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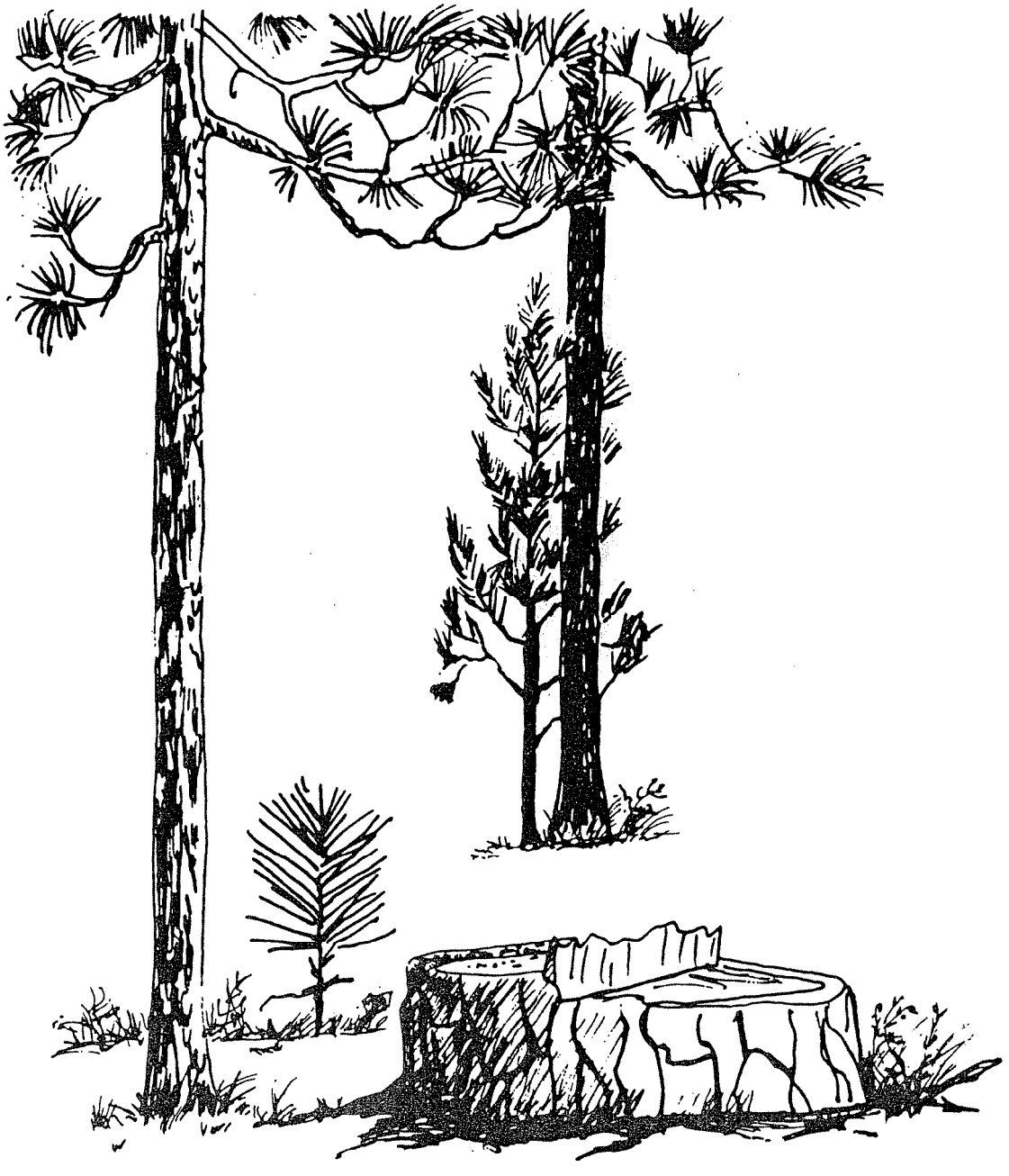
**Little Rock, Arkansas
October 29–31, 1991**



PROCEEDINGS
OF THE
SHORTLEAF PINE REGENERATION WORKSHOP

Compiled by
John C. Brissette and James P. Barnett

Little Rock, Arkansas
October 29-31, 1991

Sponsored by

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PREFACE

The purpose of this workshop was to present state-of-the-art knowledge about artificial and natural regeneration of shortleaf pine on sites in the Ouachita and Ozark Mountains. Research on artificial regeneration reported here was conducted by members of the Task Force on Shortleaf Pine Artificial Regeneration. The task force was organized in December 1984 in response to generally poor performance of planted shortleaf pine seedlings. Representatives of the USDA Forest Service Southern Region, Ouachita and Ozark National Forests, Southern Forest Experiment Station, Arkansas Forestry Commission, Oklahoma State and Louisiana State Universities, and Weyerhaeuser Company initially made up the task force. Later, the task force was joined by representatives of the University of Arkansas at Monticello and International Paper Company.

In recent years, natural regeneration of shortleaf pine has received increased emphasis and research on both even-aged and uneven-aged systems is under way. Although that research is long-term and ongoing, some important early results are presented here.

Many people worked diligently to make the workshop a success and deserve thanks. The speakers' prsentations were excellent and the subsequent discussions valuable. Moderators did an admirable job of keeping the technical sessions on schedule. The Winona Ranger District of the Ouachita National Forest provided the sites for the artificial and natural regeneration studies visited during the field trip. A number of others made valuable contributions to the meeting: Larry Willett and Jim Geisler of the Arkansas Cooperative Extension Service handled local arrangements and preregistration. Dixie Rice of the Arkansas Forestry Commission welcomed and registered participants. Dan Andries, John McGilvray, and Chuck Stangle of the Southern Forest Experiment Station helped field trip participants cross a flooded creek that blocked the path to the artificial regeneration studies. They also served as guides, leading groups between the plantings at that site. We also thank all who attended the workshop for their interest in regenerating shortleaf pine in the Ouachita and Ozark Mountains.

Papers published in this proceedings were submitted by the authors either camera-ready or in electronic media. Limited editing was done to ensure a consistent format. Authors are responsible for content and accuracy of their individual papers.

James P. Barnett
John C. Brissette
Workshop Co-chairs

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Background

Moderator:

James P. Barnett

Southern Forest Experiment Station

HISTORY OF THE SHORTLEAF PINE ARTIFICIAL REGENERATION TASK FORCE AND OBJECTIVES OF THE WORKSHOP[1/]

James P. Barnett[2/]

Abstract.--The establishment of acceptable shortleaf pine (*Pinus echinata* Mill.) plantations in the Ouachita and Ozark Mountains has been a problem for many years. However, shortleaf pine is the native species in the region and should be used for reforestation on public lands. An informal task force was formed to focus on specific research needs for shortleaf pine. Over a 5-year period, about 15 studies were conducted, including evaluations of seed pretreatments; nursery studies to improve seedling quality; studies on the use of fungicides to reduce seedling storage pathogens, on the production of high quality container stock, and on the use of root growth potential to identify optimum seedling lifting windows; studies relating seedling physiology and morphology to performance under stress conditions; and evaluations of the effects of postplanting competition control on seedling survival and growth. The purpose of this workshop is to transfer this information on artificial regeneration and present state-of-the-art information on natural regeneration to silviculturists, field foresters, and other user groups.

DEVELOPMENT OF THE REGENERATION RESEARCH PROGRAM

In late December 1984, a group of 18 people representing the Forest Service, the Weyerhaeuser Company, the Arkansas Forestry Commission, Oklahoma State University and Louisiana State University met in Hot Springs, Arkansas, to discuss the problems of shortleaf pine (*Pinus echinata* Mill.) regeneration. The objectives of the session were (1) to identify causes of poor survival of planted shortleaf pine seedlings in the Ouachita and Ozark Mountains, (2) to determine research priorities for solving the problems of poor survival, and (3) to determine who could best work on each of the priority problems. Shortleaf pine plantings in the early 1980's had little success; first-year survival averaged less than 50 percent. Discussion of the causes of this poor survival rate covered many aspects of the regeneration system, including site quality, genetics and seed, seedling production and handling, site preparation, and plantation establishmemt. There also was discussion of the conversion to loblolly pine (*P. taeda* L.) on many sites in Ouachita Mountains of Arkansas and Oklahoma. The reasons cited for the conversion were generally better establishment and superior volume production. Despite the success with loblolly pine in the area, it was apparent that the National Forests, many nonindustrial private forest (NIPF) owners, and some members of the forest industry would continue to plant shortleaf pine in the Ouachita and Ozark

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[1/] Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Chief silviculturist, USDA Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

Highlands. Therefore, much of the discussion focused on differences between the two species. Traditionally, loblolly pine reforestation techniques had been used as a model for shortleaf pine reforestation; therefore, very little regeneration research had been done specifically for shortleaf pine. The relative poor results achieved with this approach were a major concern of the group. Consequently, consensus was reached that there were many research opportunities for developing the knowledge necessary to improve the field performance of shortleaf pine. The group agreed to form an ad hoc task force to address these research needs.

The topics on which the task force felt research would be beneficial, and some specific questions asked about each, can be summarized as follows:

Forest genetics.--1s the superior survival and early growth usually observed for loblolly pine a result of genetic or seedling-quality differences between loblolly and shortleaf pine?

Seed processing and handling.--Can better seed crop uniformity and yield be achieved by improving seed orchard management? What are the optimum prechilling (stratification) lengths for the seeds from various sources (e.g., seed orchard, geographic, or family source) currently planted? How much improvement is seedling crop uniformity could be achieved with seed sizing?

Seedling production.--What characteristics are important for the optimum shortleaf pine seedling (i.e., what is the target seedling)? How do shortleaf pine seedlings differ in growth from loblolly pine seedlings? What cultural and conditioning treatments will result in the desired target shortleaf pine seedlings?

Seedling handling and storage.--What is the optimum lifting window for shortleaf pine at a particular nursery? What are the interactions among the timing of lifting, storing, and outplanting of shortleaf pine seedlings?

Stand establishment.--Are the accepted practices of site preparation, competition control, and protection as applied to loblolly pine adequate for shortleaf pine?

Although all of' these concerns had merit, the task force felt that seed and seedling quality should have the highest research priority, and the initial research emphasized these topics. Determing optimum prechilling lengths was the highest-priority topic under seed quality. Under seedling quality, several topics were given high priority. Determining and evaluating a target seedling under stress conditions was considered important. So was determining differences in growth responses to nursery culture by families, so that families with similar growth patterns could be grouped together for improved seed efficiency and seedling uniformity. In conjuction with the above topics, the task force expressed a need to determine which cultural and conitioning practices (e.g., sowing date, seedbed density, root culture, moisture stress, etc.) should be applied to bring each response group to the target specification. Another high-priority question concerned the best timing (as

determined by budset and root growth potential) of lifting and storage to ensure good performance under stressed conditions.

A PRELIMINARY TARGET SEEDLING

Basic to all the research considered was the concept of a target seedling. A target seedling should approach the best-performing seedling for the harsh sites typical of the Ouachita and Ozark Mountains. It should change as additional knowledge and experience are gained, and it will necessarily vary somewhat according to the intended planting site and planting methods. The target seeding, however, should approach the optimum seedling over time. The task force defined the following preliminary morphological characteristics of the initial target seedling:

Height: 6 to 8 inches (15 to 30 cm)
Root collar diameter: 1/16 to 3/16 inches (1.6 to 5.0 mm)
Roots: 40 percent by seedling over-dry weight;
fibrous and mycorrhizal;
taproot 4 to 8 inches (10 to 20 cm) long, with more than 7 laterals
Stems: woody, secondary needles;
well-developed bud by November 1 (at latitude 33° to 34° N).

As a result of the research program, these characteristics have been modified. It was recongized that physiological characteristics such as root growth potential and dormancy release index should be evaluated and incorporated into the target seedling concept as these parameters become better understood.

SCOPE OF THE RESEARCH

Research studies were initiated early in 1985, and over a 5-year period about 15 formal studies were conducted. Other organizations, such as the Univeristy of Arkansas at Monticello, joined the effort. The research included evaluation of seed pregermination treatments; nursery studies to improve seedling quality; studies on the use of fungicides to reduce seedling storage pathogens, on the production of high-quality container planting stock, and on the use of root growth potential to identify optimum seedling lifting windows; studies relating seedling physiology and morphology to performance under stress conditions; and evaluations of the effects of competition control at the time of planting on early performance. A bibliography of the early publications resulting from the effort of the Shortleaf Pine Artificial Regeneration Task Force is appended.

CHANGE IN REFORESTATION EMPHASIS

When this effort was initiated, planting of bare-root seedlings was the primary reforestation approach in the National Forests in Arkansas and Oklahoma. However, during the past 2 years there has been a major shift in emphasis from artificial to natural regeneration. Thus, there is less need for the information on artificial regeneration now than when this effort started. With the emphasis on natural regeneration, this workshop includes presentations on both regeneration systems.

OBJECTIVES OF THE WORKSHOP

The purposes of this workshop are (1) to present the information gained through the Shortleaf Pine Artificial Regeneration Task Force effort, (2) to provide state-of-the-art information on natural regeneration techniques, and (3) to determine what the attendees consider the high-priority research needs for regenerating shortleaf pine throughout the South, with emphasis on the Ouachita and Ozark Mountain region.

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HISTORICAL PERSPECTIVES ON REGENERATION IN THE OUACHITA AND OZARK MOUNTAINS--THE OZARK NATIONAL FOREST[1/]

0. D. Smith, Jr.[2/]

Abstract.--The level of forest management of the Ozark National Forest has changed dramatically since the Forest's establishment in 1908. Although early regeneration efforts were limited, establishment of even-aged plantation stands of shortleaf pine (*Pinus echinata* Mill.) became the major focus in the early 1960's and continued for 30 years. Recently, there has been a movement back to natural regeneration and uneven-aged management which was the mainstay of early regeneration efforts.

INTRODUCTION

The Ozark National Forest was created on March 9, 1908 by President Theodore Roosevelt. A Presidential Proclamation signed that day established a gross area of some 917,944 acres as the Ozark National Forest.' The net area at that time is unknown. This was apparantly the first protected stand of hardwood timberland in the United States (Bass 1981). A number of proclamations subsequent to that time increased or decreased the acreage within the proclamation boundary until the present configuration was achieved (USDA Forest Service 1962). Some 317,000 acres of the Forest consists of public domain lands. The remainder and bulk of the Forest (about 800,000 acres) was purchased from private ownership under the Weeks Law of 1911. Most of this land was purchased between 1930 and 1940 (USDA Forest Service 1978). Logging had begun in the Ozarks by 1879 (Bass, 1981) and increased rapidly following construction of the railroad from Little Rock to Ft. Smith. By 1890, the lumber industry in the Ozark region was well underway. Cutting progressed at a rapid rate and much of the virgin timber was cut. Entire watersheds were practically denuded. Fires followed the logging, destroying young timber and delaying renewal of the timber crop. Settlers on the mountain farms chopped and cropped until the topsoil was washed away. By the end of the 19th century, choice and valuable timber species such as cherry and walnut were hard to find. White oak and pine were to be found in only the more inaccessable locations (USDA Forest Service 1962) and much of the more assessable land had been cut over or cleared for agricultural purposes by the time the Forest was created.

EARLY REGENERATION TRIALS

In the early days, management of the Ozark National Forest was mostly custodial. Control of forest fires and establishment of boundaries were of

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[1/] Paper presented at Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Timber And Fire Staff Officer, USDA Forest Service, Ozark-St. Francis National Forests, Russellville, AR 72801.

primary importance. However, from the very beginning, reforestation of open land was recognized as an important part of forest management. The Ozark Newsletter of September 1, 1911, (just three years after the Forest was established) contained the following statement (U. S. Forest Service 1911):

> "The District Forester has requested that 100 acres on the Ozark be subjected to direct seeding before June 1912 and that 20,000 pounds of hickory, 15,000 pounds of black walnuts, 12,000 pounds of white oak, 3000 pounds of red oak and 3,000 pounds of post oak be procurred with which to do the planting."

There is apparantly an error in the acreage since this would amount to some 530 pounds of seed per acre!

This same newsletter, signed by Forest Supervisor Francis Kiefer, urged all Forest Officers to report open areas on the forest in need of planting.

A second newsletter in May 1912 reported (U. S. Forest Service 1912):

> "Planting and sowing for this season have been completed. 9 fenced tracts covering 68 acres on White Rock District were sown to black walnuts between December and April. On Sylamore District, enough walnuts were sowed in the Sartain Nursery to produce 53,000 seedlings which will be transplanted to open fields next year. As an experiment in transplanting, 3000 wild cedar seedlings were lifted and set out on a cutover portion of the Chess and Wymond sale. The extra seedlings in each seed spot on the Cap's Fork site and Oak Mt. Site were lifted and placed in failed places on the same area."
>
> "The plans for 1913 on the Ozark call for 40 acres sowing and 10 acres planting which will need to be modified so as to care for the large stock of walnut seedlings to be produced by the Sartain nursery."

Records are incomplete but it is assumed that reforestation efforts continued at about the same level until the land aquisition program began in 1919. Under this program, large acreages of old fields which were not restocking came into Government ownership creating a need for an expanded reforestation program. (USDA Forest Service 1962).

In the spring of 1929 a small nursery was established at Fairview to furnish shortleaf pine seedlings for planting these old fields. This nursery was soon abandoned because a reliable source of water could not be found and a new nursery was established at Arkansas Tech University. The first seed was sown in March of 1930. A survey that same year showed more than 12,000 acres in need of planting and the capacity of the nursery was increased to 1,000,000 seedlings (USDA Forest Service 1962). In 1933, the Civilian Conservation Corps was created and a ready source of labor to plant the seedlings became available. By 1938 the Ozark nursery was estimated to have a capacity of 4,000,000 seedlings annually and the authorized production for that fiscal year was 2,500,000 shortleaf and 100,000 other species. Seedlings were for use on the Ozark, Ouachita and Mississippi National Forests (U. S. Forest Service 1938). Small quantities of hardwood seedlings were also to be produced for experimental planting and decoration of tower sites and recreation areas.

A March 1937 report indicated that 5,000 acres had been planted with one year old shortleaf pine seedlings on an 8'X 8' spacing.

The Ozark nursery continued in operation through 1941. At this point, the record becomes hazy. While it is known that planting of old fields and newly acquired lands continued through the 1940's and 1950's, actual records are not currently available to verify acreages planted or the success of the program. There is also no indication of where seedlings were acquired. Quite likely, very little planting occurred during World War II.

The Ozark Nursery Plan Of Work for 1935 (U. S. Forest Service 1935), written by Nurseryman G. F. Erambert, makes interesting reading. This very detailed and precise document contains information on everything from weed species occurance in the nursery and recommended control methods to how to lift, sort and bundle seedlings. A memomandum dated December 3, 1935, from E. E. Carter, Chief of the Region 8 Division of Timber Management, commenting on the Plan Of Work makes two points which I think are as important today as they were back then. One is the concept that good nursery practices must be followed up with good seedling handling and planting practices. Quoting from Mr. Carter's memo:

> "My point is that the real test of root-pruning is in the survival figures after planting on comparable sites and that the nurseryman must remember that the production of the planting stock in the nursery is only one step in the process of getting a satisfactory new stand on acres now idle."

The other point is the importance of selecting the proper seed source. On this topic, Mr. Carter had this to say:

> "The form of stock as it leaves the nursery may be excellent, but the whole job may be poor if 50 or 75 years hence the resulting trees prove to be of a strain which is poorly adapted to the site on which the trees are to be planted in comparison with trees of the best strain which is adapted to that site. This is particularly true for a species like shortleaf pine, which grows over a wide range of climatic and soil factors."

MODERN REGENERATION EFFORTS

In the early 1960's a decision was made in the Washington Office of the Forest Service which had a profound effect on the reforestation program on the Ozark as well as most other National Forests. It was decided that even-aged management would become the system of choice on all of the National Forests throughout the country. Prior to that time, uneven-aged silviculture had been used on the Ozark with most harvests being improvement cuts or thinnings. Virtually all the tree planting on the Ozark had been for the purpose of restocking old fields or areas denuded by fire or by uncontrolled logging prior to acquisition of the land by the Government. The era of even-aged management brought on new demands for reforestation as clear cutting and plantation management became the norm. The results of this program are shown in table 1. Seedlings for this program have come from the Forest Service's Ashe Nursery, Arkansas and Missouri state nurseries and most recently from contracts with Weyerhauser and International Paper Company nurseries.

Table 1.--Acres planted by fiscal year in the Ozark National Forest

Year	Acres Planted		Survival Percent */	
	Shortleaf	Loblollv	Shortleaf	Loblolly
1963	3845			
1964	2202			
1965	1924			
1966	3573			
1967	3738			
1968	1190			
1969	2800			
1970	1615			
1971	1470			
1972	3236			
1973	4334			
1974	5090			
1975	4920			
1976	8181			
1977	5169			
1978	3290			
1979	3324			
1980	1800	1090	20.9	11.3
1981	3077	1503	45.5	60.5
1982	3496	1690	48.5	48.2
1983	3285	2036	39.2	51.4
1984	1934	1660	69.3	58.8
1985	1443	1152	51.5	42.3
1986	1836	1097	62.9	51.1
1987	1992	366	74.1	77.2
1988	1952	422	78.5	84.2
1989	1599	369	76.0	90.4
1990	1702	0	79.5	
1991	2313	0		

*/ Data on species breakdown between shortleaf and loblolly and on survival percentages is not currently available for years prior to 1980.

Exactly when loblolly pine began to be planted on the Ozark is unclear. Records prior to 1980 are not currently available but it is doubtful if significant acreages of loblolly were established earlier than that time. Current CISCII data for the forest indicates about 9,000 acres of loblolly forest type, all of which would be in plantations. Planting records indicate that 11,385 acres have been planted since 1980, some of which would have been replanting following failures.

Among the oldest known plantations of loblolly pine on the Ozark are those located on the Wedington Unit, west of Fayetteville, Arkansas. Some of these plantations were established by W.P.A. workers in 1939. Fomes anosus root rot has been a problem in some of these plantations but otherwise, the trees are growing quite well. Another loblolly plantation is located on the Lee Creek unit north of Ft. Smith. This plantation is at least 40 years old and appears

to be quite healthy and vigorous and is producing viable seed as evidenced by seedlings in the understory.

While survival percentages fluctuate from year to year, the trend has been generally upward. Improvement in survival can generally be attributed to better quality seedlings and better care from nursery to planting site. Differences in survival between loblolly and shortleaf on the Ozark are not consistent. Due to variations in planting sites and other uncontrolled factors, no significance can be attributed to these differences.

FUTURE TRENDS IN REGENERATION

The current controversy over use of even-aged management on the National Forests in Arkansas leaves the future of the reforestation program in doubt. The currently approved Land Management Plan for the Ozark-St. Francis allocates 348,000 acres for pine management. An additional 396,000 acres is to be managed for hardwoods and the remaining 422,000 acres is considered to be unsuitable for timber production. Within the pine working group, the plan estimates that 1,350 acres of pine and mixed pine-hardwood stands would be clear cut annually with an additional 700 acres to be seed tree cut and 600 acres to receive shelterwood cutting.

If this plan is followed, there will be a continuing need for artificial regeneration in the clear cut areas and to some degree in the seed tree and shelterwood areas to take care of failures of natural regeneration. However, with the major statewide newspapers calling for an end to use of even-aged management on the national forests and with a number of powerful citizens groups joining in the fight, it remains to be seen whether plantation management, in any form, can survive on the Ozark National Forest.

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HISTORICAL PERSPECTIVES ON REGENERATION IN THE OUACHITA AND OZARK MOUNTAINS--THE OUACHITA NATIONAL FOREST[1/]

William D. Walker"

Abstract.--Establishment of planted shortleaf pine (*Pinus echinata* Mill.) in the Ouachita National Forest has been difficult because of harsh sites and mountainous soils. However, successful survival of planted shortleaf pine will occur when quality seedling, storage time, quality site preparation, and planting seasons are considered.

INTRODUCTION

During the 1960's, as a result of research information, the decision was made on the Ouachita National Forest to plant shortleaf pine (*Pinus echinata* Mill.) seedlings on a spacing of 8 x 12 feet (454 per acre). If survival averaged 66 percent, we would have then an acceptable stand of 300 seedlings per acre.

While District Ranger on the Boston Mountain Ranger District on the Ozark National Forest during the early 1970's, I found it very difficult to have 66 percent survival for shortleaf pine after the first growing season. Twenty to forty percent of the plantations had to be replanted.

In September 1974, after becoming the Timber Staff Officer on the Ouachita National Forest, I found first year survival was no better on the Ouachita than it had bken on the Ozark National Forest (figs. 1 and 2). After discussing my concern with Forest Supervisor Alvis Owens, I contacted W. F. (Bill) Mann, Jr. and Ed Lawson of the Southern Forest Experiment Station. Without hesitation, the recommendation was made to plant more seedlings which would better fit site conditions.

Bill Mann commented:

> "Bill, you are to be commended for 'challenging the planting rates for your Forest. Until we gear planting rates and other management practices to individual sites and management goals, we will not be practicing intensive management. Only when we prescribe practices on the ground recognizing many factors will we be exercising our skills as foresters to produce near-optimum yields."[3/]

1/ Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

2/ Staff Officer, Timber, Soil, Water & Air, USDA Forest Service, Ouachita National Forest, Hot Springs, AR 71902.

"Quote from March 25, 1975, memo to William D. Walker, Ouachita National Forest from W.F. Mann, Jr., Project Leader, Southern Forest Experiment Station, Pineville, LA.

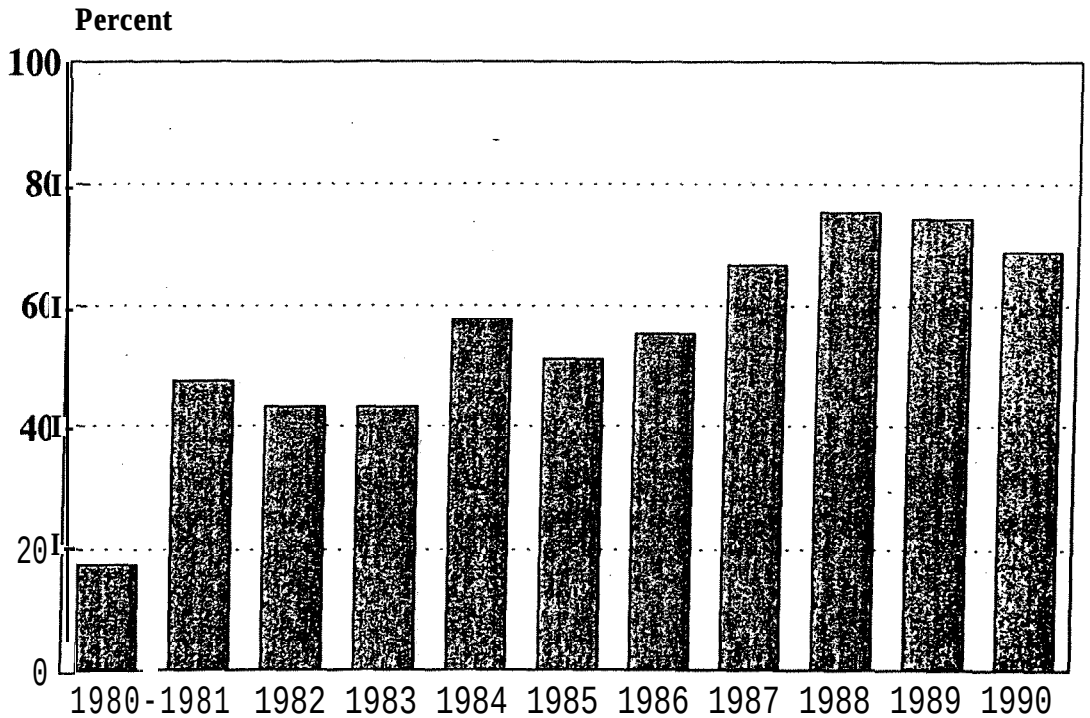

Figure 1.-- Survival by year of shortleaf pine seedlings planted on the Ouachita National Forest.

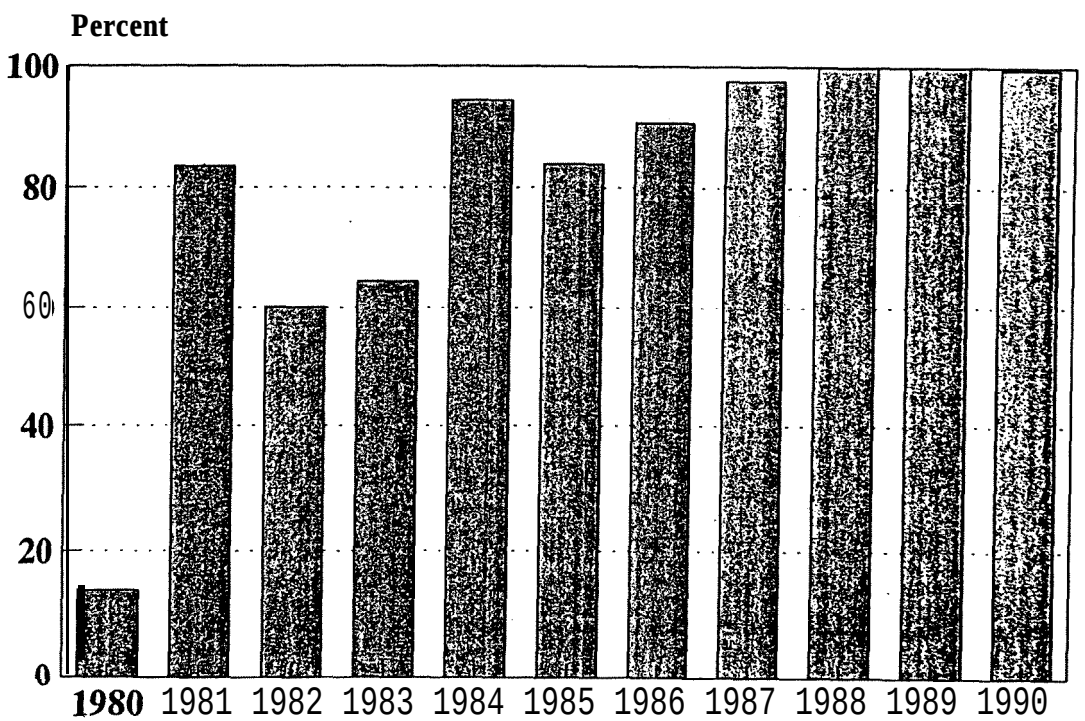

Figure 2. --Percentage of plantations with stocking at sufficient levels to be considered successfully established.

Ed Lawson comments were similar:

"It is my opinion that wider spacings providing only 400-500 seedlings per acre are inadequate for most planting sites in the mountain areas of Arkansas. Spacings should be selected to provide about 750 to 850 seedlings per acre for most management objectives. Both loblolly and shortleaf pines develop better form and produce higher quality wood when grown with some degree of competition."[4/]

During that year stocking rates started to increase and eventually were up to 778 seedlings (fig. 3).

This does not mean that I or any of the Ouachita National Forest personnel were satisfied with the low survival rates. We were less than satisfied with unacceptable plantations during the first year. We never agreed or accepted the attitude of many people that shortleaf pine was an extremely difficult species to plant. There was more to the issue than that.

At this point, we started tackling other problems affecting survival. These included:

1. Quality of seedling stock
2. Storage
3. Site preparation
4. Planting season
5. Contracting

Briefly, here is a short discussion of what we did.

QUALITY OF SEEDLING STOCK

Early in our planting efforts most of our seedlings were grown at the Forest Service Ashe Nursery in south Mississippi. We needed a seedling with a root length of 6" to 8" and equivalent top. Even with root pruning in the beds, tap roots were too long and lateral roots were totally unacceptable. Other problems included shipping for long distances, seedling storage, climate change, etc.

We found that the seedlings that met our needs best had stem heights of 6 to 8 inches, root lengths of 6 to 10 inches, and stem calipers of 4.4 to 6.3 mm. To meet these specifications, we started contracting for seedlings to be grown in nurseries within 125 miles of Mt. Ida, Arkansas.

The last few years our seedlings have been grown by Weyerhaeuser Company at Magnolia, Arkansas and Fort Towson, Oklahoma or International Paper Company near Bluff City, Arkansas. We had very good success getting quality seedlings on a timely basis from these two companies.

4/ Quote from November 14, 1974, memo to William D. Walker, Ouachita National Forest from E. R. Lawson, Project Leader, Southern Forest Experiment Station, Fayetteville, Arkansas.

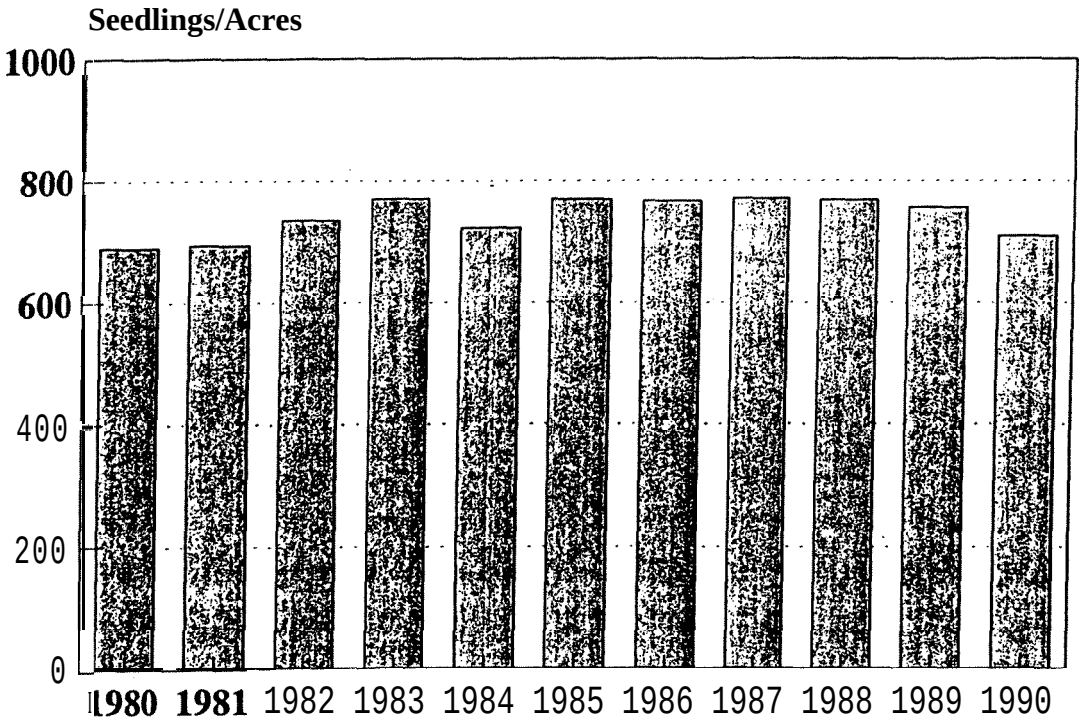

Figure 3. --Number of shortleaf pine seedlings planted per acre by year.

STORAGE

Early indications were that seedlings could be stored for long periods of time and 30 days of storage should cause no significant problems. This indication was not correct. Seedlings that were stored *for* less than three weeks had better survival than those stored for a longer period of time.

We installed cold storage facilities at each district work center. More frequent shipments were made rather than infrequent large loads. These efforts reduced storage time and improved performance.

SITE PREPARATION

Frankly, we did not always do a good quality site preparation job. It is nice to cut corners and save money, but to do a less than satisfactory job is not acceptable.

It was decided that if we could not do proper site preparation, then we should not plant. Ripping was used to prepare sites on most of the rocky and more difficult planting areas. The ripping treatment alone increased survival by 10 to 30 percent.

PLANTING SEASON

Initially, we thought that late December to late March was the best time to plant shortleaf pine. Because of the large quantities of seedlings to plant (9

to 13 million), it was difficult to finish by the end of March. We continually ran into April. Because of better record keeping, we noticed that December was a good time to plant shortleaf pine (fig. 4). April was a significantly poorer time to plant. We started planting in early December. This allowed planting to be completed by mid- to late-March.

CONTRACTING

Because of a reduction in numbers of Forest Service planting crews, planting begin to require contracting. Sufficient numbers of contract planting crews did not exist for many years to plant the 10 to 13 million trees needed for reforestation on the Ouachita National Forest (fig. 5).

Extra efforts were made to develop and maintain enough desirable contractors. This is a never ending job. No matter what is done prior to planting, it all goes for nought if a proper planting job is not done.

CONCLUSION

I have tried to briefly cover what we have done on the Ouachita National Forest to improve seedling survival if shortleaf pine. Hard work by a lot of people has made this a successful story.

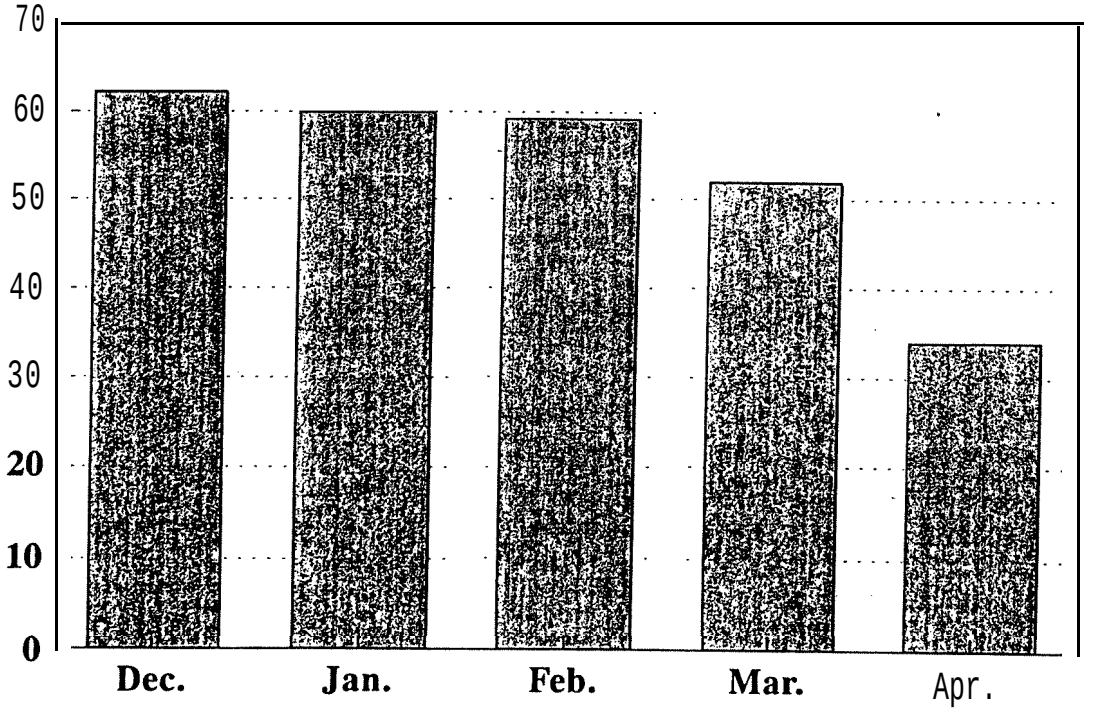

Figure 4. --Survival of shortleaf pine seedlings by the date of planting.

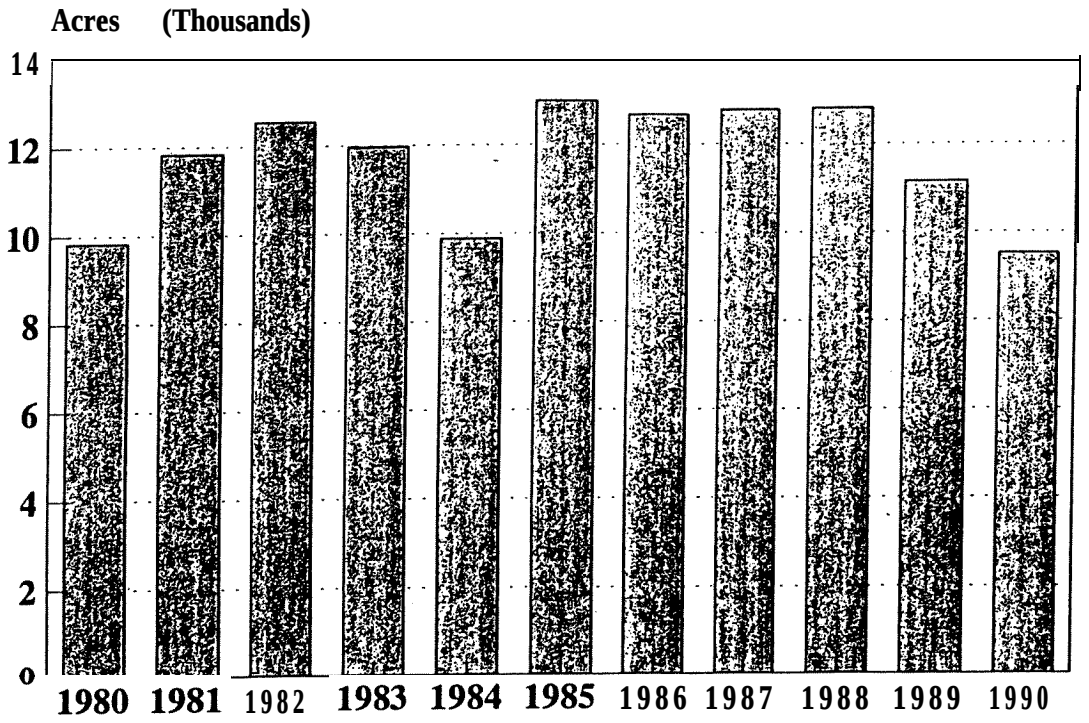

Figure 5. --Acres planted with shortleaf pine seedlings by year.

Nursery Production

Moderator:

Rick Horton

International Paper Company

PRODUCTION OF SHORTLEAF PINE SEEDLING&'

James P. Barnett[2/]

Abstract.--Uniformity in the production of shortleaf pine (*Pinus echinata* Mill.) seedlings is determined primarily by prompt and uniform seed germination, early seedling establishment, and a variety of cultural practices that are applied as the seedlings develop. The goal of the nursery manager should be to maximize performance attributes and avoid the need for corrective operational procedures such as thinning, root pruning, top pruning, and culling.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most widely distributed southern pine species, and extensive stands of shortleaf pine occur in Arkansas and Oklahoma throughout the Ouachita and Ozark Highlands. Yet little research' has focused on the production of quality planting stock, and much less information is available concerning appropriate regeneration technology for shortleaf pine than for loblolly pine (*P. taeda* L.). Consequently, regeneration efforts have shown poor results on the difficult sites in the Ouachita and Ozark Highlands (Brissette and Carlson 1987). Since information on shortleaf pine nursery culture and regeneration techniques has usually been unavailable, the gaps have been filled by using data from loblolly pine (Barnett et al. 1986). The research reported here is part of a program to develop nursery cultural procedures specific to shortleaf pine.

Shortleaf pine seedlings are produced in one growing season. In bare-root nurseries, seeds are usually sown in early April, and seedlings are lifted in the following winter from early December to late February. Preliminary recommendations for specifications of high-quality seedlings were anticipated to be as follows: heights of 15 to 25 cm, diameters of 2.5 to 5.0 mm, and a dry-weight root:shoot ratio of 4:l. Seedlings should have mostly secondary needles, a woody stem, and a terminal bud formed by early November. The root system should have more than seven primary laterals, should have a tap root 10 to 20 cm long, and should be fibrous and mycorrhizal (Barnett et al. 1986). Specifications for quality shortleaf pine container planting stock have not been developed.

SEED, SEED HANDLING, AND PRETREATMENTS

Prompt, uniform germination and early seedling establishment are essential factors in producing consistently high-quality shortleaf pine seedlings. If there is large variability in seed germination or seedling establishment, then there is little chance of producing a quality seedling crop. The goal of any nursery manager should be to have seed lots with germination greater than 90

[1/] Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Chief silviculturist, USDA Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

percent, and losses, after emergence, of less than 10 percent (Barnett 1989a). Seed lots with losses of more than 10 percent make it difficult to consistently produce high-quality crops because of the oversowing and subsequent waste of seed required to compensate for poor emergence and establishment.

Once germination occurs and seedlings become established, the nursery manager can manipulate a wide variety of environmental and cultural controls to regulate seedling development, resulting in greater seedling uniformity. Whether seedlings are produced in containers or under bare-root conditions determines the nature of the actions to be taken, but the basic biological principles are similar. The decision-making process is similar for the two production techniques.

Seed sources

Provenance studies have shown that shortleaf pine from the Arkansas-Oklahoma region is similar to shortleaf pine across the South (Tauer 1980, Wells 1978). There is relatively small variability among provenances and large variability among families (Tauer and McNew 1985). The recommended shortleaf pine seed sources for the Ouachita and Ozark Highlands are those in the local planting area or those in the more eastern areas of the northern coastal plain or piedmont (Lantz and Kraus 1987).

Collecting: and processing cones and seeds

Seed maturation varies by half-sib family. There is also variation in dormancy, which can be measured by speed of germination. Collecting, handling, and processing may affect seed quality (Barnett and McLemore 1970). Dormancy can influence the germination pattern by slowing early germination, particularly in bare-root,nursery beds where temperatures and photoperiods are often considerably less than optimal (McLemore 1969). Relatively few studies have evaluated the effects of cone maturity on seed extraction and viability. Basically, the guidelines for shortleaf pine are to make collections when cone specific gravity reaches 0.89 or less (Wakeley 1954). A graduated-cylinder technique for determining cone specific gravity is more reliable than the old method of floating cones in SAE 20 motor oil (Barnett 1979). However, cone afterripening or storage for 3 to 4 weeks should improve seed yields and perhaps seed quality (Barnett 1976).

All empty seeds should be removed prior to sowing. This practice is the easiest means of upgrading a seed lot. Normally, empty seeds are removed by mechanical cleaning equipment, including scalpers and gravity or pneumatic seed-processing equiment. However, when seed lots are small, as in lots for progeny tests, it is often convenient to use flotation to separate unfilled seeds. Flotation in 95 percent ethanol works well for separating shortleaf pine seeds (Barnett 1971b). Flotation in ethanol should be delayed until just before seed use, because if the ethanol is not thoroughly removed by drying, seeds so treated may rapidly lose viability in storage (Barnett 1971b).

Storing seeds

Careful control of seed moisture content and storage temperature is essential to maintain viability (Barnett and McLemore 1970, Barton 1961, Jones 1966). Although few specific storage studies have been conducted with

shortleaf pine seeds, the general recommendations for long-term storage are to dry seeds to 10 percent moisture content or less and hold at subfreezing temperatures. Engstrom (1966) subjected shortleaf pine seeds to -196 F temperatures for 112 days without injury. In addition, Barnett and Vozzo (1985) reported the maintenance of viability of shortleaf pine seeds for 50 years under less than optimum conditions. Seeds that are damaged or known to have low vigor can be preserved by drying to a moisture content of 8 to 10 percent and lowering storage temperatures to about 0°F (Kamra 1967).

Seed vretreatments

After high-quality seeds have been obtained and stored, they must be properly prepared before sowing. Overcoming seed dormancy is one of the major steps toward ensuring prompt and uniform germination. Typically, moist prechilling (stratification) is done after an 8- to 24-hour period of moisture imbibition. Fully imbibed seeds are placed in polyethylene bags and held at temperatures of 34° to 38°F. Length of prechilling treatment varies by the extent of dormancy present in the seeds. Although moist prechilling treatments are routinely applied to shortleaf pine seeds, few studies provide specific guidelines. Seidel (1963), working a single seed lot, found that germination speed increased progressively with lengths of prechilling up to 60 days. Barnett and McGilvray (1971) tested 16 separate and unimproved lots representing various sources and years of collection. They found that freshly collected seeds were much less dormant than stored seeds. In these tests, germination speed of stored seeds continued to increase through 56 to 70 days of prechilling.

This series of studies using half-sib sources from seed orchard collections was conducted to provide better information on the prechilling needs of these shortleaf pine seeds. In addition to evaluating a range of .pretreatments, seeds were tested under the ideal conditions (72°F and 16-hour photoperiod) of standard germination tests (Association of Official Seed Analysts 1980), under the more difficult conditions of 60°F temperature and a 12-hour photoperiod, and under nursery-bed conditions. The nursery was an experimental one on the grounds of the Alexandria Forest Center near Pineville, Louisiana. Depending on latitude and yearly climatic variability, nursery beds in early April more nearly approximate the 60°F and 12-hour photoperiod conditions than the standard laboratory conditions.

In test 1, seeds from six half-sib families were subjected to 0-, 30-, and 60-day prechilling. A fourth treatment was 60-day prechilling plus a 3-day aerated water soak. Responses to treatments were evaluated by determining germination percentages and values. The germination value reflects the speed of germination and is expressed as the peak value of the maximum cumulative percentage of germination divided by the number of days from sowing (Czabator 1962). The results of this test indicate that these seed lots were not nearly as dormant as those reported by Seidel (1963) and Barnett and McGilvray (1971). Germination of seeds tested under standard conditions and in nursery beds did not respond to periods of prechilling beyond 30 days (table 1). Seeds tested at 60°F temperatures and shorter photoperiods did benefit from the longer prechilling treatments. Had nursery-bed conditions been more adverse, seeds would have shown more response to the longer treatments.

Table 1.--Germination percentages and values for shortleaf pine seed lots subjected to different germination conditions */

Germination conditions	Germination period				Germination value			
	0	30	60	60+	0	30	60	60+
	Percent							
Lab at 60°F	0	17	62	70	0	0.6	5.7	8.0
Lab at 72°F	80	91	90	88	14.9	31.3	34.2	25.7
Nursery	45	79	76	77	2.1	9.6	11.4	12.6

*/ The germination data are means of two 100-seed samples from six different half-sib families. The 60+ treatment consists of 60 days of cold stratification (36°F) plus 3 days of aerated water soaks at 75°F.

Germination of seeds that were sown in the nursery in test 1 was measured weekly, and those that germinated during a given time were marked with colored plastic rings so that their development could be followed. In addition to germination, seedling mortality that occurred up to the end of May and seedling heights and diameters at lifting were measured. Germination peaked during the second week from sowing, but seedling mortality continued'to increase as the seeds germinated later in the season (table 2). Mortality of seedlings that germinated in the fourth and fifth weeks averaged 27 and 56 percent, respectively. It is also interesting to note that seedlings lifted from this late germination period were considerably smaller than, and were never able to compete with, those from early-germinating seeds.

In a second test of prechilling treatments, 0-, 15-, 30-, and 60-day prechilling was evaluated with and without an aerated-soak treatment (table 3). The six seed lots used in the study showed little additional response to prechilling beyond 15 days. Apparently the seed-orchard seeds evaluated in these tests were less dormant than the woods-run lots that were reported earlier, although this dormancy may have been influenced by storage. Seeds from orchards are generally larger, and studies with loblolly pines indicate that large seeds tend to germinate faster than small ones, probably because they are less dormant (Dunlap and Barnett 1983).

Table 2.--Seedling size of shortleaf nine seedlings at lifting as related to the time of germination */

Time after sowing	Germination per week	Loss of germinants to Mav 31	Seedling size	
			Height	Diameter
Days (week)	---- -Percent--------		---- -mm------	
8-10 (1)	6	12	157	4.1
13-17 (2)	52	13	160	4.0
20-24 (3)	30	18	144	3.5
27-31 (4)	10	27	118	3.1
34-38 (5)	2	56	115	2.7

*/ Seeds were sown April 2, 1985, in four replications of two 50-seed rows for each of six half-sib families. Size measurements were made in early January 1986.

Table 3.- -Germination percentages and values for shortleaf pine seed lots of test 2 subjected to different germination conditions */

Germination conditions	Days of seed pretreatment							
	0	15	30	45	o+	15+	30+	45+
	Germination percentages							
Lab at 60°F	44	92	92	94	45	87	92	94
Lab at 72°F	61	86	92	94	68	88	92	95
Nursery	42	80	87	83	54	77	86	85
	Germination values							
Lab at 60°F	4.9	22.6	28.3	33.2	8.6	25.7	34.8	71.8
Lab at 72°F	8.7	33.4	42.6	55.4	16.1	44.3	59.1	91.7

*/ The germination data are means of two 100-seed samples from six different half-sib families. The prechilling treatments followed by (+) reflect 3 days of aereated water soaks in addition to prechilling.

Soaking seeds in aerated water is a short-term technique for overcoming seed dormancy. Soaking shortleaf pine seeds in continuously aerated water at 50°F stimulates germination as much as colder soaks and more quickly (Barnett 1971a). This is a good technique for providing a rapid stimulatory effect to shortleaf pine seeds.

SOWING

There are enough seed orchards producing shortleaf pine seeds that most nursery production is now from genetically improved seeds. This production is typically grown from mixed orchard lots. However, sowing and growing stock by clonal family is now an option.

Sowing bv clonal family

Uniformity in the seedling crop can be increased by sowing by clonal or half-sib family. This technique, which is used routinely by a number of forest industry organizations, requires that cone collection and seed processing to maintained by clonal family, but it greatly reduces the genetic variability in seedling size when seeds are sown in nursery beds or greenhouses. Small differences among families in stratification procedures, germination, early nursery growth, dormancy, and storage characteristics can be used to improve seed and seedling quality (Duzan and Williams 1988). Because of the uniformity in germination rates, sowing seeds by half-sib family may increase seedling size and number of plantable seedlings. With experience and careful monitoring, it becomes feasible to group families according to similarities in growth and development. Grouping increases the practicality of the techniques and still provides for improvement in seedling uniformity,.

Time of sowing

Date of sowing is a variable that has not been evaluated with shortleaf pine. Most nurseries currently sow shortleaf pine seeds in early April. However, experience with loblolly pines indicates that seedling morphology can

be markedly 'influenced by time of sowing. This experience indicates that early sowing can increase seedling caliper and biomass (Boyer and South 1988, Mexal 1982). However, when seeds *are* sown early in a bare-root nursery, undercutting may be needed to limit height growth. Early sowing may also result in sporadic or uneven germination unless extended periods of seed prechilling are used. Delaying sowing will likely delay the formation of the initial bud and will decrease seed efficiency.

CULTURAL PRACTICES

Most shortleaf pine planting stock is produced in bare-root nurseries. However, production of container nursery stock is a viable option.

Container verus bare-root stock

The use of container-grown seedlings offers landowners a regeneration technique that has proved beneficial in regenerating difficult sites, in extending the planting season, and in establishing hard-to-regenerate species. The merits of container stock have been discussed by Stein et al. (1975) and Barnett and Brissette (1986). Several studies indicate that container stock survives and begins early growth better than does bare-root stock on harsh, droughty sites (Barnett and McGilvray, in press; Sloan et al. 1987; South and Barnett 1986). Other authors have studied bare-root seedlings of different morphologies and have attributed the greatest success to those that have high root-growth potential or root volume (Dougherty and Gresham 1988). Rapid early root growth helps to prevent seedling death or growth loss caused by water stress. A comparison of the morphological characteristics of container and bare-root nursery stock produced from the same half-sib families is shown in table 4. Although container stock is generally smaller than bare-root seedlings, because bare-root seedlings are grown in much larger numbers per unit area, the root mass of container stock is usually greater because the entire root system is retained.

Operational cultural techiaues

Maintaining high seed quality through the seed processing operations is the first critical requirement for producing uniform seedlings; the second is the use of appropriate cultural practices. For a discussion of all the cultural practices required for production of container and bare-root nursery stock, see Duryea and Dougherty (1991). This paper covers only some of the critical issues that determine whether high-quality shortleaf pine seedlings will be produced.

Transplanting and thinning.--Obtaining and maintaining an appropriate number of seedlings per unit area is critical to producing uniform seedling crops. Using seeds of low viability requires sowing multiple seeds for each seedling produced. Often such sowing results in either excess or inadequate numbers of seedlings. The bare-root nursery manager can do little to compensate for poor germination. It is feasible to supplement container cavities with ungerminated seeds by transplanting excess germinants from other containers. However, Pawuk (1982) found that unless transplanting is done promptly and before radicles elongate beyond one-half inch, the growth of transplants never compares with that of nontransplanted germinants.

Thinning is an option for nursery managers, but it is an expensive operation in either bare-root or container nurseries. An alternative to thinning is to leave the nursery beds or containers with higher densities or numbers per cavity. The low cost of this alternative must be weighed against the reduction in seedling quality and field performance that occurs when seedlings are grown under conditions of severe competition. As a general recommendation, the grower should (1) use only the best-quality seed available to avoid the need for thinning, (2) thin as needed to obtain good-quality seedlings, and (3) avoid transplanting. Both thinning and transplanting, if done, should be completed as soon as possible after sowing.

Table 4.--Morphological characteristics at the time of outplanting of container (Cont) and bare-root (Bare) shortleaf pine seedlings from selected half-sib families (adapted from Brissette and Barnett 1989)

	Characteristic and stock type							
	Shoot length		Diameter		Root volume		Shoot:root ratio	
Family	Cont	Bare	Cont	Bare	Cont	Bare	Cont	Bare
	----cm----		----mm----		---- cm^3 ----			
103	24.4	25.0	3.8	4.4	3.6	2.2	1.06	2.40
115	21.9	29.4	4.0	5.4	3.5	3.4	1.05	2.61
202	19.7	26.6	3.8	4.7	4.3	2.9	0.70	2.16
219	22.5	20.2	3.9	3.8	3.5	1.7	0.98	2.03
322	20.9	28.3	3.6	5.1	3.1	3.0	0.93	2.74
342	19.4	20.2	3.7	4.0	3.6	1.7	0.77	2.06
Mean	21.5	24.9	3.8	4.6	3.6	2.5	0.91	2.33

Root pruning.--Undercutting has been a standard practice in many southern bare-root nurseries to restrict the growth of large seedlings, sever long taproots, loosen the soil to improve aeration and infiltration, and possibly stimulate growth of lateral roots. The undercutting blade used in wrenching, a modified form of root pruning, has more of an angle to it than the typical undercutting blade. Wrenching tends to lift the bed and puts the seedlings under greater moisture stress than does the normal root-pruning operation; wrenching is usually accompanied by watering to reduce mortality of wilted seedlings. Pruning or wrenching to control shoot growth and stimulate development of a mass of short, fibrous roots must be properly timed. Undercutting is necessary to influence morphological development of the root and shoots. The scheduling of undercutting depends on the rate of seedling growth and the type of root system needed for the planting site.

Top pruning.--Although top pruning has been practiced intermittently since the mid-1930's to retard excessive top growth and maintain better root-to-shoot ratios, the current thinking is that it should be avoided. Crop management is a better approach to controlling seedling heights (Barnett 1984, Mexal and Fisher 1984). This is especially true for shortleaf pine seedlings, which are usually controlled by appropriate undercutting of the root systems. The loss of photosynthetic production that results from top pruning may also reduce performance on the severe sites where shortleaf pine is generally planted.

Culling.--Some seedlings in each nursery operation are unsuitable for field planting because they are too small, damaged, or diseased. These seedlings should be removed and discarded. Seedlings are seldom graded into the morphological grades established by Wakeley (1954) owing to reduced seedbed densities, adjustments to fertilization, and root and top pruning practices.

Usually, seedlings are either plantable or nonplantable, and any grading done at nurseries is a culling operation. A general rule is to eliminate grading and culling if fewer than 10 percent of the trees in any seedlot are small, damaged, or diseased (Lantz 1985).

Environmental controls

The nature of the soil or artificial growing medium is the critical factor affecting any nursery operation. This factor can readily be controlled in container operations (Landis et al. 1990), but in bare-root nurseries, site selection is the main determinant of the growing medium (Duryea and Landis 1984, Lantz 1985). The nature and properties of the medium greatly influence the environmental control techniques available to the manager.

Three parameters that can readily affect seedling uniformity are temperature, light, and moisture. These parameters can be controlled more easily in greenhouses than in bare-root nurseries. However, even in bare-root nurseries, the manager can use some cultural methods to manipulate the germination environment in the seedbed.

Temverature. --Temperatures for.germination and early establishment can be modified by delaying the seed sowing date to take advantage of warmer soil temperatures or by lengthening seed prechilling treatments to improve performance under cool conditions. The manager can compensate for the later sowing by careful manipulation of irrigation and early application of nutrients (Lantz 1985). Even though late sowing can increase uniformity, it can also result in smaller seedlings if the seed sowing date is delayed beyond a certain time (probably mid-April for shortleaf pine in most nurseries).

Light. --Supplemental lighting can be applied in container nurseries and can markedly affect early seedling development. Most southern species grow better outside than in greenhouse structures, where light is restricted by discoloration of the cover or by use of shadecloth (Barnett 1989b).

In bare-root nurseries, the most typical means of controlling light intensity is by covering the seeds with soil or mulch. Some covering is very helpful in maintaining good soil moisture conditions for germination, but deep covering slows germination, primarily because of the decreased availability of light (Barnett and Brissette 1986, Rowan 1980). The nursery manager should try to limit the depth of covering to about the diameter of the seeds.

Moisture.--Uniform moisture conditions are necessary for both uniform germination and uniform seedling development. Irrigation systems are used in both container and bare-root nurseries, and uneven applications of water and nutrients can result in variations in seedling size across nurseries. Proper irrigation requires considerable skill in maintaining appropriate moisture levels for germination and then reducing the watering regime after germination peaks.

CONCLUSIONS

The production of consistently uniform conifer seedlings requires the control of a wide range of cultural and environmental conditions that affect

the quality of both seeds and seedlings. The nursery manager must start with seeds of high quality, treat them properly to obtain rapid and uniform germination, and then apply cultural practices that will result in consistent seedling development. The nursery manager must be familiar with the species being grown, understand how environmental conditions affect seedling development, and be able to manipulate growth by varying cultural treatments.

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SEEDLING QUALITY AND FIELD PERFORMANCE[1/]

John C. Brissette[2/] and William C. Carlson[3/]

Abstract. —Seedbed density and the amount of nitrogen applied in the nursery affected seedling morphology of shortleaf pine (*Pinus echinata* Mill.) but did not directly affect survival or growth on two sites in the mountains of Arkansas. However, seedling morphological attributes at the time of planting were related to growth in the field through age 5. Seedling diameter, height-to-diameter ratio, and presence of an overwintering bud were attributes that related to growth after outplanting. Target seedling specifications and some nursery cultural treatments to grow high-quality seedlings are recommended.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most important species used for artificial regeneration in the Ouachita and Ozark National Forests. Success in planting shortleaf pine in those mountain forests, however, has often been limited by poorer survival and slower initial growth than generally obtained with southern pines in other National Forests throughout the Southern Region. Poor performance of shortleaf pine seedlings in the mountains may be related to (1) generally droughty soil conditions on many sites, (2) poor handling and planting techniques, or (3) the quality of seedlings produced for planting on these rather difficult sites. This paper focuses on seedling quality.

