arkansas
at Monticello
Monticello, AR 71655

David Kulhavy
SF Austin State University
School of Forestry
Nacogdoches, TX 75962

Samuel B. Land, Jr.
Mississippi State University
P.O. Drawer FR
Mississippi State, MS 39762

Dwight Lauer
ITT Rayonier, Inc.
Box 437
Yulee, FL 32097

Edwin R. Lawson
U.S. Forest Service
830 Fairview Street
Fayetteville, AR 72701

Russ Lea
NCSU School of Forestry
Box 8002
Raleigh, NC 27695-8002

Lyndon C. Lee
Savannah River Ecology Lab.
Drawer "E"
Aiken, SC 29801

Robert J. Lentz
U.S. Forest Service
4181 Jeri Lynn Court
Tucker, GA 30084

Gordon D. Lewis
SE Forest Experiment Station
200 Weaver Boulevard
Asheville, NC 28804

Jim Lewis
Dow Chemical
8002 Discovery Drive, Suite 415
Richmond, VA 23288

Robert Lilieholm
University of California
145 Mulford Hall
Berkeley, CA 94720

F. Thomas Lloyd
U.S. Forest Service
2730 Savannah Highway
Charleston, SC 29407

B. G. Lockaby
Louisiana Tech
Box 7924
Ruston, LA 71272

Nelson S. Loftin, Jr.
U.S. Forest Service
P. O. Box 2417
Washington, DC 20013

Richard Lohrey
U.S. Forest Service
120 Ivy Lane
Pineville, LA 71360

Peter L. Lorio, Jr.
U.S. Forest Service
2500 Shreveport Highway
Pineville, LA 71360

Robert Lowery
Weyerhaeuser Co.
Box 1060
Hot Springs, AR 71901

Ken Luke
Scot Paper Company
P. O. Box 899
Saraland, AL 36571

Lynn Maguire
Duke University
School of Forestry
Durham, NC 27706

Bob Maimone
NCSE School of Forestry
Box 8007
Raleigh, NC 27695-8007

John P. Martin
Westvaco
P. O. Box 1950
Summerville, SC 29484

Garland N. Mason
U.S. Forest Service
2500 Shreveport Highway
Pineville, LA 71360

Tom Matney
Mississippi State
P.O. Drawer FR
Mississippi State, MS 39762

James L. McConnell
U.S. Forest Service
1720 Peachtree Road
Atlanta, GA 30367

Wesley McDade
Clemson University
School of Forestry
Clemson, SC 29631

Tim McElwain
Container Corp. of America
P. O. Box 1469
Brewton, AL 36427

Charles E. McGee
U.S. Forest Service
Route 1, Box 43
Decherd, TN 37324

William H. McKee
SE Forest Experiment Station
2730 Savannah Highway
Charleston, SC 29407

Martha R. McKevlin
USDA-SEFES
2730 Savannah Highway
Charleston, SC 29407

B. F. McLemore
U.S. Forest Service
P. O. Box 3516
Monticello, AR 71655

K. W. McLeod
Savannah River Ecology Lab.
P. O. Drawer "E"
Aiken, SC 29801

James W. McMinn
Forestry Sciences Lab
Carlton Street
Athens, GA 30602

W. Henry McNab
SE Forest Experiment Station
200 Weaver Boulevard
Asheville, NC 28804

James Steven Meadows
Mississippi State University
P. O. Drawer FR
Mississippi State, MS 39762

Ralph Meldahl
Auburn University
108 Smith Hall
Auburn University, AL 36849

Lamar Merck
University of Georgia
Georgia Extension Service
Athens, GA 30602

Steve Metcalfe
Auburn University
School of Forestry
Auburn University, AL 36849

Joann Meyer
Champion International
P.O. Box 191
Huntsville, TX 77340

Ansel Miller
Clemson University
School of Forestry
Clemson, SC 29631

James H. Miller
U.S. Forest Service
Devall Drive
Auburn University, AL 36849

Patrick Minogue
Auburn University
School of Forestry
Auburn University, AL 36849

Alfred V. Mollitor
University of Florida
Deparmtent of Forestry
Gainesville, FL 32611

David J. Moorhead
University of Georgia
P. O. Box 1209
Tifton, GA 31793

Stuart Moss
VPI & SU
228 Cheatham
Blacksburg, VA 24061

Paul A. Murphy
South. For. Experiment Station
P. O. Box 3516
Monticello, AR 71655