Seedling quality is often defined in terms of morphology, especially diameter of the stem and, to a lesser extent, shoot length (Mexal and Landis 1990). The most widely recognized standards of morphological quality for southern pine planting stock are those describedby Wakeley (1954), which specify that, to be considered plantable, undamaged, disease-free shortleaf pine seedlings should have a root collar diameter greater than 3.2 mm. That recommendation was based on research in the coastal plain. For old-field sites in the northern part of the range of shortleaf pine, Chapman (1948) recommended a minimum diameter of 3.8 mm at 2.5 cm above groundline. He measured diameter at 2.5 cm above groundline to avoid the basal crook often present in shortleaf' pine seedlings. Although useful, these recommendations were not developed for conditions encountered when regenerating harvested stands in the Ouachita and Ozark Mountains.

Shortleaf pine has not received much attention from nursery researchers in the past. At most nurseries, shortleaf pine is cultured much like loblolly pine (*P. taeda* L.). However, in an early study, Huberman (1940) showed that shortleaf

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[2/]Principal Silviculturist, USDA-Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

[3/]Tree Physiologist, Weyerhaeuser Company, Weyerhaeuser Technology Center, Federal Way, WA 98003.

pine is slower to develop and grows longer in the nursery than loblolly pine. Therefore, altering nursery culture for shortleaf pine might improve seedling quality and field performance. Two important techniques in bare-root seedling culture are controlling seedbed density and controlling soil fertility (Switzer and Nelson 1963).

This paper reports on results, through age 5, of a study designed (1) to define targetmorphologicalspecifications for shortleafpinebare-root seedlings destined for planting in the Ouachita and Ozark Mountains, and (2) to determine the nursery culture required to grow such target seedlings.

MATERIALS AND METHODS

Nursery phase

The experimental design and details of the nursery phase of this study were described previously (Brissette and Carlson 1987a) and will be only briefly reviewed here. Seeds were from the medium-sized fraction of a bulked collection at the USDA Forest Service's Ouachita-Ozark Seed Orchard near Mount Ida, Arkansas. Seedlings were grown to 1-O bare-root stock in 1985 at the Weyerhaeuser Company's Magnolia Forest Regeneration Center in Columbia County, Arkansas. The study was laid out in a split-split plot design with four blocks. Whole plots were two levels of phosphorus (P) fertility; subplots were five levels of seedbed density; and sub-subplots were four levels of nitrogen (N) fertilizer applied during the growing season.

The levels of P fertility were (1) the base level in the soil when sampled in December 1984 (approximately 54 parts per million by the Strong Bray extraction method) and (2) an additional 138 kg/ha incorporated into the soil before seedbed preparation. In mid-April 1985, seeds were sown with a Weyerhaeuser-designed precision vacuum sower to achieve densities of (1) 160 seedlings/m^2, (2) 230/m^2, (3) 295/m^2, (4) 360/m^2, and (5) 430/m^2. Nitrogen was supplied as ammonium sulphate (21percentN) in five equal applications at 2-week intervals beginning 6 weeks after sowing. The total amounts of N applied were (1) 55 kg/ha, (2) 85 kg/ha, (3) 110 kg/ha, and (4) 170 kg/ha. All other cultural practices were based on the nursery manager's judgment. The seedlings were horizontally root pruned at 15 cm in August and November; they were not top pruned. In September, actual seedbed densities were measured at the center of each N application plot.

Field phase

In December 1985 (at the start of the lifting and planting season), samples of seedlings from each treatment combination were evaluated for seedbed density and N effects on stem diameter, shoot length, and root volume. Based on those results, a subset of treatments was chosen for evaluation of physiological attributes and for outplanting (Brissette and Carlson 1987a). Nine treatment combinations were selected to represent three levels of density and three levels of N application. The 36 plots (nursery block x density x N) chosen had measured densities ranging from 102 to 328 seedlings/m'. The low-density plots ranged from 102 to 167 seedlings/m^2 and averaged 135. The medium-density plots ranged from 196 to 242 seedlings/m^2 and averaged 220. The high-density plots ranged from 253 to 328 seedlings/m^2 and averaged 297. Within those three levels of density, treatments that received 55, 110, and 170 kg N/ha were chosen. Because

P had no effect on seedling morphology (Brissette and Carlson 1987a), treatments picked for additional study came from whole plots that did not receive additional P.

In January 1986, seedlings were carefully hand lifted from the nine selected treatments in each block of the nursery study. They were returned to the Southern Forest Experiment Station laboratory in Pineville, Louisiana and put into cold storage (approximately 3 °C). Twenty-five seedlings from each selected plot were measured for stem diameter, shoot length, and presence of an overwintering terminal bud. Stem diameter was measured at the root collar or as near to it as was discernable. If the stem was elliptical at that point, the smaller dimension was measured. Shoot length was measured from the root collar to the top of the apical dome or the tip of the terminal bud, if present. An overwintering bud was defined as one enclosed in woody, resinous bud scales. Each measured seedling was numbered and labeled and put back into cold storage.

Two sites were selected for outplanting. One was in Compartment 1130 of the Oden Ranger District on the Ouachita National Forest. The other was in Compartment 62 of the Magazine Ranger District on the Ozark National Forest. Both locations had been logged the previous year and were site prepared. At the Oden site, logging slash had been wind rowed before the site was ripped. The Magazine site was also ripped, but logging debris was burned in place. At both locations the experimental design was a split plot with four blocks, Without P as a factor in the field study, density was in whole plots and N applied was in subplots. Block integrity was maintained from the nursery experiment.

On both sites, blocks were laid out 9 rips wide and long enough to accommodate 25 trees with approximately 2.4 m between trees. Spacing between rips varied from about 2 m to about 3 m. At Oden, the rips ran up and down a very gentle southwest-facing slope. Blocks 1 and 2 were laid out above Blocks 3 and 4. At Magazine, the north-facing slope was estimated to be 10 percent or less and the rips were established on the contour. All four blocks were laid out end to end, Blocks 3 and 4 were higher on the slope than Blocks 1 and 2.

Block 1 at the Oden site was planted in early February. Air temperature was below freezing after planting, so no more seedlings were planted that day. The other three blocks were planted a week later, as were all four blocks on the Magazine site. After planting, the location of each numbered seedling was mapped. After the first, second, and fifth growing seasons, total height and groundline diameter were measured for each surviving tree.

A number of statistical procedures were used to evaluate the relative importance of nursery treatments and seedling morphology on field performance. First- and second-year survival and mean growth of the 25-tree plots were compared using quadratic response-surface regression analysis. Independent variables in the regression models were the interaction between density of the selected plots and amount of N applied, and the linear and quadratic terms of those two factors. Growth was defined as diameter^2 x height of a tree from one measurement minus diameter^2 x height of that tree from the previous measurement. That is, first-year growth was D^2H_1 minus D^2H_0, and second-year growth was D^2H_2 minus D^2H_1.

The impact of seedling morphology on field performance was studied by comparing the measured attributes--height, diameter, and presence of a bud-and

two calculated variables, D^2H and height-to-diameter ratio (H/D). D^2H is a good estimate of shoot biomass (Ruehle et al. 1984). The H/D, or sturdiness quotient, is an estimate of a seedling's ability to withstand physical damage (Thompson 1985). In a study with shortleaf pine, Chapman (1948) showed that seedlings with a relatively low H/D survived and grew better than seedlings with a relatively high H/D on a number of sites.

For the morphological comparisons, seedlings were placed in one of four classes based on first-year field performance. One class consisted of the mortality at each planting site. The other classes were determined by how well the seedlings grew (D^2H_1 minus D^2H_0) compared with other seedlings in the same block at the same location. If an individual seedling's growth was within ± 0.5 standard deviation of the mean growth for its block and site, its growth was deemed average (Avg). If a seedling's>growth was less than the range defined as Avg, it was considered below average (BA). Seedlings with growth greater than Avg were put into the above average (AA) class.

Considering first-year growth class the independent variable, analysis of variance (ANOVA) was used to confirm whether any of the measured seedling attributes differed among those classes at the time of planting. Three linear contrasts were designed to examine class differences by testing the following hypotheses for each planting site:

1. Morphological attributes of seedlings that died during the first growing season were no different than those of surviving seedlings.
2. Morphological attributes of seedlings in the BA growth class were no different than those in the Avg and AA classes.
3. Morphological attributes of seedlings in the AA growth class were no different than those in the Avg and BA classes.

Because the occurrence of an overwinteringbud may depend on seedling size, analysis of covariance (ANCOVA) was used to determine whether presence or absence of a bud affected first-year growth in the field. Initial height and diameter were covariates in a model with block and presence of a bud as the independent variables.

Using ANOVA, morphological attributes of seedlings from this study were compared with the same attributes of seedlings grown in different years. Crop year was the independent variable in that analysis and, because sample sizes varied, Bonferroni's method (Neter et al. 1985) was used to separate the years. Survival and size of seedlings in the BA, Avg, and AA classes were compared after 5 years to demonstrate the importance of first-year field performance to stand development. Bonferroni's method was used to separate the 5-year means when ANOVA indicated differences among the classes.

RESULTS AND DISCUSSION

The outcome of the nursery phase of this study has been reported (Brissette and Carlson 1987a,b). Mean stem diameter, shoot length, and root volume of the sample lifted in December were all significantly affected by seedbed density and N, but not by P. The concentrations of N, P, and potassium (K) in the shoots of December-lifted seedlings were affected by the amount of N applied, but only K was affected by density. The interaction between seedbed density and N applied had a significant impact on root growth potential.

Nurserv treatment effects

The quadratic response-surface models were not significant for first-year survival at either site (p= 0.98 at Oden and p= 0.14 at Magazine). Comparable levels of significance also characterized models for survival after 2 years (p= 0.95 at Oden and p= 0.14 at Magazine). There was much more herbaceous competition during the summer after planting at Oden than at Magazine. Possibly because of that difference in competition, first-year survival differed between the two planting sites. At Oden, the first block planted suffered 51 percent mortality, probably because it was planted during subfreezing temperatures. Overall survival of the other three blocks was 69 percent. Overall first-year survival at Magazine was 76 percent.

Similar regression models for mean first-year growth were also not significant (p= 0.44 at Oden and p= 0.16 at Magazine). Likewise, second-year growth at both sites was not affected by nursery treatments (p= 0.29 at Oden and p= 0.67 at Magazine). Consequently, although seedbed density and amount of N applied affected a number of seedling attributes, those nursery treatments did not directly influence survival or growth in this study.

Morphological effects

The importance of morphology to survival and growth was examined by classifying how seedlings performed during their first growing season, then analyzing to determine whether seedlings in those classes differed in their initial attributes. At Oden, seedlings that died the first year had a significantly shorter mean height than those that survived (tables 1 and 2). Among surviving seedlings, those in the BA growth class averaged taller and had a higher mean H/D than the better-growing trees. Seedlings in the AA class had a significantly larger mean diameter and a significantly lower mean H/D than Avg and BA seedlings. Also, significantly more AA seedlings had overwintering buds.

There were no significant differences in initial morphology between surviving seedlings and those that died the first year at Magazine (tables 1 and 2). Seedlings in the BA class had a smaller mean diameter and, as for this class at Oden, a higher mean H/D than Avg and AA seedlings. Seedlings in the AA class differed in every morphological attribute from those in the poorer-growing classes. The AA seedlings averaged taller and had larger diameters; therefore, they had a significantly greater mean D^2H. As at Oden, AA seedlings had a lower mean H/D than Avg and BA seedlings. Although the difference was marginal, more AA seedlings had overwintering buds than did seedlings in the other classes.

The effects of seedling morphology on survival and growth were parallel at the two locations. Mortality could not be clearly attributed to any morphological characteristics. Apparently, mortality was random and probably associated more with planting microsite than with any other factor. Seedlings with below-average first-year growth had a high mean H/D at both sites. At Oden, the high ratio was the result of BA seedlings being comparatively tall, but at Magazine it was because BA seedlings had relatively small diameters. Conversely, AA seedlings at both sites had significantly lower mean H/Ds than Avg and BA seedlings. These results indicate that seedling sturdiness at planting has a direct impact on first-year growth. Chapman (1948) found H/D an indicator of survival as well as growth potential.

Table 1.-Initial morphological attributes of seedlings classed by first-year performance as dead, or having D^2H growth that was below average (BA), average (Avg), or above average (AA) for their planting site and experimental block

Site	Class	N	Mean morphology at time of planting				
			Ht	Dia	D^2H	H/D	Bud present
			-mm-	-mm-	$-cm^3-$	-mm/mm-	--%-
Oden							
	Dead	324	182	4.4	3.9	42.1	42.0
	BA	201	193	4.5	4.3	44.4	39.8
	Avg	238	187	4.3	3.8	43.6	40.3
	AA	135	187	4.6	4.3	41.3	52.6
Magazine							
	Dead	200	189	4.5	4.3	42.5	46.5
	BA	222	187	4.3	3.9	44.1	45.9
	Avg	347	182	4.4	3.7	42.9	45.8
	AA	128	193	4.7	4.5	41.5	54.7
Overall mean		1,795	187	4.4	4.0	42.9	45.0

Table 2.-Significance levels of linear contrast F-tests comparing initial morphological attributes of seedlings classedby first-year performance as dead, or having D^2H growth that was below average (BA), average (Avg), or above average (AA) for their planting site and experimental block

Site	Contrast	Morphological attribute at time of planting				
		Ht	Dia	D^2H	H/D	Bud present
		p>F				
Oden						
	1. Dead vs. Survivors	0.007	0.6	0.2	0.1	0.5
	2. BA vs. Avg+AA	.06	.9	.3	.02	.1
	3. AA vs. Avg+BA	.5	.02	.2	.005	.01
Magazine						
	1. Dead vs. Survivors	.7	.5	.2	.7	.6
	2. BA vs. Avg+AA	1.0	.01	.3	.01	.3
	3. AA vs. Avg+BA	.04	.0001	.003	.02	.07

Overwintering buds were also associated with above-average growth at both sites (table 1). The importance of budset to first-year survival and growth of southern pine seedlings has been a topic of debate for decades. Wakeley (1954) included presence of winter buds as a desirable attribute of plantable seedlings. However, he was unable to show that overwintering buds resulted in slash pine (P. elliottii Engelm.) seedlings that survived or grew better than similar-sized seedlings without buds during the first growing season after outplanting. Survival and growth of lo-year-old loblolly pine trees was related to initial shoot morphology, and seedlings that had buds were superior to those that did not (Grigsby 1971). Williams et al. (1988) showed that after accounting for differences in seedling biomass, the presence of a well-formed terminal bud had no effect on the root growth potential of loblolly pine. Hallgren and Tauer (1989) were unable to demonstrate any advantage of buds on first-year field performance of shortleaf pine planted near Idabel, Oklahoma.

Showing a relationship between buds and field performance is difficult because whether or not a seedling has a bud may be confounded with other morphological attributes. For example, it could be hypothesized that the probability of an overwintering bud is greater for relatively large seedlings than for smaller seedlings, and that larger seedlings grow more after outplanting. In this study, seedlings that had buds were larger than those without buds at both sites (table 3). After adjusting for those differences using initial height and diameter as covariates, seedlings with buds exhibited greater first-year growth at Oden but not at Magazine.

Table 3.-First-year D^2H growth of seedlings with and without overwintering buds adjusted for height and diameter at planting using ANCOVA

Site	Bud status	N	Ht	Dia	Unadjusted growth	Adjusted growth
			-mm-	-mm-	-cm^3-	-cm^3-
Oden						
	Absent	326	181	4.3	6.1	5.8a[1/]
	Present	247	199	4.7	8.5	8.1b
Magazine						
	Absent	362	177	4.2	13.1	13.5a
	Present	326	196	4.7	15.4	15.0a

[1/] Within a site, means in a column followed by the same letter are not significantly different (p= 0.05).

There was a great difference in first-year growth between the sites (table 3). The greater herbaceous and woody competition at Oden may account for the poorer growth at that site. Although shortleaf pine is capable of multiple flushes during the growing season, the preformed shoot enclosed in a bud accounts for the first growth flush in the spring. Results from Oden suggest that there may have been only one flush or, if there were multiple flushes, the first accounted for most of the first season's growth on that site. If that was the case, then the presence of a bud may result in greater growth for shortleaf pine seedlings planted on harsh sites. This study was not designed to address that specific question, and more research is needed to provide a conclusive answer.

Although overwintering buds may suggest potential for above-average growth after outplanting, only half of the AA seedlings in this study had such buds. Furthermore, at neither site was survival affected by the presence or absence of a bud. Therefore, although an overwintering bud is a desirable attribute of shortleaf pine planting stock, it is of secondary importance compared with other morphological characteristics.

When morphological attributes measured in this experiment were compared with those from another study and from three crops of operational seedlings, a number of differences between crop years and nurseries were evident (table 4). For the 3 years that operational seedlings were sampled, mean heights were greater and mean diameters less than the overall means of seedlings in the study reported here. Consequently, mean D^2Hs of the operational stock were about the same, or greater, than the mean of seedlings in this study. However, mean H/Ds of operational seedlings were much greater than the mean H/D of even BA seedlings in the study.

Table 4. -Morphological attributes of seedling samples from the same seed orchard grown in different crop years at Weyerhaeuser Company's Magnolia Forest Regeneration Center (MFRC) or at International Paper Company's Arkansas Supertree Nursery (ASTN). Seedlings were grown for research (Res) or for operational (Opr) planting

Crop year	Nursery	Use	N	Mean morphology at time of planting						
				Ht	Dia	D^2H	H/D	Bud present	Root volume	S/R[1]
				-mm-	-mm-	-cm^3-	-mm/mm-	--%-	-cm^3-	-mg/mg-
1985	MFRC	Res[2]	1,800	187e[3]	4.4b	4.0c	42.9c	44.9d	---	
1986	MFRC	Res	100	215d	5.3a	6.4a	41.3c	62.0bc	4.5a	2.75c
1987	ASTN	Opr	50	241c	4.0cd	4.0bc	61.0b	54.0cd	2.7b	3.04c
1988	ASTN	Opr	100	291a	3.8d	4.2bc	78.4a	87.0a	2.1c	4.65a
1989	MFRC	Opr	100	267b	4.2c	4.9b	65.1b	79.0ab	2.9b	3.72b

[1] Shoot-to-root ratio (oven dry weight basis).
[2] Experiment described in this paper.
[3] Within a column,, means followed by the same letter are not significantly different (p- 0.05).

At Oden, the AA seedlings had a mean diameter of 4.6 mm. If that standard were applied to the three operational crops (table 4), the largest 65 percent of the 1989 crop would meet it, as would the largest 42 percent of the 1987 crop, but only the largest 15 percent of the 1988 crop would meet it.

Stand development

Stand growth and development are related to initial quality of shortleaf pine planting stock (Clark and Phares 1961, Grigsby 1975). In this study, survival at age 5 of seedlings in the BA class at Oden was significantly less than for the Avg and AA classes (table 5). There were no differences in fifth-year survival among the classes at Magazine, however. At both locations, there were significant differences among classes in D^2H growth between ages 2 and 5.

Trees at Magazine grew much better than trees at Oden, but at both sites mean growth of the AA class was greater than the Avg class, which was, in turn, greater than the BA class.

Table 5.-Survival and morphological attributes of trees at age 5 classed by first-year D^2H growth as below average (BA), average (Avg), or above average (AA) for their planting site and experimental block

Site	Class	surv	N	Ht	GLD[1/]	GLA[2/]	D^2H
		—%—		cm	mm	$-cm^2-$	$-cm^3-$
Oden							
	BA	86.5a[3/]	162	174a	32a	9a	2,440a
	Avg	99.6b	230	219b	43b	15b	4,580b
	AA	98.5b	130	261c	53c	22c	7,740c
Magazine							
	BA	80.8a	160	318a	69a	39a	16,410a
	Avg	80.4a	270	334b	77b	47b	20,790b
	AA	81.2a	103	353c	84c	57c	26,240c

[1/] GLD is ground line diameter.
[2/] GLA is ground line area.
[3/] Within a site, means in a column followed by the same letter are not significantly different (p- 0.05).

An often-used measure of forest trees and stands is basal area, the cross-sectional area of a tree or group of trees measured at breast height. Diameter was not measured at breast height in this study; however, a value analogous to basal area was calculated for each tree at age 5 based on its groundline diameter. The mean groundline area of the trees in each class at each site was then multiplied by the number of trees surviving in that class. The resulting value is the total groundline area occupied 5 years after outplanting by each first-year growth class. Those total groundline areas are proportional to the areas of the bars representing each growth class in figure 1. There was a great difference between the two sites in the area occupiedby trees, with much larger-diameter trees at Magazine. Within a site, however, it is clear that seedling growth the first year after outplanting affected subsequent growth. Overall, seedlings that grew best the first year were dominant at age 5, and seedlings that grew poorest the first year were still smallest at age 5.

Although mean groundline area was greatest for the AA class, the number of trees in that class was smallest at both locations (figure 1). At Oden, AA trees made up 25 percent of the stems but accounted for 37 percent of the total groundline area and 41 percent of the total D^2H volume of the stand. Even though there were fewer AA trees at Magazine, the results were similar. With 19 percent of the stems, AA trees accounted for 24 percent of the total groundline area and 25 percent of the total D^2H volume of the stand. Clearly then, performance of future plantations can be improved by using those morphological attributes that defined the AA class in this study as goals for seedling production.

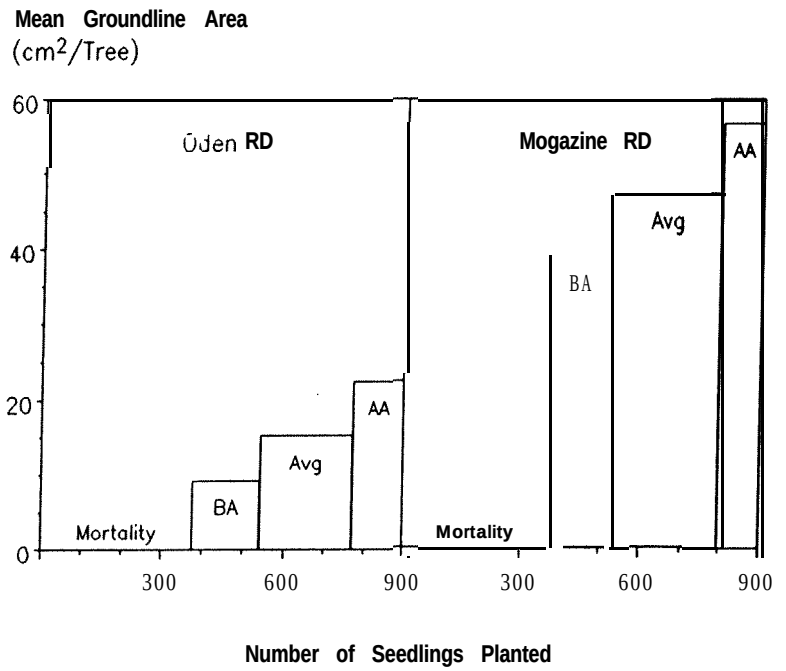

Figure 1.-Mean groundline area and number of trees at age 5 classed by first-year D^2H growth as below average (BA), average (Avg), or above average (AA) for their planting site and experimental block. Each bar is proportional to the total groundline area for the corresponding class and site.

CONCLUSIONS

Nursery seedbed density and amount of N applied affected the morphology of bare-root shortleaf pine seedlings in this study. Although those nursery treatments apparently had no direct effect on tree growth after outplanting on two sites, seedling morphology did. Based on the results of this study, including those presented earlier by Brissette and Carlson (1987b), the following target seedling specifications were found to result in superior growth in the field:

1. Mean root collar diameter of 4.6 mm.
2. Mean height-to-diameter ratio not exceeding 42.0 mm/mm.
3. Mean root volume (measured by displacement in water) of 3.1 cm^3.
4. Overwintering bud present.

The field results did not clearly define seedbed density or level of N fertilization needed to produce a high percentage of seedlings with the target specifications. However, based on early growth results reportedby Brissette and Carlson (1987b), it is apparent that to produce such seedlings, seedbed density should be kept below 235 seedlings/m^2. At lifting, mean diameter of seedlings in this study increased with increasing N (Brissette and Carlson 1987a). Height, on the other hand, increased as N was increased to 110 kg/ha, then decreased at 170 kg/ha (Brissette and Carlson 1987a). Consequently, the H/D was lowest for the highest N level. However, in a subsequent nursery study (Brissette and Carlson, unpublished), height increased linearly between 0 and 180 kg N/ha. Moreover, first- and third-year size of only one of three half-sib families was affected by the level of N applied in the nursery (see field trip notes in the

Appendix of this proceedings). Therefore, sufficient data are lacking to make a recommendation about the amount of N needed to produce high-quality shortleaf pine seedlings.

Specifications used in contracts for seedling production are, of necessity, a compromise between biological and economic considerations. From a biological perspective, the early performance of AA seedlings in this study was clearly superior to that of the other classes, and those AA trees will most likely continue to be dominant in the stands. Whether the morphological attributes that defined AA seedlings should become rigid target specifications is a management decision. Year-to-year variation in weather and other factors, and the cost of growing seedlings that meet AA standards, may preclude using these specifications in seedling production contracts. Nevertheless, the performance of AA seedlings in this study does emphasize the importance of planting high-quality seedlings on sites typical of the Ouachita and Ozark National Forests.

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Seedling Establishment

Moderator:

Clark Lantz

Cooperative Forestry, Southern Region

THE IMPACT OF LIFT AND STORE PRACTICES ON FIELD PERFORMANCE OF SHORTLEAF PINE SEEDLINGS[1/]

Stephen W. Hallgren[2/]

Abstract.--Both lift date and storage practices determine the quality of bare-root shortleaf pine (*Pinus echinata* Mill.) seedlings at the time of planting. These cultural practices strongly affect seedling physiological condition. Although no real-time measurements of seedling quality have been perfected, research has shown that root growth potential and days to bud burst are both useful indices of physiological condition and capacity for field performance. In Oklahoma and Arkansas the best lifting period for ensuring high quality shortleaf pine seedlings is December through February. When no storage is necessary seedlings may also be lifted in November and March. There is a potential for the greatest growth for early planting in late fall or early winter, especially for seedlings that are not stored, due to winter root growth and establishment of seedlings. When seedlings are packed with clay slurry the addition of benomyl at the rate of 0.5 percent active ingredient may improve field performance especially for stored seedlings lifted early and late.

INTRODUCTION

The continued productivity of shortleaf pine (*Pinus echinata* Mill.) stands depends on the development of improved regeneration technology. The date of lifting and storage conditions for bare-root seedlings are key components of artificial regeneration of shortleaf pine in the South. Procedures in these two areas have been greatly improved in the last few decades. However, the fundamental concerns remain: 1. to produce high quality seedlings, those with the greatest capacity for survival and rapid growth after transplanting into the field, and 2. to transplant to the field when conditions favor seedling establishment.

The typical schedule for producing bare-root shortleaf pine seedlings calls for sowing seed in April, tending the crop through the summer, lifting seedlings the following winter, storing seedlings for a short period and planting in winter or early spring. The quality of seedlings at the time of planting is determined by both the seedling characteristics at the time of lifting and the changes in these characteristics caused by storage. Lifting and storage can be scheduled to deliver high quality seedlings to the planting site, but this is not enough to ensure plantation success. Planting must be scheduled to ensure favorable temperatures and soil moisture for seedling establishment.

LIFT DATE

Lift date affects field performance in two ways. First, lift date determines seedling quality (which can be changed by storage). Second, lift date determines

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[2/]Associate Professor, Department of Forestry, Oklahoma State University, Stillwater, OK 74078.

when seedlings can be planted and hence planting site conditions. Seedlings should not be lifted until they have reached high quality in the nursery bed. Planting cannot begin until lifting commences and once seedlings are lifted they must be either planted immediately or stored. Planting freshly lifted seedlings avoids the risk of deterioration in storage, but weather, soil conditions and availability of a planting crew can delay planting. There is some flexibility in lift date and storage time to facilitate planting under favorable field conditions; however, seedlings should not be lifted when they are poor quality and should not be stored so long that they are ruined. As weather and soil conditions at the planting site change on both a short-term (day-to-day and week-to-week) and long-term (seasonal) basis, selection of a planting date concerns not only picking a day with favorable conditions, but also selecting the most favorable season of the year.

The traditional planting season for much of the South has been from the first of December through February, and this period has also been considered the optimum lifting season (Wakeley 1954). In the southern-most part of the region the planting season can extend one to one and a half months earlier and in the northern part one to two months later. The starting date is determined by commencement of fall rains to soften the soil for planting. The ending date occurs when increasing spring temperatures and seedling growth reduce survival potential. Guidelines for lifting have been simply to lift just before planting so that seedlings would not be subjected to deterioration in storage and to lift only when the soil is not frozen (Wakeley 1954).

Seedlina quality

Lift date has a large effect on seedling quality, because seedling morphological and physiological characteristics change continuously over the winter. Measurements of these characteristics can help to identify the lifting window for highest seedling quality. Some changes in seedling traits are related to changes in the weather at the nursery. For example, the number of chilling hours (temperature between 0 and 8 degrees C) accumulated after October 15 may be a good predictor of changes in root growth potential (RGP) (Brissette et al. 1988) and bud dormancy (Garber 1983, Carlson 1985).

The morphological traits frequently used to assess seedling quality include root-collar diameter, height, tap root length, root/shoot ratio, number of lateral roots, root volume, mycorrhizal infection, presence of secondary needles and presence of a terminal bud (Barnett et al. 1986). Research has shown that roots and shoots continue to increase in dry weight and roots increase in length throughout the winter (Huberman 1940, Garner and Dierauf 1976). This growth might be reflected in increases in root-collar diameter, root length or root volume, but it seems unlikely that these morphological traits would change enough after the rapid growth phase in the summer to be useful indicators of the lifting window. Changes in the other seedling morphology traits over the winter are also not likely to be great enough to make them useful in assessing readiness for lifting.

Although a seedling may be morphologically mature enough to transplant successfully in late summer or fall, its physiological readiness for transplanting may not occur until much later. It has been often shown that morphological and physiological components of seedling quality can develop at different rates and a high value for one does not necessarily indicate a high value for the other (Wakeley 1954). Many techniques have been developed for assessing seedling physiological condition including bud dormancy (Garber 1983, Carlson 1985, Larsen et al. 1986, Williams et al. 1988), mineral nutrition (Wakeley 1954, Larsen et al. 1988), food reserves (Ritchie 1982, Omi and Rose 1990), root growth potential (Stone et al. 1962, Feret and Kreh 1985,

Hallgren and Tauer 1989), plant water potential (Colombo 1987, McCreary and Duryea 1987, Lopushinshy 1990), vigor (McCreary and Duryea 1987), and electrical impedance (van den Driessche and Cheung 1979). All of these have been evaluated for use as predictors of field performance.

The only indicators of seedling physiological quality that could provide real-time data are mineral nutrition, food reserves and electrical impedance. The results of the measurements of these variables can be available almost immediately after sampling. Results from the other tests cannot be known until several days to weeks after sampling. In the mean time the population for which seedling quality data is desired has changed either in the *nursery* or in storage, consequently the results have *no* predictive value, They do have value for indicating reasons for relative plantation performance when the test is made at the time of planting. When the test is performed at the time of lifting these tests can be of value for indicating poor quality seedlings that could not possibly be expected to improve in storage and should not be planted.

Research on southern pines has focused on RGP and bud dormancy as indicators of seedling physiological condition. The approach has been to determine the effects of cultural practices, storage, and weather on RGP and bud dormancy. This information combined with knowledge of the seasonal pattern of RGP and bud dormancy can provide nursery managers guidelines for the best lifting period.

RGP is defined as the capacity to produce new roots after transplanting (Ritchie and Dunlap 1980, Burdett 1987). It is one of the most critical components in successful seedling establishment. There are numerous approaches to evaluating RGP under controlled conditions. Typically seedlings are transplanted to pots, grown in a controlled environment for 28 days and counted for number of new roots longer than a specified length. The test environment can affect the results and most often the tests are run under ideal conditions for growth. Although this does not represent field conditions during the planting season, the technique provides data from repeatable, controlled conditions that are comparable among lift dates and cultural treatments.

The test for bud dormancy can be done concurrently with the RGP test on the same seedlings. It simply involves recording the number of days in the controlled environment until bud burst (Carlson 1985). Seedling quality is believed to be directly related to RGP and inversely related to the number of days to bud burst (DBB). It has been shown that RGP and DBB are negatively related (Ritchie and Dunlap 1980) and data for loblolly pine tends to support this conclusion (Carlson 1985, DeWald and Feret 1987).

The preponderance of data on a variety of coniferous species including Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) (Stone et al. 1962), ponderosa pine (Pinus ponderosa Laws.) (Stone and Schubert 1959) and loblolly pine (Pinus taeda L.) (DeWald and Feret 1987) show large seasonal differences in RGP with a minimum in spring, summer and fall and a peak in the winter. Shortleaf pine also shows peak values for RGP in mid-winter (Brissette et al. 1988, Hallgren and Tauer 1989, Figures 1 and 2). The maximum values for RGP consistently occured during December through February.

Conifers appear to become more tolerant of the stress from lifting, handling, storing and planting during the fall and reach a maximum level of stress resistance at some time in the winter. The dominant environmental factors determining the timing of the changes in tolerance are probably temperature and photoperiod (Wakely 1954, Lavender 1964, Lavender and Wareing 1972). The likely site of detection of these

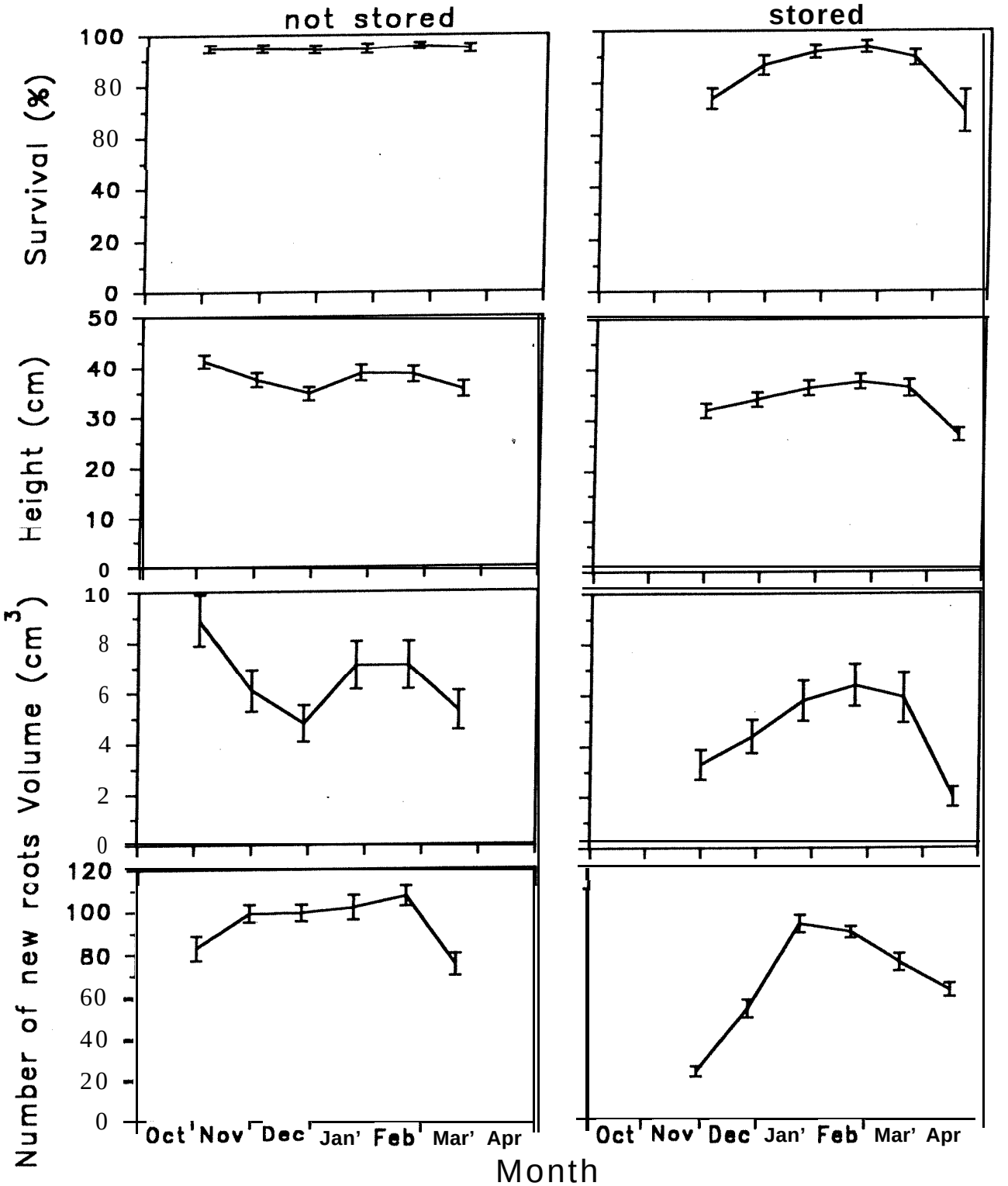

Figure l.--Effects of lift date in the 1987-88 planting season on mean number of new roots in an RGP test, mean stem volume per planted seedling, mean height of surviving trees and mean percent survival one year after planting in the field. Seedlings were planted on the coastal plain of Southeast Oklahoma. Data were averaged across 12 families and plotted by planting date for seedlings that were not stored or stored for 28 days. Points represent the mean of 10 replicates in the field (96 seedlings per replicate, 12 row plots of 8 seedlings) and 8 replicates in the RGP test (36 seedlings per replicate, 12 pots of 3 seedlings), and bars equal + or - the standard error of the mean.

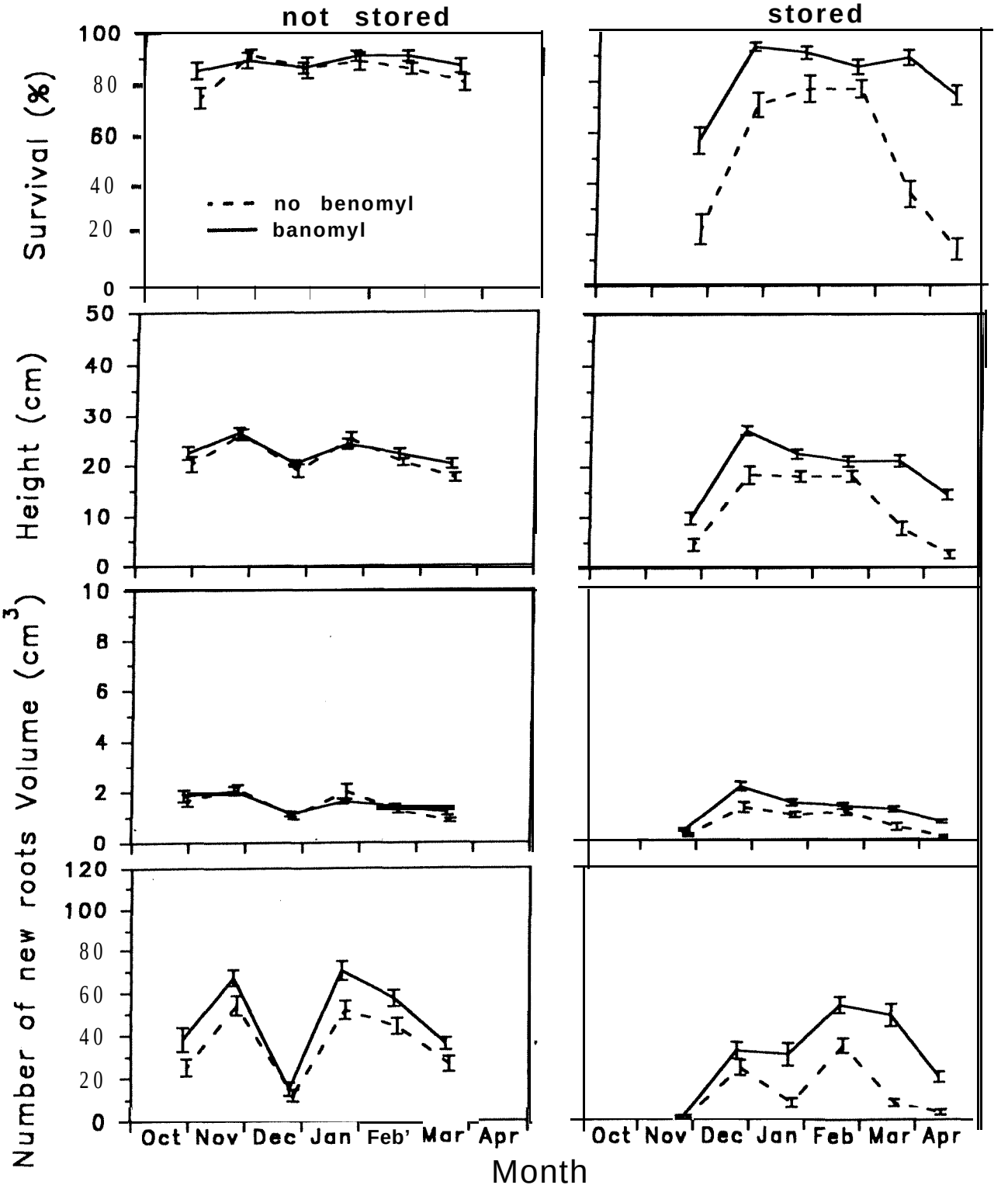

Figure 2.--Effect of lift date and benomyl treatment (0.5 percent active ingredient) in the 1989-90 planting season on mean nurnber of new roots in the RGP test, mean stem volume per planted seedling, mean height of surviving trees and mean percent survival one year after planting in the field. Seedlings were planted in the Ouachita Mountains of Arkansas. Data plotted by planting date for seedlings that were not stored or stored for 28 days. Points represent the mean of 20 replicates in the field (row plots of 10 trees) and of 33 replicates in the RGP test (3 trees per replicate) and bars equal +/- the standard error of the mean.

environmental stimuli is the seedling shoot which transmits a signal to the roots (Ritchie and Dunlap 1980). Therefore, it is logical that shoot and root physiological conditions be correlated.

The number of chilling hours is a common measure of temperature that appears to have some value in predicting plant response to seasonal changes in the environment. Georgia shortleaf pine showed a maximum RGP at 610 chilling hours and storage for 0 to 21 days did not affect the response of RGP to chilling hours (Brissette et al. 1988). In contrast, the response of RGP to chilling hours was different for unstored and stored seedlings of Oklahoma-Arkansas shortleaf pine. Unstored seedlings showed high RGP for 89 to 1135 chilling hours and seedlings stored for 28 days showed a clear optimum at 758 hours (Hallgren and Tauer 1989 and Hallgren unpublished data). Evidence has been reported that if seedlings of loblolly pine receive over 700 chilling hours in the nursery RGP may increase during storage (Carlson 1985). There is no confirming support for this occurring in shortleaf pine (Hallgren and Tauer 1989, Figures 1 and 2).

Data from three different lifting seasons have shown that seedlings lifted from early November to late March are generally high quality as assessed by RGP and field planting tests (Hallgren and Tauer 1989, Figures 1 and 2). RGP was relatively high and survival was above 80 percent one year and above 90 percent in two years for every lift with few exceptions. When seedlings were lifted from frozen soil in December 1989, they showed low RGP, but field survival was as high as that shown for earlier and later lifts from unfrozen soils (Figure 2). March lifted seedlings in 1988 showed a large decrease in RGP, and field survival was poor perhaps due to low RGP and a severe spring drought in April (Figure 1).

High seedling quality at lifting does not guarantee high field performance. If seedlings cannot be planted immediately they must be placed in storage where significant deterioration may occur. Storage will be discussed in a later section. Site conditions at the time of planting and until seedlings become established can be an overriding factor in survival and growth (Burdett 1987). Extremely poor conditions can kill all the seedlings and extremely favorable conditions can result in high survival and rapid growth regardless of their quality. Between the extremes seedling quality and planting site conditions interact to determine field performance.

Planting site conditions

Planting site conditions at the time of planting and immediately afterwards are especially important in determining seedling survival and growth, as this is the period during which the seedling is most susceptible to damage. Until the newly planted seedling produces new roots it is dependent on the planted root system for moisture and nutrient uptake. Environmental conditions such as low soil moisture and temperature can stress seedlings by reducing moisture uptake. High air temperature and low humidities can stress seedlings by increasing the transpirational demand for moisture when seedlings have a low capacity for uptake. With the passage of time the planted seedling will produce new roots that greatly increase the capacity for moisture and nutrient uptake. Favorable temperature and moisture conditions are important for maximum root growth.

In the South, the winter is an ideal time for field planting as conditions are cool and moist, Planting should not begin until enough rain has fallen to moisten the soil and fill in the rips on sites that have been ripped. This may require several inches of rainfall especially after a dry summer. In the northern part of the range of shortleaf pine freezing temperatures and frozen soil in mid-winter can separate the planting

season into fall and late winter (Wakeley 1954). The coldest month is January. One report on regeneration of loblolly pine recommended that north of 33 ° north latitude lifting should be done between January 15 and February 15 and planting should be completed before the end of March (Ursic et al. 1966). Apparently, the risks of early planting • frost, frozen soil, frost heaving, and animal damage • were believed to be greater than the advantages.

Contrary to these recommendations for loblolly pine, results of studies for shortleaf pine in Oklahoma and Arkansas north of 33" north latitude, showed excellent survival and the greatest growth for planting dates in November and December (Hallgren and Tauer 1989, Figures 1 and 2). The data suggested that the roots of seedlings from these early plantings may grow during the winter and they may be better established with a higher capacity for survival and rapid growth when the growing season begins in the spring than are seedlings from later plantings (Bilan 1961). These recent data suggest that early planting should be considered at least in part of the shortleaf pine range.

STORAGE

Current nursery and regeneration practices require seedlings to be stored for several days to several weeks between lifting and planting in the field. Artificial regeneration with bare-root seedlings requires the coordination of so many labor-intensive activities in the nursery and field that the schedule almost always includes cold storage of seedlings between packing and shipping and between delivery and planting. Although a regeneration system with no storage is the most desirable for greatest survival and growth, it is probably unreasonable to expect this to occur without a huge increase in commitment of resources to forest regeneration. In fact, the added cost of a system where no storage was required may be greater than the benefits warrant. Therefore, it is prudent to lift seedlings at a time and pack them in such a way that they can sustain a high capacity for survival and growth through several weeks of storage.

Seedlings are out of the soil for several hours during lifting and grading. They should be kept moist and cool during these activities. The seedlings should be packed and cooled to the cold storage temperature of 1 to 4 degrees C (Williston 1974) as quickly as possible. Outdoor temperatures during the lifting season oscillate above and below this ideal cold storage temperature range. When cold storage is unavailable, efforts should be made to store the seedlings in a shelter that comes as close as possible to the desired temperatures. In practical terms this usually means protecting the seedlings from direct sunlight and freezing temperatures.

At present, it appears that the most popular packing methods are bales and kraft-polyethylene (K-P) bags. Usually, a packing medium is included with the seedlings, although K-P bags can be prepared without medium (Williston 1965). Sphagum and peat moss and clay slurry are mediums suitable for both packing methods (Williston 1974). Research has shown that adding a fungicide to clay slurry may improve survival of loblolly pine compared to clay slurry alone (Barnett et al. 1988).

The advantage of bales is their low cost and the ease of handling. K-P bags are more expensive and subject to being torn (Williston 1974). On the other hand, bales will dehydrate and must be watered every 2 to 3 days while K-P bags do not require watering. Bags may overheat more rapidly than bales and should not be left in direct sunlight or stacked in large piles. Bags with a reflective surface or light color probably are less subject to overheating in sunlight than dark bags (Ursic 1956, Ursic 1963).

Although sphagum moss is relatively expensive, as a packing medium it has the advantage of high moisture holding capacity and of a low pH that discourages growth of pathogenic microorganisms during storage. One disadvantage of sphagnum moss is the hazard of workers contracting sporotrichosis (May 1985). Clay slurry sprayed on seedling roots just prior to storage has become a popular packing medium. Typically a kiln-dried kolin clay in a talc form is mixed with water at a rate that can be sprayed from a hose (Brenneman 1965).

The advantages of clay slurry include keeping roots moist in storage and during planting, keeping roots hanging down during planting due to added weight and possibly holding moisture after planting (Bland 1962). Clay slurry may offer the opportunity to deliver beneficial nutrients to the seedling just before planting (Davey 1964). There have been reports of negative, positive and no effects of clay slurry on loblolly pine survival (Williston 1967, Dierauf and Marler 1969). It is possible that pathogenic microorganisms thrive in the clay slurry and under some storage conditions damage seedlings, as it has been found that fungicides improve survival of seedlings packed with clay slurry (Bamett et al. 1988). The beneficial effects of clay slurry may be greatest when seedlings are exposed to drying conditions during planting (Williston 1967, Dierauf and Marler 1969).

Recent research has shown that shortleaf pine lifted in December through February can be expected to show minimum declines in quality during storage for up to 28 days (Hallgren and Tauer 1989, Figures 1 and 2). Earlier and later lifts show significant decreases in quality and field performance after 28 days of storage. In contrast to these results, an earlier study (Venator 1985) found that only seedlings lifted in mid-December could be stored for 30 days and still show acceptable survival of over 80 percent. Seedlings lifted in January and February showed unacceptable survival after storage.

Similar results with other southern pines led to the testing of benomyl as an additive to clay slurry (Barnett et al. 1988). Benomyl already has been shown to improve performance of longleaf pine and control brown-spot disease (Kais and Barnett 1984, Kais et al. 1986). In some cases it improved the survival of loblolly pine (Barnett et al. 1988) and in others it decreased the survival (Boyer and South 1987, Stumpff and South 1991). These contradictory results may be caused by different test conditions and varying benomyl concentrations. It appears that the concentration used for longleaf pine, 5 percent active ingredient as a percent of dry matter in the slurry, (Kais et al. 1986) was too high for loblolly pine (Barnett and Brissette 1988, Barnett et al. 1988). A recent study showed that the lower concentration of 1.25 percent active ingredient may also be too high (Stumpff and South 1991). In the case of shortleaf pine, preliminary studies have shown that 0.5 percent active ingredient may be close to the optimum concentration (Hallgren unpublished data, Figure 3). At this rate benomyl improves survival and growth of both stored and unstored shortleaf pine seedlings. The beneficial effect is greatest for stored seedlings and for early and late lifts (Hallgren unpublished data, Figure 2).

PRACTICAL IMPLICATIONS

The best lifting period for ensuring high quality shortleaf pine seedlings is December through February. When no storage is necessary seedlings may also be lifted in November and March. There may be greater growth and survival for early plantings in late fall and early winter especially when seedlings are not stored. This result may be due to winter root growth and establishment of seedlings.

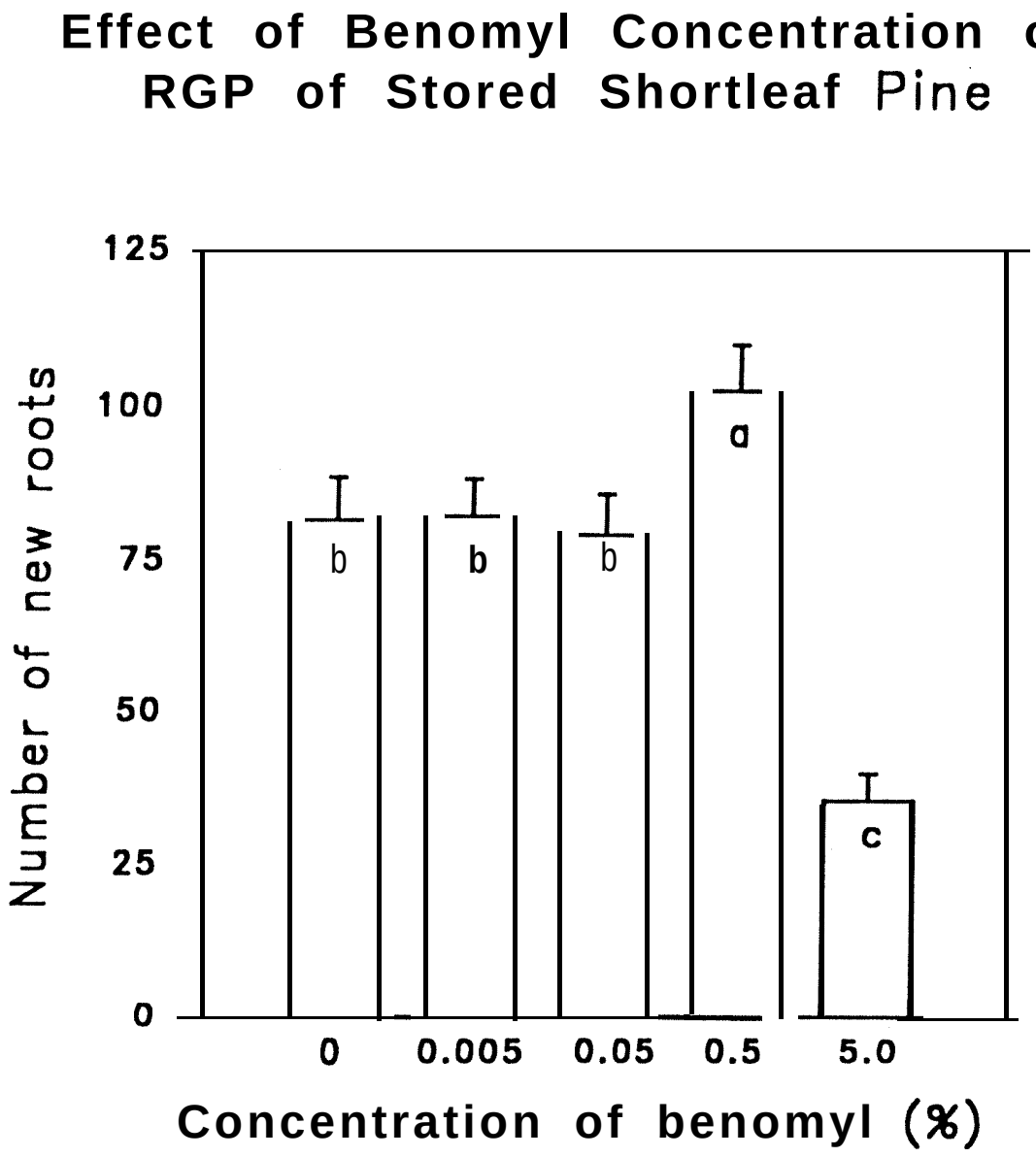

Figure 3.--Effect of benomyl concentration on root growth potential (RGP) of shortleaf pine seedlings stored 28 days. Height of bar equals the mean of 30 replicates (pots of 3 trees) and bars equal the standard error of the mean. Different letters indicate means significantly different at the 5 percent level.

When seedlings are packed with clay slurry the addition of benomyl may improve field performance especially for stored seedlings lifted early and late. The optimum concentration of benomyl is near 0.5 percent active ingredient,

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SITE PREPARATION PLAN'

Phillip M. Dougherty'

Abstract.--Site preparation can be the most expensive activity in producing a southern pine forest. This investment has to be made at the front end of a rotation and the cost carried until the end of the rotation. Thus careful consideration must be given to how much capital should be invested in site preparation. This article reviews the key steps a landowner should take to make a wise decision about which, if any, site preparation treatments should be applied to a land management unit being considered for regeneration.

INTRODUCTION

Site preparation can be the least or most expensive activity in establishing and managing a southern pine forest. The site preparation phase may consist of doing nothing, burning only or applying multiple activities such as KG-pile, burn disk and bed. In addition, preplant fertilizer and herbaceous grass control can be applied. The opportunity to spend money at this phase are almost unlimited. While doing nothing is low cost, it has its consequences on expected yield. Figure 1 illustrates the concept of balancing yield and cost.

Each site being considered for regeneration has a base soil site potential that is dictated by soil, topographic, and climatic factors. However,it is unlikely that even the base site potential yield will be obtained from an area because of the host of environmental forces shown in figure 1 that are naturally applied on the left side of the fulcrum.

The natural forces that tend to decrease yield below the base soil site potential include rust and disease, site damage, herbaceous and woody weeds, etc. There are many forces that can be applied to achieve and even increase the yields above that of the base soil site potential. However, as shown in the above illustration, as these forces are applied cost goes up. The forest manager must decide what is the appropriate amount of force (money) to invest on a given site during the establishment phase. The objectives of this paper are to outline some steps that can be taken to help converge on what level of site preparation can be justified.

I have identified six major steps that should be taken in developing a site preparation prescription. These are outlined below:

1. Determine the landowner's management objectives and his willingness to invest to accomplish these objectives.
2. Determine the base soil site potential of the area under consideration.
3. Evaluate what opportunities exist on the land.
4. Evaluate what the major limiting factors to regeneration and growth are.
5. Evaluate (1) what is needed to remove the establishment and growth limitations and (2) what the cost and benefits of removing the limitations will be.

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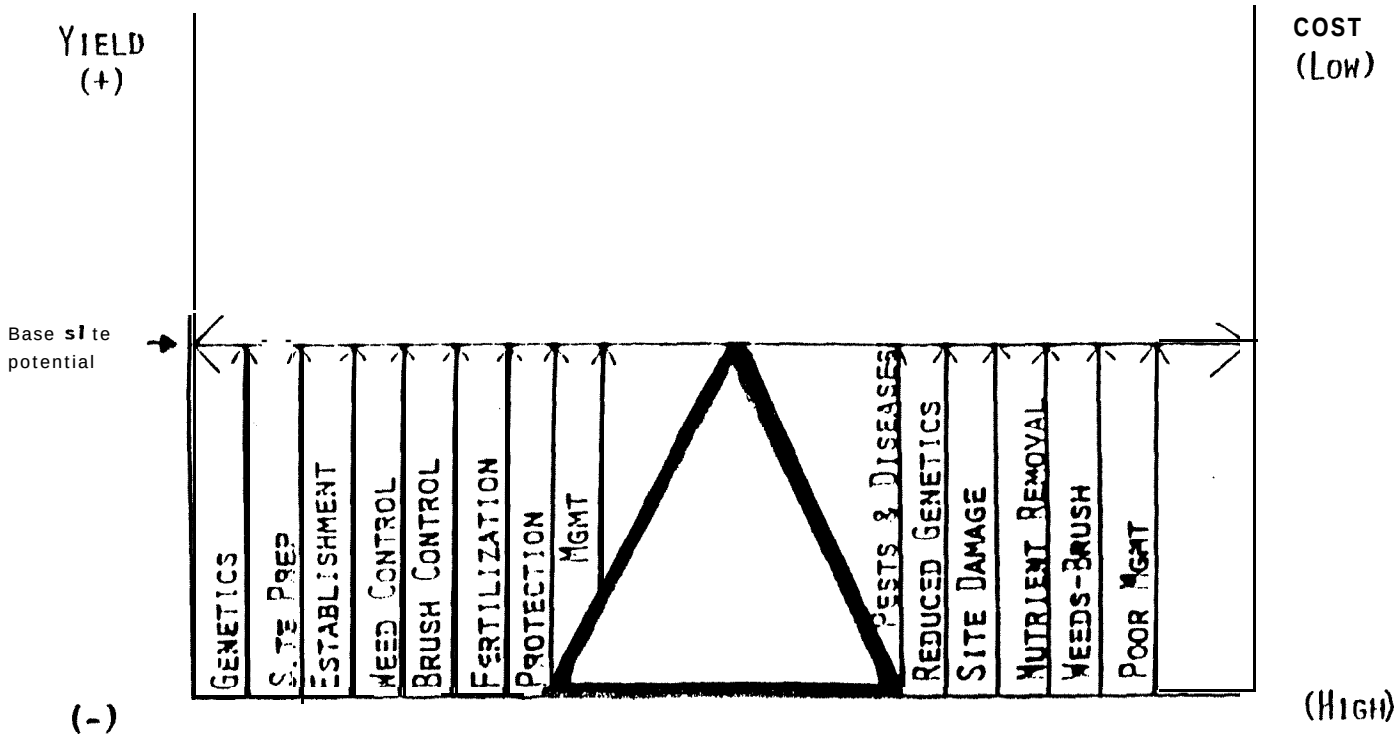
[2]Research Plant Physiologist, USDA-Forest Service, Southeastern Forest Experiment Station, Research Triangle Park, NC 27709.

Figure 1 .--Yield cost balance concept.



6. **Conduct an economic evaluation of each option and select the one that gives the best return and meets the objectives of the landowner.**

Each of these steps will be considered in more detail in the following sections.

Question #1. What is the landowners management objective(s) and his willingness to invest to accomplish these objectives?

This step is important because it defines (1) the goal which you are targeting for, (2) the planning horizon, e.g. 20 years or 40 year rotations and (3) the cash limitations that you will have to work with, As consultants or forest managers for industry or state and federal agencies, we should not be too critical when a landowner chooses to spend less than we feel is justified. However, as professionals we should always point out what opportunities exist to increase his return if he is willing to spend a few additional dollars. The less emphasis a landowner puts on timber production as the primary goal, the longer the rotation desired and the more species diversity on a given site is emphasized, the trend will be to reduce site preparation activities. Now that you've established what the landowner wants and how many dollars he is willing to spend toward timber production, the question is, How much can you justify spending based on the growth potential, site characteristics, and market potential of the products to be produced on the site? To address this issue takes us to question #2.

Question #2. What is the base soil site potential of the proposed management area?

This is the most important question to answer correctly. There are several sources of information available to help answer this question. These include:

1. Soil Survey
2. Soil descriptions - Soil Site Equations
3. Site Trees
4. Species Composition

Several topographic and soil factors have been shown to be related to site index of shortleaf pine.. Topographic features important in determining site index include shape, aspect, slope position, slope shape, and elevation. Soil factors related to shortleaf site index are depth of the A-horizon, texture of A and B horizons. The importance of these factors have been discussed in detail by Graney (1986).

Soil surveys give an estimate of site index for the modal pit (most typical profile of a series). Because most soil survey mapping is low intensity and 15-20% inclusions may be permitted, the soil series/phase mapped on your management area may be quite different than that shown on the soil survey map. It is up to you to determine if the soil on the proposed management area is better or worse than the modal pit. In fact, this is what your getting paid for. Road cuts, ditch faces, pushed up stumps and, yes, maybe even a dug pit can help you define the depth and texture of the horizons of the soil profile on your management area. When using road cuts or-ditches, etc., always use a shovel to smooth the soil face up so you get a better estimate of the boundaries between horizons and also be aware if the A-horizon has been removed or overdeepened in the construction process. With actual soil horizon information you can now use soil site equations or tables such as given by Coile (1952) or Zahner (1958) to estimate the site index of the proposed management area.

The best source of information about site potential is the tree itself. It serves to integrate the effects of (1) climate, (2) available resources (nutrients, water, light, etc.) and (3) the genetic potential of the tree on tree height growth. To get a good estimate of site index requires good site trees. This means that you have to plan before you harvest. For industry people this means the management forester must be notified well in advance of the scheduled logging of a tract. For the real progressive ones, an estimate of site index would be made during a previous stand inventory and be on file. Please do not destroy this information when a new stand is established and the inventory updated. Be sure to

recognize that previous stand management factors may have influenced the growth of the site trees. Site trees from stands that had high initial stocking and remained unthinned throughout their rotation will likely be shorter than trees growing in less dense stands and thus yield a low estimate of the site potential expected under more managed conditions. Previous high grading activities may reduce site tree height by having left the shorter trees and applying negative genetic selection. If no site trees exist on the setting information from site trees measured on adjacent settings with similar soil properties and topographic position can be useful. If loblolly is on the site and an estimate of shortleaf site index is desired equations by Coile (1952), Zahner (1958), and Harrington (1987) can be used to convert estimates of loblolly site index to shortleaf site index.

Another source of information that the forester should use is species composition. This can not be used in a quantitative sense. However, if species that indicate low site potential are present throughout a tract that is mapped as high site potential it suggest a closer examination of site index had better be made. For example, if in the piedmont a site has elm and post oak or in the Quachita mountain if a site is dominated by post oak, blackjack oak, and elm throughout the setting it suggests that it may be a site with low site potential and should be examined closely before many dollars are invested in this site.

All of these sources of information should be used to help converge on the best estimate of site potential (site index). The actual yields obtained from an area are driven by (1) the number of trees established and free to grow and (2) the site index of the land. The importance of getting your best estimate of base site potential can be illustrated by the fact that for stands will 500 tpa every one foot change in site index roughly changes yield (4" top 0.8. volume) by 100 cubic feet at age 30. The key to getting a good estimate of site index is being able to look at all of the site components, soil and vegetation. This means pre-logging examination of the site.

Question #3. What opportunities exist on the site?

Another reason for examining the site is to examine what opportunities exist on the site. Often due to favorable conditions enough established seedlings with advanced growth exist on an area to consider not site preparing and planting but instead using the available dollars to invest in competition release and growth promoting treatments on this or other existing stands. Yes, you give up the opportunity to use the families with the best genetics. But keep in mind that the best first generation family might increase the site potential by 3-4 feet. One or two years advanced growth can go a long way to offset the loss due to not using an improved seedling.

Another opportunity that has not been well studied but needs some investigation is the potential to manage residual pines that have been left after logging. On many tracts that have been logged for solid wood there may be 25-30+ square feet of basal area of pines that are slightly below merch standards (6-8" diameter). Often these trees have good form, are well pruned but have reduced crowns. Some ongoing research with loblolly pine by McLemore and Baker (1986) at the University of Arkansas at Monticello, Arkansas, suggest that these trees can recover and grow at a reasonable rate. The rate of basal area growth depends on the percent of live crown left and the diameter of the stem at the base of the crown and probably the age of the stand. The idea is that these trees only have to grow one to three inches in diameter before they become quality C/N or better saw material. Even at a slow growth rate these trees can produce a saleable product in a few years. Meanwhile natural seeding or hand planting can be done to get advanced growth of the next generation.

Another option and better consideration is to mark 80-100 trees in a stand scheduled for logging that are just below or slightly above C/N saw merch standards, but have moderate crowns and good form. You will give up some low valued pulpwood volume but you should have a well distributed stand of pines left after logging which have good potential to convert to a high value sawtimber in a short time period. Again, natural regeneration or under planting can be encouraged.

The residual stand management consideration is not a license to high grade. However, on site with low site potential or cases when low amounts of investment capital are available to re-establish a forest these options should be investigated. Some conditions to avoid this option on would be (1) on poorly drained sites where blow down is likely and (2) where the stands are very old and probably non-responsive. On these areas site preparation and planting, if the site potential justifies it, should be considered.

Question #4. What are the major factors that will limit regeneration or stand growth?

If the site potential justifies regeneration and capital is available to spend on site preparation than what type site preparation should be applied. The options for accomplishing the site preparation phase are almost unlimited. One can spend as much money as they want. The objective should be to select the site prep option that removes the establishment and growth limiting factors (1) the most economically, (2) maintains or improves the site potential and (3) is socially acceptable. Table 1 lists the common objectives of site preparation along the top margin and some site preparation methods that are available to accomplish these objectives. I have subjectively ranked them as to whether they can make a positive (+) or negative (-) contribution toward accomplishing a given site preparation objective. The more pluses an activity is assigned under a given objective indicates a better ranking, If you don't agree with the rankings, you can incorporate your information into the chart. The idea is to have a way to select the site preparation activity which maximizes all of your site preparation objectives and cost the least. For instance, if you identify that the site has no soil physical limitations, has high hardwood brush potential (many hardwood, small diameter, young age, cut high, cut in dormant season, smooth cut stump, and has species with high sprout potential) and has a high potential erosion problem then what site prep options would you choose from the table above. KG, pile burn and disk will do an excellent job in reducing the hardwoods if it is applied in the right season. However; the erosion potential which is strongly driven by slope and the percent bare soil that will be created will be high on this site. Chemical site preparation will also reduce the hardwoods and avoid the high erosion potential problem. Because there are no soil physical limitation problems chemical site preparation should be considered. If the area is so socially sensitive that chemicals can't be used and high erosion will not be acceptable you may want to shoot yourself or sell the land to the highest bidding special interest group that thinks they can manage it better than you.

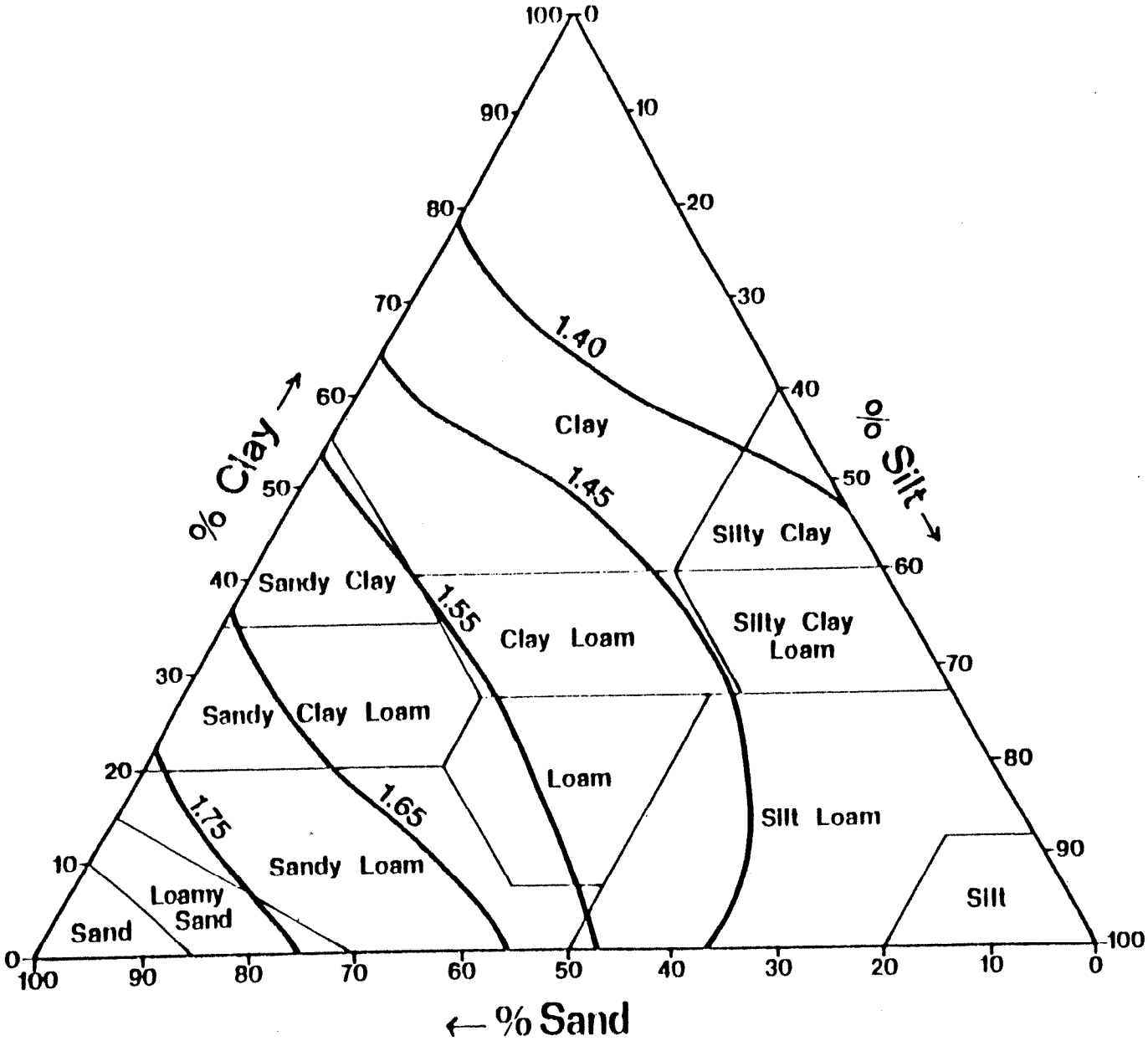
Often, recognizing what is the limiting site factors to establishment and growth is the challenging part in selecting the right method. Excessive slash and advanced competition are easy to recognize. Potential drainage (aeration) problems can be recognized by standing water or soils that are gleyed to the surface especially if they are fine textured (clayey) soils. One factor that is not easy to recognize is; if there are soil physical limitations. This is in part due to the fact that we have not done a good job in defining what soil physical conditions actually limit pine root development. The two major indicators of problems with soil physical limitation are soil texture and soil bulk density. Morris and Lowery (1988) has done the best job possible to indicate the bulk density (weight of soil/unit volume, lbs/cu.ft. or g/cm^3) and soil texture combinations that are likely to limit root growth. These combinations are illustrated in the textural triangle shown in figure 2.

Once the limiting site factors are identified and the options for removing these limitations are selected, then the last step is to conduct an economic analysis to select the most cost effective option. You should have more than one option identified at this point. If not, you haven't had your head on and you need to take a vacation and come back when you can think more clearly. One option is no fun and it's not an option anymore.

Question #5. What is the best economic option available?

To complete this phase requires four things:

Figure 2.--Textural triangle growth limiting bulk density relationship. From Morris and Lowery, 1986.



1. A good estimate of (a) the base soil site potential and (b) the number of trees you expect to get established.
2. An estimate of the cost for each activity being considered.
3. An estimate of the growth benefits of what you plan to do or growth losses expected from what you plan not to do.
4. An estimate of the real value of the products being produced.

If you do not have a good estimate of the base soil site potential, then you won't get an accurate estimation of expected yields. But of course you've done a good job of getting this information. The other component needed to enter a yield table or run a simulation program is the number of established trees. This will vary with the regeneration option you choose. A value for trees per acre can be based on expected survival rate or a targeted value can be taken.

The estimates of cost for the options being considered is the thing that can be most easily and accurately determined. Ask any (perhaps many) consultants or contractors and they will give you their estimate.

Getting estimates of growth benefits or growth losses for the various activity options you chose will not be so easy. This is especially true for shortleaf pine. But if you are willing to spend your money for a given forest management activity you must be assuming you are going to get some benefits. Write down what your assuming and then leave check plots to see if you were right. Because of limited data available for shortleaf pine, I have developed a table of "expected treatment gains" for loblolly pine as an example (table 2). These lifts are based on the assumptions that the treatment was needed (i.e. it removed an establishment or growth limiting factor) and represents an average expected value. Some responses will be less, some more. Your goal should be to construct such a table for your geographical area. One also will need to guard against double accounting. For instance, if disking reduces hardwoods and you also plan to apply a chemical that reduces hardwoods don't give both activities each full credit for controlling hardwood. Give each the partial credit they deserve.

The last step in getting the information to run your economic evaluation was to get an estimate of the expected value of the products you will produce. Product values can be obtained from sources such as Timber Mart South or various other publications. It would probably be better to use the long term price trend for your area than "todays" value. Since I am not an economist, you may want to visit with one on this aspect. One aspect you will have to decide is how much the location of your tract, its topography and road conditions will affect the bid price of your timber.

SUMMARY

With the information discussed above good sound economic analysis can be made. These analysis will be helpful in deciding which site preparation-establishment option is most likely to succeed. Nothing has a one hundred percent certainty but taking the necessary steps to evaluate your options will increase your probability of success.

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Table 1.--Estimated effectiveness of selected site preparation treatments in accomplishing site preparation objectives.

Site Prep. Method	Remove Slash	Improve Soil Surface	Physical Properties Subsoil	Maintain Short-Term Nutrient Availability	Reduce Hardwood Competition	Reduce grass or Ueed Competition	Reduce Soil Erosion	Improve Aeration
Roll, Chop, Burn, Subsoil	+++	+	++	+	+	+	-	
Burn	+		0	+	+	+ OR -		- TO 0
Roll, Chop or Tree Crush + Burn	++		0	+	++	+,- OR 0	—	
Roll, Chop, Burn Disk	+++	++	0	++	++++	+	---	+
KG-Pile-Burn	++++		0	+	++		----	
KG-Pile, Burn Disk	+++++	++	0	++	++++	++	----	++
KG-Pile, Burn Bed	++++	++	0	++	++++	++	---	++
Chemical	0 TO +	0	0	+	++++	+++		0
Chemical + Burn	++		0	+	++++	+++	--	- TO 0

+ Represents movement towards accomplishing the stated objective of site preparation.
- Represents movement away from accomplishing the stated objective.
o = Neutral impact.

Table 2.--Estimated growth gains from select regeneration activities based on loblolly pine studies.

Activity	Estimated Growth Response	Estimated Survival Response		Comments
		(percent)		
Hardwood Control	.5 cunits/1% long term Hardwood competition Basal Area Reduction	....		Hardwood control is not increasing growth above the base-site potential--It just allows growth to approach the potential.
Grass Control				
Well Drained Uplands		Cutovers	Pastures	
spot (4')	2' increase in site index	8%	20	These are the height increments expected from grass control treatment. These gains will occur early in the rotation and then it is assumed they will be maintained. This type response will affect how and when the additional volume is added to the stand.
Strip (5')	2.5' increase site index	12%	25	
Broadcast	3.0' increase site index	12%	25	
Imperfectly-Poorly Drained				
Strip	-3.0' increase site inde	8	??	
Broadcast	3.5' increase site index	12	-?	
Planting				
Machine vs hand	------	10		
Subsoiled-hand plant vs. straight hand plant	1.5'	20		Well drained, fine textured upland soils.
Soil Physical Improvement				
A'horizon	1.0"	10[b]		
A&B horizon	2.0'			
Soil Aeration Improvement				
Bedding	3.0' increase SI	10		Hardwood control benefits should also be considered if there was a potential hardwood problem.
Improved Seedlings				
Growth	2.5' increase SI/ Generation Improvement			
Reduced Rust				
Infection	50% reduction in rust e.g. (40% to 20% Generation Improvement"			

"If the treatment controls grass, or reduces hardwood this gain should be considered also.

[b]Increase over hand plant. No tillage.

"Value of response depends on rotation length and product being produced. The value of rust protection on volume production can be estimated using the GAPPS Model of Burgen and Bailey - UGA.

ROOT ZONE ENVIRONMENT, ROOT GROWTH, AND WATER RELATIONS DURING SEEDLING ESTABLISHMENT"

John C. Brissette[2/] and Jim L. Chambers[3/]

Abstract.--Effects of root zone temperature and water availability on root growth and water relations after outplanting were studied in a growth chamber experiment. Four weeks after planting, the root zone environment accounted for one-third of the variation in new root growth. That new root growth, in turn, affected xylem water potential and root system water flux. In the most favorable root environment, new roots averaged about 650 mm^2 of projected surface area. The water stress induced by transplanting, measured as xylem water potential, was alleviated by approximately 300 mm^2 of new root projected surface area. Each 10 mm^2 of new root projected surface area increased root system water flux by 2 to 3 percent.

INTRODUCTION

The establishment phase of artificial regeneration for a transplanted seedling is the period after outplanting when rates of physiological processes adjust to the new environment. Rietveld (1989) concluded that all planted seedlings, even those planted under ideal conditions, suffer some degree of transplanting stress. Transplanting stress, often the result of root loss during lifting from the nursery, can lead to severe and prolonged water deficits in bare-root seedlings. For physiological processes in planted seedlings to return to levels of undisturbed plants requires sufficient water uptake to alleviate water stress. Water uptake by transplanted stock depends initially on the old, woody roots that are planted (Carlson 1986, Chung and Kramer 1975, MacFall et al. 1990). However, to survive and grow, planted seedlings must extend their root systems with new roots.

When bare-root pine seedlings are lifted, a significant portion of their roots- -perhaps as much as 75 percent of total root length--is left in the nursery soil (Nambiar 1980, Wakeley 1954). Because of that loss, Wakeley (1954) concluded that initial survival of planted southern pines depends more on formation of new roots than on any other factor. Sutton (1980) emphasized the importance of new root growth for reestablishing intimate contact between transplanted root systems and the soil. The capacity of seedlings to produce new roots after outplanting, termed root growth potential (RGP), is often measured under controlled conditions. Expression of RGP entails two separate processes: elongation of undamaged root tips and initiation and elongation of adventitious roots (Ritchie and Dunlap 1980). Both root elongation and initiation are complex

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1/ Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

2/ Principal Silviculturist, USDA-Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

3/ Associate Professor of Forestry, School of Forestry, Wildlife, and Fisheries, Louisiana State University, Baton Rouge, LA 70803.

processes resulting from an interaction amongplantmorphology and physiology and the physical and chemical environments of the whole plant.

Two key elements of the plant environment are availability of soil water and root zone temperature. Availability of soil water for uptake by plants is best measured by water potential (Kramer 1983). Water is most available when soil water potential is near zero. As soil dries, water potential becomes more negative and water less accessible. In most soils, field capacity is about-O.03 megapascals (Mpa); -1.5 Mpa is commonly used to approximate the soil water potential at which plants become permanently wilted (Kramer 1983). Six weeks after transplanting red oak (*Quercus rubra* L.) seedlings, Larson and Whitmore (1970) found five times the RGP at field capacity as at -0.4 MPa. Ritchie and Dunlap (1980) cited unpublished data showing that loblolly pine (*Pinus taeda* L.) seedlings had RGP at initial soil water potentials as low as -1.3 MPa. Both elongation and initiation of pine seedling roots are affected by temperature; however, elongation is more sensitive than initiation (Andersen et al. 1986, Nambiar et al. 1979). In shortleaf pine (*P. echinata* Mill.), the number of new roots more than 1 cm long after 28 days at 10°C, 15°C, or 20°C increased linearly with temperature (Brissette and Carlson 1987).

Just as water potential is nearer zero in soil at field capacity than in dry soil, water potential is nearer zero in the xylem of a well-watered plant than in that of a water-stressed plant. Water potential in the xylem of plants becomes increasingly negative as transpiration induces tension and pulls water from the soil through the plant. Therefore, predawn xylem water potential (Ψ_{pd}), that is, water potential without transpiration, is the best measure of water stress within a plant (Kramer 1983). The more negative Ψ_{pd}, the greater the water stress the plant is enduring.

Root system water flux (L_R) is a measure of the capacity to absorb water and depends on root system permeability (L_P) and root surface area (A_R) (Kramer 1983), such that

$$L_R = L_P \times A_R. \quad (1)$$

As equation 1 indicates, L_R changes when either L_P or A_R change. Because unsuberized roots are more permeable than suberized roots (Carlson 1986, Chung and Kramer 1975, Colombo and Asselstine 1989, Grossnickle and Russell 1990), the degree of suberization of various portions of the root system affects L_p, and the root zone environment can determine how quickly new roots become suberized (Kaufmann 1968). Consequently, both L_P and L_R can increase markedly with a relatively small increase in A_R caused by new root growth. Plant water uptake depends on availability of water in the soil, as well as on L_R. Consequently, L_R represents the maximum capacity for water uptake; for example, if resistance to water movement in the soil and across the soil-root interface increases--as it does as soils dry (Kramer 1983) --total water uptake will be less than L_R.

Some results of an experiment on root growth and water stress of shortleaf pine seedlings during a 4-week establishment period are reported in this paper. The part of the experiment reported here had two objectives: (1) to.describe the effects of root zone temperature and water availability on RGP and (2) to measure the impact of RGP on Ψ_{pd} and L_R. Other aspects of the study are discussed in Brissette and Chambers (in press).

MATERIALS AND METHODS

Plant Material

Seedlings were grown from a single half-sib family lot (family 322) collected at the USDA Forest Service's Ouachita-Ozark Seed Orchard near Mount Ida, Arkansas. Study seedlings were grown with seedlings from several other families at Weyerhaeuser Company's Fort Towson Forest Regeneration Center in southeastern Oklahoma. About 1,000 seedlings from family 322 were carefully hand-lifted *in* late February 1989 after they had received 1,077 hours of accumulated chilling (0°C to 8°C at 20 cm above ground level). They were packed in kraft-polyethylene (K-P) bags and cold stored (at about 3°C) for up to 9 days.

On the day seedlings were put into the experiment, their roots were pruned to a length of 150 mm and the root system projected surface area was measured with a photoelectronic image analyzer (Decagon Devices, Inc., Pullman, WA). A seedling was selected only if its root system projected surface area was within 1.0 standard deviation of the mean of 100 randomly selected seedlings. The root system projected surface area of each seedling was calculated as the mean of three images; this procedure minimized error caused by overlapping lateral roots. The 126 seedlings in the experiment averaged 309 mm in height; the mean root collar diameter was 5.1 mm, and the mean root system projected surface area was 3,010 mm^2.

Environmental Controls

The experiment was conducted in *a* growth chamber that provided a constant air temperature of 20°C and a 14-hour photoperiod. Relative humidity was not controlled, but the chamber floor was kept flooded and relative humidity averaged about 75 percent. When the growth chamber lights were on, photosynthetically active radiation was greater than 750 $\mu mol\ m^{-2}\ s^{-1}$ at the top of the seedling crowns.

Two water baths were constructed to control root zone temperatures; the root zone temperatures used were 15 ± 0.5°C and 20 ± 0.5%. The 20°C bath was maintained by ambient conditions in the growth chamber. The 15°C bath was maintained by circulating water between the bath and a reservoir where it was chilled. In each water bath there were 63 root environment chambers for controlling soil water potential. Soil water potential was regulated by maintaining a growing medium at a constant height above water in a conductive column. Each root environment chamber was similar to an apparatus described by Snow and Tingey (1985) for imposing water stress on plants. Snow and Tingey's apparatus contained irrigation reservoirs for each chamber; a peat-based medium was used for the plants. For the present research, Snow and Tingey's system was modified as follows: the chambers were put in water baths to control the root zone temperature; several chambers were connected to an irrigation reservoir; and the seedlings were potted in masonry sand (figure 1).

Three levels of soil water availability were compared. A well-watered treatment was considered the control. The other water stress treatments were at less than field capacity; more water was available at level 1 stress than at level 2 stress. In two preliminary experiments, distances were established between water in the conductive columns and the root systems so that differences in mean RGP and Ψ_{pd} could be achieved. There was some mortality among the level

2 water stress seedlings. Mortality was defined as needle water content ≤ 75 percent (oven-dry weight basis) (Brix 1960), and results from such seedlings were not analyzed.

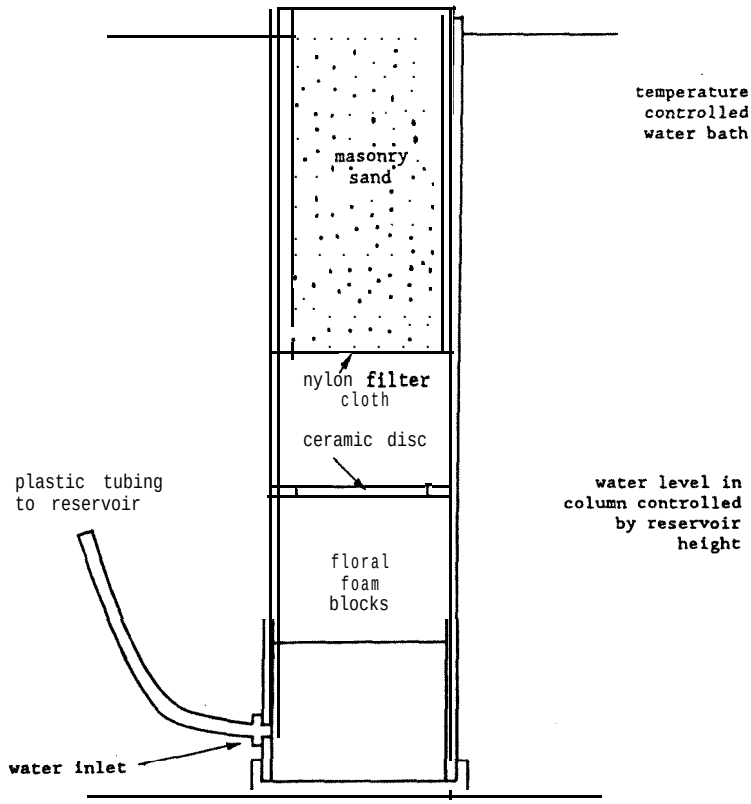

Figure 1. --Chamber used to control root zone temperature and soil water availability for individual seedlings.

Response Variable Measurements

Xylem Water Potential.--A subsample of eight seedlings in each treatment combination was chosen at random for evaluation of Ψ_{pd} 28 days after planting. The Ψ_{pd} of two or three fascicles was measured in a pressure chamber (PMS Instrument Co., Corvallis, OR). If water was not forced from the xylem by a pressure of 4.00 MPa, Ψ_{pd} was recorded as -4.00 MPa. Seedling mean Ψ_{pd} was used in statistical analyses.

Root Svstem Water Flux.--The day after Ψ_{pd} was measured, a maximum of 16 living seedlings from each treatment combination were washed from the sand with care to prevent damage to new roots. Their L_R was measured by a hydrostatic pressure method similar to one described by Carlson and Miller (1990). Each shoot was severed about 25 mm above the topmost lateral root. The stem above the root system was inserted through a rubber stopper, which was then seated in the removable top of a vessel with the cut stem protruding and the roots suspended in the base of the container. With the top secured to the base to form a pressure vessel, tap water at 20 ± 0.5°C was pumped through the apparatus at 0.3 ± 0.001 MPa. The vessel held 8 seedlings, so 12 runs were needed to measure L_R in this experiment.

Water could escape the vessel only by passing through the root systems and out the cut'stems. After a 15-minute equilibration period, L_R was measured as water exuded from the root systems. The exuded water was collected in wicks made of plastic tubes filled with absorbent tissue paper. Four samples were taken from each seedling at approximately S-minute intervals; actual time was recorded to the nearest second. The wicks were weighed to the nearest 1 mg before and after collection. Because weight and volume of water are related, weights were converted to micromoles of water exuded per second, and the mean of the four samples was used in analyses.

Root Growth Potential. --After L_R was measured, new roots were removed and their total projected surface area was measured on the image analyzer. Old roots were separated into laterals and the taproot, and their total projected surface area was measured without the error caused by overlapping roots.

A photoelectronic image analyzer measures objects in two dimensions, but roots are three-dimensional. Therefore, projected surface area is an index of actual surface area. Accordingly, the projected surface area of old roots was called "old root area index" (ORAI) and, for consistency, RGP measured by this method was termed "new root area index" (NRAI). Both ORAI and NRAI were measured to the nearest 10 mm^2.

Statistical Analysis

Analysis of variance (ANOVA) was used to determine the effects of root zone temperature and soil water availability on NRAI. There was a factorial arrangement of the two temperatures and three levels of soil water. Each soil water level was replicated 21 times at each temperature; however, temperatures were not replicated. Consequently, the experimental design was completely random. From the 21 seedlings in each treatment combination, 16 were chosen at random to measure NRAI. Because there were not 16 living seedlings in all treatments, least squares means were used to compare factor levels.

With NRAI as a covariate, analysis of covariance (ANCOVA) was used to examine effects of root zone temperature and water availability on Ψ_{pd}; both NRAI and ORAI were covariates for L_R. Regression analysis was used to describe relationships between Ψ_{pd} and L_R and those independent variables in the ANCOVA models that were significant at $p = 0.10$.

The Ψ_{pd} increased exponentially with NRAI, so a logarithmic transformation of NRAI was used to linearize the function for regression analysis. Some seedlings had no new roots; therefore, because the logarithm of zero is undefined, 1 was added to NRAI before its natural logarithm was taken.

RESULTS AND DISCUSSION

New Root Develoument

The survival rate was 96 percent; five seedlings at level 2 stress died, four at 20°C and one at 15°C (table 1). Some new root growth occurred in all treatments, although NRAI at 15°C, stress level 2, averaged less than 10 mm^2 (table 1). The maximum NRAI, 1,730 mm^2, was on a seedling in the 20°C control treatment. The only new taproot development was on that seedling and accounted for 90 mm^2 of its NRAI. That almost all new root growth originated from lateral

roots is consistent with the results of DeWald and Feret (1988) for loblolly pine seedlings.

Table 1.--New root area index (NRAI) 4 weeks after planting in different root zone environments

Water stress level	NRAI by root zone temperature		
	15%	20°C	Least squares mean
	-mm²-	-mm²-	-mm²-
Control	40 (16)	620 (16)	330 (32)
Level 1	10 (16)	260 (16)	140 (32)
Level 2	<10 (15)	20 (11)	10 (26)
Least squares mean	20 (47)	300 (43)	

NOTE. --M.S.E.=84011, for the interaction $F_{(2;84)}=6.90$, for temperature $F_{(1;84)}=21.18$, and for stress $F_{(2;84)}=8.95$. Numbers in parentheses are the number of surviving seedlings contributing to the adjacent mean.

Root zone temperature and water availability interacted to affect NRAI (p= 0.002). There was always less root growth at 15°C than at 20°C, but as soil water became less available, the amount of root growth- fell much more rapidly at 20°C than at 15°C (table 1). At level 2 water stress, the seedlings could not generate much root growth at either temperature. Thus, both factors had to be favorable for new roots to grow. Regardless of how favorable root zone temperature or water availability was, the other factor could still limit new root development. The temperature x stress interaction explained 9.8 percent of the total variation in NRAI, and the temperature and stress main effects explained 11.4 percent and 9.8 percent of the variation, respectively.

Among seedlings in the level 2 stress treatments, NRAI was negligible (table 1). Consequently, only seedlings in the control and level 1 treatments were used to examine the impacts of treatments, NRAI, and ORAI on Ψ_{pd} and L_R.

Xylem Water Potential

The Ψ_{pd} was measured on 32 seedlings in the control and level 1 water stress treatments. The ANCOVA explained 76 percent of the total variation in Ψ_{pd}; significant variables in the model were the main effects of temperature (p= 0.02), water stress (p= 0.003), and NRAI (p- 0.0001). When those variables and their interactions were used to predict the Ψ_{pd} response in a regression model, the interactionbetween transformed NRAI and stress was not significant (p= 0.4). Therefore, the simplest model for describing the effects of NRAI, water stress, and root zone temperature on Ψ_{pd} was

$$\Psi_{pd} = -1.88 + 0.195\ X_1 - 0.596\ X_2 - 1.046\ X_3 + 0.175\ X_1X_2 \qquad (2)$$

where $X_1 = \ln(NRAI + 1)$,
$X_2 = 0$ if stress = control and 1 if stress = level 1, and
$X_3 = 0$ if temperature = 15°C and 1 if temperature = 20°C.

Within each temperature, the two stress levels had different intercepts but the same slope (figure 2). The *more* negative intercepts *for* the 20°C *treatments* reflect somewhat lower water availability, probably due to greater evaporation from the surface of the warmer pots.

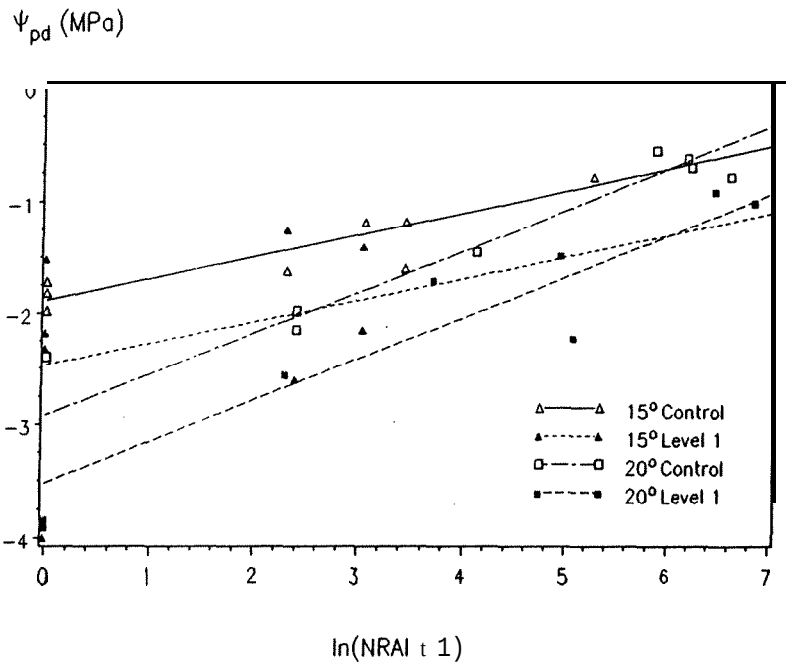

Figure 2. --Relationship between predawn xylem water potential (Ψ_{pd}) and new root area index (NRAI) 4 weeks after planting in two root zone temperatures and two levels of water availability.

Seedlings under the least water stress had Ψ_{pd}'s of about -0.8 MPa (figure 2). To achieve that, the regression model predicted that the 15°C control seedlings needed approximately 250 mm^2 of NRAI and the 20°C control seedlings needed about 310 mm^2. That much NRAI represented an increase in total root surface area of less than 10 percent. Thus, a relatively small amount of new root growth resulted in a marked improvement in Ψ_{pd}.

Root System Water Flux

The L_R was measured on 64 seedlings in the control and level 1 water stress treatments. The ANCOVA accounted for 45 percent of the total variation in L_R and the only significant independent variables were NRAI (p= 0.0001) and water stress (p- 0.068). The simplest regression model predicting L_R from NRAI and water stress was

$$L_R = 2.562 + 0.00453\ X_1 - 1.187\ X_2, \qquad (3)$$

where X_1 = NRAI and

X_2 = 0 if stress = control and 1 if stress = level 1.

Thus, seedlings from the two stress levels had different intercepts but the same slope (figure 3). Apparently, water stress affected the permeability of old roots, but not that of new roots. Water stress has been shown to make woody roots less permeable (Ramos and Kaufmann 1979). Carlson (1986) found a significant positive relationship between L_R and the volume of old roots of loblolly pine seedlings. However, in the present study, ORAI did not affect L_R. The seedlings selected for the present experiment were very similar in root system size; this uniformity most likely explains why ORAI did not significantly contribute to L_R.

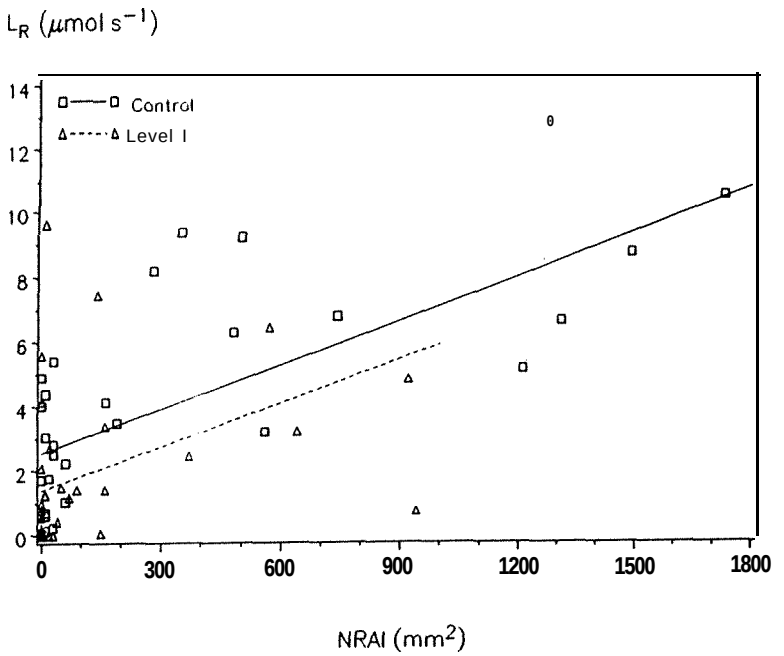

Figure 3. --Relationship between root system water flux (La) at 0.3 MPa hydrostatic pressure and new root area index (NRAI) 4 weeks after planting in two levels of water availability.

The regression model predicted that each additional 10 mm^2 of NRAI in the control treatments increased L_R by 0.045 μmol s^{-1}, which is an increase of 1.8 percent (figure 3). Because the intercept was less for level 1 seedlings, the predicted increase in L_R was greater by an additional 1.5 percent for each additional10 mm^2 of NRAI (figure 3). For example, a control seedling with 1,000 mm^2 of NRAI would be expected to have an L_R 177 percent greater than that of a seedling with no new root growth. However, a seedling under level 1 water stress conditions with 500 mm^2 of NRAI should have an L_R 165 percent greater than that of a seedling with no NRAI.

Those increases in L_R were based on a relatively moderate driving force of 0.3 MPa. It is not unusual for xylem water potential, which drives water uptake in transpiring plants, to be as low as -2.0 MPa (Kramer 1983). Consequently, a plant with xylem water potential of -2.0 MPa, growing in a soil with a water

potential of -0.5 MPa, has a driving force for water uptake of 1.5 MPa (although that driving force is tension, or negative pressure, rather than positive pressure, as in this experiment). Therefore, the amount of NRAI should have an even greater impact on L_R in rapidly transpiring seedlings than in the seedlings tested under the conditions of this experiment.

CONCLUSIONS

It has long been known that both soil temperature and soil water availability can limit root growth. This experiment shows that the interaction between the two factors can also have a significant impact on new root development after outplanting. Regardless of how favorable soil temperature or water availability may be, one factor cannot offset the limiting effect of the other. That is, root zone temperature must be favorable and soil water must be readily available for root growth to occur. However, this experiment also showed that relatively little new root growth--less than a lo-percent increase in total root surface area--is needed to increase the capability of root systems to absorb water. Increased water uptake reduces the water stress that often accompanies outplanting. Therefore, the primary goal of artificial regeneration should be to promote rapid and vigorous root growth after planting. To achieve this goal requires care and diligence when growing, handling, and storing planting stock, preparing planting sites, and planting seedlings.

ACKNOWLEDGMENTS

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POST-ESTABLISHMENT WEED CONTROL FOR SHORTLEAF PINE[1,2]

J. L. Yeiser[3]

Abstract--Three studies of weed control alternatives when planting shortleaf pine (*Pinus echinata* Mill.) in northern Arkansas are summarized. Study one examines preplant mechanical and postplant herbicidal treatments in an old pasture for efficacy, competitor re-establishment and pine seedling survival and growth through age five. Study two contrasts spot, band and total herbicidal control of herbs on a ripped site for soil moisture, competitor biomass plus seedling survival and growth through age four. Study three assesses the impact of the litter layer during stand conversion on soil moisture, inhibition of invading herbs plus pine seedling survival and growth through age two.

INTRODUCTION

Hardwood forests, primarily of oak-hickory type, are predominant in northern Arkansas (Hines, 1988). Since 1978 northern Arkansas has experienced an increase in timberlands, with much of the increase coming from pasture and cropland conversion to trees (Hines, 1988). Lack of seed trees prevents the natural regeneration of fields or pastures with pine. Establishment of shortleaf or lobolly pine (*Pinus taeda* L.) on old fields is attractive to landowners because of rapid growth, high quality wood and the availability of federal cost-sharing programs such as the Forestry Incentive and the Conservation Reserve programs which reduce landowner investment in pine establishment.

Herbaceous weeds can reduce growth and survival of newly planted pine seedlings as a result of competition for soil moisture, nutrients, light and growing space (Creighton et al., 1987; Zutter et al., 1986). Though these impacts have been documented for loblolly pine throughout much of the South, weed control research has focused neither on shortleaf pine nor on sites in northern Arkansas leaving a paucity of information for interested practitioners.

Oust[4] alone or Oust + Velpar L[4] are herbicides commonly used for the control of herbaceous weeds near newly planted pines in the South (Cantrell et al., 1985). Oust can inhibit loblolly pine root growth potential (Barnes et al., 1989) and Velpar L will injure pine seedlings if not applied properly (Baldwin et al., 1991). When applied appropriately, these

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[3]Arkansas Agricultural Experiment Station, University of Arkansas at Monticello 71655.
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herbicides provide effective control of herbaceous weeds without significant harm to pine seedlings and are, therefore, considered the industry standard.

Data documenting pine response to control of annual and perennial weeds for old-fields, prepared sites and for stand conversion within the Ozark region is limited. Herbaceous weed control efficacy and subsequent pine growth and their relationships with herbaceous biomass, seedling biomass and soil moisture are poorly documented. In order to assess these relationships, studies were established on a ripped site in the Ouachita Mountains of central Arkansas, plus an old pasture and a low-grade, oak-hickory stand *in the* Ozark region of northern Arkansas. These studies are presented to assist readers with their understanding of relationships needed to practice effective herbaceous weed control when planting shot-deaf pine in northern Arkansas.

OBJECTIVES

Study one--an old field planting

The objectives of this study were to evaluate selected preplant mechanical and postplant herbicidal treatments for: (1) first-year efficacy on unwanted perennial competitors, (2) the control and subsequent re-establishment of selected herbs in treatment plots, and (3) the survival and growth of nursery-run and improved sources of container-grown shortleaf and loblolly pines as regeneration alternatives for old pastures in northern Arkansas. Data for shortleaf pine will be presented. Readers interested in early comparisons of loblolly and shortleaf pines near Batesville, AR should see Yeiser et al. (1987).

Study two--a ripped site

The objectives of this study were to compare spot, band and total herbicidal control of herbs for: (1) first-year efficacy with a commonly used herbicide, (2) first-year soil moisture levels associated with herbicide treatments, (3) first-year fascicle water potentials of pine seedlings at four time intervals during the day, (4) first-year components of seedling biomass, and (5) first-, second-, and fourth-year survival and growth of four genetically improved families. Only objectives one and five will be discussed here. Readers interested in a full account of study objectives should see Yeiser and Bamett (1991).

Study three--stand conversion

The objectives of this study were to contrast the effects of preplant hardwood injection and burning of the litter with preplant or postplant injection of hardwoods without burning on: (1) herbaceous biomass levels, (2) litter decomposition rates, (3) soil moisture, and (4) survival and growth of both loblolly and shortleaf pines. Results for shortleaf pine and objectives one, three and four will be presented here.

METHODS

Study one--an old field planting

This study was established on Waugh Mountain located on the Livestock and Forestry Branch Experiment Station in Independence County, Arkansas. The soils are of the Gepp series -- well-drained, cherty, silt loams with moderate fertility (Ferguson et al., 1982). The estimated site index for shortleaf pine at age 50 is 75 ft.

The test site was divided into seven, 0.6 acre plots with each plot assigned one treatment. The two mechanical preplant treatments were disking and mowing. In November 1984, Area 1 was mowed within 2 inches of the ground. Area 2 was disked in February 1985 until the soil was loose to a depth of about 4 inches. Areas 3, 4, 5 and 6 received postplant herbicidal treatments as single applications in late April 1985 in 3-ft bands centered over the seedling rows (Table 1). Herbicides were mixed with water until the total carrier volume was 10 gal/a per treatment. Area 7, the check, was not treated.

Table I.--Names and rates of application for four herbicidal treatments used to release pine seedlings near Batesville, AR.

Common Name	Trade Name	Treatment Areas			
		3	4	5	6
Velpar L	hexazinone	0.50[2,3]	0.75		
oust	sulfometuron methyl	0.188	0.094	0.094	0.188
Roundup'	glyphosate			0.75[4]	0.50

'Registered Trademark of Monsanto Chemical Co.

[2]All rates are presented in lb/a of active ingredient (ai). Herbicides were mixed with water until the total carrier volume was 10 gal/a for each treatment. 0.50 lb/a ai = 1 quart of Velpar L or 1.0 pint of Roundup; 0.75 lb/a ai = 1.50 quarts of Velpar L or 1.5 pints. of Roundup; 0.188 lb/a ai = 4 oz. of Oust; 0.09 lb/a ai = 2 oz. of Oust.

[3]Based on 2 lb ai of hexazinone/gal.

[4]Based on 4 lb ai of the isopropylamine salt of N-(phosphonomethyl) glycine/gal.

Seed sources for genetically improved and nursery-run (unimproved) shortleaf pine originated in Arkansas. Seeds were sown in Styroblock® (No. 8) containers, grown five months from germination and then planted in mid-March on a 8 X 8 ft spacing with a preformed planting bar matching the dimensions of the Styroblock®. All improved seedlings originated from open-pollinated, orchard (unrogued) seed.

Seedling survival was recorded in November 1985, 1986, 1987 and 1989 and expressed as percent. Initial height and ground line diameter (GLD) were recorded immediately after

planting. Total height at ages one, two and three was recorded in inches with 5th-year-heights measured in feet. Ground line diameter was recorded for ages one, two and three with diameter at breast height (DBH) recorded at age five. Both GLD and DBH were measured in inches.

Percent reduction of all herbaceous competition as visually compared to check plots was evaluated in 10% intervals for each plot. No control was recorded as zero with total control recorded as 100%. Evaluations of plots were conducted at 30 (June 1), 60 (July 1), 90 (August 1) and 120 days (August 30) after treatment (DAT).

Prior to the application of herbicides, three-foot bands centered over seedling rows were assessed for species composition. Five species were found common to all plots: broomsedge *(Andropogon virginicus),* greenbriar *(Smilax bonanox),* beaked panicgrass *(Panicum anceps),* croton *(Croton glandulosus),* and Japanese bush clover *(Lespedeza striata);* 15 stems or clumps of each species were marked for assessment. .The treated three-foot-bands were again assessed for the frequency of the five selected herbs in July 1987. Chi-square tests were used to contrast species frequency 60 DAT and reinvasion of species as recorded in July 1987.

The study layout was a randomized complete block split-plot design with seven mechanical and herbicidal treatments as whole plots. Split plots contained five rows of five seedlings for each of the sources of shortleaf pine. There were five blocks.

Study two--a ripped site

The test area was located near Perryville, in the Ouachita Mountains of central Arkansas. Trees were clearcut and the site ripped to a depth of 18 to 24 in. in 1987. Bare-root seedlings from four shortleaf pine families were hand-planted in February 1988. Seed for planting stock was unsorted and originated from open-pollinated families (103, 115, 218 and *322).*

The study was established as a randomized complete block design with four blocks. Within each block were 16 randomly located treatment plots. Plots contained 6 rips and 6 seedlings per rip with seedlings planted on a 9 X 6 ft'spacing. Soil on the site was a stony fine sandy loam, from the Carnasaw-Pirum-Clebit series (Townsend and Williams 1982).

Three oz. of ai/a of Oust was mixed with water and applied at a volume of 10 gal/a. The solution was applied once, in April 1988, for spot (3 ft diam.), band (3 ft wide) or total control of herbs. An untreated check served as the fourth level. Total control was initiated with the Oust application and maintained through September 1988 with directed sprays of 3% Roundup and water at 45-day intervals.

Evaluations of herbicide efficacy, herbaceous biomass, soil moisture, and seedling survival and growth were initiated in May 1988, and were continued at 45-day intervals through September 1988. For all evaluations, treated portions of plots were visually assessed for reduction of herbaceous competition in 5% intervals relative to check plots.

Six stratified samples of herbaceous biomass, 2 light, 2 medium and 2 heavy relative to percent cover within the plot, were clipped from a 2-ft square sample frame and collected from each check plot. Biomass was oven-dried and expressed in lb/a. For treated plots, . biomass was estimated in lbs/a in proportion to the visual assessments of herbaceous biomass reduction.

An automatic recorder attached to six soil moisture tension blocks recorded daily soil moisture fluctuations in each plot of one replication. Precipitation was measured on site with an automatic recorder.

Seedling measurements were initiated in February 1988 and continued at 45-day intervals from May through November 1988.. Seedlings were measured again after two growing seasons in December 1989 and four growing seasons in September 1991. Seedling height was measured in cm and GLD in mm one and two years after planting. Four years after planting, seedling heights were measured in feet and DBH in inches. Data were converted to inches for analysis.

S tudv three--stand conversion

This study was located on Waugh Mountain on the Livestock and Forestry Branch Experiment Station in Independence County, Arkansas. The soils on the northern slope of Waugh Mountain are of the Gepp series -- well-drained, cherty, silt loams with moderate fertility (Ferguson et al., 1982). The estimated site index for shortleaf pine at age 50 is 70 ft.

The test site was divided into four, 0.66 acre subplots within each whole plot. Hardwoods on whole plots one and two were injected in October 1988 with Tordon 101R[5]. The litter layer on whole plot one was burned in December until bare ground was exposed. Hardwoods on whole plots three and four were injected in May 1989--plot three with Tordon 101R and plot four with Velpar L.

Evaluations of herbaceous biomass, soil moisture, and seedling growth were initiated in May and were continued at 45-day intervals through September for both 1989 and 1990. Herbaceous biomass was clipped from within a 2-ft square sample frame. Six stratified samples, 2 light, 2 medium and 2 heavy relative to percent cover within the plot, were collected from each plot. Biomass was oven-dried and expressed in lbs/a. Soil samples were taken at a 6-12 in. depth within 18 radial in. of 2 small, 2 medium, and 2 large seedlings in each plot. Samples were placed in metal cans, the lids were hermetically sealed with tape, and brought back to the lab for oven-drying. Soil moisture was expressed in percent of dry weight. Seedling height and ground line diameter (GLD) were recorded at 45-day intervals from May through September for 1989 and 1990, in February 1989, immediately after planting, and in November 1989 and 1990 after one and two growing seasons. Seedling height was measured in cm and GLD in mm. Data were converted to inches for analysis.

[5] Registered Trademark of DowElanco.

The study was established as a randomized complete block split-plot design with three blocks. Each whole plot contained six subplots. Subplots were planted with bare-root seedlings in February 1989--three with loblolly and three with shortleaf pines. Seedlings were planted on an 8 X 8 ft spacing with six seedlings per row in each of six rows. Subplots received single, postplant treatments of Velpar L+Oust (0.50 lb +0.188 oz ai/a) in 3-ft bands centered over-the-top of seedlings. Herbicides were applied in April 1989 (2.5 months after planting) or April 1990 (14 months after planting) leaving one subplot of loblolly and shortleaf pines untreated as checks.

For all three studies, analyses of variance and covariance (Ott, 1977; SAS Institute, 1982) were used to analyze treatment efficacy plus seedling survival and growth. Percent data were transformed using the arcsin $\sqrt{\text{percent}}$ transformation and analyzed for detection of significant differences. Untransformed data are reported here. Initial height and initial GLD were the covariates. Insect-damaged seedlings were included in the assessment of survival but deleted from the growth analysis. Duncan's Multiple Range test was used for mean separation, with all statistical tests conducted at the 0.05 probability level.

RESULTS AND DISCUSSION

Study one--an old field planting

Herbaceous Weed Control.--Roundup+Gust provided better early control than other treatments; peak control occurred about 60 DAT (Table 2). By 120 DAT some herbs had re-established in all treatment plots. The 0.50 lb ai rate of either Roundup or Velpar mixed with 0.188 lb ai Oust provided the best overall control. Little difference existed in the species of competitors controlled, suggesting that field conditions for the practical application of results from these two herbicide treatments will be similar. At the initiation of this study, the 0.50 lb ai rate of the Roundup mix cost $10/a more than the Velpar when mixed at the same rate. Today, the Roundup+Oust mix is less costly. Mechanical treatments did not control competitors but improved access for planting. Postplant herbicidal treatments did not impact planter access.

Based on Chi-square tests, the number of herbaceous species present on herbicide-treated plots was less than that found on mechanically treated and untreated plots after 60 DAT. Of the initial 15 establishment points located for each species, competitors at 14 of 15 points were controlled with all herbicide mixes, excluding greenbriar (*Smilax bonanox*) and Japanese bush clover *(Lespedeza striata).* Mowing and disking treatments had as many herbaceous species present after 120 days as checks. Disked plots had less total ground cover than checks. Three years after treatment, all species occupying test plots prior to treatment were present in all plots with at least 15 points of reinvasion in each plot. These data suggest that herbicide treatments disrupted normal plant succession more than the mechanical treatments tested and that normal successional processes in untreated middles and, treated strips were operating sufficiently to establish competitors on all treatment plots three years after treatment. That is, the untreated middles contained test species that produced new seeds which, in combination with old seeds existing in the litter at or prior to treatment, probably contributed to the successful reinvasion of the test bands.

Table 2.--Treatment cost and mean percent herbaceous control for mechanical and herbicidal treatments installed near Batesville, AR.

Treatment'	Cost per Treated Acre[2] (198.5 dollar)	Days After Treatment 30	60	90	120
--lb/a of active ingredient--		---------(%) herbaceous control---------			
0.50 Roundup and 0.188 Oust	50	95A	95A	92A	89A
0.75 Roundup and 0.094 Oust	47	90AB	90 B	76 B	72 C
0.50 Velpar L and 0.188 Oust	40	86 BC	91 B	88A	82AB
0.75 Velpar L and 0.094 Oust	31	80 c	86 c	80 B	78 BC
Disked	25	60 D	50 D	50 C	50 D
Mowed	15	OE	OE	OD	OE
Check	--	OE	OE	OD	OE

'Based on 4 lb of the isopropylamine salt of N-@hosphonomethyl)glycine/gal for Roundup, 2 lb of hexazinone/gal for Velpar L and 16 oz/lb for Oust.

[2]Intended for purposes of comparison. Prices vary by vendor, formulation and the quantity purchased; actual prices should be obtained from a local dealer.

[3]Treatment means having different letters within a column differ at the 0.05 probability level (Duncan's Multiple Range test).

Herbicide treatments differed in their ability to control certain species present at the time of treatment. For example, broomsedge was controlled by Roundup but not by Velpar L treatments. Beaked panicgrass was controlled with all herbicidal mixtures. Velpar+Oust provided 60-day control of croton but failed to control Japanese bush clover, both of which were controlled by Roundup treatments. None of the treatments tested controlled Carolina horse-nettle. All treatments were weak on greenbriar and highbush blackberry. The similarity of results among herbicidal treatments, both economically and environmentally, favors use of low rates of less expensive herbicides. Although all five of the selected species reinvaded treatment plots, even small differences in efficacy could contribute to the development of future plant communities with similar species of different proportion.

Pine Survival.--After one growing season, pine seedling survival was 83%. By age 5, survival had declined to 75%. Greatest reductions in survival occurred in plots treated with Roundup (Table 3). Greater survival occurred on plots receiving the higher rather than the lower rate of Roundup. Competitor cover was greater on the plot treated with the higher rate of Roundup, possibly shielding seedlings from the herbicide and thereby reducing seedling mortality. Roundup is currently not recommended for seedling release with early

Table 3.--Survival of genetically improved (I) and nursery-run (NR) sources of container-grown shortleaf pine seedlings planted near Batesville, AR and released from perennial herbs in 1985.

Treatment[1]	Survival (%) at Age							
	1		2		3		5	
	I[2]	NR	I	NR	I	NR	I	NR
-lb/a of active ingredient-								
0.50 Roundup + 0.188 Oust	64 B	72 B	48 c	52 B	48 C	44 C		
0.75 Roundup + 0.094 Oust	92 A x[3]	64 BY	72 Bx	28 Cy	72 Bx	28 Dy	68 Bx	28 C y
0.50 Velpar L + 0.188 Oust	84 A	72 B	72 B	72 A	72 B	68 B	68 B	68 B
0.75 Velpar L + 0.094 Oust	88 A	88 A	88 A	76 A	88 A	76 A	88 A	76 A
Disked	96 A x	72 By	92 A x	52 B y	92A x	52 B y	92 A x	52 B y
Mowed	92 A	96 A	80 A	88 A	72 B	84 A	72 B	84 A
Check	88 A	96 A	88 A x	64 B y	88 A x	60 B y	8 8 A x	60 B y
Source[3]	86 x	80 x	77 x	61 Y	76 x	59 y	79 x	61 y

[1]Based on 4 lb of the isopropylamine salt of N-(phosphonomethly) glycine/gal for Roundup, 2 lb hexazinone per gallon for Velpar L and 16 oz per lb for Oust.

[2]Source means within a column having different letters (A,B,...) differ at the 0.05 probability level (Duncan's Multiple Range test).

[3]Source by treatment means in a row and for a particular age having different letters (x,y) differ at the 0.05 probability level (Duncan's Multiple Range test).

applications because of damage which appears during the current and subsequent growing seasons (Downs and Voth 1985). Because of the reduced survival on the plot receiving 0.50 Roundup+0.188 Oust, trees in this treatment were not measured at age 5.

First-year mean survival was 92% for the untreated check and was not significantly different than survival for mechanical (89%) or Velpar+Oust (83%) treatments. These survival rates suggest that during the 1985 growing season competition control was not necessary to achieve acceptable pine survival. Survival five years after treatment was similar with Velpar (75%), mechanical (75%) or untreated plots (75%).

Source by treatment interactions were detected for survival (Table 3). These differences are probably the result of variation in microsite and seedling physiology unrelated to controlled study variables and therefore of little value.

Survival was initially 6% greater for improved versus nursery-run sources of shortleaf pine. After five years survival differences had increased to 18%. Differences in physiological activity at the time of application and the ability of improved pine seedlings to provide greater early growth than nursery-run seedlings may have contributed to greater early survival for improved seedlings.

Pine Growth.--Only seedlings released from competitors with Velpar+Oust had more first-year growth than check seedlings (Tables 4 and 5). By age five, these same seedlings had 82% more DBH and 37% more total height than untreated seedlings. Release of seedlings with Roundup+Oust resulted in 18% less total height and 15% more GLD than exhibited by check seedlings at age one. The initial lack of height growth may be due in part to the use of containerized seedlings that were actively growing at the time of herbicide application. Roundup is known to harm actively growing pine. At age five, Roundup treated seedlings had 23% more total height and 69% more DBH than check seedlings. Seedlings planted on mowed plots had growth similar to untreated check seedlings. Initial growth of seedlings on disked plots was poor but exceeded that of check seedlings by 6% in height and 7% in DBH at age 5.

Genetically improved seedlings exhibited more growth in height, GLD and DBH than nursery-run seedlings. These results are important because: (1) improved pine responded to improved growing conditions with more growth from the onset and (2) trends in this silvicultural field study of shortleaf pine corroborated breeding theory (Wright, 1976) and progeny test results (Zobel and Talbert, 1984).

Study two--a ripped site

Herbaceous competition and biomass.--There was little reinvasion of herbaceous weeds in treatment plots through July 1988 (Table 6). Dominant weeds on the study site were panic grasses (*Panicum* spp. L.), fireweed (*Erechitites hieracijblia* Raf.), and goldenrod (*Solidago* sp. L.). In the total control plots, excellent competition control was maintained through the first growing season. Similar competition control was observed on plots receiving band and spot treatments. Forty-five days after treatment, herbaceous biomass averaged 1689 lbs/a in

Table 4.--Total height of genetically improved (I) and nursery-run (NR) sources of container-grown shortleaf pine seedlings planted near Batesville, AR and released from perennial herbs in 1985.

Treatment'	Total Height at Age							
	1 (in)		2 (in)		3 (in)		5 (ft)	
	I[2]	NR	I	NR	I	NR	I	NR
-lb/a of active ingredient-								
0.50 Roundup + 0.188 Oust	7.2 B	7.3 B	12.5 C	15.9 B	26.5 C	31.5 B		
0.75 Roundup + 0.094 Oust	8.5 A x	5.2 Cy	20.6 B x	15.0 BCy	47.0 A x	35.4 B y	9.3 A x	7.9 By
0.50 Velpar L + 0.188 Oust	9.2 A	8.8 A	25.4 A	22.3 A	49.6 A	43.9 A	10.2 A	10.0 A
0.75 Velpar L + 0.094 Oust	9.6 A	8.4 A	25.9 A	21.5 A	51.2 A	39.6 A	10.1 A	8.0 B
Disked	7.8 Bx	6.1 Cy	20.3 B x	16.8 B y	39.8 B x	32.3 B y	8.6 Bx	6.8 By
Mowed	7.8 B	7.5 B	14.7 c	14.9 BC	33.1 B	31.8 B	8.0 B	6.8 B
Check	9.0 A x	7.4 B y	17.8 Cx	12.6 Cy	39.3 B x	26.1 Cy	7.9 Bx	6.1 Cy
Source[3]	8.4 x	7.2 y	20.0 x	17.0 y	40.9 x	34.4 y	9.0 x	7.6 y

'Based on 4 lb of the isopropylamine salt of N-(phosphonomethly) glycine/gal for Roundup, 2 lb hexazinone/gal for Velpar L and 16 oz per lb for Oust.

[2]Source means within a column having different letters (A,B,...) differ at the 0.05 probability level (Duncan's Multiple Range test).

[3]Source by treatment means in a row and for a particular age having different letters (x,y) differ at the 0.05 probability level (Duncan's Multiple Range test).

Table 5.--Diameter of genetically improved (I) and nursery-run (NR) sources of container-grown shortleaf pine seedlings planted near Batesville, AR and released from perennial herbs in 1985.