Richard R. Myers
Boise Cascade
P. O. Box 1000
DeRidder, LA 70634

Warren Nance
U.S. Forest Service
P. O. Box 2008, GMF
Gulfport, MS 39503

T. Evan Nebeker
Mississippi State University
P. O. Drawer EM
Mississippi State, MS 39762

Ted Needham
VPI & SU
228 Cheatham Hall
Blacksburg, VA 24061

Tom Nichols
Virginia Tech
Department of Forestry
Blacksburg, VA 24061

Larry Nix
Clemson University
School of Forestry
Clemson, SC 29631

Donald E. Norris
U.S. Forest Service
P. O. Box 2227
Columbia, SC 29202

Kenneth W. Outcalt
U.S. Forest Service
P. O. Box 70
Olustee, FL 32072

William H. Padgett
Alabama Forestry Commission
513 Madison Avenue
Montgomery, AL 36130

David Paganelli
VPI & SU
228 Cheatham Hall
Blacksburg, VA 24061

Kurt Pennell
2110 Gorman Street
Raleigh,
North Carolina 27606

Donald W. Peterson
U.S. Forest Service
P. O. Box 2227

Mark D. Petruncio
NCSU School of Forestry
8002
Raleigh, NC 27695-8002

Doug Phillips
U.S. Forest Service
110 Princess Lane
Clemson, SC 29631

John Pitcher
U.S. Forest Service
SOFES
Auburn, AL 36849

Phil Pope
Purdue University
Dept. of Forestry
W. Lafayette, IN 47907

M. William Pope
Potlatch Corporation
P. O. Box 390
Warren, AR 71671

Lavelle Prewitt
International Paper Co.
Route 3, Box 312-B
Natchez, MS 39120

Kurt Ray
International Paper Company
Route 3, Box 312B
Natchez, MS 39120

John Read
Great Southern Paper Company
P. O. Box 315
Troy, AL 36081

Jack Reichert
U.S. Forest Service
P.O. Box 1270
Hot Springs, AR 71901

William Retzlaff
Clemson University
School of Forestry
Clemson, SC 29631

Hans Riekerk
University of Florida
Newins-Ziegler Hall 118
Gainesville, FL 32611

Thomas Robinson
Scot Paper
P.O. Box 899
Saraland, AL 36571

Robert Rogers
Univ. of Wisconsin/
Stevens Point
CNR
Stevens Point, WI 54481

Robert W., Rose, Jr.
Westvaco
P. O. Box 1950
Summerville, SC 29484

Jim Rowan
Forestry Sciences Lab
Carlton Street
Athens, GA 30602

Bryce E. Schlaegel
U.S. Forest Service
P. O. Box 227
Stoneville, MS 38776

Eric John Schmeckpeper
NCSU School of For. Resources
Box 8002, Biltmore Hall
Raleigh, NC 27695-8002

Ron Schmidtling
U.S. Forest Service
P. O. Box 2008, GMF
Gulfport, MS 39503

Robert P. Schultz
South. For. Experiment Station
701 Loyola Avenue T-10210
New Orleans, LA 70113

Michael Scott
Savannah River Ecology Lab
Drawer "E"
Aiken, SC 29801

Mark Seaman
1st National Bank of Atlanta
P.O. Box 4148 M.C. 662
Atlanta, GA 30302

John R. Seifert
Purdue University
Box 155
Butlerville, IN 47223

Jerry Sesco
SE Forest Experiment Station
200 Weaver Boulevard
Asheville, NC 28804

Arthur T. Shearin
Clemson University
Forestry Department
Clemson, SC 29631

Eugene Shoulders
South. For. Experiment Station
2500 Shreveport Highway
Pineville, LA 71360

Bill Siegel
U.S. Forest Service
701 Loyola Avenue T-10210
New Orleans, LA 70113

Dan Sims
Region 8, U.S. Forest Service
1720 Peachtree Road, NW
Atlanta, GA 30367

David William Smith
VPI & SU, Dept. of Forestry
228 Cheatham Hall
Blacksburg, VA 24061

O. D. Smith
Ozark-St. Francis National For.
7 Cedarwood Court
Russellville, AR 72801

David South
Auburn University
School of Forestry
Auburn University, AL 36849

Donald D. Spiller, Jr.
U.S. Forest Service
1625 W. Lee Highway
Wytheville, VA 24382

Charles Stafford
Virginia Polytechnic Institute
228 Cheatham Hall
Blacksburg, VA 24061