Treatment[2]	Diameter at Age							
	1 (GLD[1]-in)		2 (GLD-in)		3 (GLD-in)		5 (DBH-in)	
	I[3]	NR	I	NR	I	NR	I	NR
-lb/a of active ingredient-								
0.50 Roundup + 0.188 Oust	.10 c	.10 B	.15 D	.21 B	.35 B	.47 B		
0.75 Roundup + 0.094 Oust	.10 c	.09 BC	.26 B	.21 B	.69 A	.55 A	.56 A	.37 B
0.50 Velpar L + 0.188 Oust	.15 A	.14 A	.33 A	.33 A	.74 A	.72 A	.54 A	.53 A
0.75 Velpar L + 0.094 Oust	.14 A	.11 B	.34 A	.30 A	.76 A	.61 A	.52 A	.41 A
Disked	.12 B x	.09 BCy	.27 B x	.22 B y	.66 A x	.59 A y	.52 A x	.34 B y
Mowed	.10 c	.11 B	.17 c	.18 C	.43 B	.41 B	.38 B	.21 c
Check	.10 cx	.07 cy	.21 c x	.15 cy	.55 Bx	.36 By	.39 Bx	.16 Cv
Source[4]	.12 x	.10 y	.25 x	.23 y	.60 x	.53 y	.49 x	.34 v

'GLD = ground line diameter.

[2]Based on 4 lb of the isopropylamine salt of N-(phosphonomethly) glycine/gal for Roundup, 2 lb hexazinone per gallon for Velpar L and 16 oz per lb for Oust.

[3]Source means within a column having different letters (A,B,...) differ at the 0.05 probability level (Duncan's Multiple Range test).

[4]Source by treatment means in a row and for a particular age having different letters (x,y) differ at the 0.05 probability level (Duncan's Multiple Range test).

Table 6.--Control of herbaceous competition about newly planted shortleaf pine seedlings with herbicides near Perryville, AR.

Variable	Sample Period[1]							
Treatment	May		Jul		Aug		Sep	
Herb Control	(Percent[2])							
Total	98	A	92	A	95	A	97	A
Band	97	A	92	A	86	B	81	B
Spot	95	A	91	A	84	B	81	B

[1]Means within a column having different letters differ at the 0.05 probability level (Duncan's Multiple Range test).

[2]Herb control estimates are relative to untreated check plots.

the untreated check plots, while the treated portions of the spot, band and total plots supported 85, 56, and 42 lbs/a, respectively, of dried herbaceous biomass. By September, dried herbaceous biomass averaged 4375 lbs/a in untreated check plots. This measure compares to estimates of 838, 820, and 146 lbs/a in the treated areas of the spot, band, and total plots, respectively.

Seedling Survival and Growth.--Seedling survival was excellent, remaining above 95% at the end of the fourth growing season. There were no differences in survival among herbaceous control levels or genetic families. Herbaceous weed control is not always needed for successful establishment of pine seedlings (Creighton et al. 1987, Zutter et al. 1986).

Height, GLD and DBH differed among treatments and families. In May, seedlings receiving herbicide treatments were shorter than those in untreated check plots. However, by the end of the first growing season, plots with total control of herbaceous competition yielded the tallest seedlings (Table 7). First-year height differences were not delineated until September. Herbicide released seedlings benefitted from higher levels of soil moisture and grew during dry months capturing more of the site's potential (Figure 1). Seedlings in the untreated check and the band plots were the shortest (Table 7). Seedlings receiving total herbaceous control displayed the largest GLDs (Table 7). pines on spot treated plots averaged slightly taller in height and larger in GLD than those on band treatments. Seedlings grown in check plots yielded the smallest diameter growth.

Growth advantages resulting from early competition control continued through the fourth growing season. Total control of herbaceous weeds during year one resulted in seedlings over 1.1 ft taller than those released with spot or band treatments (Table 7). Untreated check seedlings averaged 0.75 ft shorter than those in spot and band treated plots. Likewise, seedling DBH was largest in plots receiving total weed control (Table 7). Seedlings in spot and band treated plots exhibited 0.20 in. more DBH than untreated check seedlings.

Table 7.--Total height, ground line diameter (1988, 1989), and diameter breast height (1991) for shortleaf pine seedlings receiving four herbaceous weed control treatments near Perryville, AR.

Variable Treatment	Sample Period*							
	1988						1989	1991
	Feb[2]	May	Jul	Aug	Sep	Nov	Dec	Sep
Height	(in)							(ft)
Check	6.3	10.0 A	14.3 A	17.5 A	18.6 C	18.6 C	45.4 C	8.95 C
Spot	6.3	9.4 B	13.4 B	17.5 A	19.5 B	19.8 B	50.9 B	9.66 B
Total	6.3	‘9.2 B	13.1 B	17.4 A	20.4 A	20.8 A	55.3 A	10.76 A
Band	6.0	8.9 B	12.6 B	16.5 B	18.7 C	18.8 C	49.6 B	9.75 B
Diameter	(in)							
Check	0.11	0.15 A	0.20 A	0.24 A	0.29 C	0.32 D	0.90 C	1.15 C
Total	0.11	0.15 A	0.20 A	0.25 A	0.41 A	0.45 A	1.27 A	1.68 A
spot	0.10	0.14 A	0.19 A	0.25 A	0.35 B	0.39 B	1.06 B	1.34 B
Band	0.10	0.14 A	0.18 B	0.25 A	0.34 B	0.37 B	1.04 B	1.35 B

‘Means within a column having the same letter do not differ at the 0.05 probability level (Duncan’s Multiple Range test).

[2]Initial seedling measurements were used as the covariate.

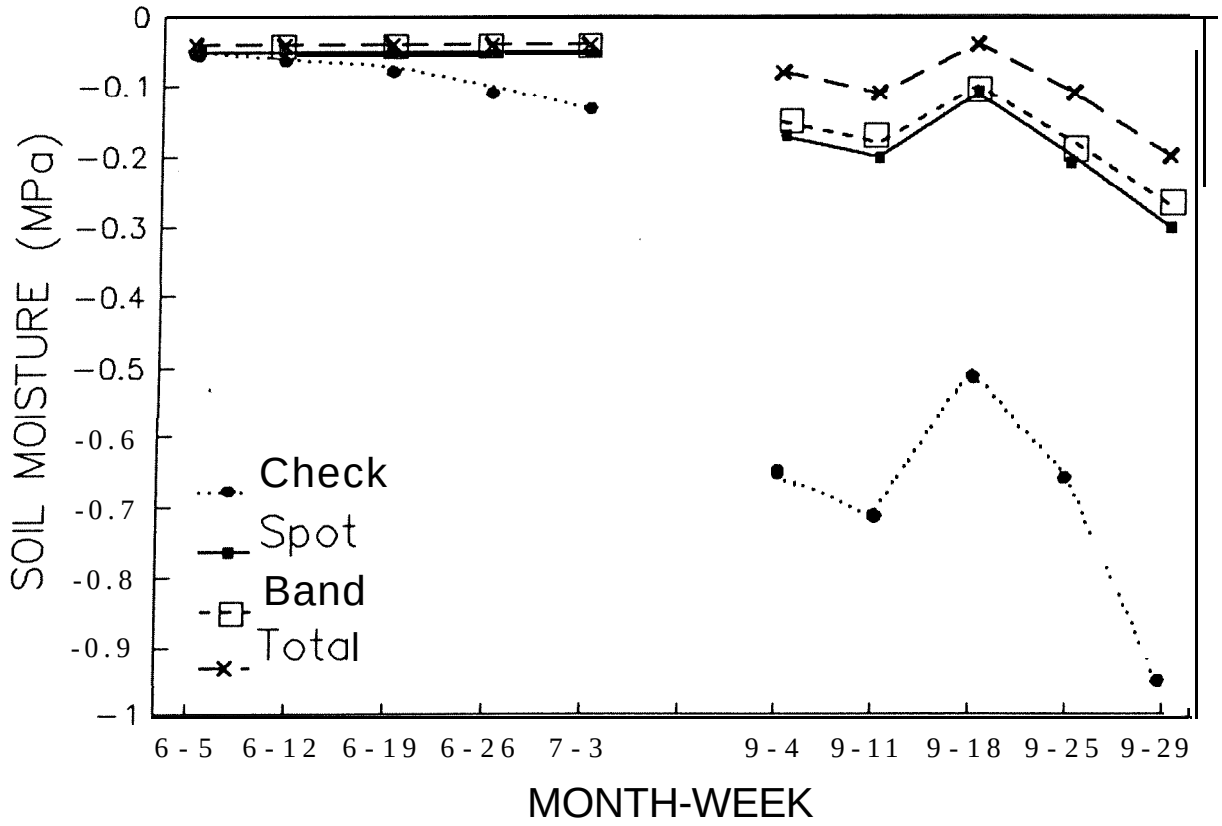

Figure 1. Weekly soil moisture tensions for June and September 1988 recorded in plots of one block that received four levels of herbaceous competition control.

Using seedlings on plots receiving total control of herbs as the index, seedlings grown in check plots realized 83% of the height and 68% of the DBH growth potential for the site, while spot and band treated seedlings realized an average of 90% and 80% of the height and diameter growth potential for the site, respectively.

Seedling growth varied among genetic family, although height and diameter ranges were smaller in magnitude than for herbicide treatment level. Families 115, 218 and 103 attained the greatest and similar height growth through the fourth growing season (Table 8). However, family 103 exhibited the smallest DBH (Table 8). Family 322 grew least in height and DBH. These results indicate differences in growth potentials among families and the ability of some to efficiently use improved growing conditions to overcome initial differences in size.

The Optimum Treatment Level.--Total control of herbaceous competition provided the best weed control, highest percentages of available soil moisture, and greatest pine growth. Although a good index of site potential, this treatment is costly, labor intensive, and impractical for ground applications on an operational scale. Spot and band treated plots yielded more available soil moisture, and greater pine growth than untreated check plots.

Table 8.--Total height, ground line diameter (1988, 1989) and diameter breast height (1991) for shortleaf pine seedlings near Perryville, AR released from herbaceous competition with herbicides.

Variable Family	Sample Period'							
	1988						1989	1991
	Feb[2]	May	Jul	Aug	Sep	Nov	Dec	Sep
Height	(in)							(ft)
115	7.1	10.3 A	13.6 A	17.5 A	19.6 A	19.7 A	49.7 BC	9.86 A
218	6.1	9.2 B	13.3 A	17.2 A	19.2 A	19.4 A	51.0 AB	9.91 A
103	6.4	9.1 B	13.6 A	17.6 A	19.7 A	20.0 A	51.2 A	9.99 A
322	5.3	8.8 C	13.0 A	16.7 A	18.7 A	18.7 A	48.7 C	9.37 B
Diameter	(in)							
115	0.11	0.15 A	0.20 A	0.25 A	0.34 AB	0.38 AB	1.08 A	1.38 B
218	0.11	0.15 A	0.20 A	0.25 A	0.35 A	0.39 A	1.08 A	1.45 A
322	0.10	0.14 A	0.20 A	0.25 A	0.35 A	0.39 A	1.08 A	1.32 C
103	0.10	0.13 B	0.19 B	0.25 A	0.33 B	0.37 B	1.03 B	1.37 B

'Means within a column having different letters differ at the 0.05 probability level (Duncan's Multiple Range test).

[2]Initial seedling measurements were used as the covariate.

After four growing seasons, growth on spot and band treated plots was similar. Additionally, there were ecological advantages for spot treatments. Shortleaf pines planted on a 9- x 6-foot spacing would result in 806 seedlings/a. Typical band treatments would control vegetation on 33% of this acre. Given the same area, spot applications would control vegetation on 13% of this acre. Therefore, in a recently established plantation, a forester who prescribed spot rather than band treatments would be able to reduce the application cost per acre and not deter pine growth during the first four years. Furthermore, spot treatments would leave 0.20-a more untreated herbaceous vegetation to stabilize soil on these upland sites, reduce visual offensiveness, and provide food or cover for wildlife, such as white-tailed deer (Odocoileus virginianus), which utilize early successional stage habitats.

Study three--stand conversion

Herbaceous biomass, soil moisture and seedling growth differed among the two approaches to stand conversion which were preplant inject and burn or underplant and release. When using the under-plant and release approach, timing of hardwood injection or use of Tordon 101 R versus Velpar L, had little impact on seedling growth making differences in litter layer biomass, herbaceous biomass and soil moisture of questionable biological significance. Consequently, subsequent discussion will be limited to comparisons between the two major approaches to stand conversion.

Herbaceous biomass.--When hardwoods were injected and the site burned prior to planting, herb control during the first or second year reduced herbaceous biomass levels below that of untreated checks (Table 9). Herbaceous biomass increased on all plots from June to September of both years. In September, herbaceous biomass on the treated plot was 24% in 1989 or 22% in 1990 of that on the untreated plot. During 1989 herbaceous biomass consisted largely of fireweed (*Erechitites hieracifolia* Raf.). In addition to fireweed, 1990 data reflects the invasion of test plots with panic grasses (*Panicum* spp), goldenrod (*Solidago* spp) and broomsedge (*Andropogon* spp.).

If hardwoods were injected as a postplant treatment and the litter layer left unburned, the application of a herbicide in April of the first year did not reduce herbaceous biomass below that on untreated check plots (Table 9), although significant herbicidal reduction of herbaceous biomass occurred in the second year.

When untreated check plots for inject-and-burn and underplant-and-release treatments were compared, only 3% of the herbaceous biomass found on the inject-and-burn area occurred in the underplant-and-release plots (Table 9). Data suggest the presence of the litter layer inhibited the invasion of competitors without any additional cost to the landowner. Since the productivity of many sites in northern Arkansas subject to stand conversion is economically marginal, competition reduction at no cost is an important and badly needed managerial tool. Landowners with highly productive sites and wanting additional weed control should apply herbicides during the second year, when the litter layer has largely decomposed, and invasion of competitors is probable.

Soil Moisture.--First- or second-year herbicidal control of invading competitors increased soil moisture above that on untreated plots for the respective year when unwanted hardwoods were injected and the site burned prior to planting (Table 10). Soil moisture declined from June to September during both years. In September, a period when soil moisture is commonly limited, moisture was 24% higher in 1989 and 33% higher in 1990 when weeds were controlled than uncontrolled.

Under-plant-and-release followed by first-year herbaceous weed control did not increase soil moisture (Table 10). Increased soil moisture did accompany the second-year herbicidal control of herbaceous competitors. A comparison of untreated check plots showed more soil moisture was present on plots converted by the under-plant-and-release than the preplant inject-and-bum approach to stand conversion. For example, in June and September of 1989

Table Y.--Dry weight for first- (1989) and second-year (1990) herbaceous biomass (lb/a) on plots planted with shortleaf pine in February 1989 near Batesville, AR.

Treatment	SAMPLE PERIOD[1,2] 1989 Jun	1989 Jul	1989 Sep	1990 Jun	1990 Jul	1990 Sep
Preplant inject and burn						
without herbaceous control (check)	1544 A	2676 A	3791 A	2014 A	4007 A	5113 A
lst-year band treatment	77 B	712 B	941 B	1389 A	3412 A	4481 A
2nd-year band treatment[3]	1490 A	2841 A	3512 A	83 B	649 B	1101 B
Under-plant with postplant release						
without herbaceous control (check)	51 x	843 X	1038 x	819 x	1943 x	4112 X
lst-year band treatment	45 x	616 x	877 X	156 X	2008 X	3817 X
2nd-year band treatment?	55 x	867 X	1201 x	65 Y	812 Y	1243 Y

'Means are from a stratified sample of 6, 2-ft square sample frames from each plot. Six stratified samples, 2 light, 2 medium and 2 heavy relative to percent cover within the plot were collected from each plot.

[2]Means within a column having different letters differ at the 0.05 probability level (Duncan's Multiple Range test).

[3]Not treated until April 1990; 1989 values are for untreated conditions.

Table 10.--First- (1989) and second-year (1990) soil moisture levels (%) for plots planted with shortleaf pine in February 1989 near Batesville, AR.

Treatment	SAMPLE PERIOD[1,2] 1989 Jun	1989 Jul	1989 Sep	1990 Jun	1990 Jul	1990 Sep
Preplant inject and burn						
without herbaceous control (check)	9.2 A	8.8 A	5.1 A	8.8 A	6.9 A	4.9 A
lst-year band treatment	11.1 B	10.6 B	6.3 B	9.7 B	9.7 B	5.2 B
2nd-year band treatment[3]	9.1 A	8.7 A	5.0 A	9.7 B	10.3 C	6.9 C
Under-plant with postplant release						
without herbaceous control (check)	11.7 x	10.1 x	9.6 X	9.7 x	10.0 x	5.3 x
lst-year band treatment	11.8 x	10.1 x	9.6 X	9.8 x	10.0 x	5.2 X
2nd-year band treatment[3]	11.8 X	10.1 x	9.3 x	10.3 Y	10.7 Y	6.1 Y

[1] Means within a column having different letters differ at the 0.05 probability level (Duncan's Multiple Range test).

[2] Weight of soil moisture over dry weight of sample.

[3] Not treated until April 1990; 1989 values are for untreated conditions.

and again in 1990, 27% and 88%, or 10% and 15% more soil moisture was present on the underplant-and-release plots than on the inject-and-burn plots, respectively. These data show that as the growing season progressed, relative soil moisture decreased on untreated plots and increased on plots receiving herbicidal control of competitors.

Seedling Survival and Growth.--Preplant injection of hardwoods followed by burning of the site resulted in 64% survival after two years. First-year control of herbs increased survival to 79% for the same period.' Seedlings receiving postplant injection of hardwoods without burning exhibited 84% survival after two years. Herbaceous weed control did not increase survival.

Preplant injection of hardwoods followed by burning of the site without postplant herbaceous weed control resulted in the least height and GLD growth (Tables 11 and 12). When the inject-and-burn approach was combined with herbaceous weed control, more 1990 height and GLD resulted from first-year (10.3, 0.26 in.) than second-year (4.2, 0.08 in.) weed control.

If pine seedlings were underplanted and released from overstory hardwoods, differences in growth in GLD from first-year control of herbaceous competitors were not detected until the second year following treatment (Tables 11 and 12). Greatest increases in height (8.3 in.) and GLD (0.38 in.) resulted when underplanted and released seedlings also received herbaceous weed control during the second year after treatment.

Using the underplant and release approach increases height (14.2 in.) and GLD (0.49 in.) over the conventional stand conversion method of tree injection and burning the site with no herbaceous weed control (Tables 11 and 12). Growth differences in height (22.5 in.) and GLD (0.75 in.) can be further increased over conventional practices if the underplant and release approach is combined with herbaceous weed control the second year after planting.

SUMMARY

Studv one--an old field planting

Preplant mechanical and postplant herbicidal treatments were compared for efficacy, competitor re-establishment and pine survival and growth. Single, over-the-top applications of selected herbicides controlled herbaceous annual and perennial competitors better than disking or mowing. The 0.50 lb/a ai of either Roundup or Velpar L mixed with 0.188 lb/a ai Oust provided the best overall control of perennial herbs. Similar species control was provided by all herbicidal treatments, and low rates were as effective as high ones. Major competitors targeted for herbicide treatment were re-established in major proportion three years after study initiation.

Pines released with treatments of Velpar+Oust exhibited the greatest growth response. Treatment with Roundup+Oust significantly reduced both survival and initial height growth of pine below that of the untreated check.

Newly planted, genetically-improved and container-grown seedlings of shortleaf pine maintained greater growth than nursery-run pines.

Table 1 L--First-year (1989) total height and ground line diameter (GLD) for shortleaf pine seedlings planted near Batesville, AR.

Variable Treatment	SAMPLE PERIOD[1] Feb[2]	Jun	Jul	Sep	Nov
Height[2] (in)					
Preplant inject and bum					
without herbaceous control (check)	6.5	11.8 A	14.3 A	15.1 A	16.6 A
lst-year band treatment	6.1	12.9 B	17.0 B	18.9 B	19.2 B
2nd-year band treatment[3]	6.3	11.5 A	14.2 A	15.0 A	16.7 A
Underplant with postplant release					
without herbaceous control (check)	6.3	12.7 X	17.3 x	19.4 x	19.9 x
lst-year band treatment	6.4	12.7 X	17.5 x	20.3 X	21.4 X
2nd-year band treatment[3]	6.5	12.5 X	17.1 x	19.3 x	20.0 x
GLD[2] (in)					
Preplant inject and burn					
without herbaceous control (check)	.16	.19 A	.22 A	.27 A	.30 A
lst-year band treatment	.12	.14 A	.23 B	.30 B	.35 B
2nd-year band treatment[3]	.13	.14 A	.20 A	.26 A	.29 A
Underplant with postplant release					
without herbaceous control (check)	.13	.15 x	.24 x	.33 x	.36 X
lst-year band treatment	.12	.15 x	.25 X	.35 x	.39 x
2nd-year band treatment[3]	.13	.15 x	.23 X	.33 x	.36 X

'Means for a variable within a column having different letters differ at the 0.05 probability level (Duncan's Multiple Range Test).

[2]Initial seedling measurements were used as the covariate.

[3]Not treated until April 1990, 1989 values are for untreated conditions.

Table 12.--Second-year (1990) total height and ground line diameter (GLD) for shortleaf pine seedlings planted near Batesville, AR.

Variable Treatment	SAMPLE PERIOD[1] Jun	Jul	Sep	Nov
Height[2] (in)				
Preplant inject and burn				
without herbaceous control (check)	26.3 A	34.8 A	38.5 A	40.8 A
lst-year band treatment	32.1 B	43.7 B	48.1 c	51.1 c
2nd-year band treatment[3]	26.8 A	35.0 A	41.8 B	45.0 B
Underplant with postplant release				
without herbaceous control (check)	31.8 x	46.1 x	52.9 X	55.0 x
lst-year band treatment	32.1 XY	47.9 XY	54.3 XY	57.7 Y
2nd-year band treatment[3]	35.6 Y	50.0 Y	59.3 Y	63.3 Z
GLD[2] (in)				
Preplant inject and burn				
without herbaceous control (check)	.50 A	.71 A	.80 A	.84 A
lst-year band treatment	.57 B	.89 C	1.03 c	1.10 c
2nd-year band treatment[3]	.51 A	.77 B	.88 B	.92 B
Underpiant with postplant release				
without herbaceous control (check)	.75 x	.96 X	1.12 x	1.21 x
lst-year band treatment	.77 x	1.01 x	1.21 Y	1.34 Y
2nd-year band treatment[3]	.73 x	1.21 Y	1.41 Z	1.59 Z

'Means for a variable within a column having different letters differ at the 0.05 probability level (Duncan's Multiple Range Test).

[2]Initial seedling measurements were used as the covariate.

[3]Not treated until April 1990; 1989 values are for untreated conditions.

Study two--a ripped site

Plots containing four families of shortleaf pines and receiving spot, band or total control of herbaceous competitors were monitored for soil moisture, competitor biomass plus seedling survival and growth. Controlling herbaceous competition with a single, over-the-top application of herbicide reduced competitor biomass and increased soil moisture thereby enabling released seedlings to grow an additional 30 days longer into dry months. Families differed in their ability to capitalize on improved growing conditions, resulting in more growth. Spot treatments may offer environmental advantages over band treatments when pine growth is similar.

S tudv three--stand conversion

Burning the litter layer during stand conversion was assessed for impact on soil moisture, inhibition of invading herbs and seedling survival and growth. Shortleaf pine seedlings planted beneath and released from a hardwood overstory exhibited greater survival (20%) and more height (22.5 in.) and GLD (0.75 in.) after two years than seedlings receiving a conventional preplant injection of hardwoods followed by burning of the site. The residual litter layer associated with the underplant-and-release approach to stand conversion mulched seedlings thereby inhibiting the invasion of herbaceous competitors, increasing soil moisture and enhancing the height (22.5 in.) and GLD (0.75 in.) of shortleaf pine seedlings after two years without additional cost to the landowner.

CONCLUSIONS

Research literature is needed documenting the response of shortleaf pine seedlings to control of herbaceous competitors in old-fields, on prepared sites and invasion during stand conversion within the Ozark region of Arkansas. Three papers are presented which suggest several points.

Control of herbaceous competitors increases the availability of light, water, nutrients and space thereby improving growing conditions for pine seedlings, resulting in significant increases in growth and often increased survival. Herb control may provide initially small increases in growth (relative to loblolly pine) which translate into larger growth differences within a few years.

When growing conditions were improved through herbaceous weed control, pine seedlings grew longer into the drier summer months and captured a greater proportion of the site potential. Genetically improved shortleaf pines responded better to improved growing conditions, showing greater growth than woods-run pines, and genetic families varied with the relative amount of increased growth and the trait (height or diameter) within which the increased growth occurred.

Controlling herbaceous competition may be achieved by several means. For well established annual and perennial sods with good access, preplant mechanical and postplant herbicidal treatments facilitate seedling establishment. Natural mulches, such as forest litter, may be used to conserve soil moisture, enhance growth and increase the profitability of marginal sites. Herbicides and natural mulches may be more appropriate for areas with limited access.

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Natural Regeneration

Moderator:

Garner Barnum

Arkansas Forestry Commission

NATURAL REGENERATION OF SHORTLEAF PINE[1/]

James B. Baker[2/]

Abstract.--Shortleaf pine (*Pinus echinata* Mill.) can be regenerated naturally using a variety of reproduction cutting methods. Even-aged stands can be established with clearcutting, seed-tree, and shelterwood cutting. Uneven-aged stands can be developed or maintained with single-tree or group selection cutting. All regeneration methods have inherent advantages and disadvantages; thus land managers must consider the management objectives and the silvical characteristics and requirements of the species before they decide on a specific method.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most widespread pine in the eastern United States. Its natural range extends over 22 states, from southeastern New York southward along the Atlantic Coastal Plain, Piedmont, and Appalachian Highlands to the Gulf Coast and westward to southern Missouri and eastern Oklahoma and Texas. Nearly half of the country's entire shortleaf pine resource is located west of the Mississippi River; however, the largest concentrations occur in the Ouachita Mountains of Arkansas and Oklahoma. Its extensive range is due in part to its adaptability to a great variety of soil, site, and climatic conditions.

Despite its extensive range and significant contribution to the southern pine resource, relatively little has been published on silvicultural and management techniques and strategies for shortleaf pine. This paper summarizes the current research and operational knowledge regarding natural regeneration of shortleaf pine.

SILVICAL CHARACTERISTICS AND REQUIREMENTS

Knowledge and understanding of some of the silvical characteristics and requirements of shortleaf pine are prerequisites to successful establishment and development of natural stands of shortleaf pine and pine-hardwood mixtures. The following sec-

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1/ Paper presented at Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

2/ Principal Silviculturist, USDA Forest Service, Southern Forest Experiment Station, Monticello, AR 71655.

tions describe elements that strongly influence shortleaf pine's ability to regenerate naturally, and identify some of the reasons for successes and failures.

Flowerins and fruiting

Shortleaf pine is monoecious. Male and female strobili emerge from late March in the southern parts of its range to late April in the northern parts. The strobili mature in about 2 weeks and pollination occurs shortly thereafter. The female strobili then slowly develop into first-year conelets that are fertilized the following spring. The conelets develop rapidly into mature cones by the end of their second summer (Lawson 1990).

The primary causes of seed-crop failure during flowering and fruiting are adverse weather conditions and seed and cone insects. Freezing temperatures (<30°F) that persist for several hours during flowering often damage or kill the male strobili. This occurrence could be common in the northern parts of the range and in mountainous terrain-- particularly *in* the valleys and on north-facing aspects. Extended periods of rain and unfavorable winds or levels of humidity during time of pollination can also reduce cone or seed production. Seed and cone insects and diseases and some animals can also damage or kill flowers, first-year conelets, or maturing 2-year cones. Foresters or regeneration specialists often have no control over these agents, but observance of local weather events and insect populations allows fairly accurate estimates or predictions of seed crops to be made over a 1- or 2-year period.

Seed production and diswersal

Shortleaf pines generally do not bear seeds until they are about 20 years of age. Trees usually produce abundant seeds when they reach a diameter of about 12 inches.

Shortleaf pines produce some seeds in most years; however, good to excellent seed crops occur every 3 to 10 years in the northern parts of the range and every 3 to 6 years in the southern parts (Lawson and-Kitchens 1983). More than 80,000 sound seeds per acre is usually considered a good seed crop; 30,000 to 80,000 seeds per acre is an average crop; while fewer than 30,000 seeds per acre is considered marginal to poor. About 50,000 seeds per acre is the minimum supply needed to adequately restock a prepared seed bed (Baker 1982).

Methods are available to estimate seed production (number of cones and/or seeds per tree or per acre) for the current year or for 1 year in advance (Grano 1957, Trousdell 1950, Wenger 1953). Evidence of good, fair, or poor seed crops should be apparent by early summer.

The number of seeds produced per tree and the number of seeds per cone can be significantly increased by releasing seed trees from competition. Thus, in stands with high stocking levels (90+ sq.ft./acre basal area), preparatory cutting (thinning) 3 to 5 years before a reproduction cut can significantly increase cone and seed production (Lawson 1990).

Seedfall usually begins in late October or early November. About 70 percent of the seeds will have fallen by early December and 90 percent by early January. Some seeds continue to fall into April, and cones often remain on the tree long after they are empty (Lawson 1990).

Seed dispersal of shortleaf pine varies with the height and stocking level of the seed source trees, magnitude of seed crop, terrain, and weather and wind conditions at time of seedfall. For average conditions, the effective seeding distance generally ranges from 200 to 300 feet downwind from the seed source and 75 to 100 feet in other directions (Baker 1987).

Reaction to competition

Young shortleaf pine is moderately tolerant of shade, but it becomes shade intolerant with age. Its tolerance for shade is less than that of most hardwood associates. Young shortleaf pine is generally slower growing and slower to dominate a site than many hardwood competitors, but it usually will endure competition for many years before succumbing. Shortleaf pine can maintain dominance on most sites after it overtops competing vegetation; however, hardwoods usually remain in the stand as intermediate and codominant associates.. On good sites (site index = 80+ feet at 50 years), though, shortleaf pine may not outgrow competing species such as sweetgum and red maple (Lawson 1990).

In young, well-stocked shortleaf pine stands, trees begin to compete with each other within a few years after establishment, and diameter growth rates decline. Even though growth rates decline, shortleaf pine can persist in very dense stands. Shortleaf pine usually responds well to release, even when the trees are approaching maturity (Lawson 1990).

Site Preparation and cultural treatments

Effective site preparation and competition control are the two most important procedures required to achieve successful natural regeneration. They should be planned and carried out in a timely manner for maximum effect. Inadequate control of competing vegetation is probably the primary reason for most regeneration failures. The type and intensity of treatment depend on local site and stand conditions, the expected seed crop, and the reproduction cutting method.

Shortleaf pine seeds do not require exposed mineral soil for germination and seedling establishment; reproduction is usually

adequate during abundant seed crop years regardless of seedbed or site conditions. When the seed crop is light, however, seedbed preparation is necessary to ensure seed contact with mineral soil and to ensure that the seed supply is used to the fullest extent. In most cases, soil disturbance from the logging operation is sufficient (Baker and others 1991).

More intensive control of competition is usually required on highly productive, moist sites than on drier, less productive soils. Competing vegetation can overtop the pines and occupy a good site much faster than a poor one.

When even-aged reproduction cutting methods (seed-tree, shelterwood, and clearcutting) are applied, a well-planned prescribed burning program in advance of the regeneration cut is the least expensive method of seedbed preparation and competition control. Prescribed burns not only reduce forest floor litter and ground vegetation but also control some of the smaller hardwoods. Midstory or overstory hardwoods should be harvested or treated with a suitable herbicide. On sites where pine regeneration is difficult to establish because of droughty conditions or excessive litter and vegetative cover, some mechanical scarification may be required.

Additional control of competing vegetation may be needed after the reproduction has been established. If weed, brush, or vine growth is dense and vigorous, release of the young pines within 3 to 5 years after establishment may be required. Once the reproduction reaches 12 to 15 feet in height and is safe from fire damage, prescribed burning may again be used to control competition in even-aged stands.

With selection cutting in uneven-aged management, site preparation is achieved almost exclusively by logging operations and the use of herbicides. If fully stocked uneven-aged stands are cut on relatively short cutting cycles of 5 to 10 years, logging operations usually scarify the site and retard the development of competing vegetation sufficiently to permit establishment of adequate reproduction.

NATURAL REPRODUCTION CUTTING METHODS

Managing for natural regeneration uses harvesting methods and cultural treatments to establish and develop a new forest stand from seed produced on or near the area. If an adequate seed source is available, managing for natural regeneration is a practical alternative to planting.

A variety of reproduction cutting methods are suited to shortleaf pine. Clearcutting, seed-tree, and shelterwood cuts establish even-aged stands; selection cutting develops or maintains uneven-aged stands.

Even-aged methods

Clearcutting.--Clearcutting can be used to regenerate small blocks, patches, or narrow strips if a seed source is available from adjacent stands. The long axis of the clearcut areas should be perpendicular to the direction of prevailing winds to encourage desired seed dispersal during seedfall. To ensure adequate seeding over the entire area, block and patch clearcuts should not exceed 8 to 10 acres in size, and strip clearcuts should not exceed 300 to 400 feet in width.

Larger areas can be naturally regenerated by clearcutting with either seed- or seedlings-in-place. Seed-in-place involves clearcutting the stand after cone maturity or seedfall but before seed germination (October through March). Probably the most common and perhaps the best application of seed-in-place is clearcutting the stand after the cones have reached maturity but before seedfall. The mature cones that are distributed in the logging slash will then open and seed will fall on a scarified site. Managers should discourage logging after seedfall because many seeds will be buried in the resulting debris.

A good seed year often leaves numerous seedlings to become established under a parental overstory. A properly timed clearcut can release these young seedlings. This technique is called clearcutting with seedlings-in-place and is often conducted by clearcutting in the late summer following a good seed year.

Ample seed crops are necessary for successful use of seed- or seedlings-in-place methods. Also, because the seed bearers have been cut, both techniques involve a high risk, since they provide only a one-time chance of successful natural regeneration.

Advantages of clearcutting include the following:

-- Management areas are easily defined and treated.
-- Harvesting and cultural operations are concentrated in time and space.
-- No high-value trees are left on the area.
-- Relatively low levels of technical skill and supervision are required.
-- Wildlife that depends on early successional vegetation will benefit.

Disadvantages include the following:

-- A large amount of logging debris is generated.
-- Fairly intensive site preparation is sometimes required.
-- No merchantable material can be harvested from the new stand for a relatively long time (15 to 20 years).
-- The site is aesthetically less desirable for a short period following harvest.
-- Wildlife that depends on mature trees may be displaced:

Table 1 provides a schedule of activities for achieving natural regeneration using the clearcutting method.

Table l.--Schedule of activities during clearcutting reproduction harvest, followed by natural regeneration (from Baker and others 1991)[1/]

Artivitv	Schedule
(1) First vegetation control burn	Spring, 6 years before clearcutting
(2) Second vegetation control bum	Spring, 3 years before clearcutting
(3) Site preparation burn	Spring in year of clearcutting
(4) Treat nonmerchantable hardwoods with herbicides	Spring in year of clearcutting
(5) Harvest all merchantable pines and hardwoods	Before October[2/], or October-March?', or fall[4/], 1 year after a good seed year
(6) Evaluate stocking	Winter, 3 years after reproduction cut
(7) Evaluate need for pine release and/or precommercial thinning	Three to 5 years after clearcutting

[1/] This table provides a complete schedule of activities that would apply to a hypothetical stand with the following characteristics: A fully stocked, 60-year-old, even-aged shortleaf pine stand having some midstory and overstory hardwoods and no previous hardwood control activities. If conditions for a specific stand differ from the hypothetical stand, then the schedule of activities may have to be altered. Some activities--for example, (1), (2), and (4)--might not be needed if a specific stand had been under a good vegetation management program.

[2/] If area is to seed from trees in adjacent stands.

[3/] If seed-in-place technique is used.

[4/] If seedlings-in-place technique is used.

Seed-tree. --The seed-tree method requires cutting all but 8 to 20 well-spaced, high-quality seed-bearing trees per acre that provide 10 to 12 ft^2/acre basal area. The number of trees depends on tree size and site conditions.

The reproduction cut should be timed so that seed will be dispersed on a site freshly scarified by logging. To ensure adequate seed supply, seed trees should be released 3 to 5 growing seasons before the harvest cut by thinning the stand to 60 to 70 ft^2/acre merchantable basal area. The preharvest release of the seed trees will enhance seed production during the first year after the reproduction cut. This technique is particularly important if the crowns of the seed trees are small. Once

at least 1,000 well-distributed seedlings per acre are well established, the seed trees can be removed.

Advantages and disadvantages of the seed-tree method are similar to those of clearcutting with the following additions:

Advantages:

-- There is no need to rely on adjacent stands for seed; thus larger areas can be efficiently regenerated.
-- Delayed removal of seed trees following stand regeneration is a safeguard against loss from fire or climatic agents.
-- Some precommercial thinning, if it is needed, can be accomplished by skidding logs from removal cut through dense patches of reproduction.

Disadvantages:

-- Seed trees may limit site preparation and slash disposal operations.
-- Seed source is exposed to lightning, wind, and other hazards.
-- Removal cut of seed trees may not be economically practical.

Table 2 provides a schedule of activities **for** obtaining natural regeneration using the seed-tree reproduction cutting method.

Shelterwood. --This method is similar to the seed-tree method except that 30 to 50 trees per acre are left to regenerate the area. The seed-producing trees should consist of 30 to 40 ft^2/acre of basal area. As in the seed-tree method, the number of trees left depends on tree size and site and stand conditions. Leaving more trees will usually provide *more* shelter, however, and help suppress competing vegetation. This sheltering effect gives the method its name and distinguishes it ecologically from the seed-tree method, which does not shelter seedlings.

A two-cut (one seed cut plus one removal cut) shelterwood is usually recommended unless the stand is overstocked. In unthinned or dense stands a preparatory cut--3 to 5 years before the seed cut--may also be required. Control of competition should be initiated before the seed cut. Prescribed fire can often adequately control competing vegetation. Once adequate pine reproduction becomes well established following the seed cut (usually within 3 to 5 years), a portion or all of the shelterwood should be removed so that the reproduction can develop. If reproduction is too dense (over 5,000 stems per acre), some precommercial thinning can be accomplished by skidding logs through dense patches of reproduction.

Table 2. Schedule of activities during seed-tree or shelterwood reproduction cutting, followed by natural regeneration" (from Baker and others 1991)

Activity	Schedule
(1) First vegetation control bum	Spring, 6 years before reproduction (seed-tree) cut
(2) Second vegetation control bum	Spring, 3 years before reproduction cut
(3) Preparatory cut[2/]	Three years before reproduction cut
(4) Site preparation bum	Spring in year of reproduction cut
(5) Select and mark seed trees	After the site prep bum in year of reproduction cut
(6) Treat nonmerchantable hardwoods with herbicide	Spring in year of reproduction cut
(7) Cut all merchantable pine and hardwoods except previously marked seed trees	Late summer or fall
(8) Evaluate stocking	Winter, 3 years after reproduction cut
(9) Remove seed trees	As soon as adequate reproduction is established (usually 2 to 5 years after reproduction cut)
10) Evaluate need for pine release and/or precommercial thinning	Three to 5 years after reproduction cut

[1/] This table provides a complete schedule of activities that would apply to a hypothetical stand with the same characteristics as described in table 1. If conditions for a specific stand differ from the hypothetical stand, then the schedule of activities may have to be altered. Some activities--for example, (1), (2), (3), and (6)--might not be needed if a specific stand had been under a good vegetation management program.

[2/] A preparatory cut may be required only if the stand is overstocked and potential seed trees are small-crowned and are poor cone or seed producers.

The shelterwood method offers the following advantages:

- **Slash disposal is less necessary than it is with the clearcutting or seed-tree methods.**
- **Shelterwood overstory often suppresses development of competing understory vegetation.**
- **Residual shelterwood trees continue to produce high-quality growth until they are removed.**
- **The method provides better site protection and is more aesthetically pleasing than clearcutting and seed-tree methods.**

Disadvantages include the following:

- -- Large numbers of residual trees are subject to logging damage and impede harvesting and site preparation.
- -- Shelterwood overstory may hinder growth of pine reproduction.
- -- The method requires a high level of technical skill and adherence to scheduled treatments and harvests.

The schedule of activities for the shelterwood reproduction cutting method is basically the same as for the seed-tree method (see table 2).

Uneven-aced methods

If the management objective is to maintain an uneven-aged stand and to harvest sawlogs at relatively frequent intervals, the selection method is an alternative on some sites. The selection method involves periodic cutting, at 3- to lo-year intervals, of selected trees from merchantable diameter classes. Fully stocked stands have 60 to 75 ft^2/acre of merchantable basal area, with two-thirds to three-fourths of the basal area in the sawlog component. In these stands, harvest-cut volumes generally approximate growth for the cutting period or cutting cycle. In stands that are not fully stocked, only a portion of growth is cut. Single isolated trees or groups of trees can be selected for harvest. If at all possible, however, the slow-growing and poor-quality trees should be cut and the best trees left so that stand quality and growth will improve. This scheme ensures that pine regeneration will come from seed produced by the most vigorous and best-quality trees in the stand (Baker and others 1991).

Maintaining an adequate uneven-aged stand structure requires establishment of reproduction only about 1 year out of 10. If site conditions are favorable, reproduction will usually develop under single-tree selection if after-cut stocking of the overstory is reduced to 45 to 60 ft^2/acre of basal area. Competing vegetation, particularly shade-inducing midstory and overstory hardwoods, should be controlled periodically to allow for establishment and development of pine reproduction.

Structure in the merchantable component of the stand can be maintained by either the BDQ method (Farrar 1980, Farrar and Murphy 1988) or by volume control in the sawtimber component of the stand (Reynolds and others 1984).

BDQ components are residual basal area (B), maximum retained diameter class (D), and the negative exponential constant between diameter classes (Q). Under the BDQ method, the diameter distribution of a hypothetical after-cut target stand is synthesized using the B, D, and Q parameters. This target stand is compared with the stand under management, and an allowable cut is generated by the difference between the two.

Under volume control, the allowable cut is determined from the previous periodic increment. A guiding diameter limit is then determined so that the allowable cut would be taken if all trees above the diameter limit were cut. In the field, however, the timber marker generally retains some trees above the diameter limit because they have not yet reached financial maturity. An equivalent volume in trees below the limit is identified for removal.

Regulation of structure in uneven-aged stands provides for regeneration at periodic intervals, the orderly development of regeneration through a range of size classes, the perpetuation of the stand, and a sustained yield of forest products.

Managing for natural regeneration with the selection cutting method offers the following advantages:

-- Periodic and flexible harvests are provided without interruption for stand regeneration.
-- The stand is upgraded if fast-growing, high-quality trees are left to regenerate the stand.
-- The stand is ***not*** as vulnerable to destruction by fire, biotic, or climatic agents.
-- The stand may be more aesthetically pleasing and provides more varied habitat for wildlife.

Disadvantages include the following:

-- Some efficient management practices, such as prescribed burning, may not be feasible.
-- Harvesting operations may be difficult and expensive.
-- A higher level of management skill and more supervision are needed than with other reproduction methods.

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SEED PRODUCTION IN NATURAL SHORTLEAF PINE STANDS[1]

R.F. Wittwer[2]

and

M.G. Shelton[3]

Abstract.--The total time elapsed between formation of flower buds and maturation and dispersal of shortleaf pine seeds is over two years, encompassing portions of three different growing seasons. A wide variety of physical and biotic environmental factors potentrally influence and ultimately determine the quantity and quality of the seed crop. Abundant moisture early in the growing season followed by moderate moisture stress later in the season has been found to increase female flowering the following spring. Only about 30 to 40% of the female flowers survive to become mature cones. In general, insects probably cause the greatest damage; however, losses due to late freezes the first year, squirrel damage the second year and hail damage have been observed. Seed yields range from none to over 1,000,000 per acre. Good crops occur 2 to 4 out of 10 years on the average and are less frequent near the limits of the species' natural range. The winged-seeds are dispersed by winds up to a maximum of 3 chains. After dispersal, insects, birds, and rodents can severely reduce the number of seeds available to regenerate a site.

INTRODUCTION

The natural reproduction of shortleaf pine (*Pinus echinata* Mill.) is principally from seed, although it has the unique ability to sprout when young trees are top-killed. The essential steps to achieve successful natural regeneration from seed are : (1) an adequate seed supply in terms of quanity and quality, (2) drspersal of seed over the regeneration site, (3) germination, which depends on the successful over-wintering of the seed and favorable environmental conditions during the spring, especially moisture and temperature, and (4) early survival, which is influenced by temperature extremes, insects, diseases, and drought (Smith 1986). Although each step is critical, seed production drives the sequence. This paper reviews the status of our knowledge concerning production and dispersal of shortleaf pine seeds. Such knowledge is critical to prescribing and implementing natural regeneration methods, because it affects the number and quality of trees to reserve for seed production, the intensity and timing of site preparation, and to a great extent the overall probability of successful regeneration.

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2/Associate Professor, Department of Forestry, Oklahoma State University, Stillwater, OK 74078.

3/Research Forester, USDA Forest Service, Southern Forest Experiment Station, Monticello, AR 71655

Seed production is a complex process influenced by a multitude of factors exerted over a long time period. Many influences are a result of the physical environment, but they also include biotic factors, such as competition levels and populations of insects, mammals, and birds. Most of these factors are beyond silvicultural control, except perhaps in a seed orchard. The erratic pattern of seed production in natural stands is closely linked to the risks associated with natural regeneration methods-- regular seed crops are a boon to natural regeneration, while infrequent crops are a curse.

THE REPRODUCTIVE CYCLE

The seed production process extends over portions of three growing seasons, from the time of flower bud initiation in late summer, through pollination the following spring, fertilization the subsequent spring, and cone and seed maturation in the fall of the third year (Krugman and Jenkinson 1974). Flower buds initiated late in the growing season of year-0 will not produce seed until the fall of year-2, and the resulting seedlings will not be considered established until the fall of year-3 (Figure 1). Thus, a given year's seed crop and the resulting regeneration is influenced by environmental conditions imposed by a wide array of physical and biotic factors, including both the means and the extremes that occur over a 4-year period.

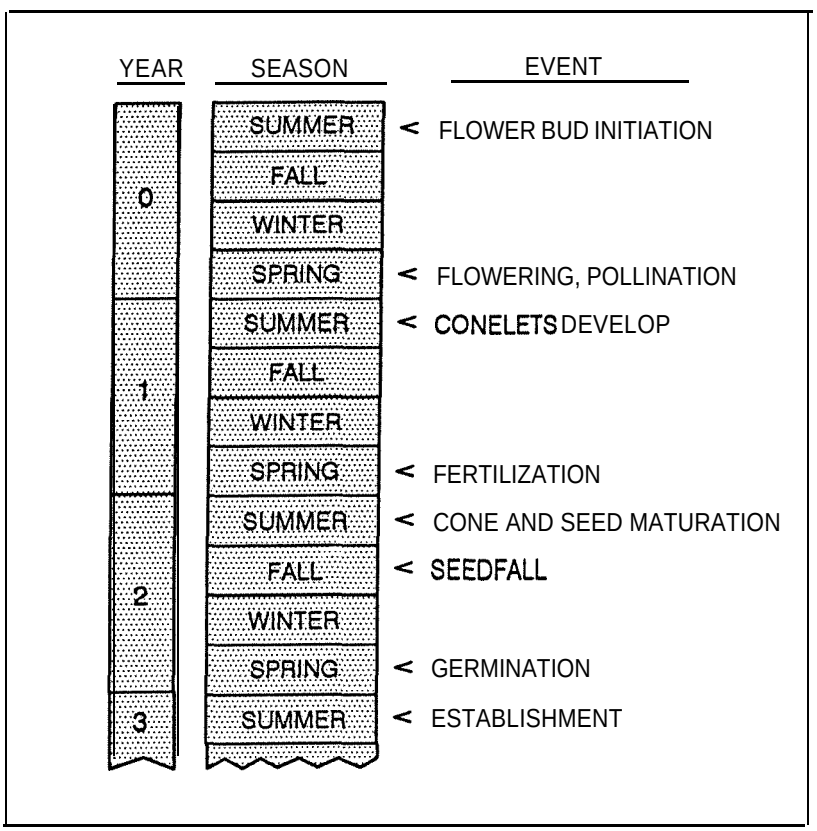

Figure 1 .--Development of a shortleaf pine seed crop.

Initiation of flowers

Shortleaf pine trees can reach sexual maturity at an early age and both male and female flowers have been reported on 5-year-old trees. However, under the competitive conditions typical of closed stands, 20 years is probably more representative of the age when cones first appear (Lawson 1990). Flower formation and development are initial determinants of eventual seed production.

Schmidtling's (1985) irrigation study in the Mt. Ida, AR seed orchard provides data on the effects of annual variation in water regimes on flower development for selected shortleaf pine clones. The severe drought of 1980 was followed by poor flowering the next season. Male and female flowering in the year following the drought (1981) was only one quarter of that occurring two years after the drought (1982). Various irrigation treatments increased female flowermg.

Experimental irrigation treatments in a loblolly pine seed orchard increased the number of female flowers when the previous years water regime consisted of sprin g irrigation followed by an imposed summer drought (Dewers and Moehring 1970). Schmidt ling (1985) found a similar trend two out of three years in the irrigation study at the Mt. Ida orchard. Perhaps this effect could be useful when attempting to predict future seed yields from natural stands. Years with abundant early-season precipitation and a late summer drought may precede good seed crops by two years. Bower and Smith (1961) imposed stress by partially girdling 50 to 80-year-old shortleaf pines and tripled cone productron the third year after treatment, suggesting a possible cultural treatment to stimulate seed production.

Pollination and cone development

Although many flowers may be initiated, destructive environmental conditions can reduce their numbers and interfere with pollination. McLemore (1977) observed that less than one-half (41%) of the female strobili of the four major southern pines developed into cones in a central Louisiana seed orchard. Losses for shortleaf were considerably greater, averaging 84 percent for two successive cone crops. Insects were mainly responsible, but an April hail storm broke leaders bearing 20 percent of the female strobili one year.

Temperatures of 25 to 28 F° severely damaged developing female flowers in east Texas while undeveloped flowers protected by bud scales escaped with little damage (Campbell 1955). The same frost killed new leaves on several hardwood species. A record low of 25 °F on May 2, 1963 in the Virginia Piedmont, well past the normal date, killed 30 percent of the female shortleaf pine flowers on a sample of 23 trees (Hutchinson and Bramlett 1964). Although pollen dispersal had started several days before, no damage was noted on male flowers. Juvenile foliage on several hardwoods was also damaged. Apparently, frost damage to hardwood leaves may forecast poor pine seed crops in the future.

Bramlett (1972) observed cone development in a natural, old-field shortleaf pine stand in Virginia for six years and found the largest losses to occur between May and September of the first year. Spring frosts, insects, and physiological abortion of first-year cones were cited as major factors contributing to the losses. All second year mortality was attributed to insects or squirrels. Squirrel damage only occurred in one year, when maturing cones were reduced by about 42 percent between July and September. Overall survival from flowering to mature cones varied annually from 3 to 65 percent and averaged 29 percent for the 6-year study period.

Insect species associated with shortleaf pine cones and seeds have been identified for natural stands in southern Arkansas (Yearian and Warren 1964) and the Georgia Piedmont (Ebel and Yates 1974). Four species were found to directly attack cones in Arkansas:

Diorvctria clarioralis, D. amatella, Pitvophthorus pulicarius and Oscinella conicola. The Georgia study examined the sequence of damage and attributed major first-year losses to Rhvacionia frustrana and to abortion, possibly caused by Leptoglossus corculus. Major second-year losses were attributed to Diorvctria spp., Eucosma cocana and Cecidomyiidae spp.

SEED YIELDS

Variation in seed yields results from complex interactions involving numerous physical, chemical, and biotic factors during the sequence of events from initiation of flower buds through cone and seed maturation and dispersal. Annual variation is critical to successful natural regeneration because it strongly affects risks. The periodicity of seed crops must be considered concomitantly with the length of time that favorable seedbed conditions and competition levels exist after the regeneration cut and site preparation. Shelton and Wittwer (this publication) indicate that the window of opportunity for securing natural pine regeneration generally lasts for about three years following the regeneration cut and site preparation. Thus, a single good seed crop during this period may be adequate for stand regeneration. infrequent seed crop may necessitate either repeated site preparation to extend the window of opportunity for regeneration or deferment of site preparation until a good seed crop is expected.

Annual variation

Yield and frequency of seed crops are important factors affecting the success of natural regeneration systems. Annual yields vary from none to more than 1,000,000 seeds per acre (Table 1). Two regional studies have been conducted in different locations within shortleaf pine's natural range-- a IO-year study (1954-I 963) in the Piedmont of Georgia, North and South Carolina (Bramlett 1965) and an unpublished' 9-year study (1965-I 973) in the Ozark and Ouachita Mountains of Missouri, Arkansas, and Oklahoma. Both studies found no correlation between stand and site characteristics (age, pine basal area or number of trees, site index) and seed production. There were generally about three "good" crops during the 9- or 10-year observation period. These good seed crops had over 100,000 seeds per acre, which is the estimated quantity required to attain adequate stocking on a scarified seedbed (Haney 1962). The Piedmont study observed that seed production increased in a north to south gradient. For example, a 5--year period in Virginia did not have a single satisfactory crop, while good crops were found 40 to 50 percent of the time in Georgia at the southern extent of the study. Stephensen (1963) reported four good crops in ten years, between 1950 and 1959, in east Texas; the good crops exceeded 200,000 per acre, but the other years were nearly total failures.

Influence of stand conditions

The broad, regional studies found poor correlations between stand characteristics and seed production. This undoubtedly reflects the overall dominance of complex regional variation in environmental conditions and biotic factors. However, on a local level, seed yields have been found to vary with stand density with maximum production occurring at moderate densities. On the Cumberland Plateau in Kentucky, 15 seed trees per acre produced 50 to 60 percent more seed than 6 trees during a 2-year period (Dale 1958). Hebb (1955) found greater seed production in east Texas shortleaf pine stands after harvesting to leave 30 trees per acre (shelterwood) than in higher residual stand densities after single-tree

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1/ E.R. Ferguson. Variability of shortleaf pine seed production by area and time. Final Office Report Summary, August 1, 1975. USDA Forest Service Southern Forest Experiment Station, Fayetteville, AR.

Table 1. Summary of selected shortleaf pine seed yields observed for various geographic locations and stand conditions.

LOCATION	OBSERVATION PERIOD	STAND DESCRIPTION	ANNUAL SEED YIELD RANGE (thousand seeds per acre)	ANNUAL SEED YIELD MEAN (thousand seeds per acre)	FREQUENCY OF GOOD CROPS[3] % of years	SOURCE
Piedmont						
Virginia	5 years	1/	4-86	15	0	Bramiett 1965
North Carolina	10 years	1/	2-261	72	33	
South Carolina	10 years	1/	0-1 193	141	20	
Georgia	10 years	1/	O-1143	228	50	
interior Highlands						
Kentucky	1 year	6 seed trees	107-122	115	--	Dale 1958
		15 seed trees	151-201	176	--	
Arkansas	3 years (1964-66)	10 seed trees	2/	103	--	Yocum and Lawson 1977
	3 years (1965-67)	10 seed trees	2/	285	--	
	3 years (1966-68)	10 seed trees	2/	305	--	
Missouri	5 years	50 ft^2/ac (thinned)	7-820	253	40	Phares and Rogers 1962
	5 years	70 ft^2/ac (thinned)	5-578	147	40	
	5 years	90 ft^2/ac (thinned)	2-362	88	20	
	5 years	110 $ft/^2ac$ (thinned)	2-214	60	20	
	5 years	138 $ft/^2ac$ (unthinned)	2-182	49	20	
Coastal Plain						
Texas	10 years	seed-tree	O-I 185	118	--	Stephenson 1963
	10 years	shelterwood	0-1221	122	40	
	10 years	selection	O-I 044	104	40	

[1] Site specific stand conditions not reported. Averge shortleaf pine basal area ranged from 67 to 144 sq. ft. per acre.
[2] Annual yields not reported.
[3] Good crop is defined as > 100,000 seeds/acre.

selection harvesting. Apparently the single-tree selection system employed in this comparision provided insufficient release to stimulate seed production or removed some of the best seed producers.

Thinning 30-year-old stands in Missouri to residual densities of 50, 70, 90 and 110 sq. ft. basal area per acre increased seed production over unthinned (138 sq. ft. basal area) stan ds (Phares and Rogers 1962). Yields showed an increasing trend with decreasing density and the authors concluded that maximum production could occur at a density lower than 50 sq. ft. basal area per acre. Removal of understory hardwoods was also tested in the unthinned and the 70 sq. ft. basal area treatments, and seed production increased 310 and 140 percent, respectively, compared to no hardwood removal.

Periodicity

The long-term studies over lo-year periods reported by Bramlett (1965) and Stephenson (1963) found the 3 and 4 good seed years, respectively, to be separated by 1 to 3 year intervals with little or no seed. However, Dale (1958) found good yields in two consecutive years, the only years sampled, ranging from 115 to 175 thousand per acre. Seed yields for a S-year period in the Missouri Ozarks were poor the first two years, followed by two consecutive good seed years, and then a year with essentially no seed (Phares and Rogers 1962). This variation in periodicity of seed production seems to indicate the overwhelming influence of local environmental conditions for a given locale, rather than any inherent biological control of reproductive cycles.

MANAGEMENT OF SEED YIELDS

"Management" of seed yields in natural stands may be somewhat of a misnomer because the determining environmental and biotic factors are generally not under silvicultural control. However, there are examples of increased seed production due to various cultural practices, suggesting some opportunities to silviculturally enhance seed yields. The ability to forecast seed yields would also benefit scheduling regeneration cuts and site preparation.

Seed production in managed uneven-aged stands is not generally felt to be as critical as in even-aged regeneration methods. This is because the periodic cuts and competition control treatments associated with uneven-aged management provide numerous opportunities to secure adequate regeneration. In addition, sufficient stocking of merchantable trees is retained in uneven-aged stands so that sustained rates of growth and yield may continue through several cutting cycles without obtaining regeneration.

Practices to increase seed vields

Vigorous, large-crowned trees produce the most seed (Lawson 1986) and practices that provide more growing space, light, nutrients, and moisture to individual trees should be effective. Phares and Rcgers (1962) attributed the increased seed production following removal of understory hardwoods in SO-year-old shortleaf pine in Missouri to greater soil moisture availability. Comparison of stand density levels of 50, 70, 90, 110, and 138 (unthinned) sq. ft. basal area per acre found the lowest stand density to produce the highest seed yields. Yocum (1971) released 8- to 12-inch dbh shortleaf pines in the Ouachita Mountains of Arkansas by cutting and/or using herbicides on all competing trees within a 30-ft radius and approximately doubled cone production (3-year totals were 498 vs. 1096 cones per tree). Release also caused a small but significant increase in the number of seeds per cone (35 vs. 38).

Several procedures can be implemented on an operational level to enhance seed yields when using even-aged regeneration methods. Selection of quality seed trees is a simple

yet effective way to increase seed yields in the seed-tree and shelterwood methods. Vigorous, dominant and codominant trees should be selected that are over lo-inches in dbh, have well-formed stems, and display a past history of fruitfulness through the presence of old cones. Because of the dispersal pattern of shortleaf pine seed, the quality and number of seed trees are much more important than trying to achieve a uniform spatial distribution.

The number of seed trees also affects seed yields, and this is the basic difference between the seed tree and shelterwood methods. When seed crops limit the success of natural regeneration, the greater seed tree densities retained in the shelterwood method may be an asset. For example, Brender and McNab (1972) found that loblolly pine seed crops in the lower Piedmont were classified as good or excellent 50% of the time for the shelterwood method and 20% for the seed-tree method.

Because of the 2-year period required for seed production, the enhanced seed yields resulting from the reduced competition created by the regeneration cut may not be evident for two or more years after the cut. Unfortunately, this is out of phase with competition levels, which are typically most favorable immediately following the regeneration cut and site preparation. Thus, a preparatory cut is advisable 5 to 10 years in advance of the regeneration cut in overstocked stands to improve the vigor of the future seed trees. Trees will then be in a high state of vigor when the regeneration cut is made, which increases the likelihood of good seed crops.

Experience gained in the management of southern pine seed orchards has shown that fertilization usually increases female flower production markedly (Sprague et al. 1979). Fertilization with high amounts of potassium and phosphorus doubled seed production in a 37-year-old natural stand in Missouri as compared to a normal fertilizer treatment (Brinkman 1962). This study also found heavy stands of grasses and herbs developing in response to fertilization and cautioned about likely competitive effects and the need for vegetation management.

In seed orchards, irrigation has produced additional gains over fertilization alone. However, moderate moisture stress at the time of flower initration seems to induce cone production (Sprague et al. 1979) and female flowering is increased (Dewers and Moehring 1970). Cone production on partially girdled shortleaf pines was tripled the third year after wounding, which may reflect the moisture stress imposed by this treatment (Bower and Smith 1963).

Forecasting seed yields

Given the two-year production period for pine seed crops, some approximation of anticipated yields should be possible at least one year in advance of maturity by evaluating immature cones. Procedures for predicting seed crops 20 months in advance, based on population estimates of female flowers, have been developed for southern pine seed orchards (Fatzinger et al. 1988). Trousdell (1950) described a method of forecasting annual variations in seed crops for natural loblolly pine stands. The procedure requires counting the previous-, current- and next-year's cones on sample branches obtained from felled trees. It is assumed that the relative seed yield from the old cones is known and the increase or decrease in the number of cones measures the expected change in seed crops. Read (1953) applied the method to shortleaf pine in Arkansas and found regeneration success was closely related to the seed crops forecasted by this method.

Wenger (1953), working with loblolly pine, estimated the number of maturing cones in late summer with reasonable accuracy when the observer counted the visible cones through binoculars from a single vantage point and doubled the observed number. The number of sound seed per cone may vary widely in different seed years and it is advisable to estimate the

number of sound seeds per cone as well as the number of cones (Bramlett and Hutchinson 1964).

SEED DISPERSAL

Timing

Information on the expected time of seed dispersal is important in planning harvesting and site preparation. Timing of shortleaf pine seed dispersal has been found remarkably similar in studies from the Carolina's and Georgia (Bramlett 1965), Kentucky (Allen 1963), Arkansas (Yocum 1968) and Texas (Stephenson 1963). Dispersal starts in late October or early November, peaks during November and is usually 90 to 100 percent complete by December 31 (Figure 2).

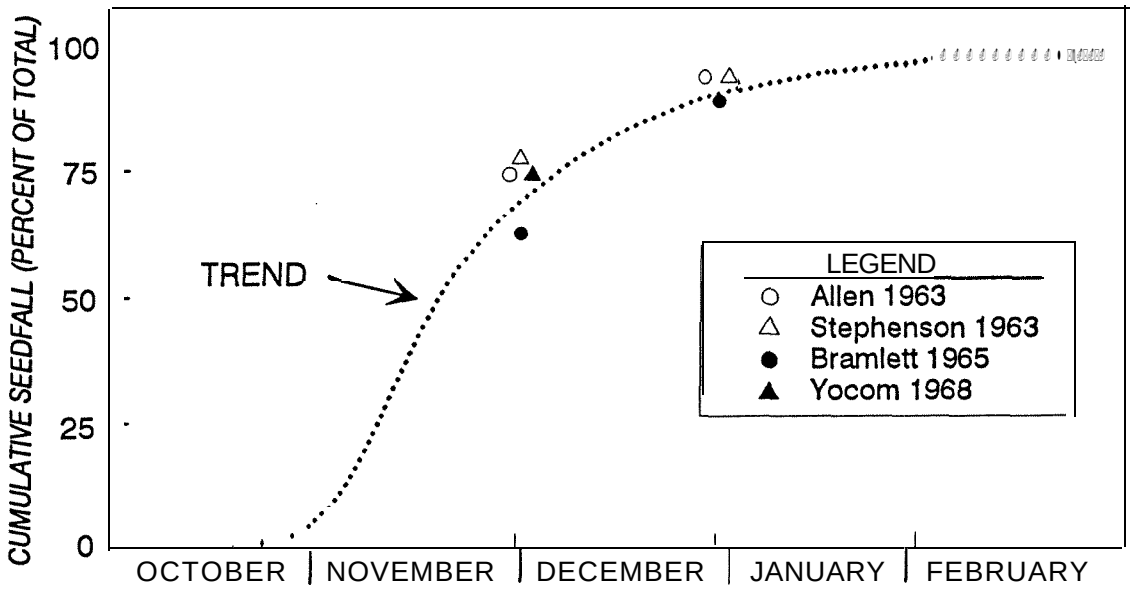

Figure 2.--Cumulative shortleaf pine seedfall reported by selected studies. [Note: Yocum did not report a specific value for December 31, but indicated that seedfall was virtually over. Data presented from Stephenson are for the 1951 seedcrop only.]

Preliminary results after two years of monitoring (1989 and 1990 crops) in eastern Oklahoma conformed to this trend'. In Texas, Hebb (1955) found periods of highest seedfall to follow or coincide with the passage of cold fronts accompanied by low humidity and high winds from the north and west. Seed dispersal may not coincide with direction of the prevailing winds in much of the range of shortleaf pine, where mostly humid, southerly winds occur (Ruffner and Bair 1984). Cones may persist of several years after seeds have dispersed.

Distance

The winged seeds of shortleaf pine are disseminated by wind which aids their dispersal. Yocum (1968) measured seed dispersal into forest openings in the Ouachita Mountains and found 50 percent of the seeds fell within 1 chain and 85 percent within 2.5 chains of the adjacent seed-producing stand with trees 70 feet tall. Stephenson (1963) concluded that seed dispersal in clear-cut strips was satisfactory up to 2 chains, but adequacy

[1] Data on file, Department of Forestry, Oklahoma State University.

beyond 3 chains was doubtful. This dispersal should be adequate to regenerate group selection openings that are 1 to 2 acres in area. The dispersal pattern of shortleaf pine seed reduces the need for evenly-spaced seed trees with both even- and uneven-aged regeneration methods.

SEED CONSUMPTION

Seed-eating animals also play an important role in determining the seed supply after dispersal (Smith and Aldous 1947; Stephenson, et al. 1963), but their influence is difficult to quantify. Seed-eating animals are an ever present drain on the annual seed crop and their impact varies from trivial during bumper years to devasting in below average years. Trousdell (1954) found that rodent populations peaked during the first year following the regeneration cut, which coincided with an increase in the number of seeds required to produce a seedling. The presence of logging slash may affect this trend by providing favorable cover for rodents.

There is little applicable information on the importance of seed consumption in natural shortleaf pine forests. In an east Texas study, populations of small rodents in a mixed, loblolly-shortleaf pine forest were found to peak in winter when pine seeds were on the forest floor (Stephenson et al. 1963). Resident populations at this time were estimated at 2-4 mice per acre. Estimated consumption of pine seeds was 0.5 to 1 pound per acre, equivalent to recommended direct seeding rates, but considerably less than total yields in a good seed year. Caged mice preferred pine seeds over those from other native plants. Undoubtedly, populations of seed-eating animals are highly variable in both time and space. In one locale they may be critical while not in another. For example, Phares and Liming (1961) sowed untreated seed in spots with a light soil covering in the Missouri Ozarks and found losses to birds and rodents were negligible. However, Seidel and Rogers (1965) recommended seed repellent treatments for the same region.

CONCLUSIONS

Seed crops in natural shortleaf pine stands are highly variable due to a wide range of environmental and biotic influences. This variation lowers the reliability of natural regeneration methods in these stands. Research has identified some cultural treatments that can improve seed production. Available information on the pine reproductive cycle and important environmental factors permits forecasting seed crops with some degree of reliability. Reliance on natural methods to promptly regenerate shortleaf pine would benefit greatly from a better understanding of the factors influencing the seed production process and more reliable methods of forecasting seed crops.

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EFFECTS OF SEEDBED CONDITION ON NATURAL SHORTLEAF PINE REGENERATION[1/]

Michael G. Shelton and Robert F. Wittwer[2/]

Abstract. --Seedbed conditions interact with seed supply and competition to determine the amount and spatial distribution of regeneration. Litter inhibits pine germination and establishment by modifying the environment of the seed and acting as a barrier to root development. Mineral soil is the most favorable pine seedbed; the least favorable seedbed is deep layers of litter and areas covered by logging slash. Logging creates a wide range of seedbed conditions by displacing and fragmenting the forest floor, creating slash, and destroying ground vegetation. Logging often provides the only seedbed preparation needed for stand regeneration, although additional competition control is usually warranted. Prescribed burning and mechanical methods can be used to improve both seedbed conditions and competition levels in even-aged systems. Applications should be made before seedfall, and both the residual seedtrees and the site must be protected from damage.

INTRODUCTION

Regeneration is the bridge between harvesting an old stand and establishing a new one. Prompt, successful regeneration is critical to sustained productivity of forest lands for both timber and nontimber resources. As with most forestry operations, natural regeneration bears certain risks. However, these risks can be minimized through use of forestry practices that provide favorable conditions for regeneration.

The natural regeneration process is complex and depends on adequate seed supply, favorable seedbed and environmental conditions, and relative freedom from competition. Conditions created by these factors vary widely from favorable to unfavorable and are subject to different degrees of silvicultural control. Seedbed and competition can be readily modified by site preparation, but some environmental conditions, such as moisture supply, are difficult to modify because they are a function of site characteristics and weather fluctuations. Seed production is moderately affected by silvicultural treatments. These four factors are interrelated, and the levels of one may modify the effects of the others. For example, a bountiful seed supply may offset unfavorable seedbed conditions or high competition levels. However, unacceptable conditions in a single factor, such as a poor seed crop, may result in regeneration failure regardless of the suitability of other factors.

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[2/] Research Forester, USDA-Forest Service, Southern Forest Experiment Station, Monticello, AR 71655; Associate Professor, Department of Forestry, Oklahoma State University, Stillwater, OK 74078.

THE SEEDBED DEFINED

The term seedbed refers to the condition of the soil surface as it affects the germination and early establishment of the species targeted for management. The surface of the mineral soil may be displaced, exposed, or covered by a layer of unincorporated organic matter and/or rocks. Seedbeds composed of organic matter are also referred to as duff, litter, organic matter, rough, ground cover, and debris.

Germinating seed and young seedlings live their first few critical weeks in small microsites only a few inches in any dimension (Smith 1986). Seedbed conditions strongly affect the environment within these microsites. If critical factors are favorable or at least not unfavorable, the volume of the microsites gradually increases as the seedlings develop. The environmental factors that control germination and early seedling development differ from those that are significant after the tops and roots have extended a few inches above and below the soil surface. For example, reduced solar radiation, temperature extremes, and evaporative loss of soil moisture because of understory vegetation may be favorable to a germinating seed, but these effects become detrimental as seedling requirements for both light and moisture expand.

Seedbed and competition are closely related through their mutual effect on seedling establishment. Distinguishing between the effects of these two factors is difficult where vegetation forms dense mats at or near the soil surface, as do some grasses and vines. However, seedbed and competition affect seedling establishment through different mechanisms. Seedbed effects are exerted when the litter from vegetation acts as a barrier separating the seed from mineral soil. In contrast, competitive effects occur when pine seedlings and other vegetation struggle for limited resources (light, water, and nutrients). This distinction between seedbed and competition effects is critical in interpreting the response of regeneration to cultural treatments. Some site preparation methods simultaneously modify both seedbed conditions and competition levels (prescribed burning and mechanical methods), while others principally control the levels of competition (herbicides and manual methods). Competition control indirectly affects seedbed conditions by reducing the rate of litter production and enhancing decomposition, but the effects are very gradual when compared to those of prescribed burning and mechanical methods of site preparation.

The seedbed is primarily the disturbed forest floor after the regeneration cut and site preparation. Characteristics of the undisturbed forest floor strongly influence the resulting seedbed conditions, and thus it is of considerable interest to this discussion.

THE UNDISTURBED FOREST FLOOR

The forest floor is one of the most distinguishing features of a forest ecosystem. It consists mainly of shed parts of vegetation--such as leaves, branches, bark, and stems--in various stages of decomposition above the soil surface, but it also teems with a wide variety of fauna and flora. Thus, the forest floor is an important component of forest ecosystems in terms of stand nutrition, regeneration, and soil protection. A substantial portion of the annual nutrient requirement of the forest ecosystem is supplied through mineralization of materials stored in the forest floor and soil surface

(Switzer and Nelson 1972). The crucial nutritional and protective roles of the forest floor should be considered before site preparation methods that create favorable seedbed conditions by destroying a portion of the forest floor are prescribed (Bengtson 1981).

The makeup of the forest floor represents the balance between inputs from litter fall and outputs from decomposition. Any factor that affects either of these opposing processes will be reflected in the quantity of forest floor material present in a stand. Characteristics of the vegetation, site (climate, soils, and topography), disturbance history, and weather fluctuations all affect forest floor properties.

Forest floor properties change during the life of a stand. For example, loblolly-shortleaf pine (*Pinus taeda* L. and *P. echinata* Mill., respectively) stands generally display the following stages of development: (1) a phase of rapid accumulation in young stands in which weights approach 17,000 to 22,000 pounds per acre during their second decade, (2) a long period of relative stability in which weights maximize at 22,000 to 34,000 pounds per acre at about 60 years of age, and (3) a period of declining weights to levels of 11,000 to 17,000 pounds per acre, reflecting the successional shift in composition from pine to hardwoods (McGough 1947, Metz 1954, Switzer et al. 1979). Forest floor depth is also of interest from a seedbed perspective. In old-field pine stands of the North Carolina Piedmont, Coile (1940) found an average depth of 1.5 inches at 20 years, which increased to 2.8 inches at 80 years. These depths are considerably greater than the mean of 1.3 inches reported by Shelton (1975) for mature pine stands in the Coastal Plain of Mississippi and the 1.3 inches reported by Grano (1949) for similar stand conditions in Arkansas.

EFFECTS OF THE HARVEST

The regeneration cut generally creates the most drastic disturbance during the life of a stand. It changes the forest floor into a mosaic of different local conditions (Campbell et al. 1973, Dickerson 1968, McMinn 1984, McMinn and Nutter 1988, Miller and Sirois 1986). Logging affects seedbed conditions by redistributing and fragmenting the forest floor, creating logging slash, and destroying ground vegetation. Areas in which skidding has disturbed or scraped away the forest floor are ideal for establishing pine regeneration, while areas covered by dense logging slash are not. Within any logged area there will be a full range of conditions, and the area1 extent and spatial distribution of each seedbed condition will govern the need for subsequent site preparation.

The effects of logging on seedbed conditions depend on (1) site properties, such as soils, terrain, and access; (2) stand conditions, such as harvested volume, tree size, species, and merchantability limits; (3) season and weather conditions; and (4) equipment. Some of these factors, such as termination of logging in wet weather, setting merchantability limits, and controlling access, are regularly controlled in timber-sale contracts.

Strip clearcutting a loblolly pine stand in the Coastal Plain of Virginia resulted in 49 percent of the area disturbed, 34 percent undisturbed, and 17 percent covered by slash (Pomeroy and Trousdell 1948). In loblolly-shortleaf pine stands of southern Arkansas, Grano (1971) observed that a seedtree cut removing 5,600 board feet and 6 cords of pulpwood per acre exposed 25 percent

of the surface to mineral soil. Campbell et al. (1973) found that the area disturbed by skidders used in clearcutting a loblolly pine stand in the Piedmont of Georgia was 1 percent in log decks, 4 percent in primary skid trails, 15 percent in secondary skid trails, and 2 percent in miscellaneous disturbances; the total area disturbed was 23 percent. Merchantability limits and season of harvest affected the exposure of mineral soil in the harvest of an oak-pine stand in the Upper Piedmont of Georgia for whole-tree fuel chips (McMinn and Nutter 1988). A l-inch diameter limit resulted in twice the exposed mineral soil as a 4-inch limit (71 versus 35 percent), and a winter harvest resulted in slightly more mineral soil exposed than a growing season harvest.

The amount of slash created by the harvest depends on the volume and species harvested, merchantability limits, products removed, and the season of the year (that is, dormant versus growing season). Logging slash has both detrimental and beneficial effects during stand regeneration. Slash hinders the establishment of regeneration, increases fire risks, negatively affects the visual resource, and may harbor populations of seed-eating animals. Dense accumulations of slash, such as tops, inhibit regeneration by preventing the seed from reaching mineral soil as well as by producing deep shade. Grano (1949) reports that pine seedling establishment under slash was only one-tenth of that occurring on a seedbed of pine litter. On the other hand, slash has a beneficial effect on soil properties by providing a source of organic matter, holding the residual forest floor in place, and preventing soil erosion. In some cases, stumps and scattered branches create favorable microsites for seedling establishment by funneling rainfall into the areas and reducing evaporation. Regardless of its effects, however, slash is a necessary by-product of logging, and its mitigation is complicated in stands being regenerated naturally by the presence of residual seedtrees.

SEEDBED EFFECTS ON GERMINATION AND ESTABLISHMENT

Each plant species has particular seedbed requirements. A basic tenet of natural regeneration is to favor the target species by creating a favorable seedbed (Smith 1986). The inhibitory effects of litter on the germination and establishment of small, wind-disseminated seed are well known for southern pines (Dougherty 1990, Grano 1949, Liming 1945, McMinn 1981, Pomeroy 1949, Trousdell 1950) and for many other species (Koroleff 1954). Southern pine seed have a greater chance for successful germination and establishment in contact with mineral soil than with litter. Deep accumulations of litter act as a barrier, separating the seed from mineral soil.

It is generally accepted that the influence of seedbed condition on germination and establishment is exerted through moisture availability and the barrier that litter presents to development of the radicle. Under controlled conditions, Pomeroy (1949) found that germination of loblolly pine seed depended on the capacity of seed to absorb moisture from the substrate. Seed in contact with moist soil were observed to germinate very rapidly, while germination of seed in contact with organic matter was restricted. Most of the seedling mortality (83 percent) observed by Pomeroy was the result of failure of the radicle to come in contact with a substrate that it could penetrate. Damping-off was the second most prevalent cause of seedling mortality (11 percent).

The complex process of germination and establishment is affected by a host of factors, and it would be simplistic to attribute all inhibiting effects of the seedbed to a single factor. Seedbed effects undoubtedly involve broad differences in the biology (pathogens, consumers), chemistry (pH, nutrients), environment (moisture, light, temperature), and physical structure (depth, composition) of each specific seedbed condition. For example, damping-off of southern pine seedlings in nursery beds has been found to increase with appreciable quantities of organic matter (Wakeley 1954). Seedbed effects are undoubtedly modified by weather conditions (wet versus dry spring weather, late freezes, etc.) during germination.

Following a bumper seed year, Grano (1949) found a negative exponential relationship between litter depth and pine seedling establishment in loblolly-shortleaf pine stands in southern Arkansas, as shown in the following tabulation:

Litter depth in inches	Pine seedlings per milacre
0.0 - 0.5	26
0.6 - 1.0	14
1.1 - 1.5	10
1.6 - 2.0	4
2.1 - 2.5	4
2.6 - 3.0	1
3.1 - 3.5	2

Although the number of seedlings sharply declines with litter depth, there is no point at which establishment is totally prevented. The occurrence of some seedling establishment even at the deepest litter levels undoubtedly reflects the highly variable nature of the forest floor.

In addition to amount or depth, the species composition of the seedbed litter also affects the rates of pine seedling establishment. Hardwood litter appears to be more inhibiting than pine litter (Clark 1948, Grano 1949, USDA Forest Service 1949). For example, Grano (1949) found 4.6 times more pine seedlings established in seedbeds composed of pine litter than in hardwood litter within the same stand; a similar comparison *for* pine-hardwood litter was 2.2 times. The mechanism for this difference may reflect differences in the morphology of pine and hardwood foliage (a needle leaf versus a broad leaf).

Seed production and seedbed conditions interact to determine the amount of regeneration (fig. 1). Seed supply drives this relationship--even ideal seedbed condition and competition level will not offset a poor seed crop. Managers can use this relationship to exert some control over stocking, but control is not nearly as great as in plantation culture. If a good seed crop is expected, low levels of site preparation can be used, or fewer seedtrees can be retained. However, most managers do not have the luxury of anticipating seed crops and modifying their site preparation accordingly. Thus, advance planning is critical in implementing natural *regeneration* methods. In the real-world environment, it is probably best to use low to moderate levels of site preparation and to accept the fact that remedial treatments may have to be prescribed in some stands.

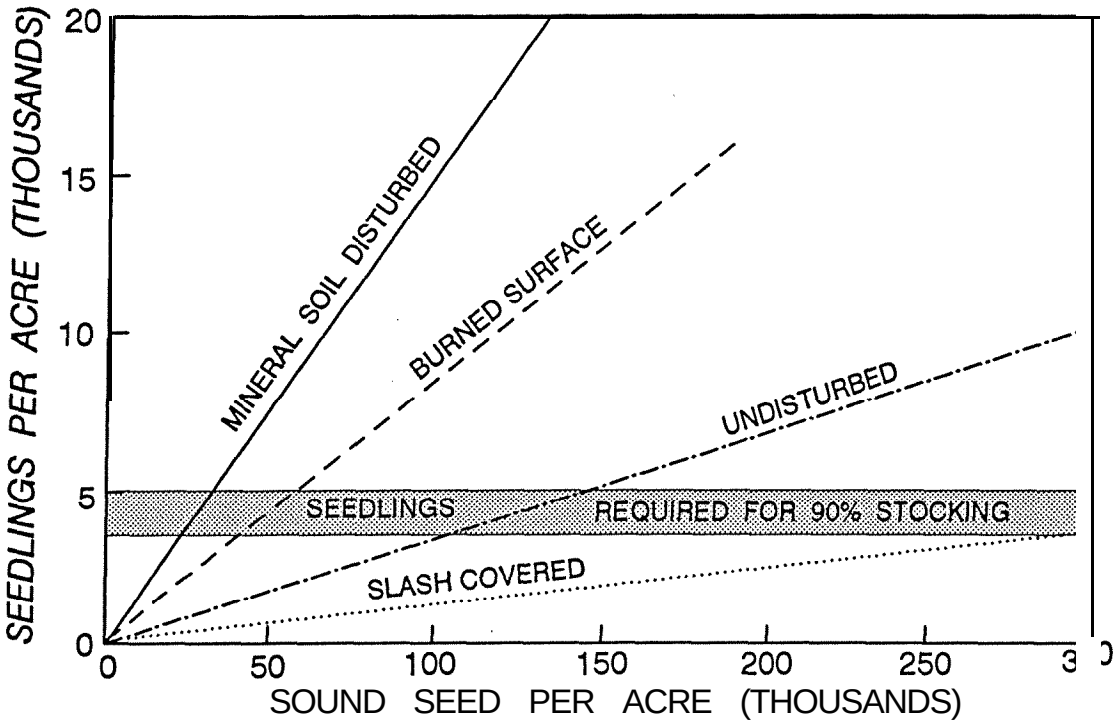

Figure 1. --Effects of seed supply and seedbed condition on the density of loblolly pine seedlings (Trousdell 1950).

SEEDBED MODIFICATION THROUGH SITE PREPARATION

Each stand must be individually assessed for site preparation needs. If high volumes are harvested, logging usually provides sufficient disturbance to create favorable seedbed conditions for pine regeneration, and supplemental competition control may be the only additional site preparation required. Competition control using herbicides may be ideal for such stands because it minimizes further soil disturbance. In contrast, seedbed conditions in other stands may be substantially improved by additional site preparation. The goal of any seedbed preparation treatment should be to reach an acceptable balance between disturbance to create favorable microsites for seedling establishment and retention of forest floor material for stand nutrition and soil protection. Various methods of site preparation can be used to achieve this goal.

Application of site preparation methods for natural regeneration is restricted when compared to the cavalier clearcut-site prepare-plant sequence of plantation culture. Prescribed burning is generally not an option in uneven-aged management because fire destroys the advance pine regeneration required to sustain uneven-aged stands (Crow and Shilling 1980). Some exceptions to this rule might include stands with a very long cutting cycle or stands with no regeneration in place. Experience has shown that cyclic harvests in uneven-aged stands provide adequate seedbed preparation, although competition control is periodically required.

Restrictions also apply to methods used in even-aged stands. Seedbed preparation in clearcuts relying on seed-in-place or seedlings-in-place must be completed before harvest to prevent damage to seed or seedlings. However, block and strip clearcutting, which rely on the adjoining stand as a seed source, do not restrict the application of site preparation other than in proper timing. In the seedtree and shelterwood methods, seedtrees are retained temporarily on the site after the regeneration cut. The presence of these trees may limit the use of mechanical methods, especially use of larger equipment, and it may increase the risk associated with postharvest burning. Because of these limitations, low to moderate levels of site preparation are generally employed in natural regeneration methods. In addition, experience has shown that intensive treatments often lead to overstocking.

Prescribed Burning

Prescribed burning can be used to simultaneously improve-seedbed conditions and to reduce levels of competition in regeneration methods for even-aged stands. Ideally, a burning program should be initiated at least 6 years before the regeneration cut, so that multiple burns can be conducted (Crow and Shilling 1980). The initial burns are principally for competition control because periodic burns have little long-term effect on forest floor weights unless they are frequent or intense (Metz et al. 1961). The burn immediately before the regeneration cut serves for both seedbed preparation and competition control.

If multiple burns have not been conducted, a single preharvest burn will improve seedbed conditions in stands with deep forest floors, but it will have little long-term effect on competition control (Yocom 1972). Justification for a single preharvest burn depends on depth of the forest floor, intensity of the harvest, and seed crop. Obviously, a deep forest floor coupled with a light harvest and an average seed crop warrants preharvest burning. But the point at which it becomes a necessity rather than an option is rather obscure. In conversion areas where no logging is planned, Rogers and Seidel (1965) recommend a prescribed burn for seedbed preparation before direct seeding shortleaf pine if the hardwood forest floor is over 1 inch deep. Preharvest burning might routinely be conducted before the regeneration cut because it facilitates timber marking and logging, in addition to being fairly inexpensive.

Postharvest burns are also possible, and they have the added advantage of reducing fine logging slash, which occupies more area than coarse slash. Areas with fine slash tend to burn very hot and thoroughly, producing favorable seedbed conditions (Boggs 1991). However, a number of restrictions and cautions apply to conducting postharvest burns. Damage to residual seedtrees must be prevented by selecting the proper burning conditions and by removing logging slash from around the base of trees. In addition, postharvest burns should be coordinated with the timing of seedfall. Several options are possible, depending on when logging is completed and the anticipated levels of the upcoming seed crop. Summer logging followed by late summer or early fall burns maximize regeneration, but suitable burning conditions, which limit fire intensity where high fuel loads exist, are infrequent during this period. Restrictions to winter burns focus on destruction of viable seed in the litter (Smith and Bower 1961). Winter burns can be applied if the seed crop was unacceptable and there is nothing to lose. In addition, winter burns may be conducted during bumper seed years and may be

desirable to prevent overstocking (Cain 1986). Burns may be delayed several years until fuel loads decline to more acceptable levels or in anticipation of a good seed crop.

Burning also has a role in maintaining favorable conditions over an extended period if regeneration difficulties are experienced. However, a regeneration survey should be conducted to determine the adequacy of existing regeneration, and realistic goals for acceptable stocking should be set. The shelterwood method may be particularly well suited to repeated postharvest burns because of the greater fuels produced compared to clearcuts or seedtree areas.

Generalizations about the effects of burning on seedbed conditions are difficult to make because fire intensity and fuel conditions vary tremendously. Pomeroy and Trousdell (1948) report that a postharvest burn created favorable seedbed conditions on 81 percent of the area leaving 18 percent undisturbed; logging slash was reduced from 20 percent to 1 percent by the burn. For a fell and burn site preparation after a seedtree cut in the Ouachita Mountains, Boggs (1991) reports that 25 percent of the area was classified as a hot burn, 42 percent as a medium burn, and 33 percent as unburned. After logging a mature Douglas fir stand and a slash reduction burn, Dryness and Youngberg (1957) found the area was 17 percent undisturbed, 30 percent disturbed by logging, 45 percent with a light burn, and 8 percent severely burned. Clearly, the spatial effects of postharvest burning are highly variable, which undoubtedly reflects the variable fuel loads after logging. This irregularity may be beneficial in preserving a portion of the forest floor for site protection.

The results of a number of studies testing burning for seedbed preparation are compiled in table 1. Increases in the seedling establishment due to burning range from 1 to 5 times that of the unburned controls, with a mean of 3 times.

Mechanical Methods

Various combinations of mechanical equipment can be used either before or after the regeneration cut to improve seedbed conditions and control competition. Mechanical methods expose mineral soil by fragmenting and redistributing the forest floor; if executed after harvest they will also reduce the area occupied by logging slash. Mechanical equipment may be as simple as a tractor dragging an old stump or as sophisticated as a bulldozer with a shear. Disks, bulldozers, rotary cutters, and fireplows have been successfully used for site preparation in even-aged natural regeneration methods. Mechanical site preparation generally produces more uniform conditions than burning, resulting in higher seedling densities (table 1). However, mechanical methods are more expensive than burning (Straka et al. 1989) and result in higher levels of soil disturbance, increasing the potential for soil erosion. For example, Beasley and Granillo (1985) found that clearcutting with mechanical site preparation in southern Arkansas resulted in about 50 percent exposure of mineral soil. The studies compiled in table 1 indicate that bulldozing consistently results in more seedlings than disking, but amounts were often excessive. Generally, mechanical site preparation should be reserved for sites with severe competition problems, which are usually the better sites.

Table 1. --Selected studies testing site preparation methods used in natural regeneration or direct seeding of shortleaf pine alone or in mixtures with loblolly pine.[1/]

Stand condition	Location	Method	Seedlings per acre (thousands)	Tree percentage[2/]	Source
		Prescribed burning			
Shortleaf (clearcut)	Ouachita Mts of AR	Unburned DS	0.5	--	Bower and Smith (1961)
		Burned DS	2.4		
Shortleaf/ loblolly/ hardwoods (sawtimber)	Nacogdoches, T X	0 years after burn	--	6.3	Ferguson (1958)
		1 year after burn	--	4.9	
		2 years after burn	--	3.5	
		3 years after burn	--	2.1	
Loblolly/ shortleaf (ST and SW)	Crossett, AR	(cut 1946)			Meyer (1955)
		ST/unburned	0.8	--	
		ST/burned	4.1	--	
		SW/unburned	3.6	--	
		SW/burned	12.6	--	
		(Cut 1947)			
		ST/unburned	4.1	--	
		ST/burned	13.4	--	
		SW/unburned	7.5	--	
		SW/burned	18.2	--	
Shortleaf (10 ST)	Ouachita Mts. of AR	Unburned/undisturbed	--	0.4	Yocom and Lawson (1977)
		Unburned/disturbed	--	1.0	
		Burned/undisturbed	--	1.0	
		Burned/disturbed	--	1.3	
		Mechanical methods			
Shortleaf (sawtimber)	Piedmont of NC	Undisturbed	0.3	0.3	Haney (1962)
		Scarified	2.2	2.0	
Shortleaf (6-15 ST)	Cumberland Plateau of KY	Logged only	2.2	--	Sander (1963)
		Disked	5.3	--	
		Bulldozed	9.2	--	
Shortleaf (clearcut)	Bent Crk. Exp. Forest, NC	Unscarified DS	6.0	--	USDA Forest Service (1949)
		Scarified DS	28.0	--	
Shortleaf (not given)	NC and SC	Unscarified	0.4	--	USDA Forest Service (1957)
		Scarified	2.6	--	

Table 1. *continued*

Stand condition	Location	Method	Seedlings per acre (thousands)	Tree percentage[2/]	Source
Shortleaf (6-12 ST)	Ballrock Forest, KY	6 ST/logged	2.0	--	USDA Forest Service (1958)
		6 ST/disked	4.5	--	
		6 ST/bulldozed	9.2	--	
		12 ST/logged	4.0	--	
		12 ST/disked	8.8	--	
		12 ST/bulldozed	11.9	--	
Shortleaf (sawtimber)	Lebanon Exp. Forest, NJ	Control	0.4	--	Wood (1939)
		Raked	0.4	--	
		Dug	1.1	--	
		Scalped	2.1	--	
----------Both prescribed burning and mechanical methods----------					
Loblolly/ shortleaf (small openings)	Crossett, AR	Phase I/Control	0.5	--	Cain (1987)
		Log/herbicides	12.6	--	
		Burn/herbicides	4.3	--	
		Mow/disk	12.8	--	
		Phase II/Control	7.0	--	
		Mow/disk	40.0	--	
		Mow/herbicide	32.9	--	
Loblolly/ shortleaf (9 ST)	Crossett, AR	Injected	6.0	--	Grano (1971)
		Disked	10.8	--	
		Burned/injected	8.1	--	
		Bulldozed	33.9	--	
Shortleaf (poorly stocked)	Jasper, AR	Untreated	1.8	0.4	Maple (1965)
		Herbicides	3.2	0.4	
		Burned	4.6	1.3	
		Brushcutter	13.3	2.9	
Shortleaf (clearcut)	Ouachita Mts. of AR	Herbicides DS	1.5	--	Smith et al. (1960)
		Herbicides /furrowing DS	2.2	--	
		Herbicides/burn DS	3.0	--	
		Burn only DS	2.0	--	

I/Abbreviations: seedtree (ST), shelterwood (SW), and direct seeded (DS); for example, 6 ST indicates 6 seedtrees per acre.

2/ Number of seedlings established as a percentage of the number of sound seed.

Wahlenberg (1960) observed that disking is often hindered by the stumps and logging debris created by the harvest, and Brender (1973) suggested delaying mechanical site preparation for 2 years after the regeneration cut so that the partially decomposed slash can be more easily broken up. As with prescribed burning, regeneration can be maximized by delaying mechanical treatments until a good seed crop is anticipated.

CHANGES IN SEEDBED CONDITIONS THROUGH TIME

Seedbed conditions are dynamic, and they continue to change after the harvest or site preparation. Decomposition is enhanced by the harvest because of the disturbance and fragmentation of the forest floor and the creation of open stand conditions. Additionally, litter produced by residual trees is only a small fraction of that found in the original stand. These changes shift equilibrium levels of organic matter to much lower amounts. For example, McClurkin et al. (1987) found that the forest floor decomposed rapidly following clearcutting of loblolly pine stands (46 percent loss in 21 months). Fine logging slash also disappears rapidly because decomposition is promoted by its high surface area and nutrient content. Fine woody slash was observed to lose 73 percent of its weight during a 6-year period compared to 42 percent for large woody slash (Mattson et al. 1987). This rapid loss of organic matter after logging and site preparation further enhances the seedbed conditions for pine regeneration.

Unfortunately, concomitant changes typically occur in the competing vegetation that negate the favorable seedbed conditions. Grasses, herbs, vines, and hardwood sprouts are particularly opportunistic in the resource-rich environment created by the regeneration cut, and they rapidly respond to usurp the niches intended for pine seedlings. Many competitors of the southern pines have a similar preference for seedbed conditions. The rapid development of competing vegetation typically ends the opportunity for securing natural pine regeneration.

The window of opportunity for natural pine regeneration depends on initial stand conditions, site quality, logging disturbance, and site preparation (Ferguson 1958, Grano 1971, Meyer 1955, Trousdell 1954). The loss of favorable conditions is progressive and may be expressed as the ratio of the number of sound seed produced to the number of resulting seedlings (the seed-to-seedling ratio). On Coastal Plain sites, acceptable conditions generally exist for 2 or more years after the regeneration cut, depending on the intensity of site preparation (fig. 2). The seed-to-seedling ratio is lowest during the first season after harvest and increases thereafter. Differences among site preparation methods clearly become more pronounced through time, with the lower values occurring for the more intensive methods.

This relationship emphasizes the importance of timing and the risks that complicate the establishment of natural regeneration and frustrate forest managers. If a good seed crop occurs during the first season after the regeneration cut, logging only, burning, and disking would all provide about the same pine stocking, and additional site preparation efforts would largely be in vain. But if a good seed crop does not occur until the third year after harvest, additional site preparation may make the difference between success or failure due to competition levels. Very infrequent seed crops would seem to justify intensive site preparation to extend the opportunity for natural regeneration. However, a more tenable alternative would be to reapply low-

intensity methods when a good seed crop is expected or to employ the more predictable plantation culture. Less is known about the window of opportunity for natural regeneration on the poorer mountain sites, but favorable conditions there are likely to persist much longer.

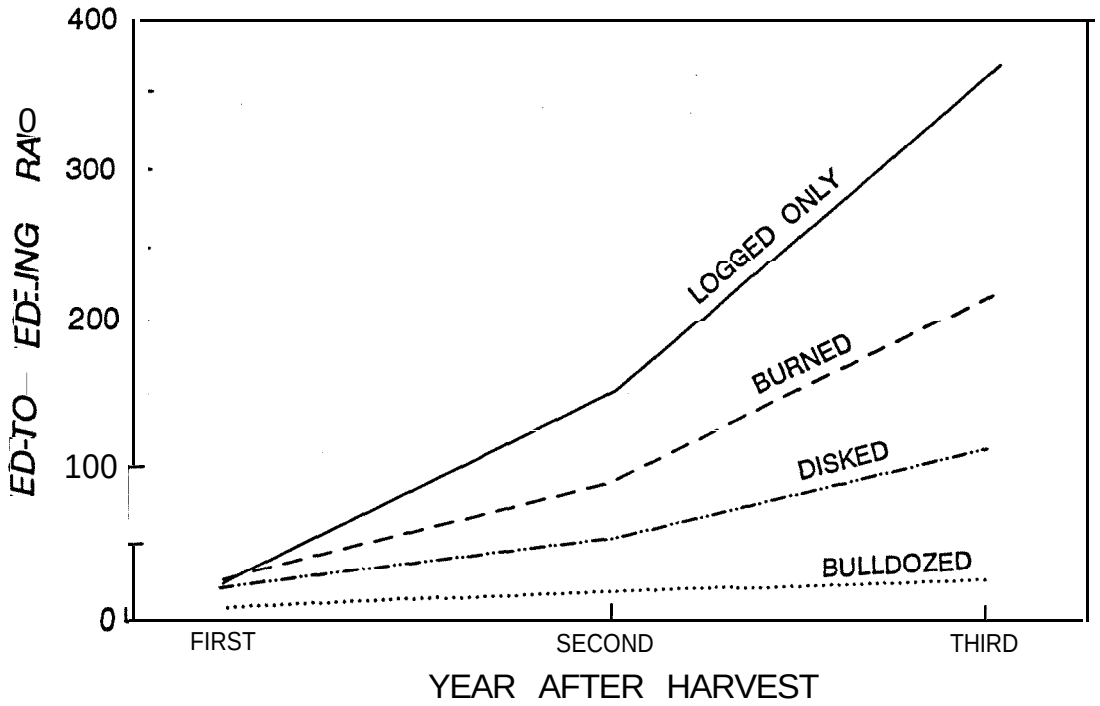

Figure 2.--The seed-to-seedling ratio observed over a 3-year period in a loblolly-shortleaf pine seedtree area that was site prepared by three methods and the logged-only control (Grano 1971).

Remedial treatments should be applied if adequate regeneration has not been established when unacceptable conditions for natural regeneration develop. The effectiveness of such treatments will be maximized if they are applied just before a good seed crop. Treatments may be limited to competition control; seedbed conditions may actually be favorable because decomposition has reduced both litter and slash.

CONCLUSIONS

The best strategy for successful natural regeneration is to plan and manage for an adequate seed supply, a favorable seedbed, and low levels of competition. Such efforts will minimize risks and costs of obtaining natural regeneration by facilitating the use of low-intensity site preparation methods to improve both seedbed conditions and competition levels. Mineral soil is the most effective seedbed for shortleaf pine, but the objective of seedbed preparation should not be to create extensive areas of exposed and displaced soil. A residual forest floor is critical for site protection, soil moisture retention, and nutrient conservation. For initial establishment, a small number of suitable microsites may be sufficient to regenerate a stand if there is adequate and well-dispersed seed (Smith 1986). Intensive site preparation should normally be reserved for the better sites, where competition is often a problem.

Logging provides a fair degree of site preparation, in terms of seedbed preparation and competition control. The logging operation often creates sufficient areas with exposed mineral soil and disturbed litter to regenerate an area, especially if the seed supply is good and residual competition is controlled. Logging effects can be enhanced by encouraging loggers to disperse their activity, perhaps by limiting the number of passes made on secondary skid trails. Logging effects can also be enhanced by encouraging high utilization in terms of both merchantability limits and species. Simple practices, such as cutting pulpwood from sawlog tops or merchandising small hardwoods, increase logging activity and coverage, while reducing and dispersing slash. Unfortunately, local timber markets may not accommodate such frugal practices.

Specific guidelines for evaluating the suitability of both seedbed and competition before and after the regeneration cut are generally lacking for natural regeneration methods. Such guidelines are needed so that specific cultural treatments can be prescribed for specific stand conditions. Many studies have demonstrated that mineral soil is the best pine seedbed, but practical questions remain about the links between area1 coverage and spatial distribution of each seedbed condition and resulting regeneration. In addition, many studies have focused on the early phases of stand regeneration without describing long-term dynamics. Thus, a full understanding of the thresholds of minimum stocking or the attributes of mixed species stands has not been achieved.

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Making Regeneration Work

Moderator:

Jim L. Chambers

Louisiana State University

SITE INDEX RELATIONSHIPS FOR SHORTLEAF PINE [1]

David L. Graney [2]

ABSTRACT

Abstract. Existing information about site quality relationships for shortleaf pine (*Pinus echinata* Mill.) in the Ozark-Ouachita Highlands is reviewed in this paper. Estimates of site quality, whether from direct tree measurements or indirect estimates based on soil and site features, are only local observations for many points on the landscape. To be of value to the land manager, a system of site quality evaluation based on identifiable units of the landscape must be devised. Physiographic site classification systems may provide the basis for reliable site quality evaluation in the Ozark-Ouachita area.

INTRODUCTION

Shortleaf pine has the widest botanical range of the southern pines: greater than 400,000 square miles over 22 States. In the Ozark-Ouachita Highlands, shortleaf pine grows naturally on most upland soils and is a significant component of upland forests in each physiographic province. In the Ozark Plateaus Province, shortleaf pine occurs in the southern and eastern portions, where it is found occasionally in pure stands but more commonly mixed with hardwoods on ridges and south and west slopes. In the Ouachita Province, shortleaf pine is a major component of most upland forest stands.

Shortleaf pine adapts to a variety of soil and site conditions, thus resulting in considerable variation in productivity throughout its range.

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[2] Research Forester, USDA-Forest Service, Southern Forest Experiment Station, Monticello, AR 71655.

Site indexes at 50 years can vary from more than 90 feet on deep, well-drained sandy loams of major stream flood plains in the Ouachitas to less than 30 feet on shallow, rocky, or clayey soils in eastern Oklahoma and southwestern Missouri (Graney 1974, Graney and Burkhart 1973).

Yield and quality vary greatly with site quality. To gauge returns from silvicultural treatments and to select a species for management on a given site, forest and land managers need reliable site quality estimates for shortleaf pine and major associated species. Information about site quality relationships for shortleaf pine is limited mainly to the eastern and western portions of its range (Carmean 1975). Little, if any, additional information on shortleaf pine site quality has been published since the mid-1970's (Graney 1986).

Site quality is usually expressed as site index (the height of the dominant and codominant trees at an index age of usually 25 or 50 years), which can be measured either directly by site curves or species comparisons or indirectly by soil-site relationships and by soil survey or site classification methods.

DIRECT MEASUREMENT

Site index curves

With the site index curve method of direct estimation, height and age measurements from free-growing dominant and codominant trees are compared with published site index curves or tables to estimate how tall the trees were or will be at the index age. This method is both simple and accurate when suitable trees and stands exist for measurement and reliable site index curves and tables are available.

In addition to the regional natural stand shortleaf pine curves in Miscellaneous Publication 50 (USDA Forest Service 1976), local site index curves have been developed for natural shortleaf pine stands in the Piedmont (Coile and Schumacher 1953), the Ouachita Mountains of Arkansas and Oklahoma (Graney and Burkhart 1973), and the Ozark Highlands of southern Missouri (Nash 1963, Graney and Popham 1981). Site index curve? have also been developed for shortleaf pine plantations in southern Illinois (Gilmore and Metcalf 1961, Gilmore 1979); the Interior Uplands of Tennessee, Alabama, and Georgia (Smalley and Bower 1971); and the Ozark Highlands of southern Missouri (Graney and Popham 1981). The importance of accurate localized curves has been indicated by several studies showing that height growth patterns for pine and hardwoods may vary considerably by species, locality, soil condition, and site index class (Carmean 1972, Graney and Burkhart 1973, Graney 1976, Zahner 1962).

Significant errors caused by inaccurate curves are most probable in very young or very old stands. If uncertainty as to the reliability of regionwide or local harmonized curves exists, trees as close to the index age as possible should be selected for site index measurement to minimize errors. Using trees appreciably younger or older than the main stand can cause errors in site index estimates, because such trees often have height growth patterns different from those of the main stand.

Graney and Burkhart (1973) found that height growth patterns for natural shortleaf pine stands in the Ouachita Mountains differed from those indicated by the curves of Coile and Schumacher (1953) and of Miscellaneous Publication

50 (USDA Forest Service 1976) and that the pattern of growth varied by site index.. For site index classes 40, 60, and 80, the local and regional curves agreed fairly well for all sites and ages older than 50 years. For younger ages, the Ouachita Mountain and Miscellaneous Publication 50 curves are similar for poor sites, but Miscellaneous Publication 50 curves tend to overestimate site index on medium to good sites. The *curves* of Coile and Schumacher (1953) underestimated for all site index classes at stand ages of 35 years or less.

Site index curves (25-year base) constructed from tree section data representing 200 shortleaf pines in 99 plantations in southern Missouri were compared with curves for plantations in the Interior Uplands (Smalley and Bower 1971) and with 25-year base curves for natural stands in the Ouachita Mountains (Graney and Burkhart 1973). Except for poor sites, both the Interior Uplands and Ouachita Mountains *curves* produce accurate estimates for Missouri plantations between the ages of 15 and 30 years. However, for younger and older plantations, errors of 3 to 5 feet may occur.

On medium to good sites, the rate of height growth declined more rapidly in Missouri plantations than for the pines in the other regions. This decline in the rate of height growth should be carefully considered when making long-term projections of plantation yields. For example, the mean site index (25-year base) of the 99 plantations sampled in southern Missouri was 5.5 feet greater than the mean of 76 natural stands sampled on similar sites in the same area. When plantation heights at age 26 were projected to age 50, the average site index for plantations was nearly 10 feet higher than the measured site index for the 50-year-old natural stands, and many plantations were assigned the unlikely site index of 80 to 85 feet.

Species comparisons

Many even-aged stands are suitable for site index measurement, but they may not contain shortleaf pine in the dominant or codominant crown classes. In some areas, the shortleaf pine site index can be estimated by measuring the site index of existing species and then using comparison graphs or equations to determine the site index of shortleaf pine. Such graphs or equations are available for shortleaf pine and several associated species in the piedmonts of Virginia, North Carolina, and South Carolina (Olson and Della-Bianca 1959) and in the Southern Appalachians (Doolittle 1958). Eguations comparing shortleaf and loblolly pine (*Pinus taeda* L.) in mixed stands have been developed for the Piedmont of North Carolina (Coile 1948), the Coastal Plain of northern Louisiana and southern Arkansas (Zahner 1957, 1958) and for southern states (Harrington 1987).

Most comparisons have shown that, except on poor sites, the site index for shortleaf pine growing in mixed stands tends to be lower than that of associated pine and hardwood species. Site index differences between shortleaf and loblolly in mixed stands are usually 10 to 15 feet on better sites in the Carolina Piedmont and 0 to 10 feet, depending on the soil and site condition, in the western part of the range (Walker and Wiant 1966). However, some recent evidence indicates that shortleaf pine is more competitive with loblolly on better sites than on poorer ones (Harrington 1987). On equivalent sites in the Arkansas and Missouri Ozarks, the shortleaf pine site index will equal or exceed values for oak species on all but the best sites. On sandy soils common to the broad, gently sloping mountaintops in the Boston Mountains of Arkansas, shortleaf pine site index averages 6 to 10 feet higher than black, northern red, or white oaks (*Quercus velutina* Lam., *Q. rubra* L., *Q. alba* L.)(Graney 1976).

INDIRECT METHODS

Where suitable site index trees are not available, land managers need methods to estimate site quality regardless of species composition or existing stand conditions. Soil survey, soil-site techniques, and site classification

methods have received the most emphasis as indirect methods of site quality estimations.

Soil surveys

Although soil surveys for agricultural lands have been made for more than 80 years, not much attention has been given to forest lands until recently. In most States, modern soil maps are now prepared for both agricultural and forest lands.

Most modern soil survey reports include an average site index or a range in site index values for each soil series. When these average site index values are based on many measurements over the range of site conditions common to a given soil, comparisons of average values can provide general productivity levels for a given species on different soils or for a number of species on the same soil series. Often, however, average site index values for various species and soils are based on few actual site index measurements, and estimates of productivity can be misleading.

A greater problem in using soil taxonomic unit site index averages arises from the often excessive variation in site index within a *given* soil series (Carmean 1961, 1975; Graney 1976, 1977). Many of the differences in site index are caused by wide variations in the soil or topographic factors within the soil series. Features such as depth of surface soil, subsoil texture, aspect, slope position, and slope shape (which are often strongly correlated with site quality) could be used in determining phases of established soil series. Although the range in soil and site characteristics for individual series has been narrowed substantially in recently published surveys, even the best soil survey maps are unreliable for strict office or computer site quality estimates (Harding and Baker 1983).

Productivity of Ozark-Ouachita soil groups

Ozark Plateau. --Topography within the Ozark Plateau is gently rolling to steep, and elevations range from about 500 to 1,500 feet above sea level. The area is underlaid by essentially horizontally bedded sandstones, and cherty limestones and dolomites of Cambrian to Mississippian age. Upland soils are

light colored and medium textured, and most are medium in depth. Fragipans are' common on ridgetops.

Shortleaf pine site index data for similar soils were combined into three major groups: soils of limestone and dolomite origin (Noark, Clarksville, Poynor, Doniphan, and Macedonia series); soils of sandstone origin (Coulstone, Brockwell, Portis, and Boden series); and soils containing a fragipan (Lebanon, Captina, Wilderness, and Nixa series) (Graney and Ferguson 1972). Average shortleaf pine site index was quite similar for the three soil groups, and overall range in site index was about the same for Arkansas and Missouri (table 1).

Table 1. -Shortleaf pine site index at acre 50 vears for maior soil qroups of the Ozark-Cuachita Highlands

Soil group	Number of plots	Site index (feet)	
		Mean	Range
		Ozark Plateau	
Limestone-Dolomite	164	58	48-74
Sandstone	126	58	43-77
Fragipan	78	57	45-72
		Boston Mountains	
	41	58	48-73
	59	58	50-67
	50	61	50-78
		Ouachita Mountains	
Shallow	48	58	41-70
Shale	156	57	30-75
Sandstone	171	62	41-83
Alluvial-Colluvial	114	66	48-96

Boston Mountains.--The Boston Mountains consist of broad, gently rolling mountaintops whose sides are an alternating series of steep, simple slopes and gently sloping benches. Elevations range from about 500 to 2,500 feet.

Soils common to mountaintops and upper slopes are mostly shallow to moderately deep and medium textured and are derived from sandstone residuum (Mountainburg, Hartsells, and Linker series) of Pennsylvanian age. Soils common to steeper side slopes are fine textured and are derived from shale residuum (Enders series). The mountain benches are typified by deep, well-drained, medium-textured soils derived from sandstone and shale colluvium (Nella and Leesburg series). Average shortleaf pine site index (58 to 60 feet) was also similar for the soil groups, although the range in site index is greater for the colluvial and shale soils (table 1) (Graney and Ferguson 1971).

Ouachita Mountains.--The Ouachita Mountains generally consist of a series of east-west ridges and structural valleys. Narrow-topped mountains with steep side slopes alternate with rolling to gently sloping valleys. Elevations range from about 500 to 2,800 feet above sea level. Rocks in the area are primarily of sedimentary origin, range. in age from Ordovician to Pennsylvanian, and consist of cherts, shales, slates, sandstones, and novaculites. All geologic materials have been intricately folded and faulted, and at many places they dip at angles of 40° or more from the horizontal. Because of the inclined and fractured nature of the parent materials, tree roots can often penetrate to considerable depths even though the soils are generally shallow.

Soils common to ridges and upper slopes are shallow (Clebit and Bismark series), while soils on lower mountain slopes and rolling valleys are deeper and are derived from shales (Carnasaw and Bengal series) or from sandstone (Sherwood, Pirum, and Zafra series). Still deeper soils derived from sandstone and shale colluvium (Octavia and Panama series) are found on some mid-to lower slopes and in smaller drains. The common terrace soils are Avilla and Wetsaw (old terrace) and Speer and Rexor (low terrace). Average site index for shortleaf pine varied widely among soil groups (table 1), but

the ranges in site index for the groups overlapped considerably (Graney 1974). Site index ranges varied from about 30 feet for shallow soils to nearly 50 feet for the low terrace soils. The range in site index for all soils in the Ouachita Mountains was 66 feet, considerably more than the overall range for shortleaf pine in the Ozark Plateau (34 feet) or the Boston Mountains (30 feet) (Graney 1976).

Soil-site relationships

The most recent comprehensive review of quality evaluation for forest sites in the United States listed 24 papers on soil-site relationships for shortleaf pine and associated species (Carmean 1975). However, even with the information in the summary, site relationships for the species are not well understood, because shortleaf pine covers a wide geographic range that includes extreme variation in physiography, soils, 'and climate. The soil-site studies, however, have identified some general trends in the soil and topographic site features most often associated with differences in shortleaf pine site quality. Specific site relationships for shortleaf pine on the major soil groups of the Ozark Plateau, Boston Mountains, and Ouachita Mountains have also been described (Graney 1976).

Soil features most often correlated with shortleaf pine site quality are surface soil thickness; depth to a restricting, mottled, or less permeable horizon; surface soil texture; subsoil texture; and subsoil consistency. The surface soil is generally considered to be the most favorable for fine root development and absorption of nutrients and moisture. The relationship between surface soil thickness and site quality is usually curvilinear: where surface soils are shallow, small increases in surface soil thickness can be associated with large increases in site quality. Coile (1948) found that shortleaf pine site index increased rapidly as the thickness of the A horizon of North Carolina Piedmont soils increased from less than, 1 inch to 6 or 8 inches. Site index changed little when a horizon thickness was greater than 8 inches.

The best shortleaf pine sites are usually on well-drained, medium-textured soils. Texture and stone content affect the levels of available moisture,

nutrients, drainage, and aeration. Thus, coarse-textured soils generally have lower site qualities because the moisture-holding capacity and nutrient levels of the soil are limited. Medium-textured soils make good sites because they have adequate available moisture and nutrient levels, good soil structure, internal drainage, and sufficient aeration, all of which favor root development. Fine-textured soils generally have adequate soil moisture and nutrients, but they are often of lower site quality because of dense clay subsoil with poor structure, internal drainage, and aeration. In the Boston and Cuachita Mountains of Arkansas and Oklahoma, the poorest pine sites were associated with subsoil clay contents of more than 50 percent (Graney 1974).

Topographic features affecting shortleaf pine site quality are aspect, slope steepness, slope position, slope shape, and elevation. The best sites are generally on north- or east-facing, gently sloping, concave, or lower slope positions, while poor sites are on narrow ridges and south- or west-facing, steep, convex upper slopes. Topographic features are often highly correlated with soil depth and profile development, amounts of available soil moisture and nutrients, and microclimate (Carmean 1975; Graney 1974; Lee and Sypolt 1974). Generally, on steep and mountainous terrain, topographic features are more closely correlated with site quality; on more level terrain, soil variables are more important in determining site quality.

On mountainous terrain, aspect is often strongly correlated with site quality. In the Ozark-Ouachita area, the site index of shortleaf pine on north aspects averaged 4 to 7 feet higher than on south aspects (Graney 1976; Hartung and Lloyd 1969). In the Georgia Blue Ridge Mountains, the shortleaf pine site index averaged 10 to 20 feet higher on north aspects than on south aspects (Ike and Huppuch 1968).

Slope position and shape are related to many of the soil properties that influence site quality. Midslopes and lower and concave slopes generally have deep, colluvial soils with relatively thick surface horizons. Upper slope soils are usually shallow and have relatively thin surface horizons. In mountainous areas with "bench and bluff" topography, upper and lower slope positions can occur along the entire length of mountain slopes. In these

areas, site quality changes significantly within a distance of a few feet, and slope shape and position must be integrated to accurately define the relationship between site quality and topographic features (Graney 1976, 1977).

In the mountains of western Arkansas and northern Georgia, shortleaf pine site index was significantly lower at the higher elevations. At elevations above 2,000 feet in the Boston and Ouachita Mountains of Arkansas and Oklahoma, shortleaf pine site index averaged 4 feet less than on the lower slopes (Graney and Ferguson 1971; Graney 1976). At 3,000 feet elevation in the Blue Ridge Mountains of northern Georgia, the shortleaf pine site index averaged about 9 feet less than the site index of pines growing at 1,800 feet (Ike and Huppuch 1968). In western Arkansas, sites with higher elevation have shorter growing seasons and a greater proportion of the shallow, residual soils than are observed for the lower elevation sites.

Throughout the Ozark-Ouachita Highlands, the site index for shortleaf pine in mixed pine-oak or oak-pine stands is significantly lower than the site index for relatively pure shortleaf pine stands on either old-field or non-old-field sites (Graney and Ferguson 1971, 1972; Graney 1974, 1976). On equivalent sites, pure shortleaf pine stands averaged 5 to 10 feet higher in site index than pines in mixed pine-hardwood stands. In southern Missouri, the site index for pure shortleaf pine plantations averaged more than 5 feet greater than plantations in which hardwoods had not been effectively controlled.

A major source of error for the indirect estimation of site index comes from using soil-site prediction equations and tables derived for other geographic areas; the soil and topographic conditions in the area where the equations and tables are used for site prediction should be similar to those where the equations or tables were developed. Errors can also occur if site prediction equations do not accurately reflect the true correlations between site features and the index in the study area. Few soil-site prediction equations have been tested with independent soil-site data sets to determine whether equations produce reasonable estimates of site quality within the

study area. Soil-site equations have shown mixed success in predicting site index for. stands not used to derive the equations. Equations for bottomland hardwoods in the lower Mississippi Valley (Broadfoot 1969) and black oak in the Missouri Ozarks (McQuilkin 1976) were inaccurate when tested with additional plot data from within the study areas. But shortleaf pine and upland oak soil-site equations for the major physiographic divisions of the Ozark-Ouachita Highlands produced accurate predictions on check plots (Graney and Ferguson 1971, 1972; Graney 1974, 1976, 1977). Such conflicting results indicate that all soil-site equations, both new and existing, should be adequately tested for reliability before they are used as site quality predictors.

Physiographic site classification

Although foresters and soil scientists have studied soil-site relationships for shortleaf pine and associated species for nearly 60 years, no reliable techniques have been developed for evaluating potential site quality for an individual site or management unit. Much information has been accumulated on soil and site factors influencing shortleaf pine site quality; however, site evaluations based on soil-site equations or soil taxonomic units have rarely been successful.

A site classification system should be relatively simple, practical, and applicable to all sizes and classes of ownership. The scale and intensity of delineations should be appropriate for a wide variety of management objectives (Smalley 1984b). The recent physiographic site classifications for the Interior Uplands (Smalley 1979, 1980, 1982, 1983, 1984a, 1986), Alabama-Mississippi (Hodgkins et al. 1979), Louisiana (Evans et al. 1983), and Southern Appalachians (McNab 1987) represent significant advances toward effective classification of site quality.

The classification system described by Smalley (1984b) involves stratifying the landscape according to the hierarchical significance of physiography, geology, soils, topography, and vegetation. The basic management units and landtypes are visually identifiable areas that have similar soil and productivity and have resulted from similar climatic and

geologic processes. Each landtype is described in terms of nine elements that relate geographic setting, soils, moisture, fertility, and most common woody vegetation. Each landtype is evaluated in terms of productivity for selected species and species desirability for timber production, and each is rated for soil-related problems that may affect forest management operations. The site classification system was developed to allow foresters and other resource professionals to make onsite determinations of productivity and should provide a site-dependent framework for forest management planning.

CONCLUSIONS

Site index curves and soil-site equations and tables have been developed for direct and indirect estimates of shortleaf pine site quality within the major physiographic divisions of the Ozark-Ouachita Highlands. However, estimates of site quality, whether from direct tree measurements or indirect estimates based on soil and topographic features, are only local observations for many points on the landscape. To be of value to the land manager, a system of site quality evaluation based on some identifiable unit of the landscape must be devised. The system should include all available knowledge of soils, site index, and soil-site relationships for each species that can be reasonably managed in a given area. Some precision in site quality estimation may be sacrificed, but such a system would have the advantage of identifying a manageable portion of the landscape. Physiographic site classification efforts in Louisiana, Alabama-Mississippi, Southern Appalachians, and the Interior Uplands provide an excellent base for site evaluation.

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CHOOSING THE RIGHT SHORTLEAF PINE SITE--A FOREST SERVICE VIEW[1/]

Robert N. Kitchens"

Abstract.--Shortleaf pine or shortleaf pine-hardwood mixtures are being favored on most sites where shortleaf is the predominate pine species. The practice of replacing shortleaf pine with loblolly or pitch pine is declining. The large planting program of the recent past is giving way to natural regeneration. Silviculturists must become proficient in establishing regeneration of shortleaf in seed tree, shelterwood, and uneven-age systems.

INTRODUCTION

A critical decision in managing the vegetation on any site is what species or species combinations to feature. On National Forest sites being managed for timber production, silviculturists use a host of biological and policy information to determine the species or species mix. Current and past practices will be discussed to help the reader understand present policies.

THE RESOURCE

Shortleaf pine is the most widespread of any pine in the southeastern United States. It grows in 22 States over more than 440,000 square miles and on a great variety of site and soil conditions (Lawson and Kitchens 1983). National Forests in the South have about 12.6 million acres in federal ownership. About 4.3 million acres are classed as wilderness or other categories that exclude timber management. That leaves about 8.3 million acres designated as suitable for timber management and other multiple-uses (fig. 1). Of those suitable acres, about 2 million are typed as shortleaf pine or shortleaf pine-hardwood (USDA Forest Service 1991). The largest part of the shortleaf pine and shortleaf pine-hardwood acres are on the Ouachita and Ozark National Forests in Arkansas and Oklahoma which have about 1.5 million acres of these types. This comprises 75 percent of the Southern Region totals. Most of the remaining acreage is located on three forests, Daniel Boone in Kentucky, Chattahoochee-Oconee in Georgia, and the National Forests in Texas. Each of these three units have over 100,000 acres of shortleaf and shortleaf-hardwood types. Almost all National Forests except the Caribbean have some shortleaf pine, although it occurs only as an occasional tree in the National Forests in Florida. The above figures do not include any acres typed as loblolly-shortleaf or as hardwood-shortleaf pine, although shortleaf pines occur as important

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1/ Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

2/ Silviculturist, USDA-Forest Service, Southern Region, Atlanta, GA 30367.

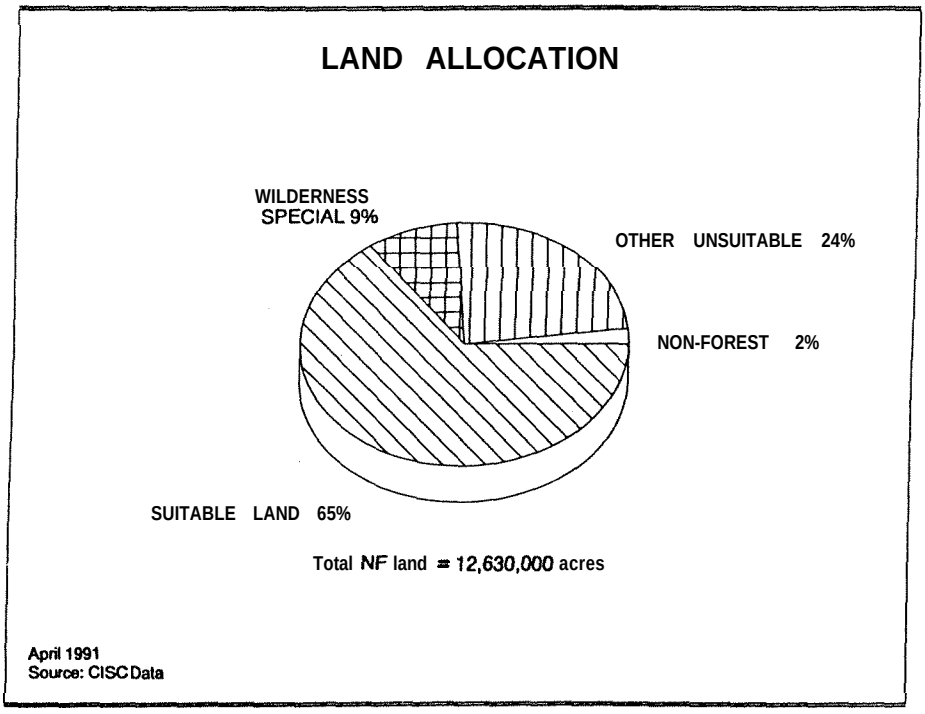

Figure 1. --Allocation on land on National Forests in the South.

components in these and other forest types. Standing timber volume of shortleaf pine is second only to loblolly pine on the Southern National Forests.