Klaus Steinbeck
University of Georgia
School of Forest Resources
Athens, GA 30602

Nancy J. Stumpff
Savannah River Ecology Lab
Drawer "E"
Aiken, SC 29801

R. M. Taylor
U.S. Forest Service
18 Rochelle Street
Brandon, MS 39042

J. Lamar Teate
Director
Louisiana Tech University
Ruston, LA 71272

Bill Terry
Container Corp.
P. O. Box 135
Callahan, FL 32011

Robert Teskey
University of Georgia
School of Forest Resources
Athens, GA 30602

Robert C. Thatcher
U.S. Forest Service
2500 Shreveport Highway
Pineville, LA 71360

Allan Tiarks
U.S. Forest Service
2500 Shreveport Highway
Pineville, LA 71360

David Todd
Champion International Corp.
37 Villa Road, Suite 319
Greenville, SC 29615

John Toliver
Louisiana State University
101 Forestry Building
Baton Rouge, LA 70803

John Torbert, Jr.
Virginia Polytechnic Institute
Room 228, Cheatham Hall
Blacksburg, VA 24061

John L. Troth
Weyerhaeuser Co.
P. O. Box 7
Mountain Pine, AR 71956

Leonard Tucciarone
Union Camp Corp.
P. O. Box 410
Waycross, GA 31501

Charles Tuttle
Auburn University
School of Forestry
Auburn University, AL 36849

Stanley Ursic
Southern Forest Experiment Station
P. O. Box 947
Oxford, MS 38655

Paul C. Van Duesen
Southern Forest Experiment Station
701 Loyola Avenue
New Orleans, LA 70113

David H. Van Lear
Clemson University
Department of Forestry
Clemson, SC 29631

Tom Vermillion
Crown Zellerback
Box 400
Bogalusa, LA 70427

Clyde Vidrine
Louisiana Tech University
School of Forestry
Baton Rogue, LA 70803

J. A. Vozzo
U.S. Forest Service
P. O. Box 906
Starkville, MS 39759

Dale Wade
Southern Forest Fire Lab.
Rt. 1, Box 182A
Dry Branch, GA 31020

Nancy C. Walczyk
Union Camp Corp.
P. O. Box 1391
Savannah, GA 31402

Thomas A. Waldrop.
SE Forest Experiment Station
2730 Savannah Highway
Charleston, SC 39407

Roger Walker
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37831

Eric Watson
Champion International Corp.
37 Villa Road, Suite 319
Greenville, SC 29615

Ozzie O. Wells
South. For. Experiment Station
P. O. Box 2008, GMF
Gulfport, MS 39503

A. D. White
Scott Paper Co.
P. O. Box 369
Monroeville, AL 36461

Fred M. White
NC Division of Forestry
P. O. Box 27687
Raleigh, NC 27611

Timothy White
N. C. State University
812 Merrie Road
Raleigh, NC 27606

Thomas Williams
Clemson University
P. O. Box 596
Georgetown, SC 29442

Thomas J. Wiswell
Container Corp. of America
P. O. Box 1267
Fernandina Beach, FL 32034

Robert F. Wittwer
Oakloma State University
Department of Forestry
Stillwater, OK 74079

Andrew Wolgemuth
NC State University
3221-L Calumet Drive
Raleigh, NC 27610

Frank Woods
University of Tennessee
P. O. Box 1071
Knoxville, TN 37901

Galen M. Wright
Purdue University
Route 1, Box 264-B
Dubois, IN 47527

Ken Xydias
Continental Forest Industries
P. O. Box 7038
Garden City, GA 31418

Shepard M. Zedaker
VPI & SU, Dept. of Forestry
232 Cheatham Hall
Blacksburg, VA 24061

Furcy J. Zeringue, II
LSU School of Forestry
113 Forestry Building
Baton Rouge, LA 70803