An examination of standing timber volumes and drains is quite interesting in light of some critics claims of overcutting in Southern National Forests. Total growing stock on suitable acres is about 17,800 million cubic feet (MMCF) (fig. 2). Growth each year is about 579 MMCF and harvest is about 205 MMCF (USDA Forest Service 1988) (fig. 3). Therefore not even one-half of growth is being harvested. This is akin to one having a bank account and each year not spending half the interest and none of the principal. It is hard to see how this can be called "overcutting" unless one is opposed to any harvest at all.

PAST PRACTICES

Once a decision has been made to regenerate a stand, the silviculturist determines the species to feature in the new stand. In general, guidelines have specified that if the site index was 70 feet or above for oak and the conditions allowed for adequate oak regeneration, hardwoods would be featured in the new stand. More often than not, if pines were predominately occupying the site or had been an important component in the recent past, pine regeneration was specified. Then, the related questions of natural versus artificial regeneration and what pine species was desired had to be answered. Outside of the Arkansas, Oklahoma, and Appalachian Mountains and National Forests in Texas, if planting was to be done, loblolly was usually

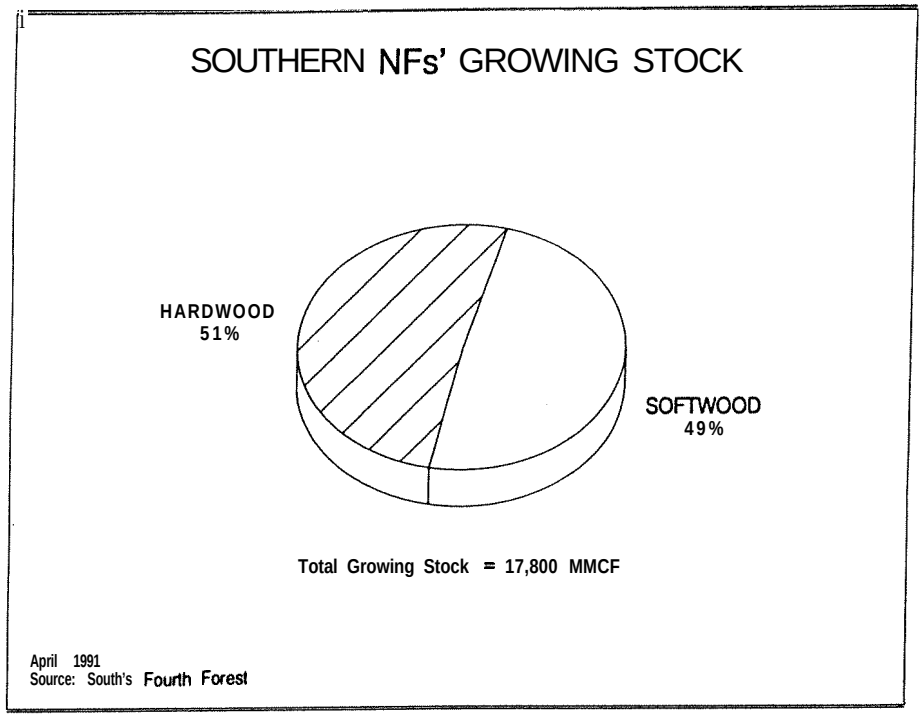

Figure 2. --Total growing stock on National Forests in the South.

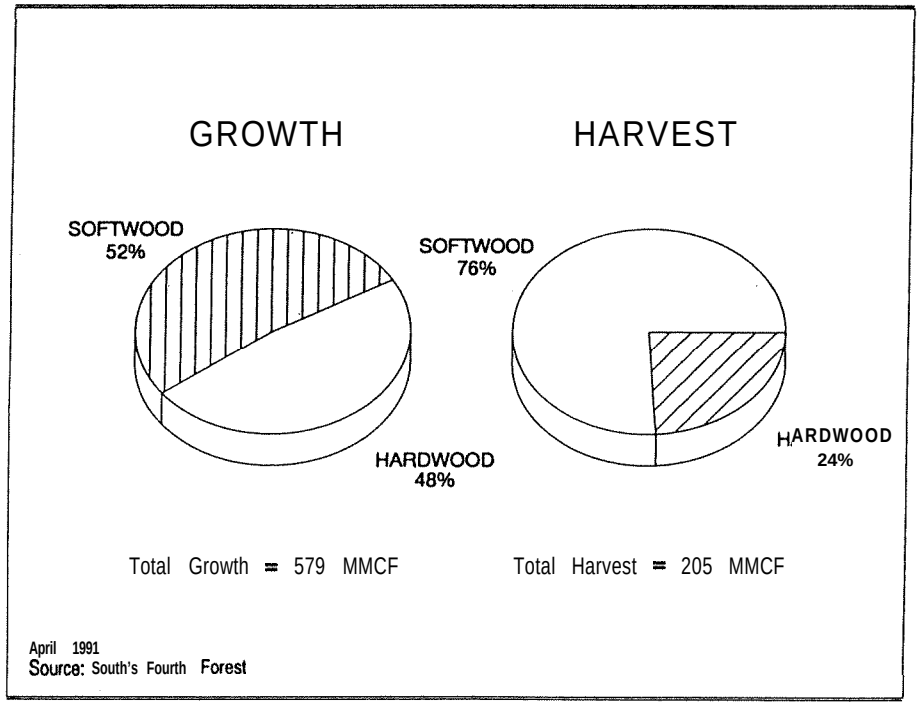

Figure 3. --Annual growth and harvest volume for the southern National Forests.

favored over shortleaf. Even so, shortleaf was planted on some acres each year on about every forest where it was native.

During the mid-1980's, the Southern Region annually regenerated 100,000 acres and planted 70,000 of those acres. Shortleaf pine planting amounted to about 20,000 acres per year. The trend is now downward. In FY 90, planting was done on 65,700 acres and shortleaf accounted for 16,600 acres.

In 1959, a shortleaf pine tree improvement program was initiated for National Forests in the Southern Region. Commercial quantities of seed come on line during the mid-70's and after the 1984 seed crop, practically all National Forest planting of shortleaf pine was from first-generation improved seed (Kitchens 1986). There is now enough orchard' seed in storage to meet foreseeable reforestation needs.

PRESENT POLICIES

Forest plans and present policies represent several significant changes from the recent past. Shortleaf pine will be the favored pine species on more acres than before simply because loblolly pine will not be planted on former shortleaf sites on the Ozark and Ouachita National Forests. In fact, planting of any pine species will be less because National Forest managers are opting for less clearcutting and more dependence on seed tree, shelterwood, and selection regeneration methods. The trend away from clearcutting as the primary reproduction method is steep. Note from the accompanying chart, the Southern Region went from about 108,000 acres of clearcutting in 1987 to 37,000 in 1991 (fig. 4).

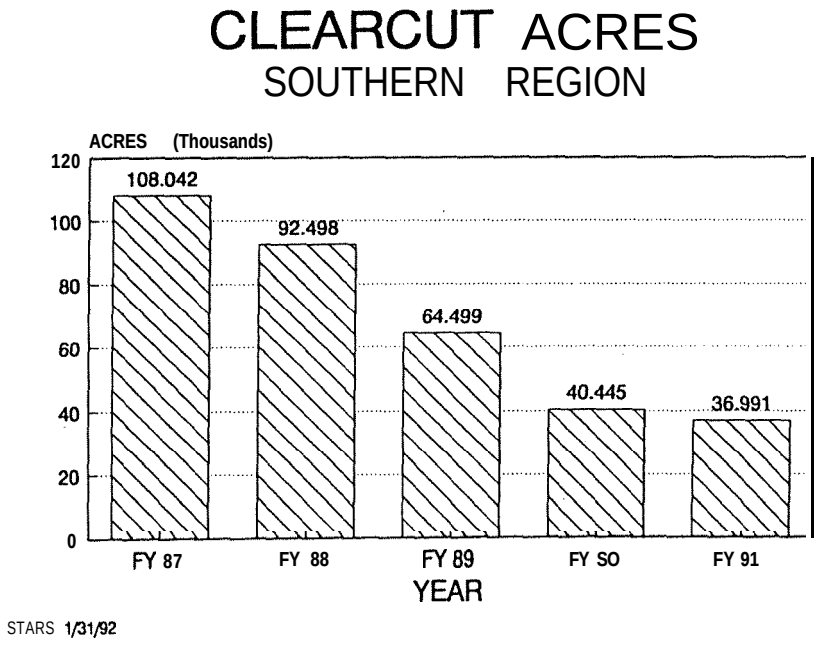

Figure 4.--Acres clearcut on the National Forests of the South by year.

Since natural regeneration will be depended on more than planting or seeding, forests that have historically opted to plant loblolly more than shortleaf will now be faced more with reproducing whatever species is now on a particular site. This could lead toward more prescriptions for regenerating mixed species on site also. The author viewed one such prescription on the Homochitto National Forest in Mississippi where the silviculturist prescribed for longleaf planting and loblolly and shortleaf natural regenerating all in one stand. The stand had distinct ridges and depressions that indicated the prescription could be achieved.

Some former shortleaf pine acres will be lost to hardwoods. Currently, larger acreages are being placed in stream and intermittent watercourse protection areas and on some forests, no timber management is permitted in these areas. As the pines within these zones die, they will be replaced with hardwoods. Some forest plans are prescribing for larger hardwood components in pine stands and thus pine will decline in response to the increased hardwood component. Just how much influence these additional hardwoods will have is a question being researched by Dr. Jim Baker and his fellow New Perspectives researchers. Studies are already in place on the Ouachita National Forest.

CLOSING

The sites chosen to grow shortleaf as a timber resource will be determined by first deciding, using Forest Plan guidance, soil surveys, and species currently on the site, whether to regenerate to pine, hardwood, or a mixture of pine and hardwood. If pine or a mixture is chosen, then the regeneration method is prescribed. If shortleaf is the pine on the site or an important component of the pine species on the site, then most likely shortleaf will be prescribed in the new stand and either planted or regenerated from seed of trees already present. Loblolly will not be favored over shortleaf except where the site is within the natural loblolly range and even then shortleaf will be regenerated on a higher proportion of those sites than in the past.

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CHOOSING THE RIGHT SITE - A FOREST INDUSTRY VIEW[1/]

Mike R. Strub[2/]

Abstract. --Results from several studies indicate that loblolly pine grows faster than shortleaf pine during the first ten years. Both species grow at similar rates until about age 50 after which the shortleaf grows faster than loblolly. This makes loblolly the species of preference when returns must be realized in a less than 50 year rotation.

INTRODUCTION

Loblolly pine has been planted as the preferred species on many acres in the south. Shortleaf pine is the native species in many areas where loblolly is being planted. Faster early growth rates is a primary reason for planting loblolly pine.

SPECIES COMPARISON

Shortleaf and loblolly pine were grown in adjacent blocks by the Texas Forest Service at the Siecke Experimental Forest in south eastern Texas. Both blocks were managed in a similar fashion. After 57 years of growth several dominant trees were cut from each block, and stem analysis was used to determine tree height at the end of each years growth. Figure 1 shows average dominant height growth for each species. The loblolly pine grew faster until the early teens. Both species grew at about the same rate until the late forties when the shortleaf grew faster. Figure 2 shows the average dominant height for each species over time. The loblolly pine shows a' five foot height advantage from the mid-teens to mid-thirties.

[1/] Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Forest Biometrician, Weyerhaeuser Company, PO Box 1060, Hot Springs, AR 71902.

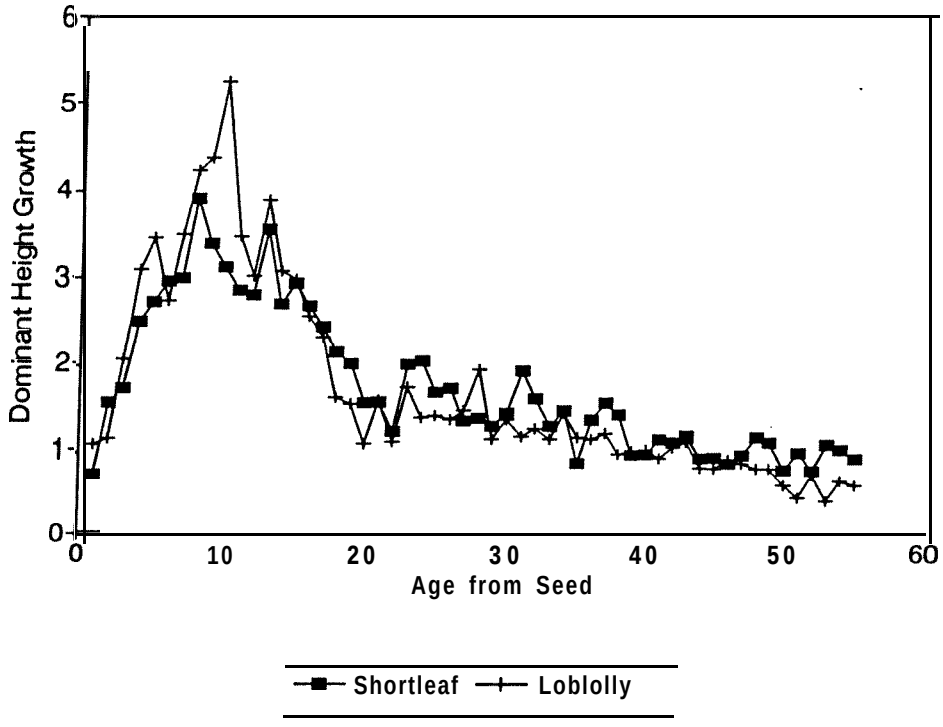

Figure 1. --Dominant height growth of block plantings in south eastern Texas.

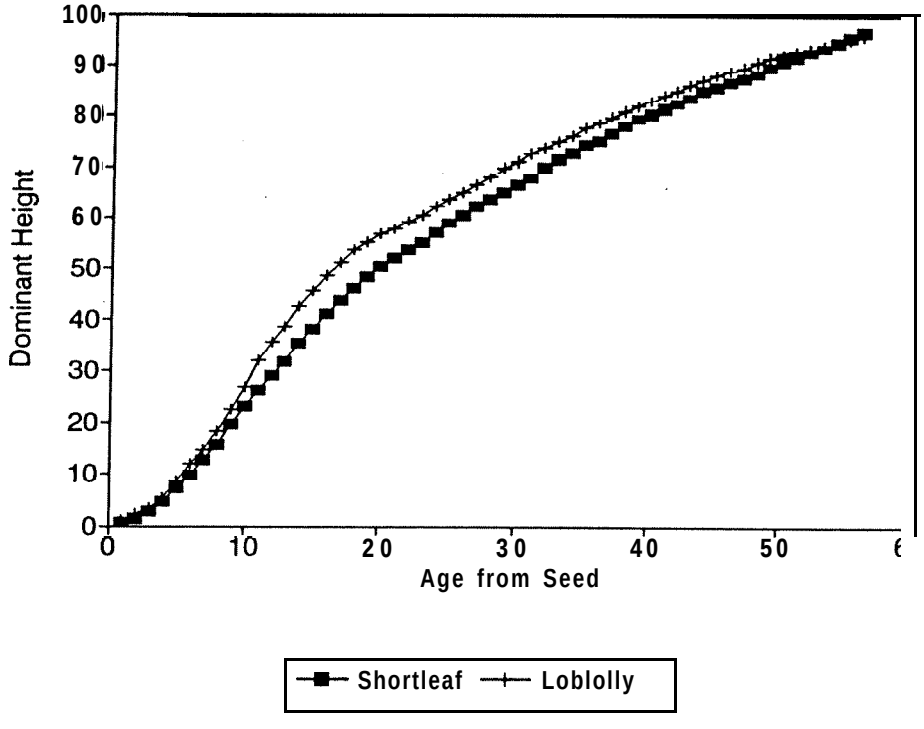

Figure 2. --Dominant height of block plantings in south eastern Texas

Similar paired blocks of shortleaf and loblolly pine have been planted on some of the worse sites on Weyerhaeuser land in Arkansas and Oklahoma. Most of the plantings were on rocky hill tops in droughty areas. Plots were installed in each block and have been measured at age 9 and 14. Data from all locations are similar, a location in the mountains of south eastern Oklahoma is presented as a typical example. Figure 3 shows a height advantage for loblolly pine similar to that observed in east Texas. Figure 4 shows a 25 to 30 square foot basal area advantage of loblolly over shortleaf. Figure 5 shows a one inch average diameter advantage of loblolly over shortleaf. The Weyerhaeuser species comparisons have performed similarly to the east Texas blocks through the most recent measurement.

A STRATEGY FOR QUICK RETURN ON INVESTMENT

Intensive forest management can provide a plentiful source of wood. However intensive forest management requires heavy investment at time of planting. An earlier return on these investments can be realized with loblolly pine and it's faster early growth rates. If rotations are expected to be in excess of fifty years, and early revenue from thinnings is not important, then shortleaf pine would be an appropriate species choice.

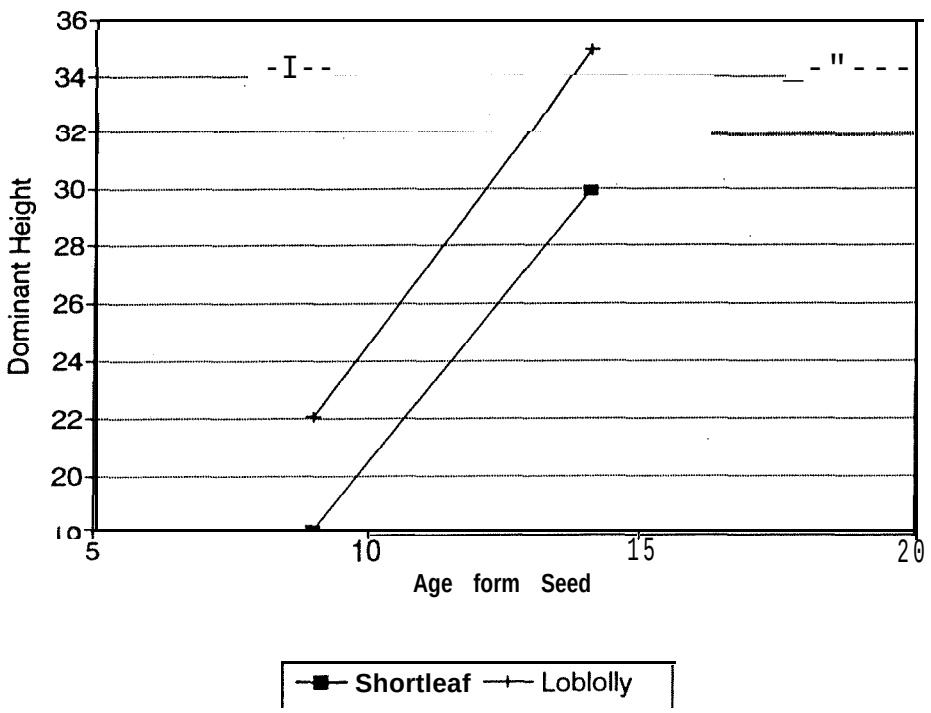

Figure 3. --Dominant height of block plantings in the mountains of eastern Oklahoma.

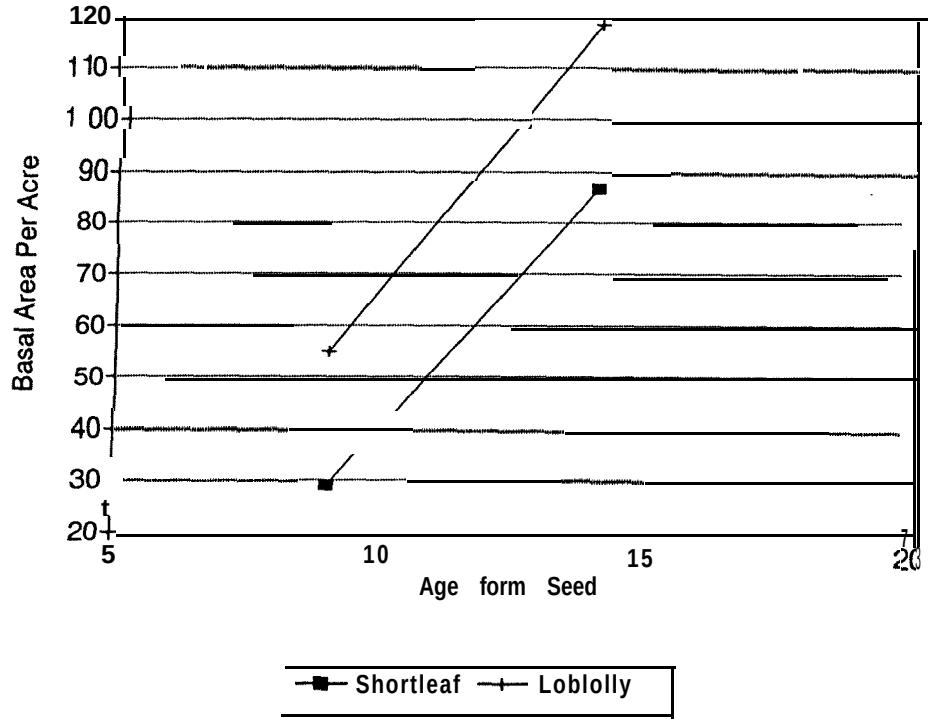

Figure 4.--Basal area per acre for block plantings in the mountains of eastern Oklahoma.

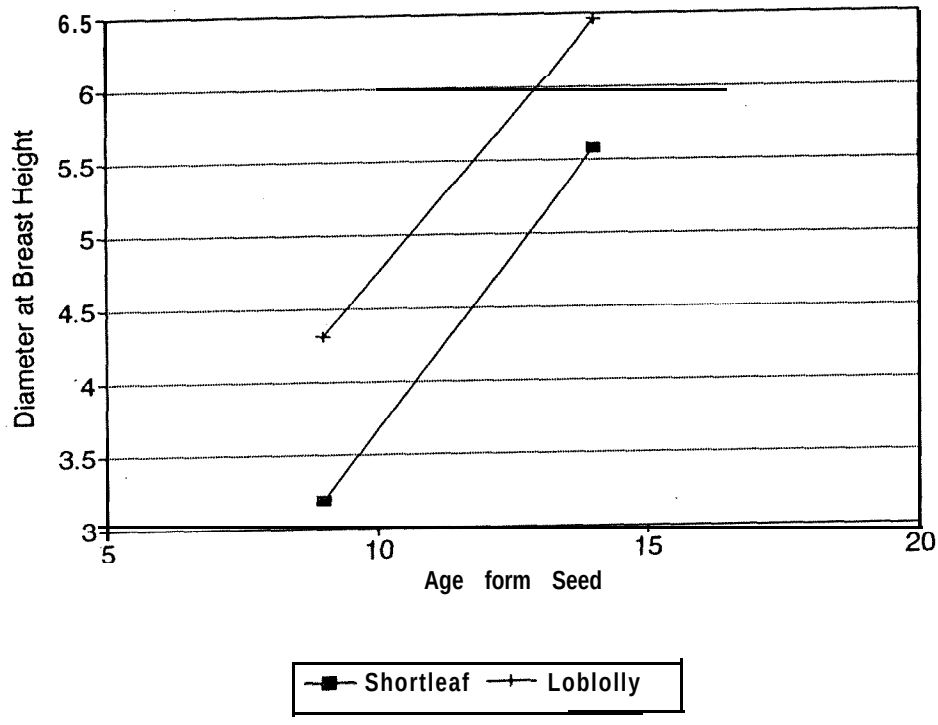

Figure 5.--Average diameter at breast height for block plantings in the mountains of eastern Oklahoma.

MAKING NATURAL REGENERATION METHODS WORK WITH SHORTLEAF PINE[1/]

Roger W. Dennington[2/]

Abstract. --Natural regeneration methods will work successfully when forest managers understand and properly apply the technology fundamentals.

INTRODUCTION

The process of renewal is the most critical stage in the entire life of a forest stand. This brief period sets stand density and species composition which are very influential in future forest productivity. It also starts the economic clock ticking with what is normally the major financial investment in the life of the timber stand. Critical as this process is, it often falls short of our expectations. Sometimes it outright fails. This seems to be more often true with natural regeneration than artificial methods.

Why do natural regeneration methods sometime fail? Is it because we lack adequate technology? Is it because of natural occurrences beyond our control? Or is it because we fail to properly apply existing technology? The most often correct answer is the latter -- our failure to understand and/or properly apply existing technology. In spite of the fact that Shortleaf Pine (*Pinus echinata* Mill.) has received less research attention than any one of the other southern pines, we still have adequate knowledge to make evenaged natural regeneration methods work.

To make these methods work, forest managers must consider themselves to be in a partnership with nature. As with most successful partnerships, each partner contributes something to the endeavor. Additionally, understanding the other partner's strengths and weaknesses is important. Such understanding allows for adjustments to alter, offset, or compensate for the inadequates of the other partner. This knowledge of our partner is embodied in the biological sciences. As will be seen later, when armed with this understanding, forest managers can strongly influence, but not fully control, the natural regeneration process.

[1/] Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Silviculturist, USDA-Forest Service, Southern Region, -Atlanta, GA 30367.

NATURAL REGENERATION FUNDAMENTALS

Like most human endeavors, the success or failure of the natural regeneration process can be traced *to* the execution (or lack of) of basic fundamentals. Four interdependent components make up the natural regeneration fundamentals for southern pines. These four cornerstones are:

- an adequate seed supply
- a receptive seedbed
- ample soil moisture
- adequate freedom from competing vegetation

When these parts come together at the same time and place, the stand is regenerated. When one or more of these four essential components is missing or inadequate, the regeneration process is not successful.

What is considered adequate, receptive, and ample varies by site and environmental conditions. Forest managers must create the best combination of conditions using timely and carefully orchestrated silviculture treatments. Examples of such treatments include:

- Applying a preparatory cut for seedtree crown development several years before the regeneration process begins
- eliminating woody stem competition that is too large to control with fire before the seed cut
- leaving enough seedtrees per acre to produce adequate seedfall during medium seedyears
- observing developing seed crops and timing a seedbed preparation treatment just prior to seedfall.

Most forest managers can readily identify these basic parts to the natural regeneration methods (seed supply, seedbed, etc.). But these parts are much like a jigsaw puzzle in that they must be placed together in an interlocking manner for the method to work. The timing and degree of intensity in which these parts are put together is essential. The importance of timing can be seen in these examples:

Activity	Timing	Results
Seedbed preparation burn	August when no cones are present in seedtrees	No seedling establishment. (Question: will a new seed crop be present next fall and will the seedbed still be receptive?)

Seedbed preparation burn	August two years before a good cone crop matures in seedtrees	Seed may fall on an unreceptive seedbed with a poor or marginal seed catch resulting
Seedbed preparation burn	August before a good cone crop matures in October and November	An excellent chance of a good seed catch

Intensity of treatments is a quantitative measurement which effects results as seen in these examples:

Activity	Intensity	Results
Chemical control of competing woody competition	Only stems larger than 4-inches DBH are controlled (the site has 5,000 woody stems per acre that remain uncontrolled)	Seed that germination will not likely result in an established, free-to-grow seedling
Seed cut is applied	Only 5 marginal seedtrees per acre, are retained	An adequate supply of seed is not likely to develop

RESULTS FROM HYPOTHETICAL CONDITIONS

A worksheet has been developed to show the regeneration results from some of the many combinations of conditions that forest managers might encounter (Figure 1). Four broad groups of conditions are shown for each of the four basic natural regeneration components. In reality, no sharp lines of demarcation separate these conditions from each other as might be suggested by the form entries. Using legend codes as shown on the form, a series of hypothetical combination of conditions is constructed to show possible regeneration results.

Table 1 can be used to see the relative values of various seedtree retention and cone crops levels. Columns 1, 2, 3 and 5 exhibit several combinations of seedtrees, cones, and seed per acre. Shortleaf pine cones yield about 25 to 38 full seed each or an average as shown in this illustration as Column 4, 30 seeds per cone (USDA Forest Service 1990). On the average, only about 1 percent of the sound seed which fall to a receptive seedbed will produce an established seedling (Yocom and Larson, 1977). Column 6 reflects this seed to seedlings ratio. Column 7 shows the number of seedlings that might be expected under various seedtree and cone crop quanties.

Table 1.--Simulated shortleaf pine natural regeneration scenarios

(1) Seedtree per acre	(2) Cones per tree	(3) Cones per acre	(4) Seed[1/] per cone	(5) Seed per acre	(6) Ratio[2/] Seed: Seedling	(7) Seedlings per acre
10	50	500	30	15000	.01	150
10	100	1000	30	30000	.01	300
10	200	2000	30	60000	.01	600
10	300	3000	30	90000	.01	900
10	400	4000	30	120000	.01	1200
15	50	750	30	22500	.01	225
15	100	1500	30	45000	.01	450
15	200	3000	30	90000	.01	900
15	300	4500	30	135000	.01	1350
15	400	6000	30	180000	.01	1800
20	50	1000	30	30000	.01	300
20	100	2000	30	60000	.01	600
20	200	4000	30	120000	.01	1200
20	300	6000	30	180000	.01	1800
20	400	8000	30	240000	.01	2400
25	50	1250	30	37500	.01	375
25	100	2500	30	75000	.01	750
25	200	5000	30	150000	.01	1500
25	300	7500	30	225000	.01	2250
25	400	10000	30	300000	.01	3000

1/ AG HB 654, 1990
2/ Yocom and Larson, 1977

CONCLUSIONS

Natural regenerations should not be used when the four fundamental components (adequate seed supply, receptive seedbed, ample soil moisture, and adequate freedom from competing vegetation) can not be expected to come together in the right combinations within a reasonable time. However, when forest managers, working with the powerful but sometimes unpredictable forces of nature, . cause these right combinations to occur, the natural regeneration methods will work well.

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Figure 1

UNDERSTANDING THE BASIC REQUIREMENTS FOR SUCCESSFUL NATURAL REGENERATION OF SOUTHERN PINE STANDS

Basic Requirements for Successful Natural Regeneration	Hypothetical Combination of Conditions							
1. ADEQUATE SEED SUPPLY	✓	X	?	2/3	2/3	?	2/3	✓
2. RECEPTIVE SEEDBED	✓	✓	2/3	?	✓	✓	2/3	✓
3. FREEDOM FROM COMPETITION	✓	✓	✓	2/3	2/3	✓	?	✓
4. AMPLE SOIL MOISTURE	✓	✓	✓	✓	✓	✓	✓	X

Condition Code Legend	
✓	Optimum
2/3	2/3 Optimum
?	Marginal
X	Unacceptable

Regeneration Results							
FULL STOCKING	ZERO STOCKING	VERY POOR STOCKING	VERY POOR STOCKING	ADEQUATE STOCKING	ADEQUATE STOCKING	OK STOCKING MUST BE RELEASED	VERY POOR STOCKING

Definition of Basic Requirement Conditions				
Basic Requirements	Conditions for SHORTLEAF PINE			
	Optimum	2/3 Optimum	Marginal	Unacceptable
ADEQUATE SEED SUPPLY	MORE THAN 300M SEEDS PER ACRE	200M-300M	100M-200M	LESS THAN 100M
RECEPTIVE SEEDBED	SEED CAN REACH 75%+ OF FOREST FLOOR	50-74%	25-49%	LESS THAN 24% OF FOREST FLOOR RECPTIVE
FREEDOM FROM COMPETITION	95%+ OF AREA VOID OF DOMINATING COMPETITION	60-94%	30-59%	LESS THAN 29%
AMPLE SOIL MOISTURE	APRIL-OCTOBER DRY PERIODS DO NOT EXCEED 10 DAYS	11-16 DAYS	17-23 DAYS	MORE THAN 24 DAYS

Other factors RODENT POPULATIONS, CATTLE GRAZING, POST-GERMINATION FIRES, STABLE SOILS,

ARTIFICIAL REGENERATION OF SHORTLEAF PINE. PUT IT ALL TOGETHER FOR SUCCESS'

John G. Mexal[2]

Abstract. --Successful artificial regeneration of shortleaf pine (*Pinus echinata*) plantations requires careful attention to detail from seed source selection through outplanting. Much of the poor survival in the past can be attributed to a lack of understanding about the cultural requirements of shortleaf pine. This began to change in 1984 with the institution of the the Shortleaf Pine Regeneration Taskforce. Since 1985, 15 studies have been installed in Arkansas and Oklahoma to address seedling production and establishment. Information generated by these studies have resulted in increased survival of shortleaf pine in both Ozark and Ouachita National Forests. This paper discusses some of the research accomplishments that led to this success-.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is unique among the southern pines. It has the widest natural range thriving on shallow rocky soils of the Interior Highlands. Superior wood properties make it a favorite among foresters. However, until recently it has been one of the most neglected species from a silviculture standpoint. Small seed makes it difficult to grow to acceptible size in the nursery. Consequently, it has a history of poor survival following outplanting. For example, survival of shortleaf pine in the Ouachita and Ozark National Forests in the early 1980s was less than 50 percent; about 40 percent of the reforested acres required replanting.

All this began to change with formation of the Shortleaf Pine Regeneration Taskforce in.1984. This consortium of National Forest staff, USFS researchers, and industry personnel designed a program to address shortleaf pine regeneration. Fifteen studies were designed and installed over a 6-yr period. New standards for site preparation and seedling quality were defined. Survival increased from less than 50 percent to near 80 percent on both national forests (figure 1). The objective of this paper is to highlight some of the successes of this program.

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[1] Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991. New Mexico Agric. Exp. Sta. Scientific Paper No. 409.

[2] Professor, Department of Agronomy and Horticulture, New Mexico State University, Las Cruces, NM 88003.

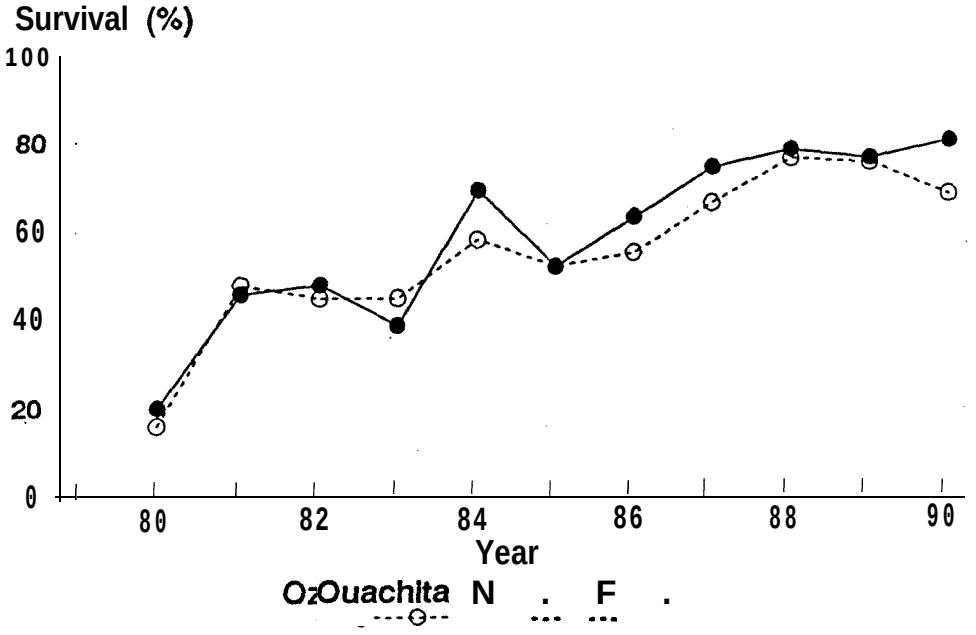

Figure 1. Survival of shortleaf pine seedlings of the Ouachita and Ozark National Forests (after Walker and Smith, this volume).

Successful reforestation programs require the integration of many diverse disciplines into one unified system. These disciplines range from seed source selection and seedling production to site preparation and to, finally, training of planting crews. When any discipline is neglected, stands fail and costs escalate. Less obvious, but equally important is the reduced yield brought about by inattention to detail. Furthermore, each step requires periodic reexamination to ensure current technology is employed to maximize the return on any investment. It is no longer acceptable to use recommendations from 40 years ago, or even 15 yrs ago, without confirming that they offer best management approaches in view of technology and circumstances.

SEED PRODUCTION

The first step in any reforestation system is the selection of superior sources for the region. Wells and Wakeley (1970) published guidelines for moving shortleaf pine seed (figure 2). They recommended sites in Arkansas be replanted with local seed, or seed from east Texas and western Louisiana (Zone 5) or seed from the east but north of the 17°C isoline (Zone 3). These recommendations prompted rapid expansion of shortleaf pine seed orchards. Nearly 270 ha of first-generation seed orchards were established between 1959 and 1967 (Kitchens 1986). These orchards

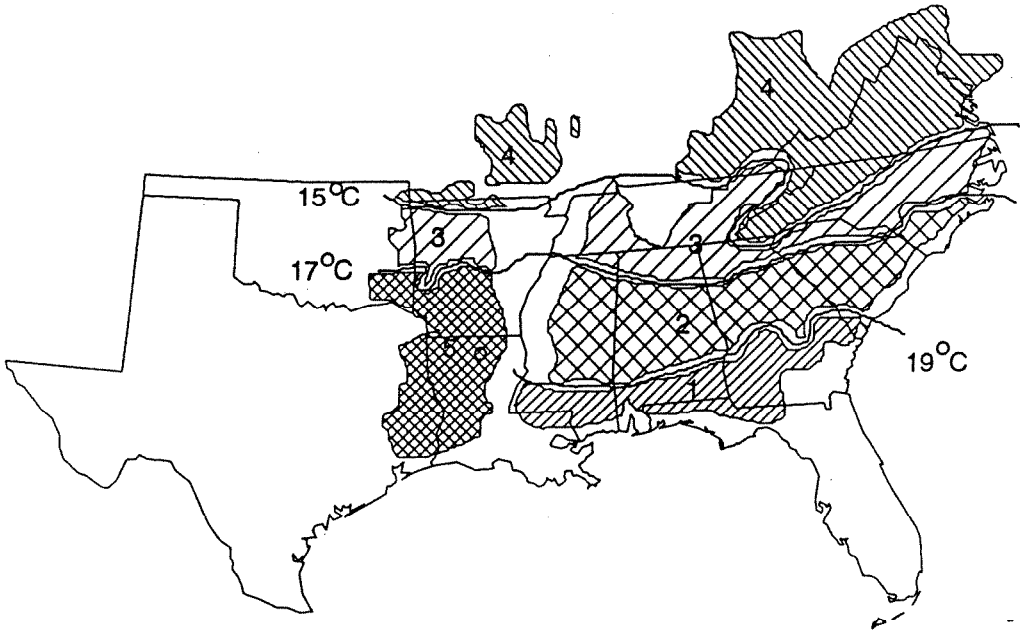

Figure 2. Seed collection and planting zones for shortleaf pine (Wells and Wakeley 1970).

should produce 15,000 kg of seed per year or roughly 300 million viable seed. This is far more than needed for current reforestation efforts with shortleaf pine. Thus, the best 5-10 percent could be used for seedling production to maximize genetic gain.

These shortleaf pine seed orchards are 25-32 years old. Ideally, they should have been rogued several times and contain only the best genotypes based on long-term studies. Furthermore, they probably should have been replaced by second generation orchards by now (O'Laughlin et al. 1991). They have not. In fact, second generation orchards are just now being installed. Sustained gains from tree improvement programs are possible only if seed production follows genetic test results. Genetic results are available, at least for certain traits such as littleleaf resistance of full-sib genotypes (Ruehle et al. 1984). Information such as this should be used to develop second generation seed orchards. This information is already in use for other species. In fact, nurseries are producing seedlings from second generation loblolly pine (*P. taeda* L.)orchards. . For other species (*Pseudotsuga menzesii* and *Pices* spp.), outstanding genotypes are being produced vegetatively to increase genetic gains. Similar programs will ensure the long term viability of shortleaf pine as a regional timber resouce. In the absence of continued improvement of the genetic base, shortleaf pine will be surpassed by species having less promise for certain sites and products.

NURSERY PRODUCTION

Tremendous advances have been made in shortleaf pine seedling culture in the past 30 years. Consequently, target seedling specifications have become more restrictive (table 1). For example, the acceptable range in height has been narrowed, minimum and optimum root collar diameter have increased and root parameters have been developed. These recommendations are compiled from many studies over the years. The studies ranged from seed biology to cold storage of harvested seedlings. As a result, many cultural practices have changed. Early on, shortleaf pine was a victim of its own biology. Because it is a small-seeded species, shortleaf pine was sown earlier than other southern pines. It was grown at high densities (>500/m^2) because it grew more slowly (Wakeley 1954)"

Table 1. Shortleaf Pine Seedling Targets (Bareroot).

	Mexal & south 1991	Anon. 1989	Barnett et al. 1986	Wakeley 1954
Shoot Height (cm)	15-25	20	15-25	10-30
Root Collar Diameter (mm)				
Cull	<4.0	--	<2.5	<3.0
Optimum	<5.0	4.8	2.5-5.0	<3.0
R/S	>0.4	0.4	0.4	--
Lateral Roots (No.)	>7	>5	7	--
Tap Root Length (cm)	--	15	IO-20	
Terminal Bud	--	Present	Well-Developed	Present
Mycorrhirae	Many	Abundant	---	---

Unfortunately, the high seeding rate often negated the benefit of early sowing. Thus, seedlings were small when lifted, and survival following outplanting was often low.

Seed treatment.

Proper seed treatment maximizes the proportion of seed resulting in target seedlings. Treatments include: clonal collection and sowing, removal of empty and damaged seed by flotation, sizing seed to improve uniformity, and stratification to speed emergence. These simple and inexpensive techniques can result in large gains in uniformity while assuring genetically superior seedlings reach the planting site. Failure to implement these techniques decreases long-term growth and yield. Dierauf (1973, unpubl.) found bulk sowing of half-sib loblolly pine seed eliminated the best genotypes. In this study, genotypes judged superior in terms of long-term growth germinated slower in the nursery, and were outcompeted by the faster emerging, inferior genotypes. Therefore, implementing these techniques not only

improves nursery practices, but also improves long-term growth and yield.

Stratification is the final pretreatment before sowing. However, it is often inappropriately used, Stratification tests are usually based on laboratory tests that invariably indicate 30-day stratification results in the highest germination (e.g. Barnett and McGilvray, this volume). However, the minimum length of stratification is often 60 days, if the tests are conducted under low temperatures, or consider speed of germination, or are based on nursery results.

The ultimate test of stratification is increased number of target seedlings in the nursery. Stratification speeds emergence, which permits earlier growth. Thus, seedlings that emerge earlier in the season are larger at harvest (figure 3). Furthermore, early emergers are more likely to survive to harvest. In this study, seedlings emerging during the first two weeks were the largest at the end of the growing season, and accounted for 60% of the germinants surviving to harvest. If the late emergers survived to harvest, culling would have effectively removed most of these.

Seedling aualitv.

Many factors contribute to the term seedling quality. Often, quality is viewed as a black box with dimensionless parameters. This is not the case. Quality refers to the growing and handling system used to produce seedlings. A quality system requires the

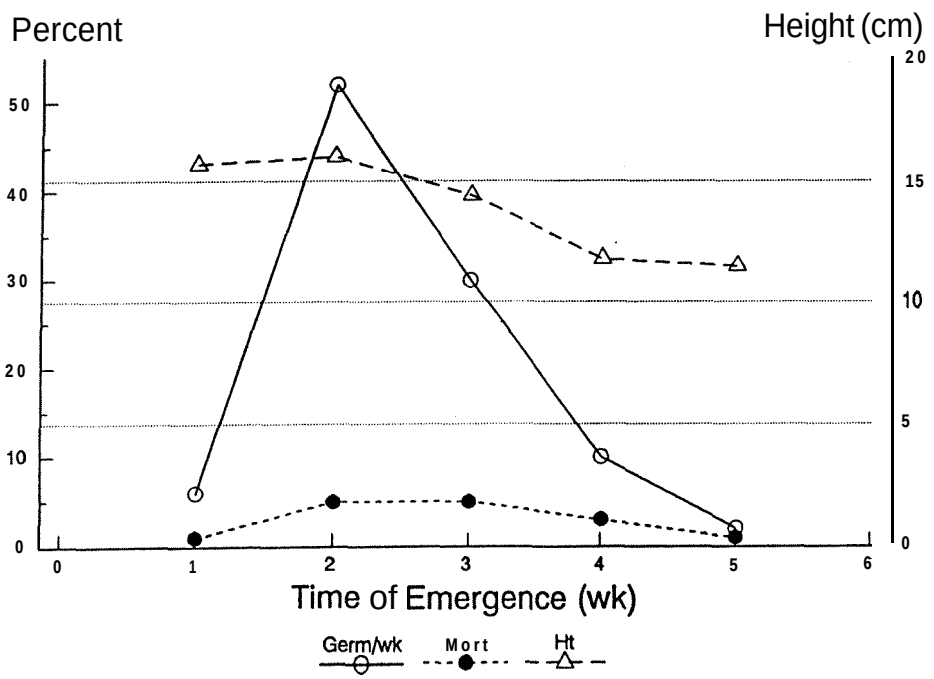

Figure 3. Effect of time of emergence on mortality and height of shortleaf pine seedlings (after Barnett and McGilvray, this volume).

adoption of state-of-the-art technology. It incorporates research information into a production scheme, virtually guaranteeing quality (high performance). Such technology for shortleaf pine currently includes: seed treatments (see above), sowing early, growing at low seedbed densities ($\simeq 200/m^2$) (Brissettte and Carlson 1987), and fertilizing with moderate rates of nitrogen (Brissette et al. 1989).

All of the aforementioned nursery practices ultimately increase the size of nursery seedlings, and improve the balance between shoot biomass and root biomass. Mexal and Dougherty (1982) demonstrated the importance of the R/S ratio in survival of loblolly pine seedlings. Work by Brissette and Barnett (1989) indicates it can also predict early growth of shortleaf pine (figure 4). Height growth of containerized and bareroot shortleaf seedlings was correlated with R/S ratio following outplanting. Generally, the containerized seedlings that suffered minimal root disturbance had greater growth than the bareroot seedlings. *Greater* growth in the first year results in greater volume production over the rotation of the stand (South et al. 1988).

POST-HARVEST HANDLING

Post-harvest handling includes timing of lifting, sorting, length of storage, method of storage, and transportation. Without research, the post-harvest handling characteristics of shortleaf pine might be expected to be similar to loblolly pine. In fact, Wakeley (1954) found planting date affected the survival of

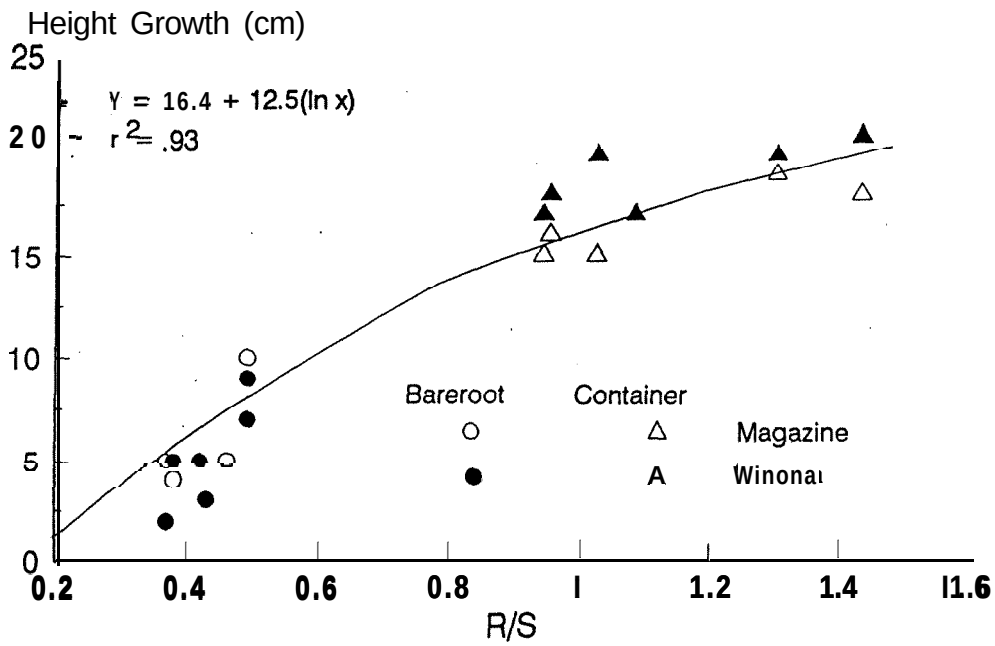

Figure 4. Relationship between R/S and height growth of bareroot and containerized shortleaf pine seedlings (after Brissette and Barnett 1989).

shortleaf pine and other southern pines similarly. However, these seedlings were planted hot with minimum cold-storage.

It was only recently that Venator (1985) found shortleaf pine was sensitive to storage. Hallgren (this volume) expanded this work to the Arkansas/Oklahoma region (figure 5). Whereas, Wakeley (1954) reported average survival of 92 percent for hot plantings in Loiusiana, Hallgren reported survival averaging 83 percent for the northern region. Furthermore, survival of

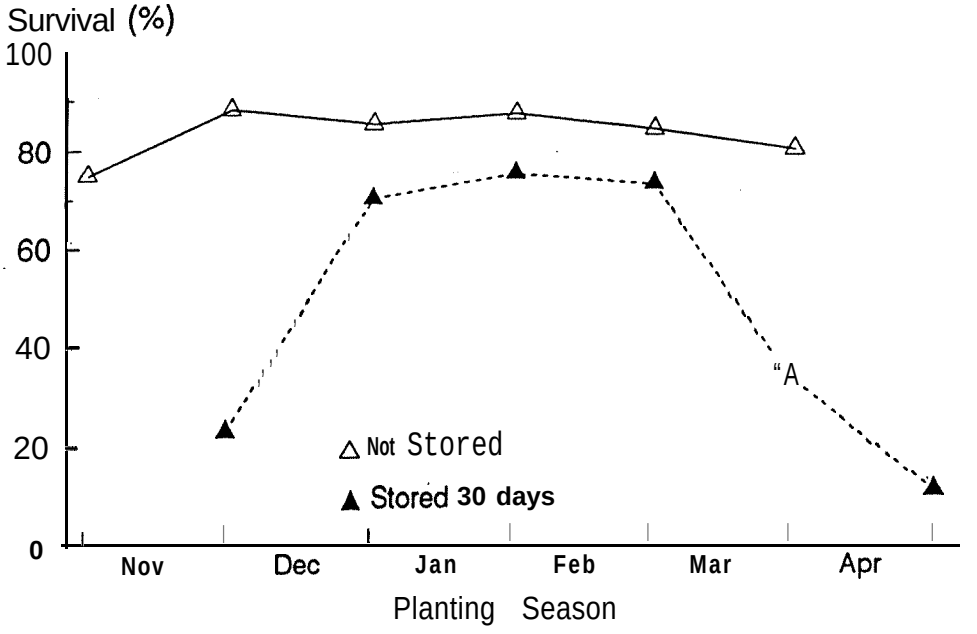

Figure 5. Effect of lift date and 30-day storage on the survival of shortleaf pine seedlings in Arkansas and Oklahoma (after Hallgren this volume).

seedlings stored 30 days was sensitive to cold-storage. Seedlings lifted in mid-winter and stored averaged only 73 percent survival. Survival of seedlings lifted in fall or early spring averaged only 22 percent.

Survival of shortleaf seedlings is apparently correlated with the seedlings' ability to regenerate new roots following outplanting. Brissette et al.(1988) found root growth potential (RGP) of shortleaf pine sensitive to chilling hour accumulation (lift date). They found maximum RGP after lifting occurred after 610 hours. While they did not find a strong interaction with cold storage, Hallgren (this volume) did report maximum RGP following storage for seedlings lifted after about 700 hours.

An exciting prospect for improving the storage life of shortleaf pine seedlings is the use of Benomyl[R] as a root dip. Barnett et al. (1988) found treated seedlings could be stored for at least 6 weeks with no reduction in survival (figure 6). Non-treated seedlings suffered a 15 percent reduction in survival after only 3 weeks, and a 60 percent reduction after 6 weeks storage. Hallgren (this volume) reported similar findings.

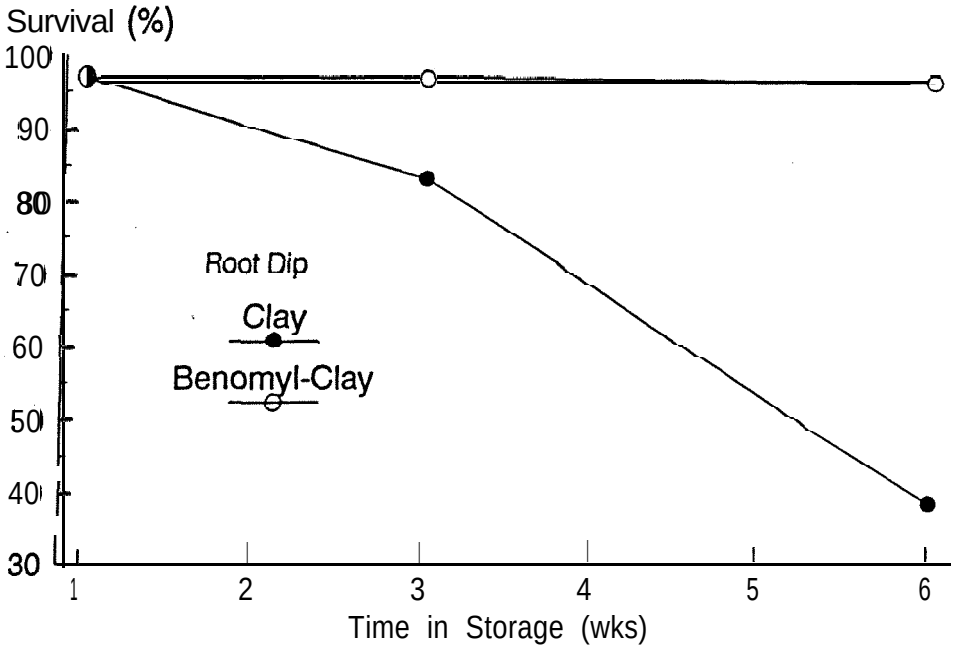

Figure 6. Improvement in survival of stored shortleaf pine seedlings following treatment with Benomyl[R] (after Barnett et al. 1988).

While storage has a strong effect on survival, it appears to have little effect on growth following outplanting (Hallgren this volume). Height two years after outplanting appears to be a function of planting date (figure 7). Maximum growth occurred for seedlings planted in December and January. This result agrees with the hypothesis of South and Mexal (1984). Apparently, root growth through the winter afforded the early-planted seedlings greater opportunity for height growth the following spring and summer. Planting in mid-March and April reduced growth 10-30 percent.

For maximum performance, seedlings should be lifted in December and January and planted by late February. Roots should be treated with Benomyl[R]. The length of storage should be dictated by lift date, but should not exceed 6 weeks.

SITE PREPARATION

Site preparation is the reforestation practice that has the greatest range in cost (Dougherty, this volume). It can range from $0 to several hundred dollars per hectare. As with most expenditures, you usually get what you pay for. Low expenditures can result in difficult planting, low survival and reduced growth from severe competition. However, high expenditures do not always return a positive benefit. Practices. such as piling and burning can cause severe soil compaction, which reduces tree growth and may encourage the incidence of littleleaf disease. Two practices that are obvious choices for shortleaf pine reqeneration are ripping

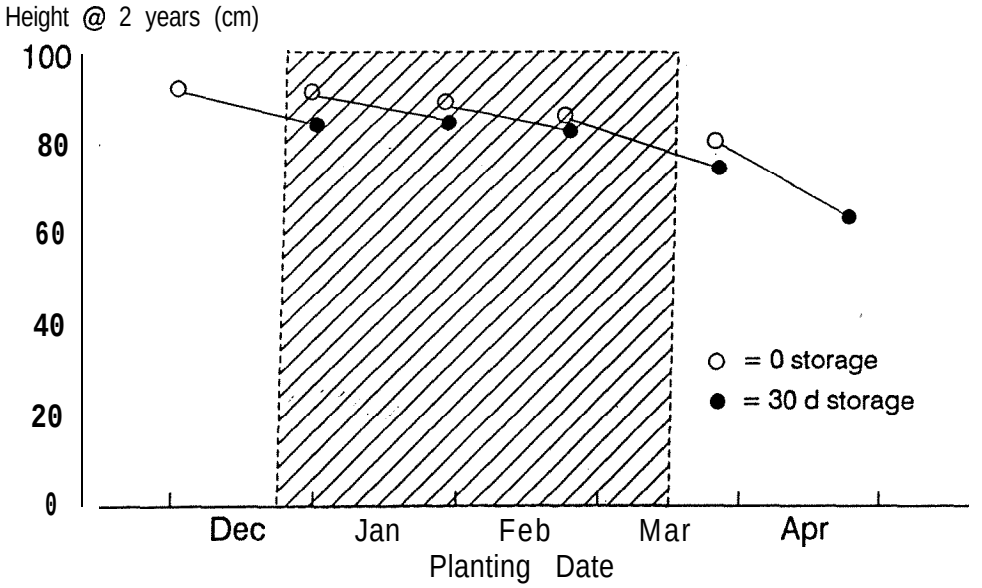

Figure 7. Planting date and 30 day storage affect height growth of shortleaf pine seedlings (after Hallgren this volume).

and chemical weed control. Ripping has been a common practice in the Ouachita Mountains since the early 1970s (Sossaman et al. 1980). It improves seedling survival and growth by creating a weed-free area with improved soil moisture and plantability. The ripper blades tend to pull large cobbles out of the trench, effectively increasing the percent soil in the trench. Often plantability is improved by ripping. The ripping trench may also serve as a catchment basin for subterranean water flow.

Chemical weed control improves soil moisture by removing the vegetation that would utilize it. Yeiser (1992) found the growth response of shortleaf pine to weed control lasted at least two years following either spot or total weed control (figure 8). The improved growth was at least in part the result of improved water relations. Seedlings had higher water potentials, both at the beginning and end of the first growing season.

In this study, total weed control resulted in greater growth than spot weed control. However, on sites where tipmoth (R. frustrana) is a serious concern, some weeds can actually protect shortleaf from severe infestations. Potentially, spot weed control can result in greater growth than total weed control by providing some protection against tipmoth.

PLANTING

Establishing quality seedlings on reforestation sites is one of the most critical links in the reforestation program. Yet, it is the one job delegated to poorly paid and often poorly trained temporary workers. Successful reforestation requires quality control through the establishment phase. This is the point where

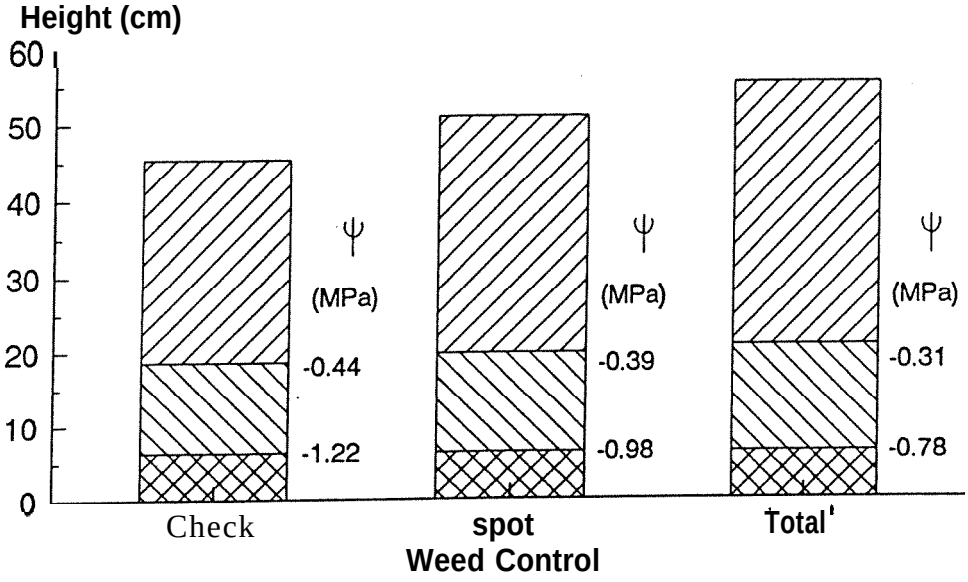

Figure 8. Effect of spot and total weed control on the growth and shoot water potential of shortleaf pine at the beginning and end of the first growing season (after Yeiser 1992).

all the good efforts of researchers, geneticists, and nursery managers can be lost. Poor planting can reduce growth and yield over the life of the plantation or result in poor survival, necessitating a complete replant of the site.

The evidence of poor planting quality is not always apparent. Harrington, et al. (1986) reported 30 percent of planted shortleaf pine lacked a taproot compared to 15 percent of the seeded in place seedlings (figure 9). Only 43 percent of planted seedlings had a single vertical taproot compared to 68 percent of the seeded plants. Furthermore, seedling with vertical taproots exhibited greater height growth than trees with deformed root systems.

Mexal and Burton (1980) also found root quality affected growth of loblolly pine seedlings at least through the first four years in the plantation. The two major parameters affecting growth were the number of first order laterals and the depth of planting. Tree volume (D^2H) increased linearly as the number of first order lateral roots increased up to 19. Tree volume decreased with increasing planting depth. However, planting depth is confounded by the concommitant root deformation. Tree planters rarely increase the size of the planting hole as the portion of the seedling planted below ground increases. Thus, deep planting usually results in root deformation.

Harrington, et al. (1986, 1989) examined root system orientation of surviving trees. They did not examine the effect of root deformation on seedling survival. However, Brissette and Barnett (1988) found root deformation also decreased survival of loblolly pine seedlings. Shallow planting was the most

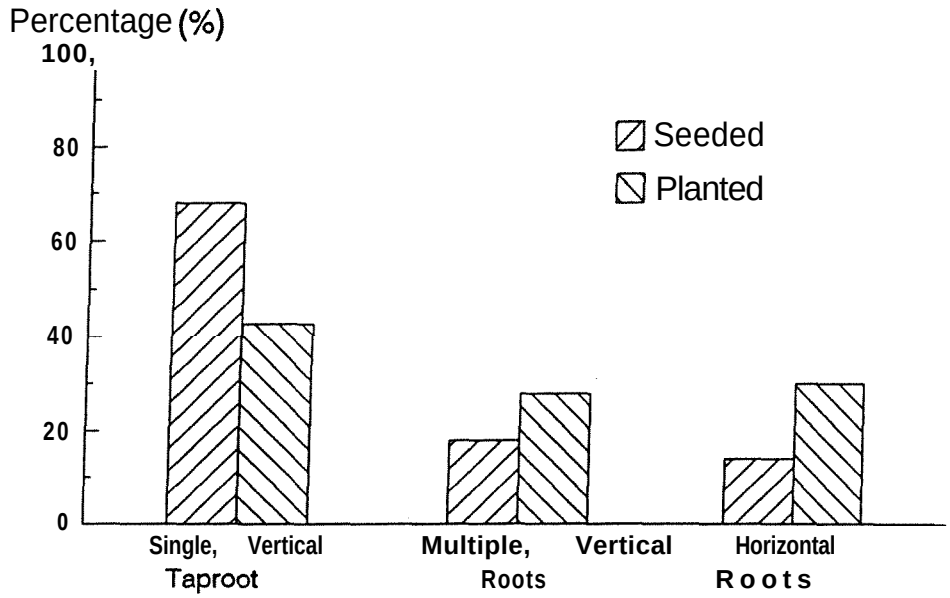

Figure 9. Root quality of planted and seeded shortleaf pine (after Harrington et al. 1986).

detrimental, but J-rooting also decreased survival. Thus, high survival and early growth requires proper planting. This includes preservation of the lateral roots, planting the taproot vertical and planting to the correct depth. Shallow planting will kill the tree. Deep planting (>5 cm above the base of the needles) increases the likelihood of J-rooting and reduces survival and growth.

AFTERCARE

Once regeneration has been successfully achieved, the forest enters a *new* phase where care is no less important. Perhaps the most important criterion in stand management is regulating the competition. Given that early weed control is effective (Yeiser, this volume), the sources of competition would be hardwood sprouts and other planted pines. Hardwood competition can be controlled by fire and chemical means. Mechanical control is not feasible from an economic standpoint. Effective management of hardwood competition can result in 40 percent volume increases (Lowery 1986).

Competition can also occur from other shortleaf trees. Stands must be managed to their fullest potential for the full complement of forest products including aesthetics, wildlife, and wood products. If they are not managed given available resources, then the National Forests heritage is being squandered.

CONCLUDING REMARKS

In closing, I would like to tell you a true fish story relayed to me by Dr. M. Southward, a noted biological statistician. Salmon fishing is important in the state of Washington. The Columbia river, in particular, was heavily fished during the annual salmon run. As in most biological phenomena, the timing of these fish arriving followed the classic binomial distribution. A few fish would arrive early and a few would arrive late. Most of the fish arrived at the intermediate times which coincided with the heaviest fishing activity. Eventually, the "middle" fish were all caught before spawning and this part of the population became extinct. However, the two "tails" of the population remained intact and now the river has two salmon runs each year; one earlier than the original and one later than the original.

The questions that begged to be asked by resource managers are:

"Did we do wrong?" Given the level of our knowledge at that time the answer is possibly No! We used the best information at the time and planned *on* a limitless supply of salmon.

"Would we manage the resources the same way again?" Absolutely not! Our original prescription did not foster sustainability.

"Can we restore the original population?** Probably not bv direct intervention! We certainly would not want to import salmon from another river. These may destroy the remnant original population, and certainly alter the genetic makeup.

As land managers in the Ouachita and Ozark Mountains, you are faced with a similar dilemma. We have created "unnatural" forest stand conditions in the 1990s by using what must be correctly termed state-of-the-art management practices during the 1940s, 1950s and 1960s. We now know some of these practices were poor and steps should be taken to correct the existing situation. However, we should not perpetuate a management regime based on a popular conception of what the "natural" forest should be. Management should be based on sound, state-of-the-art biological principles. Unfortunately, the ability to address biological issues in forest management are often constrained by political, fiscal and even temporal issues.

Those issues can be overwhelming. In fact, according to Dr. Gerald Thomas, a world renown range scientist, you are locked in a battle between the ecos, the ecologists and the economists. The so-called ecologists want to preserve their impression of a natural shortleaf pine forest, a forest brought about by fire suppression, and probably some timber high-grading. The ecologists team include proponents such as Senator Pryor, Jane Fonda, Meryl Streep and Robert Redford. Their weapons include political power, money and name recognition.

The so-called economists want to manage public lands to provide diverse benefits, including an economic return from land management. This team consists of Smokey Bear, a totally discredited and now dead symbol of forest land management. His weapons include facts and an objective, informed clientele. Unfortunately, the facts change as our knowledge grows, and our

informed clientele often are influenced more by glamorous sound-bites than by droll, scientific posturing. Consequently, issues such as Alar, 2,4,5T and Even-Aged Management in Arkansas are lost before the battle is joined.

Furthermore, scientists tend to discredit themselves by acknowledging that the facts change as our knowledge grows. Thus, we often equivocate. We use words such as "tend" or "relative" or "we think". Our opponents show no temerity in their speech. It is filled with action words such as "loss", "destroy" or "I know".

We can change our forest management by a Walk in the Woods. We can change our understanding of forest biology by exploring New Perspectives in forest research. But until we understand how to communicate with and educate our diverse clientele, our forests will be held hostage by well-intentioned, but often misinformed, public advocates.

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RESEARCH NEEDS FOR IMPROVING SHORTLEAF PINE REGENERATION[1/]

Mary Anne Sword and James P. Barnett[2/]

Abstract.--The participants in the Shortleaf Pine Regeneration Workshop were asked to help develop a list by priority of continuing research needs for improving shortleaf pine (*Pinus echinata* Mill.) regeneration. In a reflection of the changing management emphasis in National Forests, the participants expressed a need for research on increased use of natural regeneration as well as on ways to maintain a hardwood component and achieve a mixed, uneven-aged stand structure. Other research priorities included improvement of many aspects of shortleaf pine artificial regeneration, better comprehension of diversity and dynamics in shortleaf pine ecosystems, and improved understanding of the public's objectives for the National Forests.

DEVELOPMENT OF THE CURRENT STATE OF KNOWLEDGE

When the Shortleaf Pine Artificial Regeneration Task Force effort began, little published information was found concerning shortleaf pine seed and seedling physiology, nursery production, or regeneration techniques. A series of investigations were undertaken by USDA Forest Service, industry, and university scientists. This research focused on the improvement of seed and seedling quality, site preparation, planting technique, and release methods used for shortleaf pine artificial regeneration.

Midway through these research efforts, management objectives for shortleaf pine in the National Forests in Arkansas and Oklahoma were modified. From the original emphasis on artificial regeneration using the clearcut silvicultural system, guidelines were changed to emphasize natural regeneration using seed-tree, shelterwood, and selection silvicultural systems. Moreover, maintenance of a significant hardwood stand component as well as a mixed, uneven-aged stand structure became desirable.

At present, management objectives in National Forests within the shortleaf pine range have expanded to encompass greater use of natural regeneration. As a result, forest practitioners are faced with the need for successful artificial and natural regeneration. In addition, an understanding of the intimate relationship between shade-intolerant shortleaf pine and more shade-tolerant hardwood species, as well as understanding of the dynamics of mixed, uneven-aged stands, will dictate future shortleaf pine management practices on these National Forest lands.

[1/] Paper presented at the Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Research Plant Physiologist and Research Forester, respectively, USDA Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

The Shortleaf Pine Regeneration Workshop was conducted to furnish state-of-the-art information for improvement of both artificial and natural shortleaf pine regeneration. As a part of the workshop, a facilitated session was conducted to develop a list of additional research needs.

APPROACH TO DEVELOPING RESEARCH NEEDS

Throughout the workshop participants were encouraged to develop a list of informational needs that they felt were important for improving shortleaf pine regeneration. Each of the approximately 60 participants had an opportunity to propose specific research items in round-robin fashion until all ideas were recorded. The items listed were then discussed and consolidated when appropriate. Twenty-eight areas were listed in which information is needed to ensure responsible management of shortleaf pine forests.

Each participant then identified five items with the highest research priority. The votes were tabulated and a list of priority research needs was developed.

RESEARCH NEEDS FOR SHORTLEAF PINE REGENERATION

Increased use of natural regeneration, as well as ways to maintain a hardwood stand component and achieve a mixed, uneven-aged stand structure, dominated the list of research priorities (see Summary of Shortleaf Pine Research Priorities). Other priorities included improvement of many aspects of shortleaf pine artificial regeneration, better comprehension of the diversity and dynamics of the shortleaf pine forest ecosystem, and improved understanding of the public's objectives for National Forests.

The forester's need for better control of natural regeneration took precedence over other research priorities. Specifically, a system for accurately predicting shortleaf pine seed yield is urgently needed. In addition, definition of both satisfactory seedbed characteristics and appropriate densities of vegetation competition are needed to ensure the establishment of shortleaf pine seedlings. Participants also emphasized a need for underplanting guidelines. Information on the utility of underplanting in shortleaf pine stands subject to either poor advanced regeneration or unsatisfactory natural regeneration is desired. Moreover, the optimum time of underplanting with regard to seasonal and developmental stand characteristics must be determined.

Prescribed fire has become an essential tool in shortleaf pine management. Recent modification of National Forest management objectives has recognized hardwood tree species as a desirable component of stands managed for shortleaf pine production. Therefore, workshop participants expressed a need for information on the use of prescribed burning practices in shortleaf pine stands that contain a desirable hardwood component.

The increased use of natural regeneration methods, the recent desire to maintain shortleaf pine stands with a significant hardwood component, and the new interest in adjusting stand structure from even- to uneven-aged suggest that previous guidelines for determining intermediate stand activity may be

less than optimal. This fact was demonstrated by the workshop participants' desire for field guides to assess naturally regenerated and uneven-aged shortleaf pine stands and growth and yield models for mixed, uneven-aged stands.

It is hoped that this evaluation of research needs for improving regeneration of shortleaf pine will be useful to those continuing research with shortleaf pine and shortleaf pine-hardwood mixtures. Clearly, numerous important research problems remain to be addressed.

SUMMARY OF SHORTLEAF PINE RESEARCH PRIORITIES[3/]

Forest Regeneration

Natural Regeneration

- o' Develop a reliable system for predicting shortleaf pine seed yields. (1)
- o Identify the utility of underplanting bare-root nursery and container stock in shortleaf pine natural regeneration systems. (3)
- o Idenfity seedbed and competition guidelines for natural regeneration of shortleaf pine. (5)
- o Determine shade management strategies for competition control and seedling development. (5)
- o Identify the appropriate timing of underplanting in naturally regenerated shortleaf pine stands. (7)
- o Identify the ecology of naturally regenerated shortleaf pine seed (seedfall, viability, stratification, predation, disease, germination, seedling establishment). (7)
- o Determine the effects on stand development of leaving seed-trees on the site. (9)

Artificial Regeneration

- o Determine the potential of direct seeding for regeneration of uneven-aged shortleaf pine and shortleaf pine-hardwood stands. (10)
- o Develop morphological specifications for optimum shortleaf pine seedlings for outplanting at specific sites. (11)
- o Develop optimum nursery cultural practices for production of container and bare-root hardwood (Quercus spp.) planting stock. (11)
- o Identify shortleaf pine stock types and *genotypes* that are site-specific. (12)
- o Determine the physiological mechanism of shortleaf pine seedling bud set in the nursery and identify modification of nursery cultural practices for its regulation. (13)
- o Develop guidelines for long-term cold storage (>30 days) and freezer storage of shortleaf pine nursery stock. (13)
- o Improve planting-tool design to accommodate larger seedlings. (14)

[3/] Each of the workshop participants voted for 5 of 28 research priorities. The research priority rank (1 through 14) is shown in parenthesis.

Shortleaf Pine-Hardwood Stand Management

Impact of Hardwoods on Management for Pine

- o Determine the effect of the hardwood component on use of prescribed fire in shortleaf pine-hardwood stand management. (2)
- o Assess the production of timber and nontimber resources when large hardwoods are maintained in a shortleaf pine stand during regeneration. (9)

Even-aged Management of Shortleaf Pine-Hardwood Stands

- o Develop field guides for assessing naturally regenerated and uneven-aged shortleaf pine stands. (4)
- o Compare merchantable timber volumes of naturally and artificially regenerated shortleaf pine stands. (7)
- o Determine appropriate shortleaf pine and hardwood stockings in shortleaf pine-hardwood stands. (8)
- o Determine the effect on growth and yield of cutting cycle frequency in older shortleaf pine stands. (10)
- o Develop an expert system for shortleaf pine management. (12)

Uneven-aged Management of Shortleaf Pine-Hardwood Stands

- o Develop field guides for assessing naturally regenerated and uneven-aged shortleaf pine stands. (4)
- o Determine the effect of increased shortleaf pine stand entries on soil productivity. (6)
- o Compare merchantable timber volumes of naturally and artificially regenerated shortleaf pine stands. (7)
- o Determine appropriate shortleaf pine and hardwood stockings in shortleaf pine-hardwood stands. (8)
- o Develop growth and yield models of mixed, uneven-aged shortleaf pine stands that include the effects of hardwood-pine competition. (9)
- o Develop an expert system for shortleaf pine management. (12)
- o Determine management strategies for increasing the number of age classes in shortleaf pine stands when converting from even-aged to uneven-aged management systems. (13)

Ecology of Shortleaf Pine-Hardwood Stands

Species/Genetic Diversity

- o Identify silvicultural practices that reduce, maintain and increase species and genetic diversity in planted and seeded shortleaf pine stands. (6)
- o Identify trends in current management practices that, over time, may be responsible for loss of species diversity in shortleaf pine stands. (12)

Stand Development

- o Understand developmental patterns of shortleaf pine-hardwood stands. (11)

Policy

- o Identify the objectives of various publics for the National Forests. (11)

Field Tour

Lifting Window for Shortleaf Pine Planted in the Ouachita Mountains

Stephen W. Hallgren
Oklahoma State University

The overall goal is to improve shortleaf pine regeneration technology in order to increase plantation success on the Ouachita Mountains.

Support:

Ouachita National Forest, Southern Forest Experiment Station and Oklahoma State University

Objectives:

1. Determine the lifting window for unstored and stored shortleaf pine
2. Determine whether benomyl added to the clay slurry before storage improves field performance.
3. Determine whether seedling traits are associated with good field performance.

Materials and Methods:

Plant material: 1-O shortleaf pine, USFS seed, Weyerhaeuser Co., Fort Towson, OK nursery

Treatments:

1. 6 x 2 x 2 factorial
2. 6 lift dates, 28 day intervals from early November 1989 through late March 1990.
3. unstored versus stored for 28 days at 1-3° C
4. benomyl at 0.5 percent active ingredients versus no benomyl

Planting Sites: Seedlings were planted at three sites, Winona District, Billy Creek and Mena, on the Ouachita NF (Figure 1). Planting sites were clearcut, site prepared and ripped prior to planting.

Root Growth Potential: growth chamber, 25° C day 15° C night, 16 hour photoperiod, 28 days, number of new roots greater than 1 cm long

Experimental Design: A randomized complete block design was used. The experimental unit was a 10 tree row plot in the field and 3 trees in a 1 liter pot for the RCP test. There were 20 replicates at each field site and 33 replicates for the RCP test.

Measurements:

laboratory: RGP, height, diameter, number of first order lateral roots, presence of a bud and secondary needles

field: 1 st year survival, height and diameter

Preliminary Findings:

1. The lifting window for good survival and growth of unstored seedlings was November through March (Figures 4, 5 and 6).

2. The lifting window for a good survival and growth of stored seedlings was December through February (Figures 4, 5 and 6).

3. The most effective concentration of benomyl was 0.5 percent active ingredient (Figure 3).

4. Benomyl improved the survival and growth of both stored and unstored seedlings (Figures **4, 5** and 6).

5. The beneficial effect of benomyl was greatest for the early and late lifts (Figure 4, 5 and 6).

6. Seedlings lifted from frozen nursery soils in late December showed reduced RCP, field survival and growth (Figures 4, 5 and 6).

7. Stored seedlings planted into slightly frozen soil in late December did not appear to have reduced survival or growth (Figures 4, 5 and 6).

8. RCP was generally a good predicter of relative field performance (Figures 4, 5 and 6).

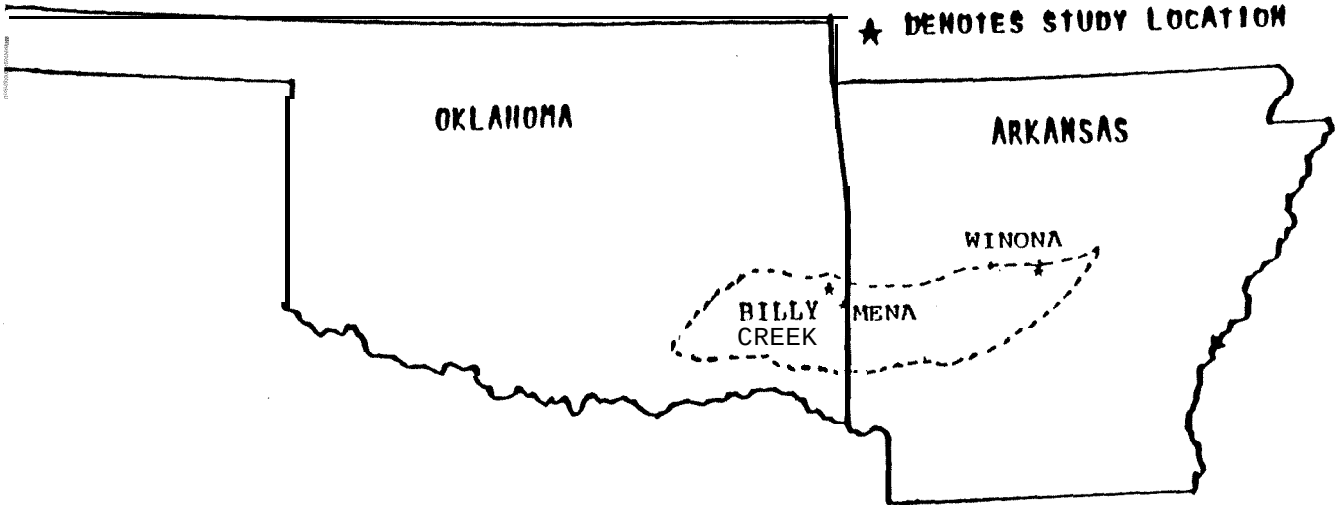

Figure 1. Planting sites

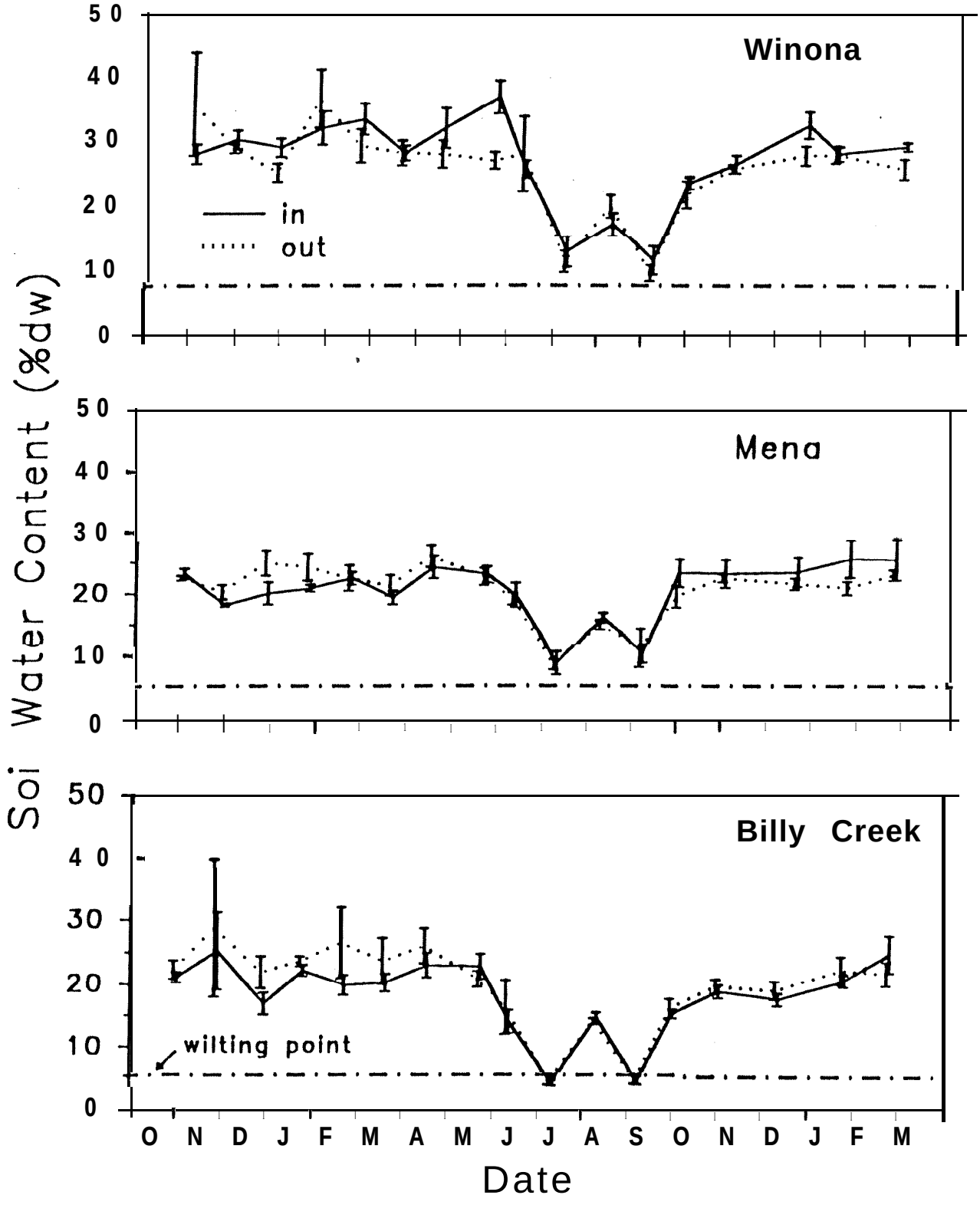

Figure 2.--Mean monthly soil moisture content (% dry weight) in and out of the zone of ripped soil at the 3 planting sites from October 1989 to February 1991. Points equal the mean of 6 samples; wilting point indicates estimated soil moisture content at -1.5 MPa soil water potential and bars equal +/- the standard error of the mean (SEM).

Effect of Benomyl Concentration on RGP of Stored Shortleaf Pine

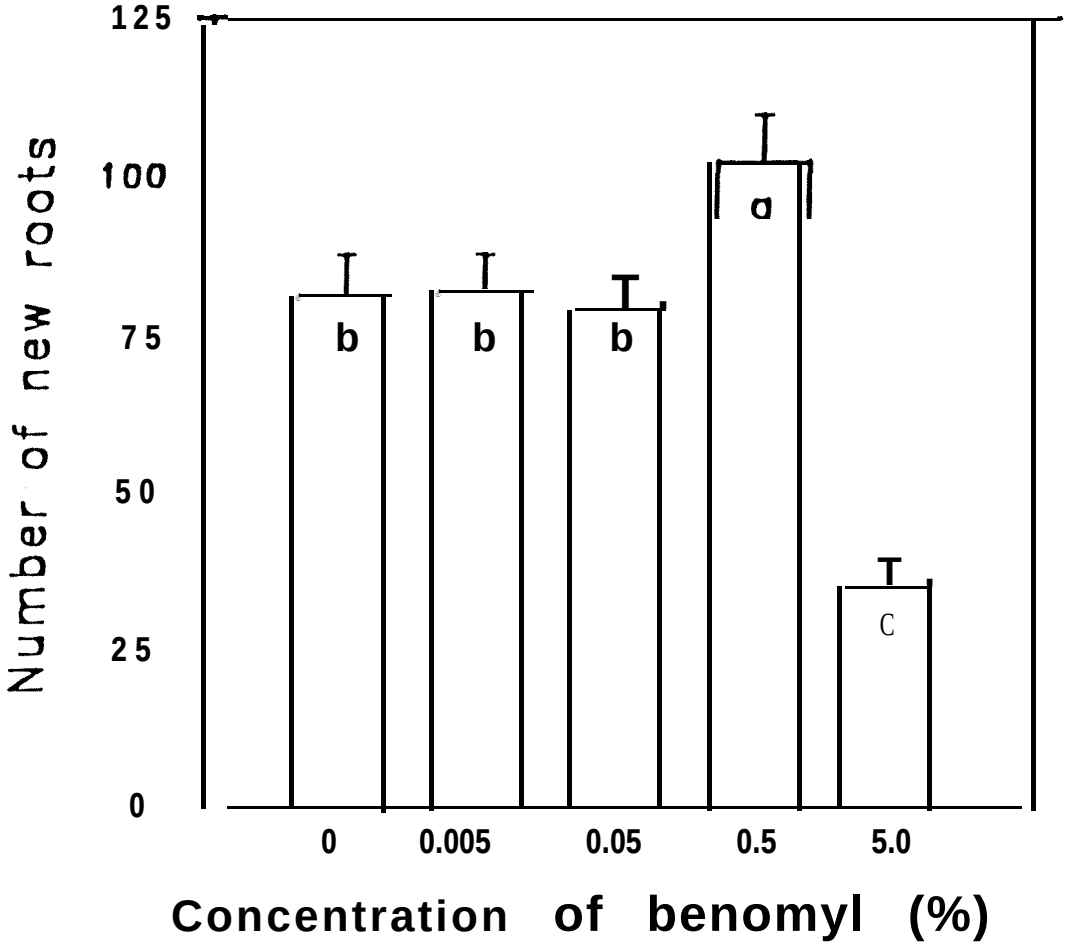

Figure 3.--Effect of benomyl concentration on root growth potential (RGP) of shortleaf pine seedlings stored 28 days. Height of bar equals the mean of 30 replicates (pots of 3 trees) and bars equal the standard error of the mean. Different letters indicate means significantly different at the 5 percent level.

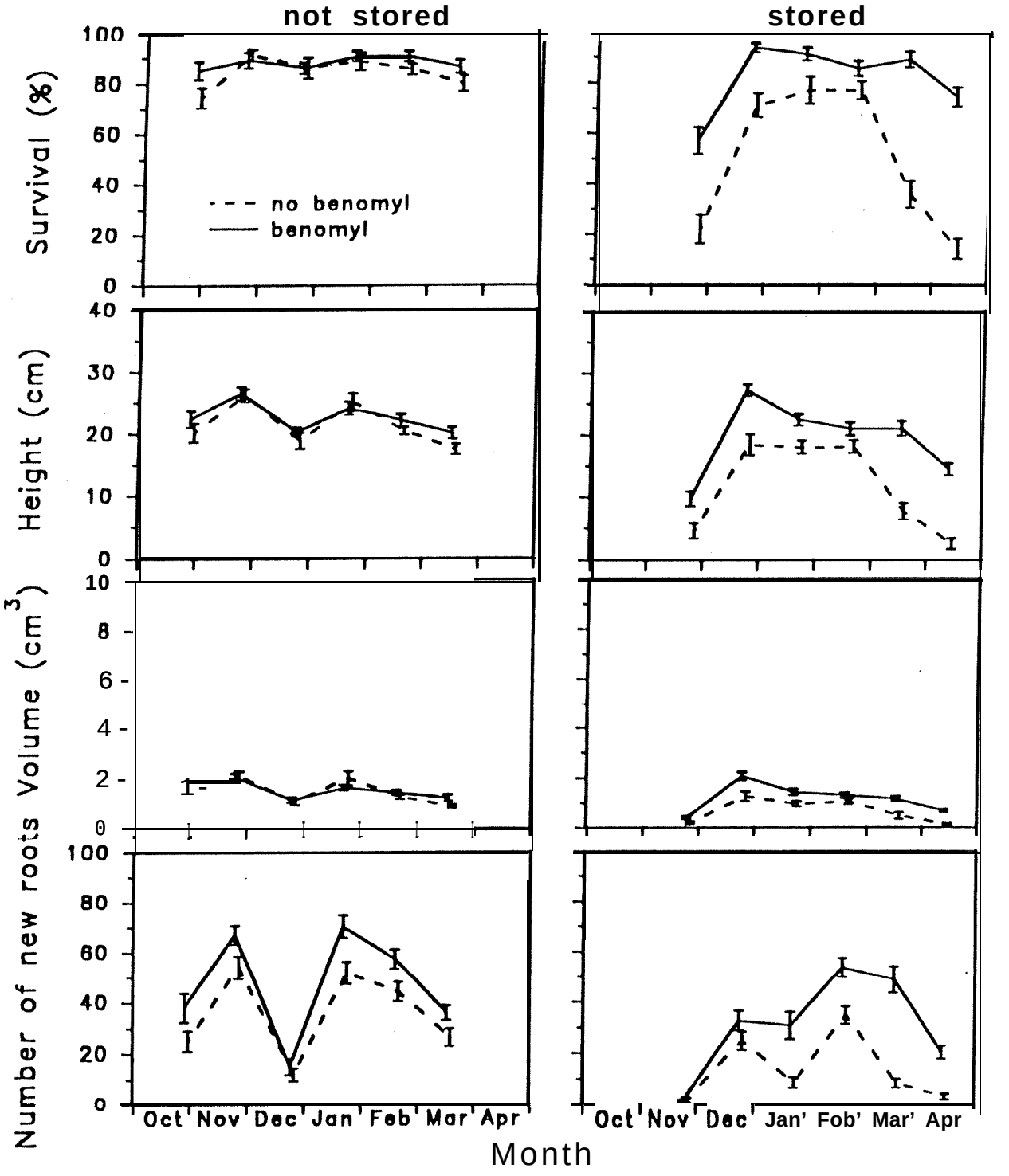

Figure 4.--Effect of lift date and benomyl treatment (0.5 percent active ingredient) in the 1989-90 planting season on mean number of new roots in the RCP test, mean stem volume per planted seedling, mean height of surviving trees and mean percent survival one year after planting in the field. Seedlings were planted on the Winona District of the Ouachita NF. Data plotted by planting date for seedlings that were not stored or stored for 28 days. Points represent the mean of 20 replicates in the field (row plots of **10** trees) and of 33 replicates in the RCP test (3 trees per replicate) and bars equal +/- the standard error of the mean.

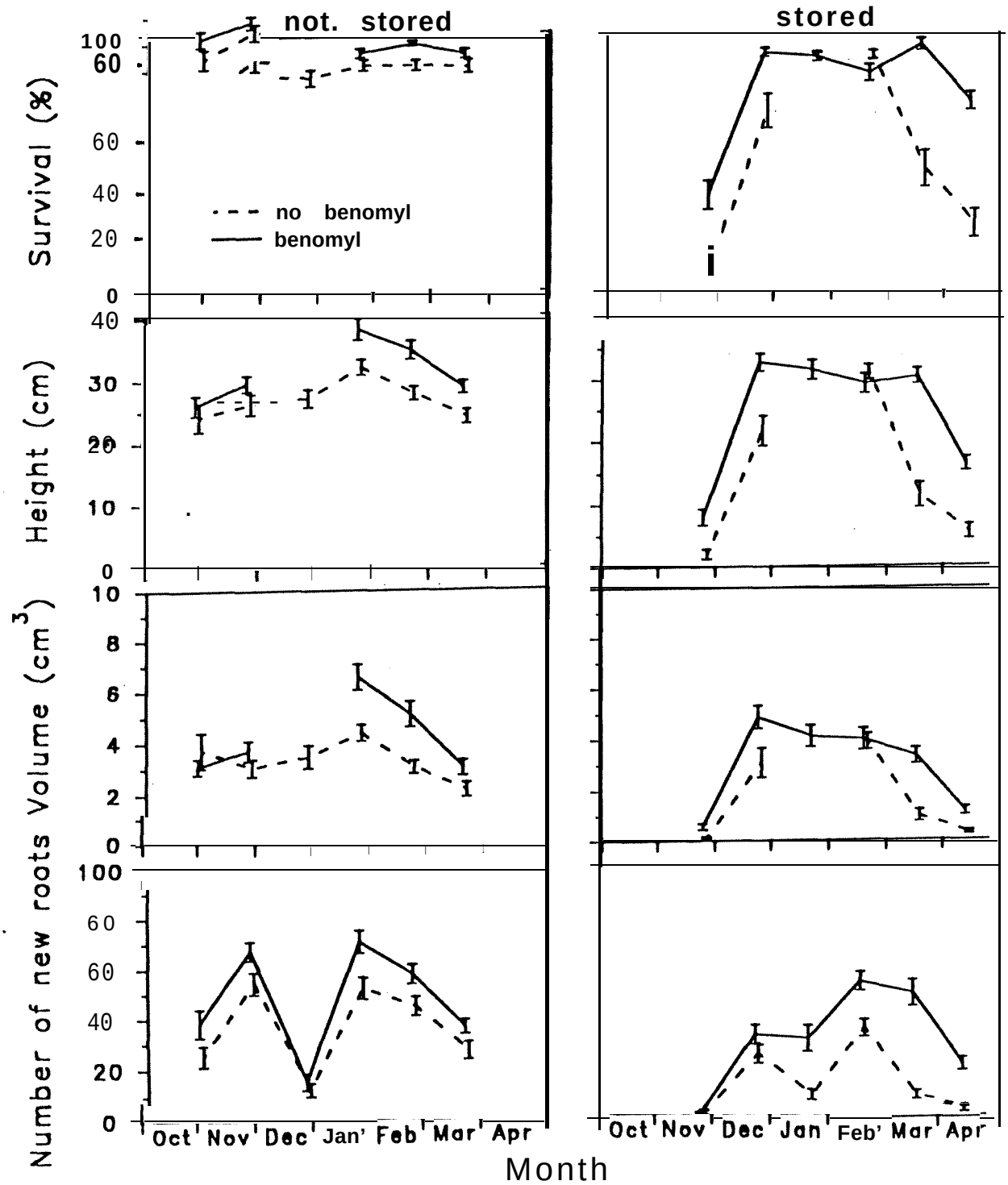

Figure 5.--Effect of lift date and benomyl treatment (0.5 percent active ingredient) in the 1989-90 planting season on mean number of new roots in the RGP test, mean stem volume per planted seedling, mean height of surviving trees and mean percent survival one year after planting in the field. Seedlings were planted in the Ouachita Mountains near Mena, Arkansas. Data plotted by planting date for seedlings that were not stored or stored for 28 days. Points represent the mean of 20 replicates in the field (row plots of **10** trees) and of 33 replicates in the RCP test (3 trees per replicate) and bars equal +/- the standard error of the mean.

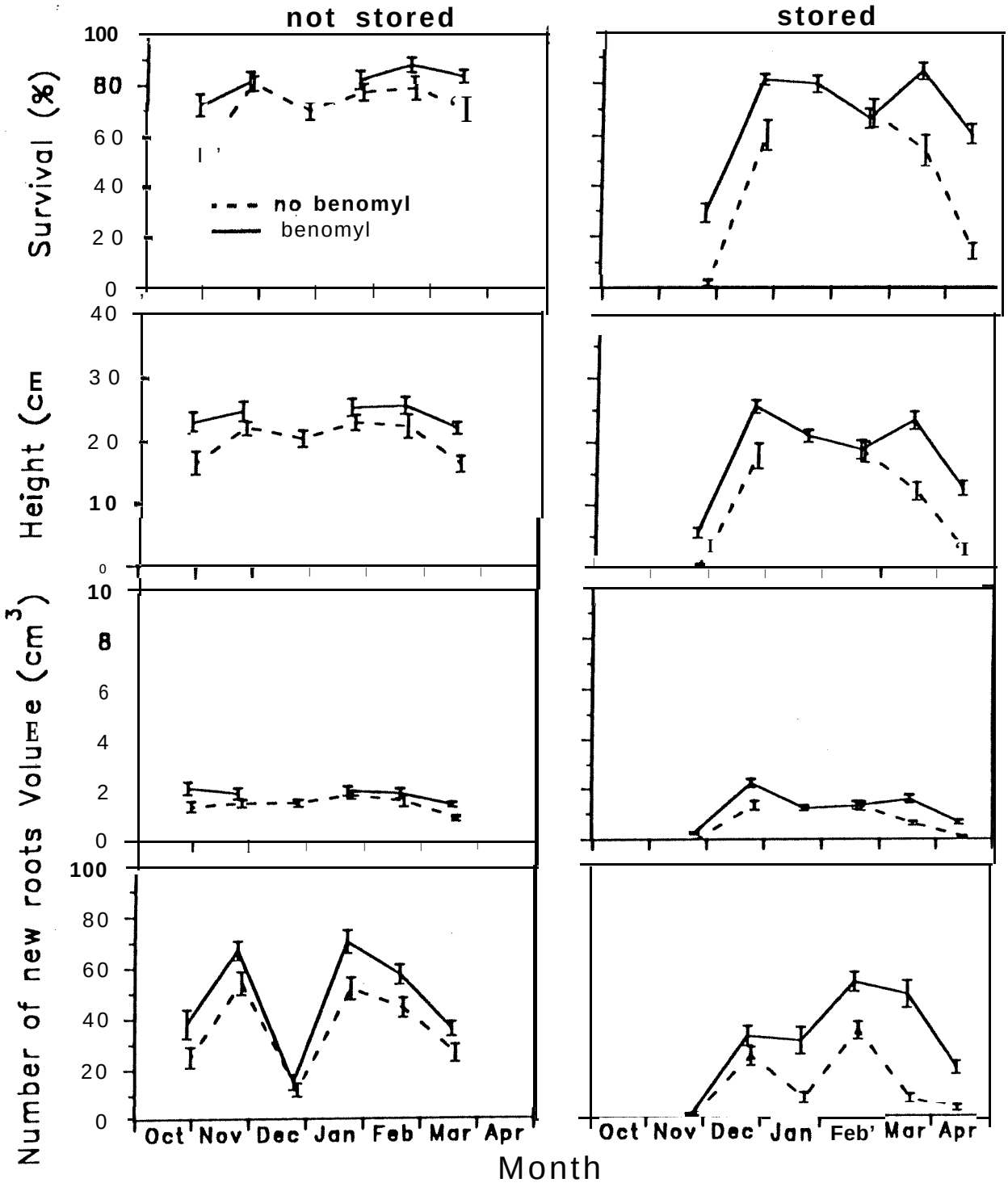

Figure 6.--Effect of lift date and benomyl treatment (0.5 percent active ingredient) in the 1989-90 planting season on mean number of new roots in the RCP test, mean stem volume per planted seedling, mean height of surviving trees and mean percent survival one year after planting in the field. Seedlings were planted on the Kiamichi District of the Ouachita NF near Billy Creek. Data plotted by planting date for seedlings that were not stored or stored for 28 days. Points represent the mean of 20 replicates in the field (row plots of **10 trees)** and of 33 replicates in the RGP test (3 trees per replicate) and bars equal +/- the standard error of the mean.

MULTIFAMILY COMPARISON OF BARE-ROOT AND CONTAINER GROWN SHORTLEAF PINE SEEDLINGS FOR THE OUACHITA AND OZARK MOUNTAINS[1/]

John C. Brissette and James P. Barnett[2/]

Harvested sites in the Ouachita and Ozark Mountains have often been difficult to regenerate because of harsh site conditions and sometimes because of poor quality planting stock. This study was one of several initiated as part of the Task Force on Shortleaf Pine Artificial Regeneration in the Ouachita and Ozark Mountains. An earlier study had suggested that there was much genetic variation among shortleaf pine seedlings produced from a seed orchard bulked lot. That variation made interpretation of treatment effects difficult. This and other studies conducted by members of the task force used seedlings from half-sib family collections in order to account for genetic variation and, thereby, allow more accurate explanations of treatment effects.

This study was initiated in 1986 by Jim Barnett and John Brissette. Seeds were obtained from the USDA Forest Service Ouachita and Ozark seed orchard located near Mount Ida, Arkansas. Cones were collected by orchard personnel from six clones and represent three geographic sources that make up most of the seed orchard. Those families with an identification number in the 100's are from east Ouachita, the 200's are from west Ouachita, and the 300's are from the Ozark.

Bare-root seedlings were grown at Weyerhaeuser Company's Magnolia Forest Regeneration Center in southwest Arkansas. Families were assigned at random to adjacent rows across a nursery bed and re-randomized for each of seven replications. They were grown at a density of about 250 seedlings per m^2 (23 per ft^2). Nursery and cultural practices were applied based on the best judgment of the nursery manager. Top pruning was not done.

Container seedlings were grown at the Forest Service laboratory in Pineville, Louisiana. They were grown in Ray Leach "Stubby" cells filled with a 1:1 peat-vermiculite medium. The volume of each cell is approximately 115 cm^3 (6.1 in^3), and the density is about 500 per m^2 (46 per ft^2). Five trays, or replications, of each family were grown.

In general, bare-root seedlings were taller (fig. 1) and had greater diameters (fig. 2) than container seedlings. The ratio of height-to-diameter, an index of sturdiness, was more favorable for bare-root seedlings in some families and for container seedlings in other families

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[1/] Presented as a field-tour stop on the Winona District of the Ouachita National Forest; Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

"Research Foresters , USDA-Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

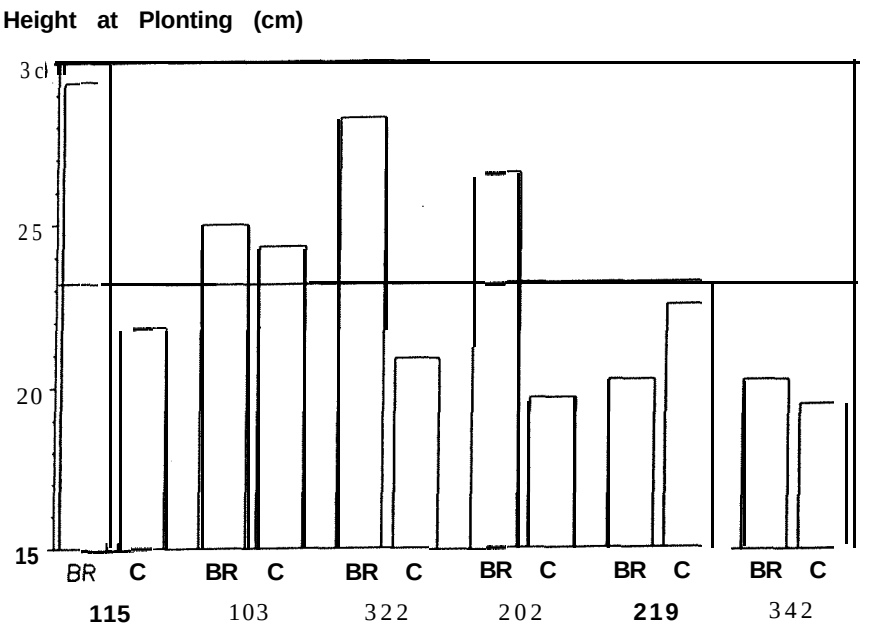

Figure 1. --Mean height at time of planting bare-root (BR) and container (C) seedlings from six half-sib families of shortleaf pine. The horizonal line is the overall mean height (23.2). The families are ranked from left to right by decreasing mean height.

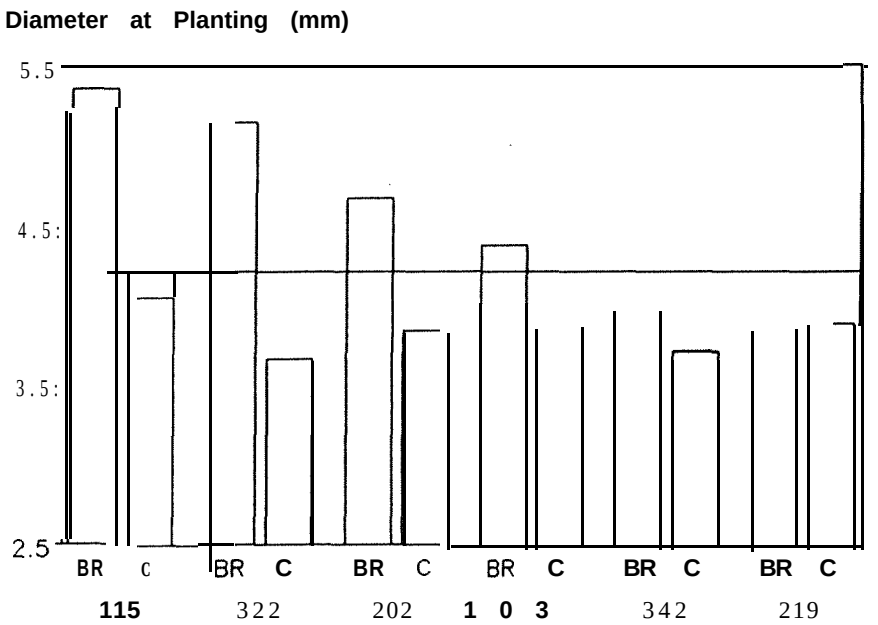

Figure 2. --Mean root collor diameter at time of planting bare-root (BR) and container (C) seedlings from six half-sib families of shortleaf pine. The horizontal line is the overall mean diameter (4.2 mm), The families are ranked from left to right by decreasing mean diameter.

(fig. 3). Among all families, container seedlings had greater root volume, a measure of the amount of roots planted, than bare-root seedlings (fig. 4).

Outplanting sites were regeneration areas on the Winona Ranger District, Ouachita National Forest and the Magazine Ranger District, Ozark National Forest. Both sites were ripped during site preparation and seedlings were planted in the rips; container seedlings in December 1986 and bare-root seedlings in February 1987. The study was planted in a split-plot experimental design with 6 blocks. Stock type was in whole plots and family In subplots. Each block x stock type x family combination was represented by a 25-tree row plot.

First-year survival on both sites exceeded 94 percent for all families and both stock types (Brissette and Barnett 1989). Among all families on both sites, container seedlings grew more than bare-root seedlings during the First year in the field (Brissette and Barnett 1989). Thus, although container seedlings were smaller than bare-root seedlings when planted, at the end of the first growing season, they were 'significantly larger.

After 3 years, survival of container seedlings was significantly greater than survival of bare-root stock on both sites (table 1). The interaction between stock type and family, and differences among families were not significant for survival at either site.

Table 1 .--Survival and total height of container and bare-root seedlings 3 years after planting on two sites.

Site Stock type	Survival (%)	Height (cm)
Winona RD		
Container	97.8a*/	124a
Bare-root	92.7b	104b
Magazine RD		
Container	95.6a	170a
Bare-root	92.0b	153b

*/Within a site, survival and mean height followed by the same lower case letter were not significantly different (p-0.05).

Between the first and third years at Winona, container seedlings grew an average of 84 cm in height, compared to average growth of 77 cm for bare-root stock. Thus, after 3 years, container trees were significantly taller than bare-root trees (table 1). Height differences among families were significant. The tallest two families differed from the shortest two (fig. 5). There was no interaction in third-year height between stock type and family.

Results at the Magazine site were similar. Height growth of container trees between the first and third years averaged 132 cm, while that of bare-root stock averaged 122 cm. Consequently, container trees were

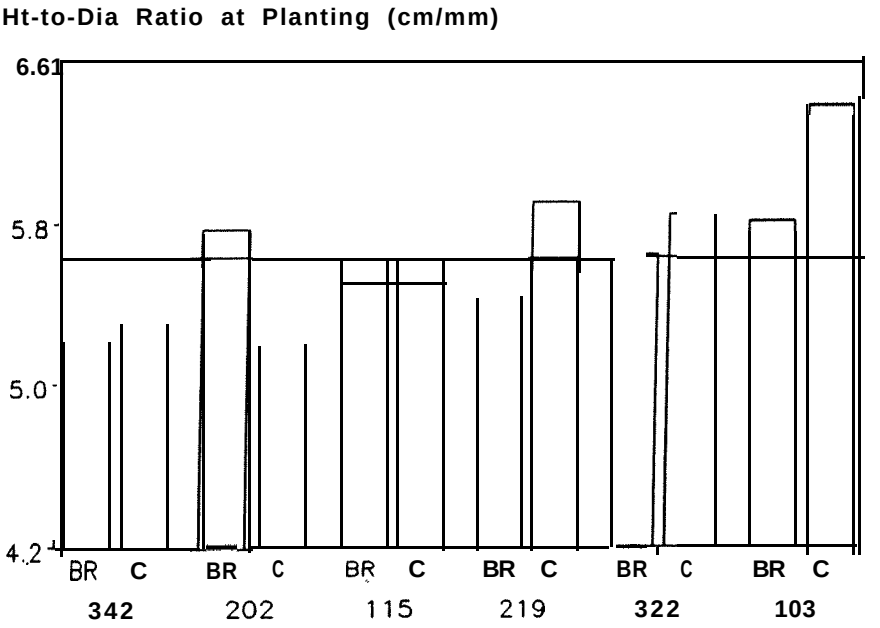

Figure 3. --Mean height-to-diameter ratio (sturdiness index) at time of planting bare-root (BR) and container (C) seedlings from six half-sib families of shortleaf pine. The horizontal line is the overall mean ratio (5.6 cm/mm). The families are ranked left to right by increasing mean height-to-diameter ratio.

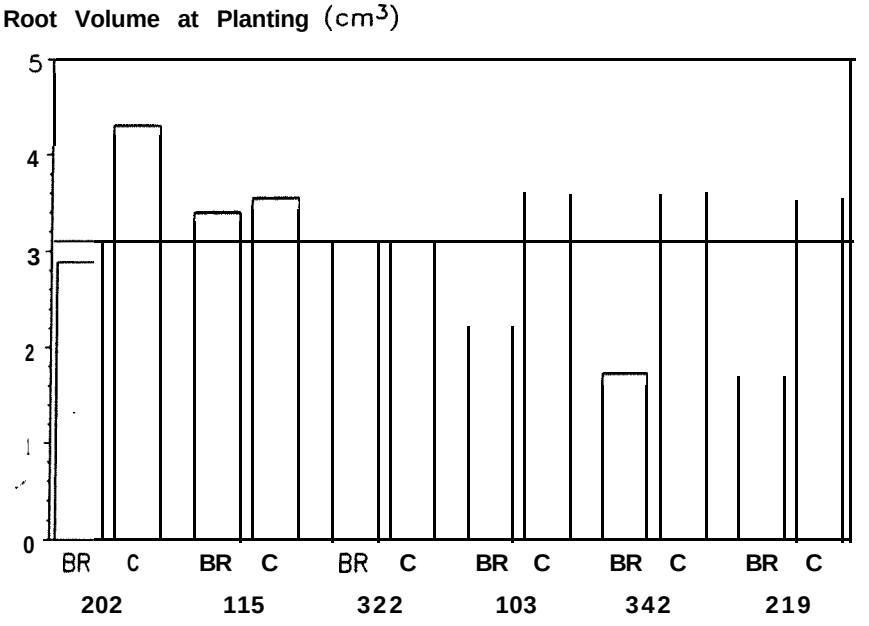

Figure 4. --Mean root volume at time of planting bare-root (BR) and container (C) seedlings from six half-sib families of shortleaf pine. The horizonatal line is the overall mean root volume (3.1 cm^3). The families are ranked from left to right by decreasing mean root volume.

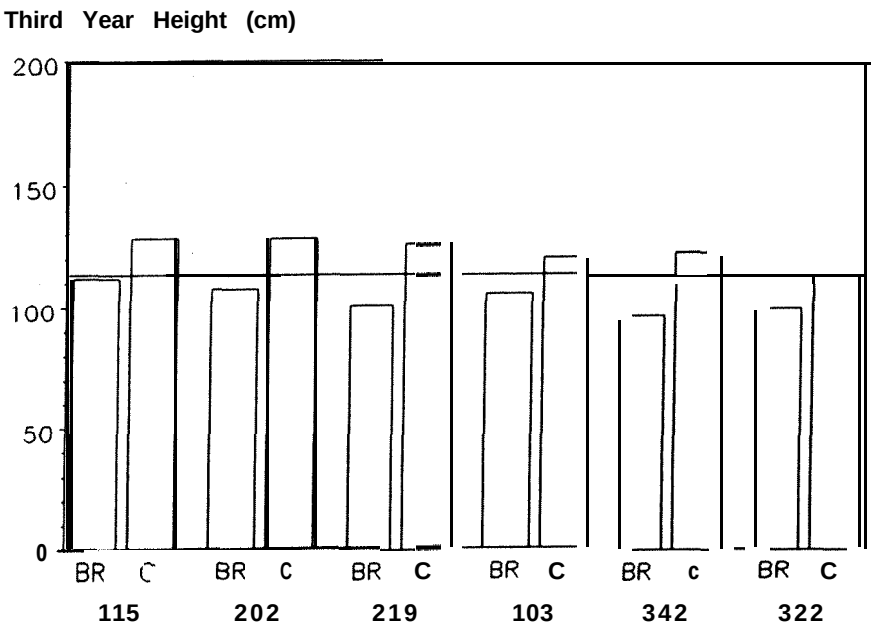

Figure 5.--Mean height of bare-root (BR) and container (C) seedlings from six half-sib families of shortleaf pine 3 years after planting on the Winona Ranger District. The horizontal line is the overall mean height at 3 years (114 cm).

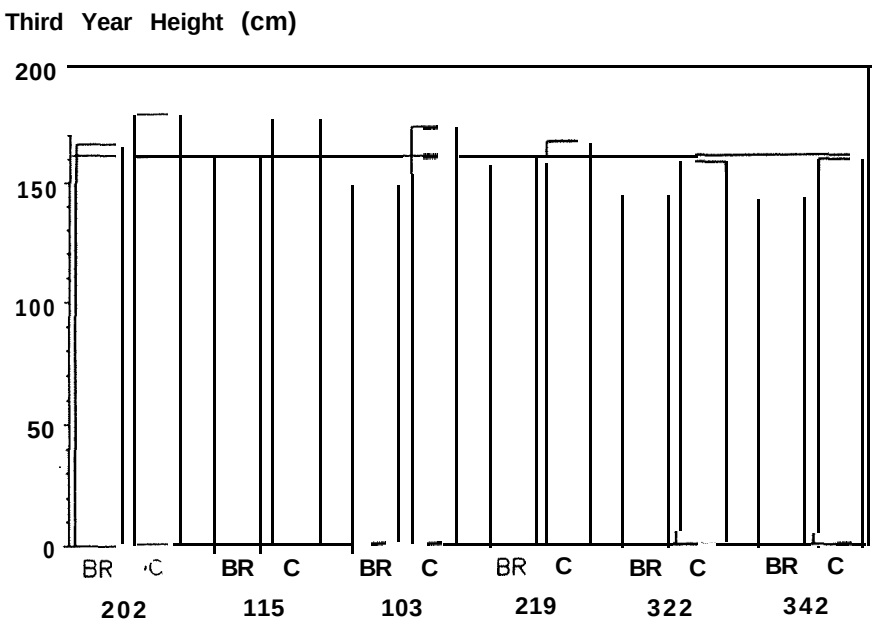

Figure 6. --Mean height of bare-root (BR) and container (C) seedlings from six half-sib familes of shortleaf pine 3 years after planting on the Magazine Ranger District. The horizontal line is the overall mean height at 3 years (161 cm). Families are ranked from left to right by decreasing mean height.

significantly taller than bare-root trees after 3 years (table 1). Height differences among families were significant; the two tallest families differed from the three shortest families (fig. 6). As at Winona, the interaction between stock type and family was not significant.

Including family in the experimental design helped clarify the effect of stock type, especially on the Magazine site. The experimental design accounted for 79 percent of the variation in third-year height at Winona. The main effect of stock type explained 27 percent of the variation in height, while the family main effect explained just 5 percent. At Magazine, the experimental design accounted for 71 percent of the variation in third-year height and, similar to the Winona planting, the stock type main effect explained 26 percent of the variation. However, at this site, the main effect of family was much more important --explaining 24 percent of the variation in third-year height.

LITERATURE CITED

Brissette, J. C. and J. P. Barnett. 1989. Comparing first-year growth of bare-root and container plantings of shortleaf pine half-sib families. P. 354-361 in Proc. 20th Southern Forest Tree Improvement Conference. Sponsored Publ. No. 42, Southern Forest Tree Improvement Committee.

MONITORING THE WEATHER AT A PLANTING SITE ON THE WINONA RANGER DISTRICT, OUACHITA NATIONAL FOREST[1/]

J. C. Brissette, C. D. Andries and C. M. Stangle[2/]

INTRODUCTION

Successful artificial regeneration depends on many factors, including: seedling quality, site quality, care exercised during handling and planting, and the environment during seedling establishment. The nursery manager and forester can control, or at least influence, the first three. However, little control of the seedling environment after outplanting is possible. Nevertheless, the environment, especially weather, can be monitored to better understand the establishment process and help explain field performance.

Electronic data loggers andnumerous sensors are available enabling nursery managers and foresters to automatically monitor weather on a daily or evenhourly basis. One such weather station was installed on the Winona Ranger District, Ouachita National Forest. The station was one of several located at planting sites throughout the United States as part of the Reforestation Improvement Program. The Reforestation Improvement Program (RIP) is a joint National Forest System-Forest Service Research effort to increase survival and growth through implementing quality control at each step of the artificial regeneration sequence. As part of RIP, a number of weather variables are measured both in nurseries and at planting sites in order to evaluate weather impacts on seedling development and establishment.

At Winona, approximately one-fourth of Compartment 1434 was site prepared for four consecutive years, beginning in summer 1985. A weather station was installed near the center of the compartment in December 1986. A sample of Ouachita-Ozark shortleaf pine seedlings grown at the contract nursery was planted when the weather station was installed and again each year until the 1989-90 season. In each of those seasons, one or more research studies under the Task Force on Shortleaf Pine Artificial Regeneration in the Ouachita and Ozark Mountains were also planted at the Winona site.

WEATHER STATION EQUIPMENT

A number of weather sensors are monitored under RIP, including air and soil temperature, relative humidity, wind speed and direction, solar radiation, soil moisture, and precipitation (Table 1). The data logger at Winona is a Model 824 EasyLogger® from Omnidata International. The EasyLogger is a self-contained, battery operated, multichannel portable recording system. Starting date and time, scanning and recording intervals, and units of measure can be programmed into the system. The equipment is programmed to scan most sensors every 5

[1/] Presented as a field-tour stop on the Winona District of the Ouachita National Forest; Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Principal Silviculturist and Forestry Technicians, USDA-Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

minutes and report the mean (or maximum or minimum values) of those scans on the hour (Table 2). Precipitation is not measured on a scan interval, it is recorded as it occurs (Table 2).

Table 1. Variables measured and sensor types used at the Winona Ranger District weather station.

Variable	Sensor	Location
temperature		
air	thermistor	1.5 m (5 ft)
air	thermistor	20 cm (8 in)
soil	thermistor	1 cm (0.4 in)
soil	thermistor	15 cm (15 cm)
relative humidity	solid-state	1.5 m
wind		
direction	wind vane	2 m (6.5 ft)
speed	anemometer	2 m
solar radiation	pyranometer	2 m
soil moisture	resistance block	15 cm
precipitation		
volume	tipping bucket	60 cm (2 ft)
intensity	tipping bucket	60 cm

Data are stored on erasable-programmable-read-only-memory (EPROM) packs which can be removed and replaced without interrupting data logging. A 64K EPROM is sufficient for one month's data, which has over 20,000 data entries.

The remoteness of the weather station precludes monthly sensor calibration.. Calibration is performed at times of planting, measurement, or systemmalfunction and averages three times per year. For calibration, a thermocouple thermometer is used to check the thermistors. Relative humidity is checked using a portable, electrically aspirated psychrometer. The rain gage is checked by pouring a known amount of water at a measured flow rate into the tipping bucket. The wind vane is checked against a hand-held compass. There are no calibration checks of the anemometer, pyranometer, or soil moisture block; these sensors are replaced at periodic intervals.

Table 2. Data recorded and units of measure at the Winona Ranger District weather station.

Variable	Data Recorded Min	Max	Mean	Total	Unit of Measure
temperature					
air, 1.5 m	X	X	X		°F
air, 20 cm	X	X	X		°F
soil, 1 cm		X	X		°F
soil, 15 cm			X		°F
relative humidity			X		%
wind					
direction			X		azimuth
speed		X	X		mph
solar radiation				X	langley min^{-1}
soil moisture			X		bars
precipitation					
volume				X	in
intensity					in sec^{-1}
climate indices					
growing degree days				X	
chilling hours				X	

WEATHER SUMMARY

Data from an EPROM are transferred to Lotus l-2-3 software on a computer using an electronic EPROM reader and communication software. A slow baud rate of 1200 is used to minimize transmission errors. Hourly data are saved in worksheets and macros provide a report of observations that are out the expected range for each sensor. 'Other macros summarize data by day and month, saving the summaries in additional worksheets. Summaries include averages and minimum and maximum values, and frequency distributions of wind direction by quadrant. Macros also calculate useful indices of climate, such as accumulated chilling hours and growing degree hours and days.

Data collected at Winona are useful for characterizing weather during seedling establishment and early growth. Figure 1 presents daily maximum and minimum air temperatures at 1.5 m (5 ft) for 1987. Data were mathematically "smoothed" to show trends more clearly than actual data points could. Besides the evident seasonal trend in temperature, figure 1 illustrates that temperature

extremes fluctuate most in spring, when planted seedlings are becoming established. Figure 2 shows precipitation was fairly consistent during spring and summer 1987, and November and December was a relatively wet period. Figure 3 presents daily maximum wind speeds in 1987 and again shows greatest variation during early spring.

Figure 4 characterizes soil conditions during the 1987-88 planting and growing season. In shortleaf pine, very little root growth occurs below 10 °C (50 °F) (Brissette and Carlson 1987). Consequently, new root growth after outplanting would have been negligible until late March 1988. Soil water is most available to plants at field capacity, which is near 0 bars, and is essentially unavailable at 15 bars. Thus, back-to-back droughts shown in figure 4 between May and August 1988 would have stopped root development and put seedlings, especially those planted the previous winter under, water stress. Figure 4 also demonstrates how quickly the upper 15 cm of soil dries and re-wets during summer, a period with high potential evapotranspiration. The relationship between soil moisture and soil temperature is also evident in figure 4.

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Brissette, J. C. and W. C. Carlson. 1987. Effects of nursery bed density and fertilization on the morphology, nutrient status, and root growth potential of shortleaf pine seedlings. P. 198-205 in Proc. Fourth Biennial Southern Silvicultural Research Conference. USDA For.. Serv. Gen. Tech. Rep. SE-42.