Bruce Zutter
Auburn University
School of Forestry
Auburn University, AL 36849

APPENDIX II--ALPHABETICAL LIST OF AUTHORS

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ADAMS, John C.	1, 417
ALLEN, H. L.	203
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DEAUMAN, William C.	128
DELL, Tommy R.	469
DICKENS, Dale F.	279
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DUBA, Stuart E.	305
EDWARDS, Jerry L.	252
EDWARDS, M. Boyd	65
ERIKSSON, M.	422
FARRAR, Robert M., Jr	241, 429
FERET, Peter P.	4, 18
FISCHER, B. C.	53, 266
FOSTER, C. Darwin	128
FOX, T. R.	203
FRANCIS, John K.	346
FROELICH, Ronald C.	469
GIBSON, Harry G.	146
GILLESPIE, Marcey A.	341
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GLOVER, Glenn R.	279
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GRANEY, David L.	171
GREENE, W. Dale	212
GRELEN, H. E.	523
GRESHAM, Charles A.	87
GROTON, J. P., Jr.	379
GULDIN, James M.	198
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HATCHELL, Glyndon E.	395
HAYMOND, J. L.	154
HILEMAN, Leslie H.	558
HODGES, J. D.	110, 163, 220, 273, 438, 471, 485
HOLT, H. A.	266
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HU, S. C.	231, 550
HUNT, Ellis V., Jr.	436
IZLAR, R. L.	100
JANZEN, G. C.	273
JOHANSEN, R. W.	514
JOHNSON, Jon D.	34
JOHNSON, Robert L.	163, 220
JONES, Earle P., Jr.	105, 468
JORGENSON, Jacques R.	363
KARR, B. L.	469
KAYS, J. S.	137
KELLOGG, G. R.	337
KENNEDY, Harvey E., Jr.	507
KIMMINS, J. P.	203
KLUENDER, R. A.	100
KORHNAK, L. V.	528
KREH, Richard E.	4, 18, 327
KRINARD, Roger M.	190
KROLL, James C.	128
KU, Timothy T.	340
KULHAVY, David L.	128
LANFORD, Bobby L.	212
LANTAGNE, D. O.	61, 85
LAWSON, Edwin R.	558
LEA, Russ	178
LENHART, J. David	436
LILIEHOLM, R. J.	550
LLOYD, F. Thomas	466
LOCKABY, B. Graeme	417
LOHREY, Richard E.	451, 470
LOMAX, Timothy J.	340
LORIO, Peter L., Jr.	485
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McCONNELL, James L.	252
MCDADE, W. D.	337
McGEE, Charles E.	519
McLAUGHLIN, S. B.	315, 410
McLEMORE, B. F.	97
McMINN, James W.	159
McNAB, W. Henry	331
MAGULRE, Lynn A.	467
MATNEY, T. G.	110
MEADOWS, J. S.	220
MELDAHL, R. S.	45, 422
MILLER, A. E.	11
MILLER, James H.	65
MINOGUE, P. J.	292
MOLLITOR, A. V.	360, 445
MUNCY, Jack A.	493
MUNSON, Kenneth R.	351
MURPHY, Paul A.	241
NANCE, Warren L.	469
NEBEKER, T. E.	247, 471
NEEDHAM, T. D.	61
NELSON, Larry R.	305
NIX, L. E.	154, 227, 375
OUTCALT, Kenneth W.	122
PEARSON, H. A.	523
PETRUNCIO, Mark	178
POPE, P. E.	53, 146, 266, 403
RAY, K. F.	11
RIEKERK, H.	528
RINK, George	261
ROGERS, Robert	216
ROGERSON, Thomas L.	171, 558
ROSE, R. W.	11, 25
SANDER, Ivan L.	216
SARIGUMBA, Terry I.	79
SCHLAEGEL, Bryce E.	507
SCHMECKPEPER, E. J.	132
SCHMIDTLING, R. C.	573
SCHMITT, J. J.	247, 471
SEIFERT, J. R.	53
SHEARIN, A. T.	227
SHOULDERS, Eugene	255, 469
SIEGEL, William C.	183
SMITH, D. Wm.	137
SNOW, Glenn A.	321
SOLOMON, J. D.	247
STAFFORD, C. W.	57
STUMPFF, Nancy J.	34
THILL, R. E.	523
THOMAS, C. E.	422
TIARKS, Allan E.	390
TORBERT, J. L.	57, 85, 327, 369
TRACEY, David	128
TUTTLE, C. L.	45
URSIC, S. J.	565
VAN LEAR, D. H.	337, 501
VENATOR, Charles R.	125
VIDRINE, Clyde G.	118
VOZZO, J. A.	42
WALDROP, Thomas A.	493
WALKER, R. F.	315, 410
WELLS, O. O.	261
WEST, D. C.	410
WHILES, R. P.	25
WILLIAMS, Thomas M.	536
WOODRUM, W. G., III	154
WRIGHT, G. M.	266
ZEDAKER, S.M.	137, 309
ZEIDE, Boris	93
ZUTTER, Bruce R.	279, 292