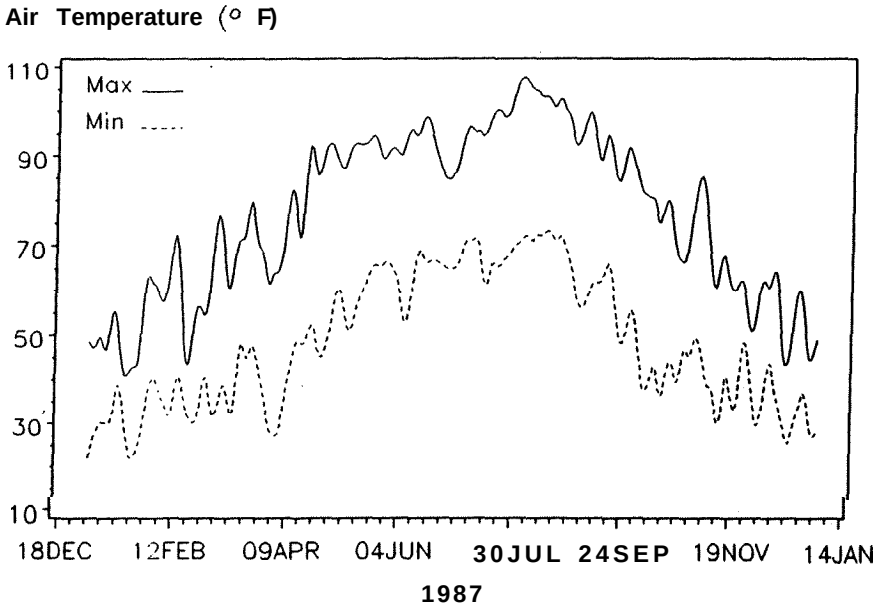


Figure 1. Daily maximum and minimum air temperature 1.5 m above ground level at Winona during 1987.

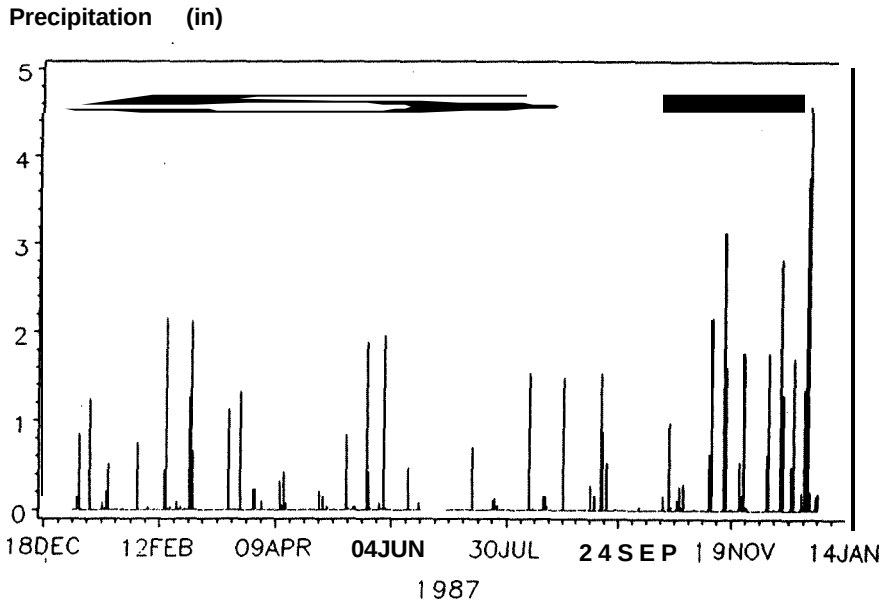


Figure 2. Daily total precipitation at Winona during 1987.

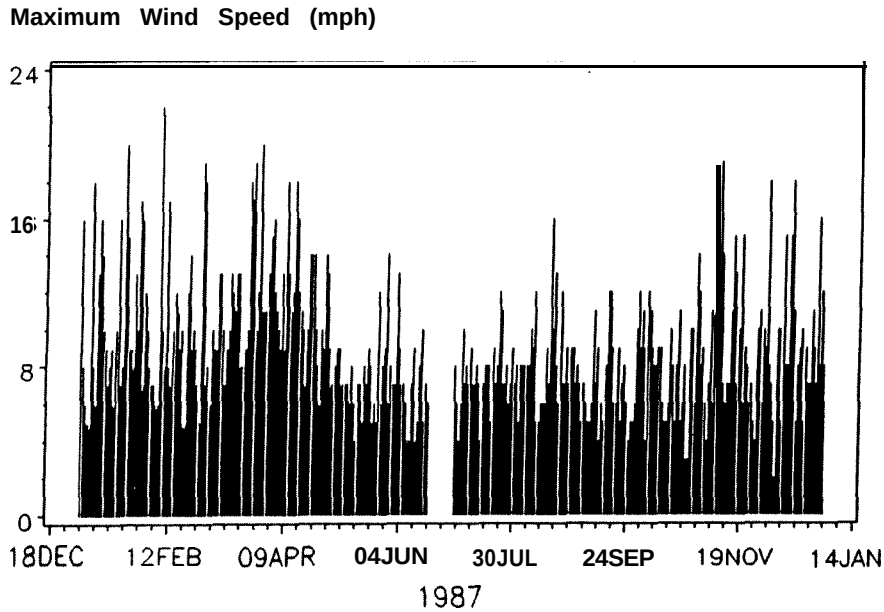


Figure 3. Daily maximum wind speed at Winona during 1987.

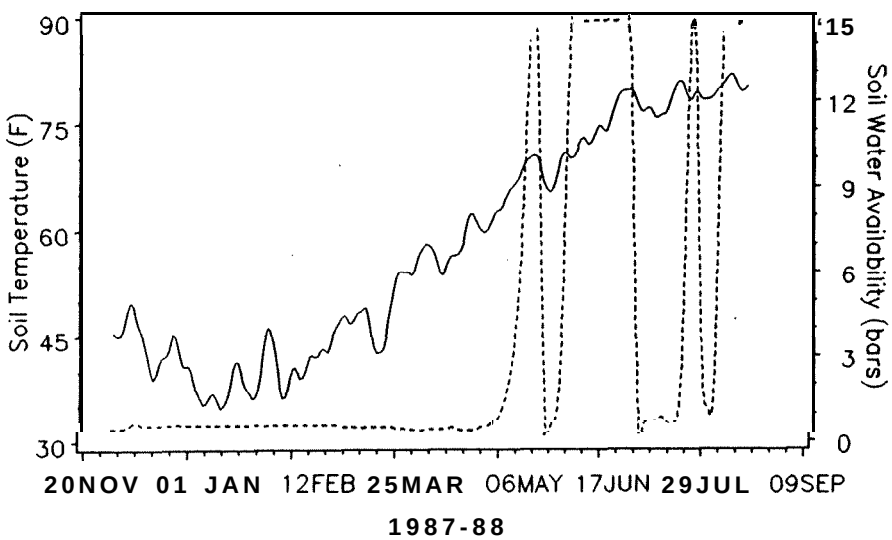


Figure 4. Daily mean soil temperature and soil water availability at Winona during the 1987-88 planting and growing season.

EFFECTS OF NITROGEN FERTILIZATION ON SEEDLING CHARACTERISTICS AND FIELD PERFORMANCE OF BARE-ROOT SHORTLEAF PINE PLANTING STOCK[1/]

John C. Brissette[2/]

INTRODUCTION

This study was initiated to follow up on a previous experiment about effects seedbed density and nitrogen (N) fertilization have on seedling quality and field performance. Results through age 5 of that initial experiment are presented in these proceedings (Brissette and Carlson, page). In that study, first year results clearly showed benefits of growing shortleaf pine seedlings at relatively low densities; however, the effects of N fertilization on seedling quality and field performance were not as obvious (Brissette and Carlson 1987).

The objectives of the study described here were to determine the pattern of response to N fertilization for various morphological attributes and field performance of shortleaf pine seedlings. To reduce variation in seedling morphology encountered in the earlier study, this research used seedlings from half-sib families.

MATERIALS AND METHODS

Seeds for this study were collected from several individual clones in the Forest Service Ouachita and Ozark seed orchard near Mount Ida, Arkansas. The experiment was laid out in a split-plot design with four blocks at Weyerhaeuser Company's Maganolia Forest Regeneration Center in southwestern Arkansas. Families were in whole plots and N fertilizer levels were in sub plots. Four families were sown in April 1987, two originating from the Ouachita National Forest and two from the Ozark National Forest. The target density was 250 seedlings per m^2. One Ouachita families had low germination, resulting in low seedbed density and seedlings not comparable to those in the other families. Consequently, results for that family are not reported here.

Seedlings were fertilized with a range of N from 0 to 180 kg N ha^{-1} at 30 kg ha^{-1} intervals. For each level, ammonium sulfate was supplied in 5 equal applications at 2 week intervals beginning 6 weeks after sowing. Fertilizer was applied with a Gandy® drop-type fertilizer spreader pulled behind a tractor.

Morphological attributes were measured on a sample of seedlings from each treatment combination and another sample was outplanted. Responses were analyzed using regression. Because increased N resulted in a linear response for all attributes measured, only a subset of nursery treatments was outplanted. Seedlings from the three families with similar seedbed densities and four fertilizer levels (0, 30, 90, 180 kg N ha^{-1}) were planted on two sites.

[1/] Presented as a field-tour stop on the Winona District of the Ouachita National Forest; Shortleaf Pine Regeneration Workshop,, Little Rock, AR, October 29-31, 1991.

[2/] Principal Silviculturist, USDA-Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

Planting sites were regeneration areas on the Winona Ranger District, Ouachita National Forest and the Magazine Ranger District, Ozark National Forest. Both sites had been ripped during site preparation. The study was planted late January 1988, in the same experimental design used in the nursery, except there were fewer treatment combinations. Each block x family x fertilizer level combination was represented by a 25-tree row plot, planted in the rips.

RESULTS AND DISCUSSION

For most seedling morphological attributes there were differences among families. Figures l-4 show effects of family and N level on height, diameter, root volume, and presence of an overwintering bud.

Overall, seedlings were larger at Magazine than at Winona after one growing season (Figures 5 and 6). At Winona, increased N fertilization in the nursery resulted in larger seedlings after one year in the field for two of the three families -(Figure 5). The level of nursery N affected first-year size of only Family 342 at Magazine (Figure 6).

Three years after outplanting, trees at Magazine had a larger mean size than those at Winona (Figures 7 and 8). At both sites, Family 342 showed increased third-year size with increased nursery N fertilization.

These results show the value of manipulating N fertilization in the nursery to produce shortleaf pine seedlings with desired morphological attributes. A number of studies have shown a relationship between shortleaf pine seedling morphological quality and field performance (see Brissette and Carlson, these proceedings). However, over the range of total N tested in this experiment, only one of three half-sib families showed a response in field growth to the amount of N applied in the nursery.

LITERATURE CITED

Brissette, J. C. and W. C. Carlson. 1987. Effects of nursery bed density and fertilization on the morphology, nutrient status, and root growth potential of shortleaf pine seedlings. P. 198-205 in Proc. Fourth Biennial Southern Silvicultural Research Conference. USDA For. Serv. Gen. Tech. Rep. SE-42.

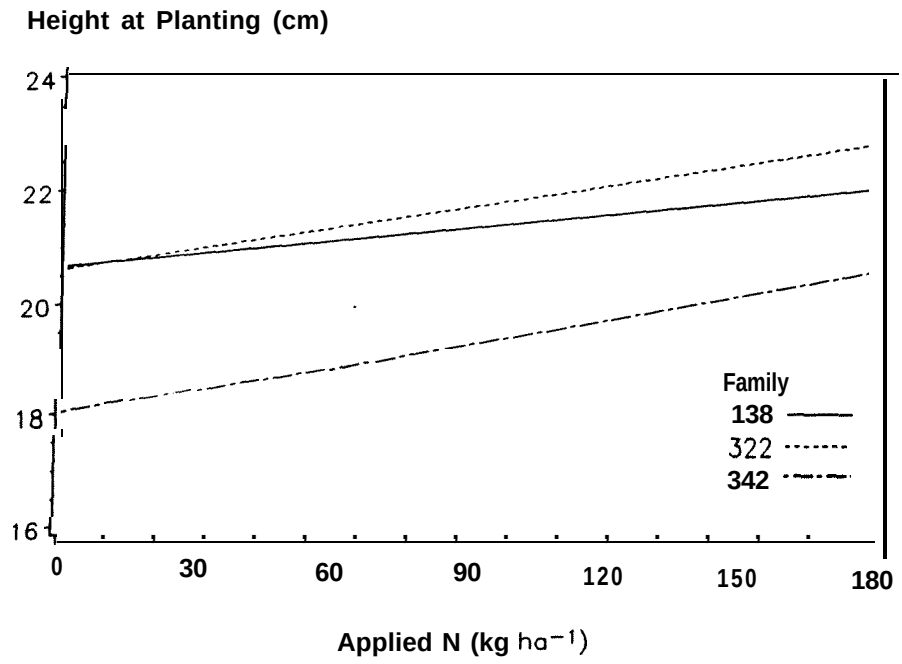


Figure 1. Relationship between initial height and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

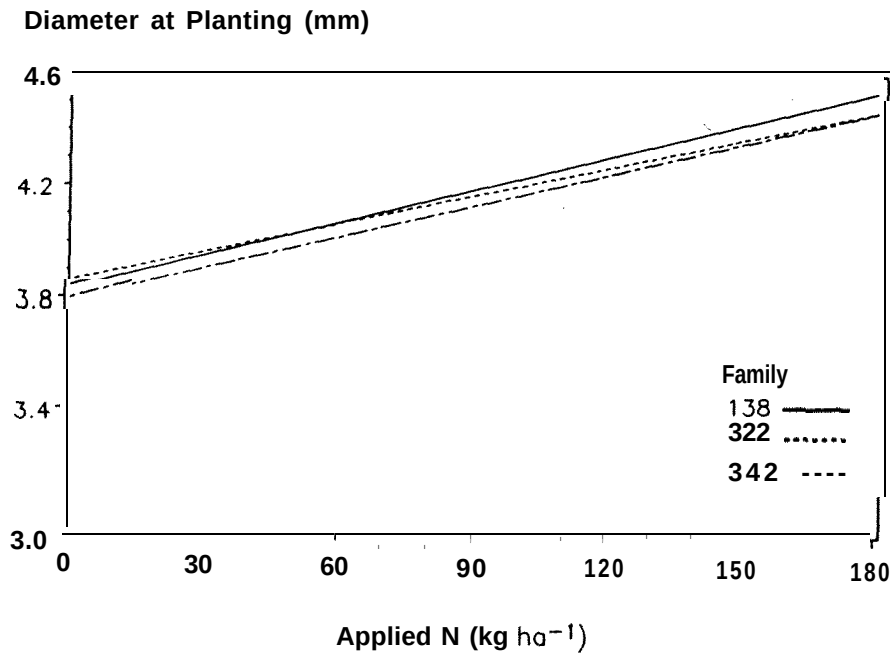


Figure 2. Relationship between initial root collar diameter and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

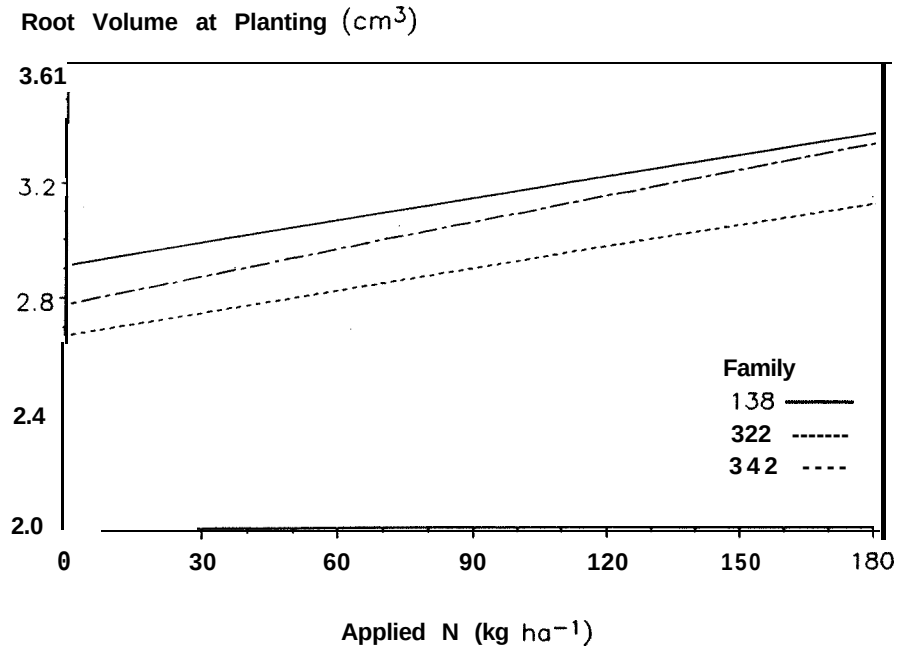


Figure 3. Relationship between initial root volume and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

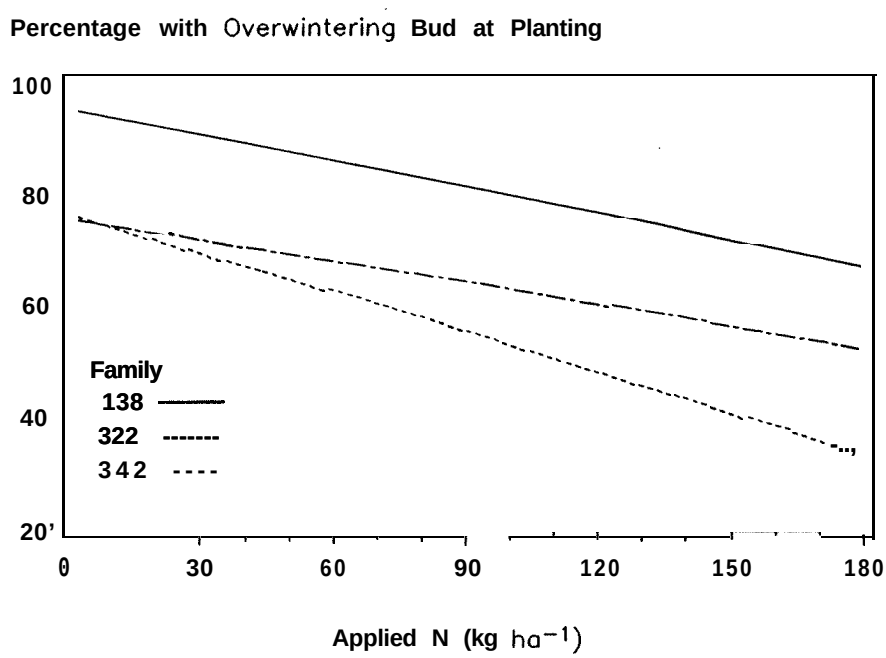


Figure 4. Relationship between the percentage of seedlings with an overwintering bud and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

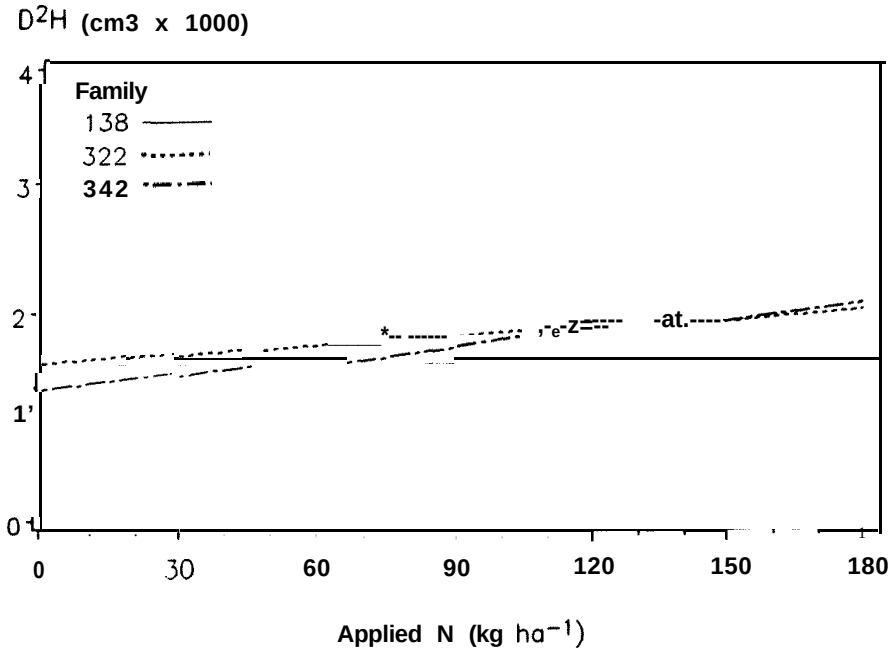


Figure 5. Relationship between D^2H after 1 growing season at Winona and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

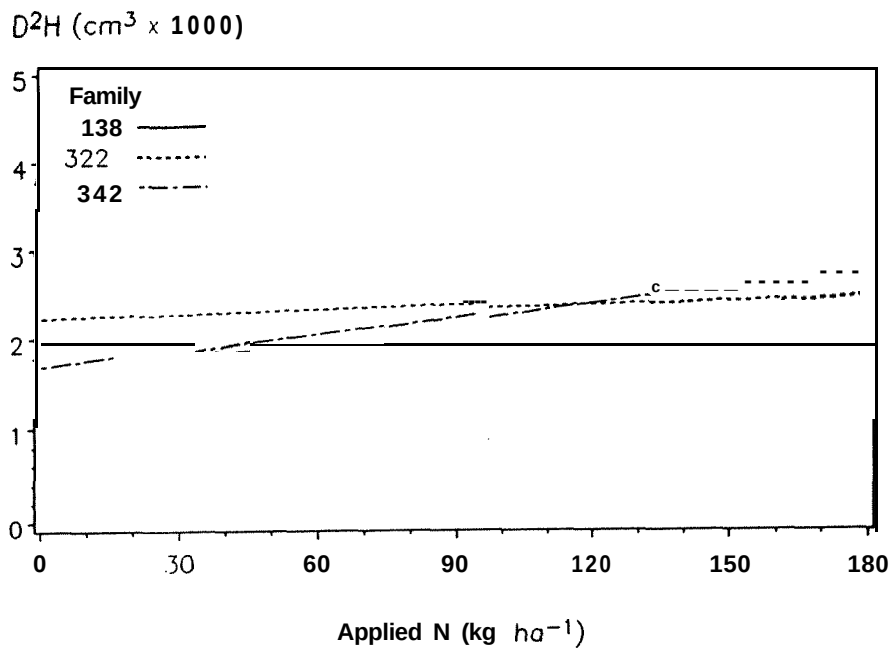


Figure 6. Relationship between D^2H after 1 growing season at Magazine and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

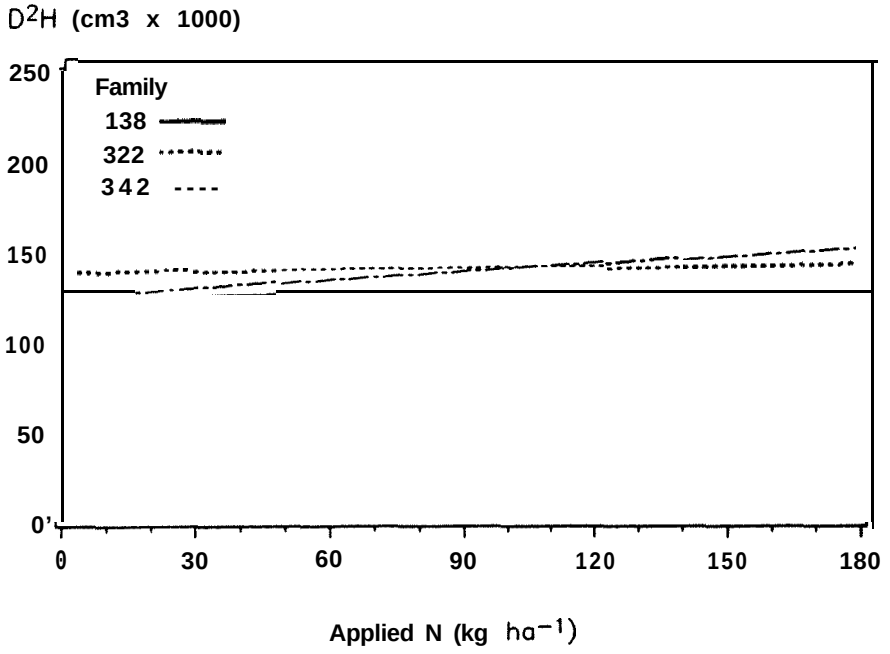


Figure 7. Relationship between D^2H after 3 growing seasons at Winona and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

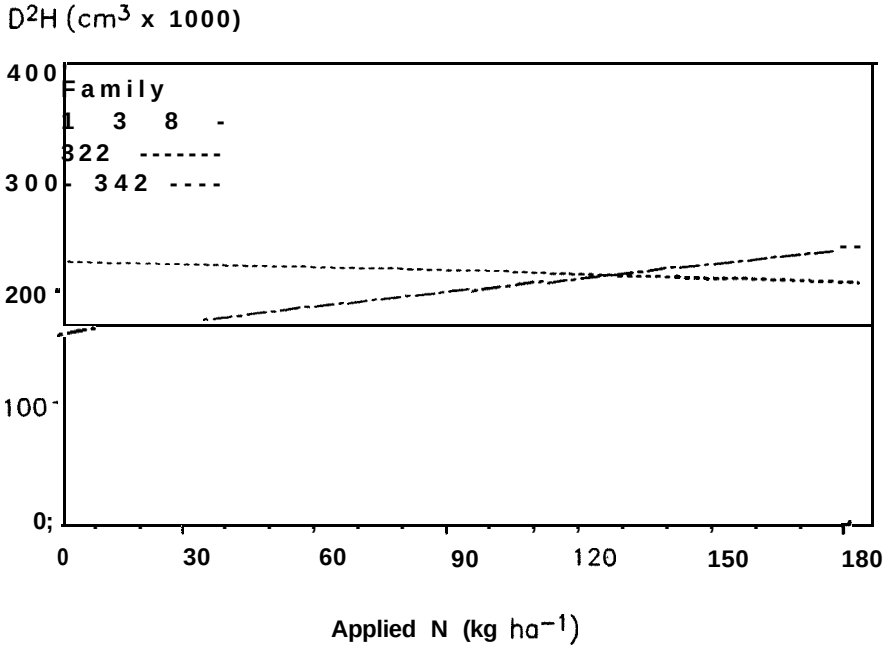


Figure 8. Relationship between D^2H after 3 growing seasons at Magazine and amount of nitrogen applied in the nursery for three half-sib families of shortleaf pine.

UNEVEN-AGED MANAGEMENT OF PINE AND PINE-HARDWOOD MIXTURES IN THE OUACHITA MOUNTAINS[1/]

Michael G. Shelton and James B. Baker[2/]

INTRODUCTION

Each management system used in forestry has distinct advantages and disadvantages. These differences enable forest managers to select the system which best meets the individual needs of a particular area. Such choices have to be made to provide a desirable mix of goods and benefits from the forest, because no single management system is ideal for every situation. Uneven-aged management is often suggested as an alternative to even-aged management, which frequently involves clearcutting. Unfortunately, our experience with and scientific knowledge of uneven-aged management lags far behind that of even-aged systems. To alleviate this disparity, the Ouachita National Forest and the Southern Forest Experiment Station launched this long-term research project in 1988 to study uneven-aged management of shortleaf pine and pine-hardwood mixtures in the Ouachita Mountains. The successful use of uneven-aged management in the southern pines has to date been limited to pure stands. However, the maintenance of a hardwood component is desirable to enhance biological diversity, wildlife habitat, and aesthetics. The initial research effort has been expanded since its initiation to involve an interdisciplinary evaluation of both uneven-aged and even-aged management so that comparisons can be made.

The study's goals are: (1) to determine the levels at which pine and hardwoods are biologically compatible in uneven-aged stands, and (2) to evaluate the timber, wildlife, water quality, aesthetics and biodiversity associated with each management alternative so that sound decisions concerning the tradeoffs among these resources can be determined.

SOME UNEVEN-AGED PRINCIPLES

Through periodic partial cuts, uneven-aged stands are managed for a continuous forest cover with recurring natural regeneration of the desired species. Tree growth and development occur over a wide range of age or diameter classes to provide a sustained yield of forest products. A managed uneven-aged forest is characterized by trees of many sizes, intermingled or in small groups. Each acre of an uneven-aged forest would ideally consist of many seedlings and saplings, some medium sized trees, and a few mature trees. This size-class distribution would essentially remain the same throughout time. Natural regeneration of the target species develops in the small openings created by the harvest of mature trees, providing the trees of future harvests.

[1/] Presented as a field-tour stop on the Winona District of the Ouachita National Forest; Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Research Foresters, USDA-Forest Service, Southern Forest Experiment Station, Monticello, AR 71655.

The periodic harvests in uneven-aged stands are principally in the sawtimber-size trees on the site. However, areas with excessive numbers of pulpwood-size trees may be thinned and poor-quality trees may be cut. A basic tenet is to cut the worst and leave the best to develop into high-quality sawtimber. Since trees are cut either singly or in small groups, the visual impact of harvesting is much less than any other management system. Thus, uneven-aged management may be ideal for areas where scenic beauty, aesthetics, and recreation are priority values.

METHODS

Studv Site

The study site is typical of the forested landscape of the Ouachita Mountains. The elevation ranges from 640 to 800 feet, and the side slopes are dissected by numerous ephemeral drainages. Each replicate shown in Figure 1 represents a particular topographic position: replicates 1, 2, and 3 are on the lower, middle, and upper north slopes, respectively; replicate 4 is on an upper south slope. The site index for shortleaf pine ranges from 55 to 60 feet at 50 years, and white oak site index ranges from 50 to 55 feet at 50 years. The best site is on the lower north slope and site quality slightly declines going up the slope.

The present stand originated after harvest of the virgin shortleaf pine forest in the 1910's. Typical harvests of that era involved cutting the pines to a 14-inch stump limit and perhaps harvesting the higher quality red and white oaks. A ragged, cutover stand composed of submerchantable pines and scattered, low-quality hardwoods remained after harvest. Periodic fires were common both before and after harvest of the virgin forest. Although these fires undoubtedly killed much of the shortleaf regeneration, they also created an ideal pine seedbed and prevented the establishment of a significant hardwood component. During the three decades following harvest, enough regeneration escaped the periodic fires to establish an irregularly-aged shortleaf pine stand. Fire control was implemented in the 1930'9, which corresponds with the establishment of a significant hardwood component. Because of these past events, the pines generally ranged in age from 50 to 85 years and the hardwoods from 40 to 70 years.

Before harvesting, the basal area averaged 90 ft^2 per acre for the pine component and 31 ft^2 per acre for the hardwoods. White oak was the most prevalent hardwood, with lesser amounts of post oak, black oak, blackjack oak, and southern red oak. The midcanopy was principally composed of young oaks, with occasional hickory, red maple, serviceberry, blackgum, and dogwood. The understory was composed of tree saplings (mainly of the tolerant species) and a variety of common shrubs (e.g., huckleberries and hawthorns).

Design and Treatments

Each pine-hardwood combination is replicated four times in a randomized complete block design, providing a total of 16 1.6-acre plots. Every tree on the interior 0.5 acre of each plot is numbered so that its growth and development can be tracked through time. In addition, ten O.Ol-acre subplots were established within each net plot to evaluate the amount of regeneration and its development through time. Wildlife habitat, water quality, aesthetics and biodiversity will also be monitored over a lo-year period.

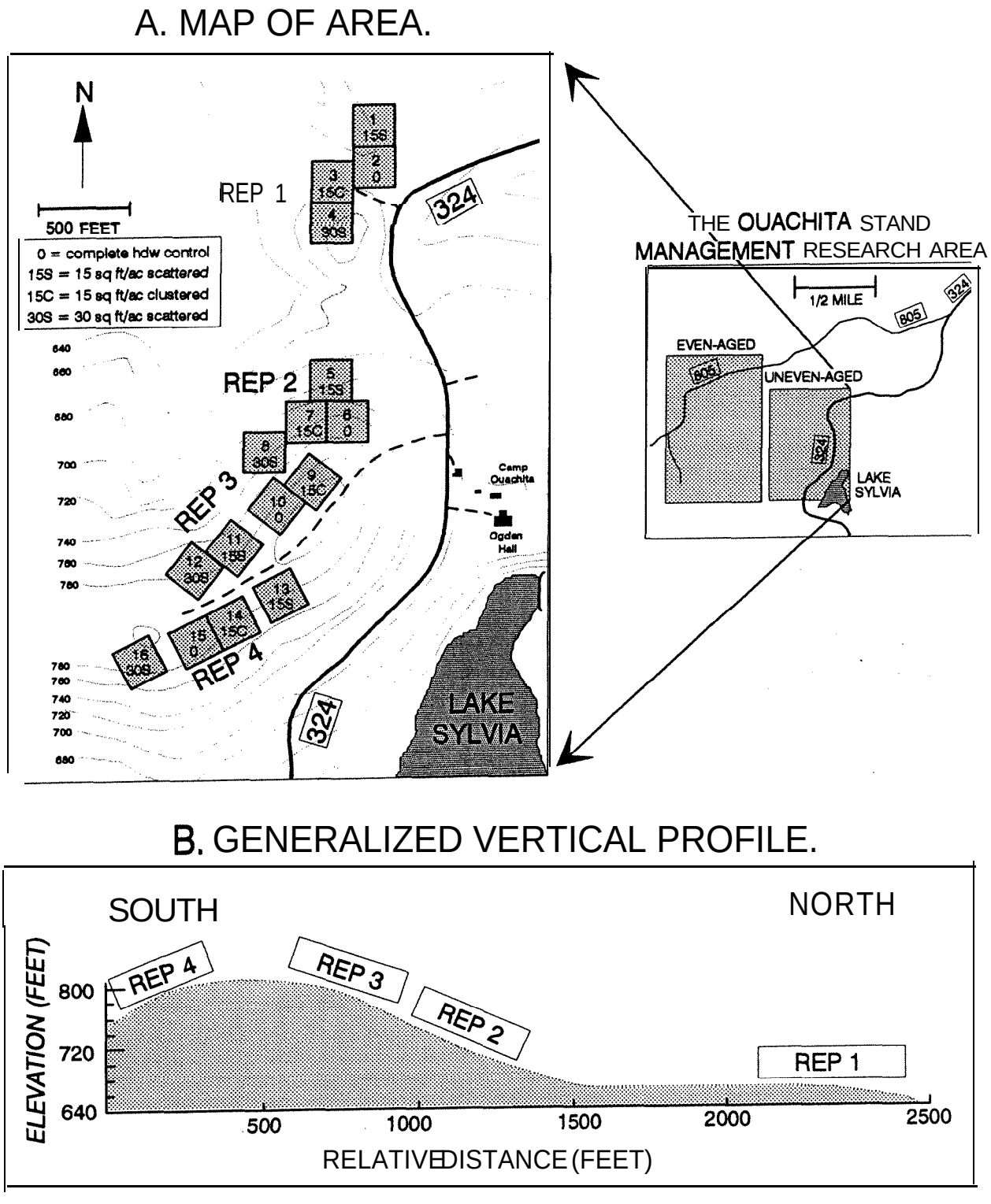


Figure 1. --Map and vertical profile of the uneven-aged management research area.

The pine component on all plots was treated in the same manner using guidelines developed at the Crossett Experimental Forest in southern Arkansas. These guidelines for single tree selection specify, in order of importance, the residual basal area, maximum diameter, and the shape of the diameter distribution. The ideal stand structure is shown in Figure 2A. However, this balanced structure will usually not exist in stands not currently under uneven-aged management. The initial harvest implementing uneven-aged management was designed to approach the ideal structure as closely as possible, while maintaining the target basal area and maximum diameter. This is done by harvesting trees in the diameter classes where there are surplus trees but leaving enough of a surplus to reach the target basal area. Minor adjustments were made to leave the higher quality trees as future growing stock. Trees with low vigor and major defects were also harvested regardless of their size. The resulting diameter distribution from this effort is shown in Figure 2A. The deficiencies in the smaller size classes are typical during the transition to uneven-aged management. These deficiencies will be alleviated when (or possibly if) regeneration occurs and develops into these size classes. It may require several lo-year cutting cycles before a balanced structure in attained.

The pine component on the study area was harvested during the late winter and early spring of 1989. Harvested pine volumes averaged 3,300 board feet Scribner per acre (Table 1). After harvest, the residual pine volumes averaged 6,300 board feet per acre. About 80% of the residual basal area of 60 ft^2 per acre was in the sawtimber component.

Four hardwood treatments are tested in combination with the uniform pine basal area as follows:

(1) Intensive hardwood control- no commercial markets existed for the hardwoods on the study area; thus, all hardwoods with a groundline diameter of over 1 inch were killed using herbicides during the spring of 1989. This treatment implemented the traditional guidelines for uneven-aged pine stands (see Figure 3A).

(2) Moderate hardwood stocking/clustered arrangement- 15 ft^2 per acre of hardwood basal area was retained in a clustered distribution among the residual pines. Openings created by the harvest of mature pines were void of both pines and hardwoods (see Figure 3B).

(3) Moderate hardwood stocking/scattered arrangement- 15 ft^2 per acre of hardwood basal area was retained in a uniform distribution over the plot. Openings created by pine harvest may have residual hardwoods (see Figure 3C).

(4) High hardwood stocking/scattered arrangement- as in (3) above except that twice the hardwood basal area (i.e., 30 ft^2 per acre) is retained (see Figure 3D).

SOME PRELIMINARY RESULTS

The sustainability of uneven-aged stands depends on obtaining periodic regeneration and providing environmental conditions suitable for its subsequent development. The most critical influence of hardwoods within

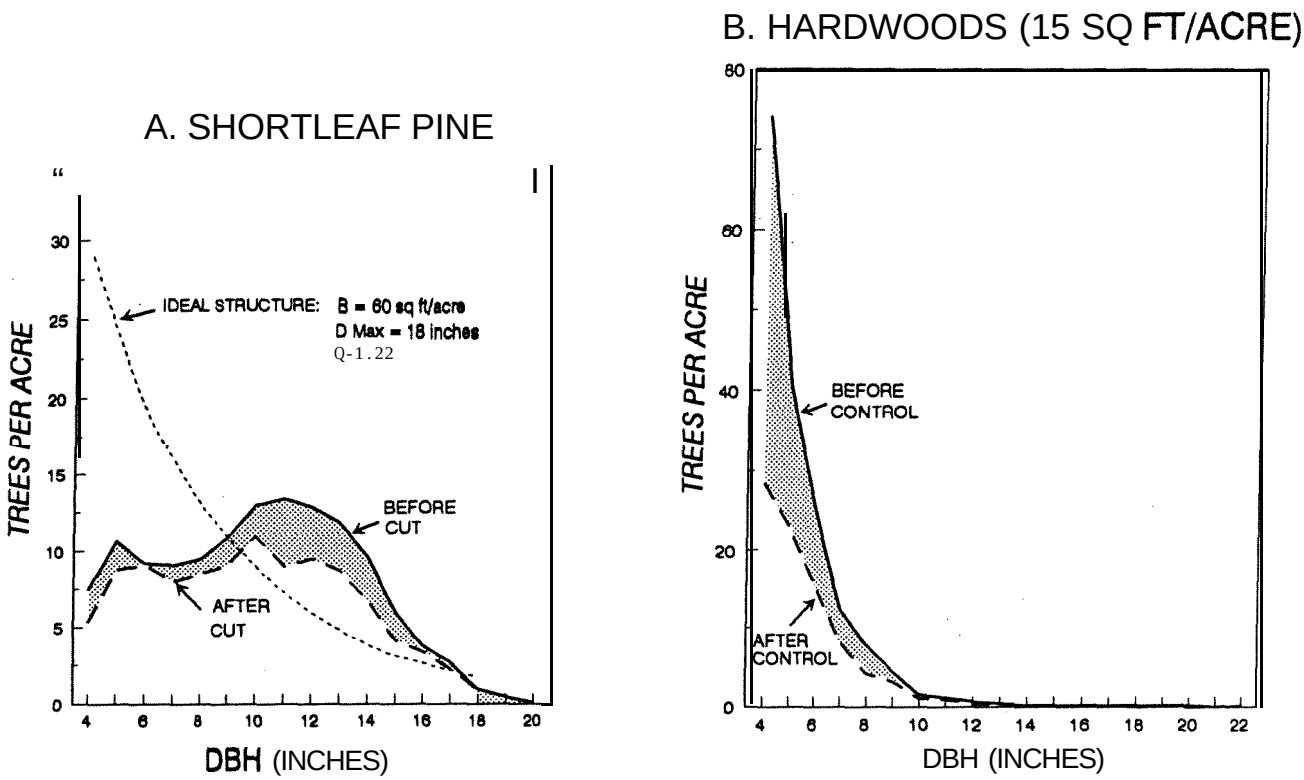


Figure 2.--(A). The ideal and observed structure of the pine component of the uneven-aged study before and after harvest. (B). An example of the hardwood structure before and after implementation of the 15 square feet per acre-scattered treatment.

Table 1. --The pine component before and after harvest.[1/]

Property	Before	cut	After
Merch. trees per acre	145	39	106
Sawtimber trees per acre	83	27	56
Merch. basal area (ft^2/acre)	90	28	62
Sawtimber basal area (ft^2/acre)	74	24	50
Merch. volume (ft^3/acre)	2,530	810	1,720
Sawtimber volume (ft^3/acre)	1,950	660	1,290
Sawtimber volume (Doyle bf/acre)	6,200	2,130	4,070
Sawtimber volume (Scribner bf/acre)	9,620	3,280	6,340
Sawtimber volume (Inter. bf/acre)	11,280	3,840	7,440

[1/]Merchantable trees are 3.6 inches DBH and larger; sawtimber trees are 9.6 inches DBH and larger.

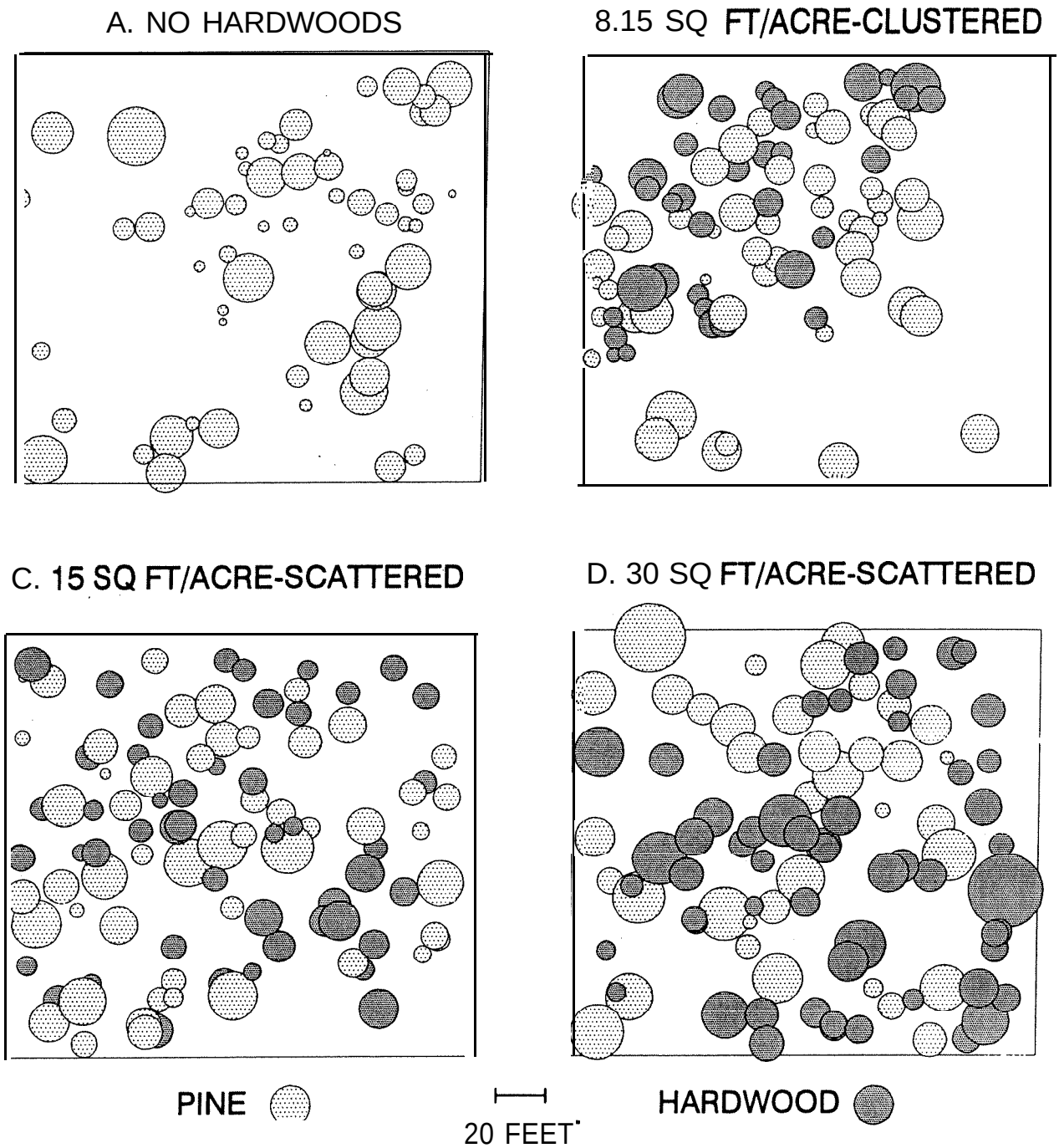


Figure 3. --Map of the residual trees in the interior 0.5-acre plots of the upper north slope (replicate 3). The width of each symbol represents the crown diameter and is drawn to scale.

uneven-aged pine stands will probably be exerted through the establishment and development of adeguate regeneration of the intolerant pines.

Monitoring regeneration began during the summer of 1989 which was the first growing season following the initial harvest and hardwood control on the study area. The survey indicated very few pine seedlings from the 1988 seed crop, although there was a small component of older seedlings from previous years. Pine seedfall was measured during the fall and winter of 1989/90; about 170,000 sound seed were produced per acre, which was a good seed crop for shortleaf pine. A regeneration survey conducted during the early summer of 1990 indicated an average of 2,680 new seedlings per acre from the 1989/90-seed crop with 70% milacre stocking. Thus, only about one out of every 65 seeds produced a seedling in the early summer. What happened to all those seeds? Many seeds were consumed by insects, birds and rodents; others did not obtain the environmental factors needed for successful germination and establishment. Although 2,680 seedlings per acre seem like more than enough to regenerate a stand, they were subjected to numerous environmental stresses, such as the severe summer-water deficits typical of the shallow, rocky soils of the Ouachitas and the varying levels of competition associated with the hardwood treatments, residual overstory pines, and understory. These stresses reduced both seedling numbers and growth (Table 2). The best survival and growth of pine seedlings occurred in pine-only treatment and worst *in* the treatment with high hardwood stocking. Monitoring indicated that the 1990/91 seed crop was essentially a failure.

The amount and composition of the understory also responded to the hardwood treatments. Following the pine harvest and hardwood control, the plant community making up the understory changed dramatically for some treatments (Table 3). The increase in coverage was inversely related to the level of retained hardwoods. Increases were mainly in vine, grass and herbaceous components, whose response was mainly due to the increased resources, such as light, nutrients and moisture, after the pine harvest and hardwood control. For example, light intensity under the pure pine canopy was about 60% of full sunlight compared to 25% under the canopy of pine with 30 ft^2 per acre of hardwoods. Increased light levels are beneficial to both shortleaf pine and its competitors. Our long-term monitoring of regeneration will determine which species wins the race for a favorable canopy position. Although a dense understory may hamper the development of pine seedlings, the understory provides suitable habitat for a diverse group of animals, screens logging debris, and protects the soil from erosion.

Table 2.--Development of the pine seedlings from the 1989/90-seed crop.

Property	Hardwood Treatment[1/]			
	0	15C	15s	30s
Seedlings/acre June 1990	3,800	1,700	1,800	3,400
Seedlings/acre Dec. 1990	2,200	550	650	750
Seedlings/acre Sept. 1991	1,900	500	120	400
Survival (%) June 1990-Sept. 1991	50	29	7	12
Seedlings/acre >0.5 feet tall in Sept. 1991	1,500	400	50	0
Milacre stocking (%) for seedlings >0.5 feet tall in Sept. 1991	52	25	5	0
Seedling hgt (ft) Dec. 1990[2/]	0.20	0.23	0.17	0.13
Seedling hgt (ft) Sept. 1991[2/]	0.72	0.84	0.57	0.32

[1/] Pine basal area of 60 ft^2 per acre plus the following: no hardwoods (0), 15 ft^2 per acre of clustered hardwoods (15C), 15 ft^2 per acre of scattered hardwoods (15S), and 30 ft^2 per acre of scattered hardwoods (30S).

[2/] Measured on the largest two seedlings per milacre if present.

Table 3.--Total coverage of the understory after harvest.

Hardwood Treatment	Understory Coverage-%[1/]		
	1989	1990	Change
0	15	40	25
15C	20	37	17
15s	16	26	10
30s	17	16	-1

[1/] Evaluated in June of each year.

ESTABLISHING EVEN-AGED PINE AND PINE-HARDWOOD MIXTURES IN THE OUACHITA MOUNTAINS USING THE SHELTERWOOD METHOD[1/]

Michael G. Shelton and James B. Baker[2/]

INTRODUCTION

This study was established in 1989 as a joint effort among the Ouachita National Forest, the Southern Forest Experiment Station, and the University of Arkansas at Monticello. It encompasses an interdisciplinary approach that will evaluate the timber, wildlife, water quality, and aesthetic resources of the shelterwood method of stand regeneration. Information generated in this effort will aid land managers in making wise choices in the application of the tested regeneration systems.

The shelterwood study provides an even-aged backdrop so that comparisons can be made with the uneven-aged portion of the overall research effort. However, it is important to bear in mind that even-aged stands have a distinctive beginning and ending point, whereas uneven-aged stands are essentially maintained continuously through time. Thus, the comparisons made in this endeavor are focused at the critical establishment phase of even-aged stand development.

The goals of the study are: (1) to determine the levels at which pine and hardwoods are compatible in the shelterwood regeneration method by evaluating the amount, spatial distribution and development of regeneration and measuring the growth and yield of the retained seedtrees, (2) determine the damage to regeneration caused by the eventual seedtree harvest, and (3) to evaluate the wildlife habitat, water quality, and aesthetics of shelterwood stands so that comparisons can be made with uneven-aged stands.

SOME EVEN-AGED PRTNCIPLES

Even-aged management is directed toward providing a suitable environment for a group of similarly aged individuals. It is an efficient system that is commonly used in agriculture and forestry to manage a wide variety of living organisms, from cotton to chickens to trees. It is efficient because the requirements of nearly all living organisms are closely linked to their age or stage of development. Even-aged management is especially well suited to the development of intolerant tree species that require full sunlight to achieve maximum rates of growth. Since all individuals are in the same developmental stage, an even-aged stand is characterized by a high degree of uniformity in size, and a single main canopy is typical. The size differences that occur in an even-aged stand generally reflect the vigor and competitive status of the individual trees rather than differences in age. Once established, the trees of an even-aged stand are managed by periodic thinnings to maintain acceptable growth rates of desired products throughout the rotation.

[1/] Presented as a field-tour stop on the Winona District of the Ouachita National Forest; Shortleaf Pine Regeneration Workshop, Little Rock, AR, October 29-31, 1991.

[2/] Research Foresters, USDA-Forest Service, Southern Forest Experiment Station, Monticello, AR 71655.

Rotation age refers to the time when the trees have attained the size and quality that meet a predetermined set of management objectives. Long before the rotation age is approached, plans should be made concerning the regeneration method that will be used to establish the next stand. There are a number of options available for regenerating even-aged stands. Artificial methods involve clearcutting all of the merchantable trees in a single operation and planting tree seedlings. In contrast, natural regeneration methods retain varying levels of mature trees to produce the seeds needed to establish the next stand. Both artificial and natural regeneration methods have a unique set of advantages and disadvantages that must be carefully considered in their application to each particular situation.

This study is designed to evaluate the effectiveness of the shelterwood reproduction method in establishing even-aged shortleaf pine-hardwood stands. The shelterwood method gradually removes the mature trees in a series of partial cuts, which will release selected seedtrees for enhanced seed production. After adequate levels of natural regeneration have been secured, the seedtrees may be removed; this usually involves a 5- to lo-year period. The shelterwood method retains more seedtrees than other natural regeneration methods, and thus maximizes seed production. This may be favorable in regenerating shortleaf pine, which does not produce bountiful seed crops. The increased seed production associated with the shelterwood method minimizes the need for intensive site preparation. In addition, the larger number of mature trees retained in a shelterwood may make the stand more visually pleasing during the regeneration phase, and the enhanced growth of these trees *may* increase timber yields.

METHODS

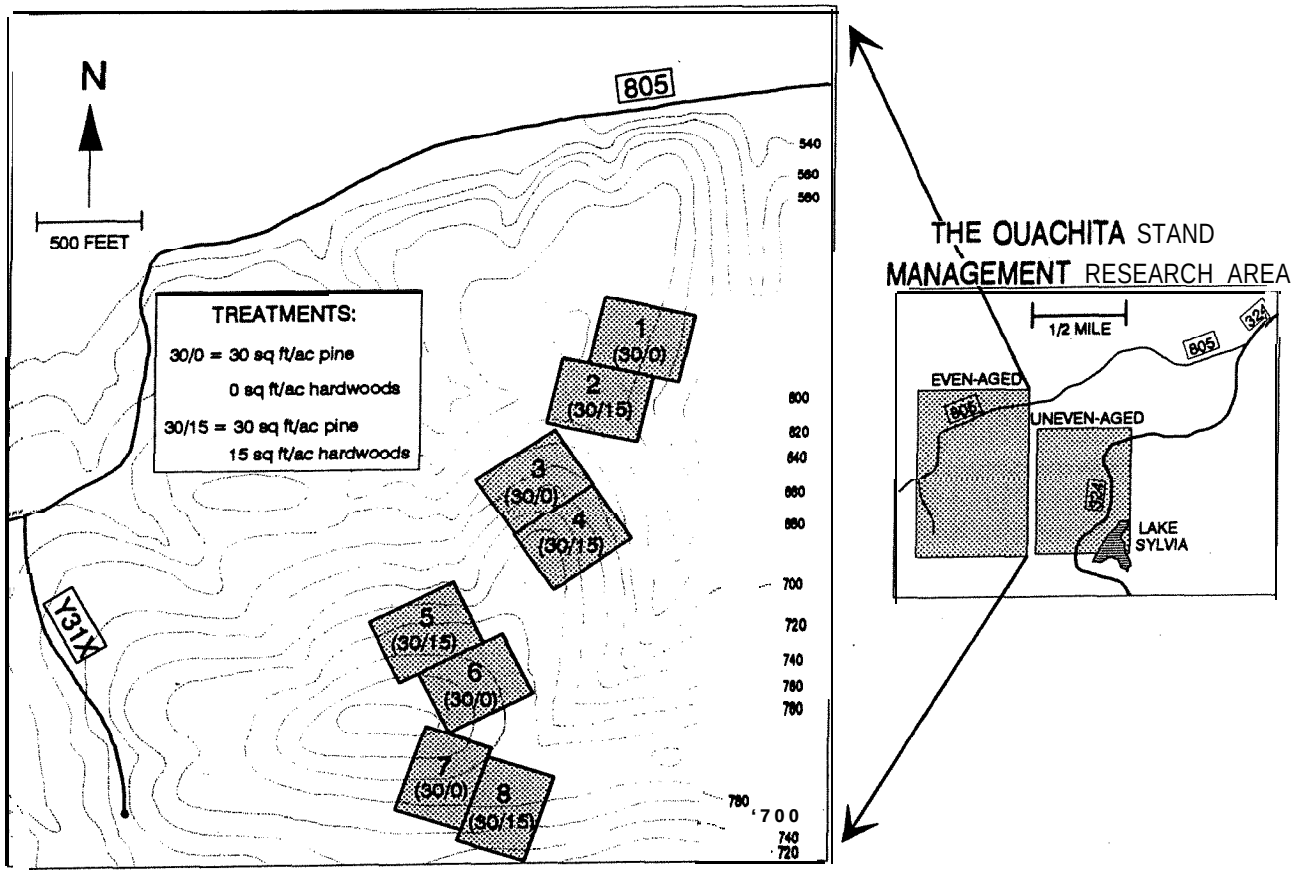
Studv Site

The study site is typical of.the forested landscape of the Ouachita Mountains and is very similar to the uneven-aged study site located 0.5 miles to the east (Figure 1A). The elevation ranges from 620 to 840 feet. Each replicate shown in Figure 1B represents a unique topographic position which is matched in the uneven-aged study: replicates 1, 2, and 3 are located on the lower, middle, and upper north slopes, respectively; replicate 4 is on the upper south slope. The site index for shortleaf pine ranges from 55 to 60 feet at 50 years. The best site is on the lower north slope and site quality slightly declines going up the slope. The dominant shortleaf pines and oaks are generally from 65 to 75 years old. Before harvesting, the pine basal area averaged 74 ft^2 per acre and hardwood basal area averaged 41 ft^2 per acre. Compared to the uneven-aged study area, this area had slightly less pine stocking and slightly more hardwoods. White oak was the most prevalent hardwood, with lesser amounts of post oak, black oak, blackjack oak, and southern red oak. The midcanopy was composed principally of oaks, with occasional hickory, red maple, serviceberry, blackgum, and dogwood.

Design

The study compares two overwood compositions (pure pine versus mixed pine-hardwoods) and two methods of submerchantable-hardwood control (chemical versus manual). Treatments are arranged in a split-plot design with four randomized complete blocks (Figure 1A). Overwood composition makes up the main plots, and submerchantable-hardwood treatments are the subplots. Each overwood composition is imposed on a 3.5-acre main plot that contains two 1.75-acre subplots. Every tree on the interior 0.70 acres of each subplot is

A. MAP OF AREA.



B. GENERALIZED VERTICAL PROFILE.

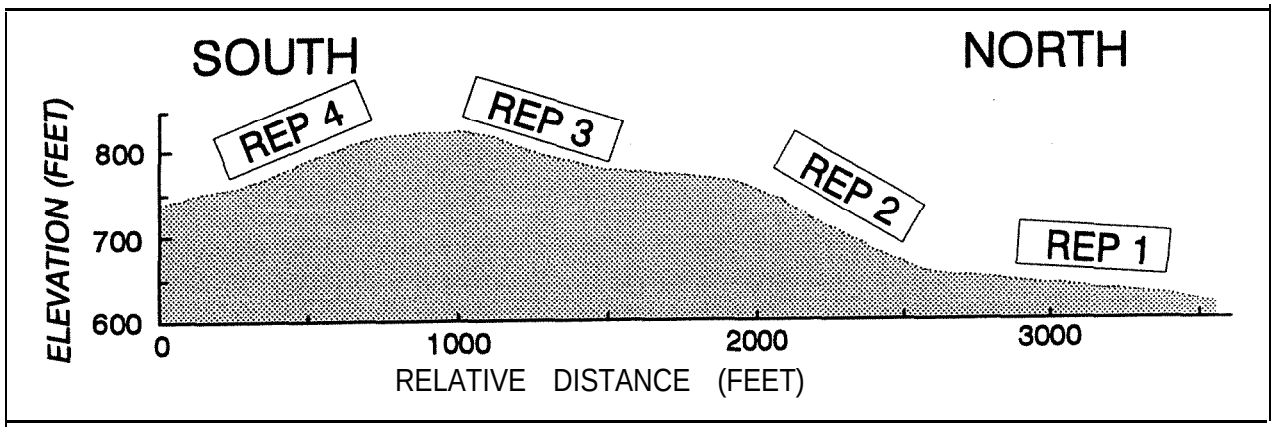


Figure 1.--Map and vertical profile of the shelterwood research area.

numbered so that its growth can be determined. In addition, eighteen 0.01-acre regeneration plots were established within each subplot to evaluate the amount of regeneration and its development through time.

Overwood Treatments

Pure pine. A basal area of about 30 ft^2 per acre of pine seedtrees was retained. Selected trees exhibited a past history of good cone production, ranged in size from.10 to 18 inches in d.b.h., and displayed high vigor and stem quality. The spatial distribution of the seedtrees was as uniform as possible, but spacing was secondary to the other selection criteria. There was an average of 28 seedtrees per acre and they averaged 14 inches in d.b.h. (Figure 2 and Table 1). The harvested volume averaged 3,800 board feet Scribner per acre for sawtimber and 5 cords per acre for pulpwood, and the volume retained in residual seedtrees was 3,600 board feet per acre. All merchantable hardwoods were harvested. Merchantable pines were harvested during the winter of 1989, but an exceptionally wet spring delayed the hardwood harvest until the summer of 1990.

Mixed nine-hardwoods. The pine component was treated as in the pure pine overwood. However, a component of desirable hardwoods (15 ft^2 per acre) was retained along with the pine seedtrees. Red and white oaks of good form and vigor were selected whenever possible. About one-quarter of the retained hardwoods were red oaks and three-quarters were white oaks. Larger trees were favored, because they will produce high shade, resist logging damage, and have a greater mast-producing potential. An average of 42 hardwood trees per acre with a mean d.b.h. of 8 inches were retained on the pine-hardwood plots.

Submerchantable-Hardwood Treatments

After harvest of the merchantable trees, there was an average'of 170 submerchantable hardwoods per acre. These trees were treated in September 1990 in the following manner:

Manual control. All submerchantable trees with a ground-line diameter of 1.0 inch and larger *were* felled with a chain saw.

Chemical control. Submerchantable trees were felled as in the manual treatment, but the cut surface was treated with a herbicide to reduce sprouting.

SOME PRELIMINARY RESULTS

Differences in the overwood treatments are indicated by the crown maps shown in Figure 3. Although the pine basal area was twice that of the hardwoods in the pine-hardwood shelterwood, the crown coverage of the hardwood component was nearly equal to that of the pine component. This reflects the relatively large crowns of the hardwoods when compared to the pines. Crown coverage also affected the light intensity under each overstory condition, which was 83% of full sunlight in the pine-only shelterwood compared to 56% in the pine-hardwood shelterwood.

The regeneration survey conducted the first growing season after the regeneration cut indicated that the pines and oaks were very similar in both milacre stocking and density (Table 2). No differences between either overstory or submerchantable treatments were apparent for the first growing

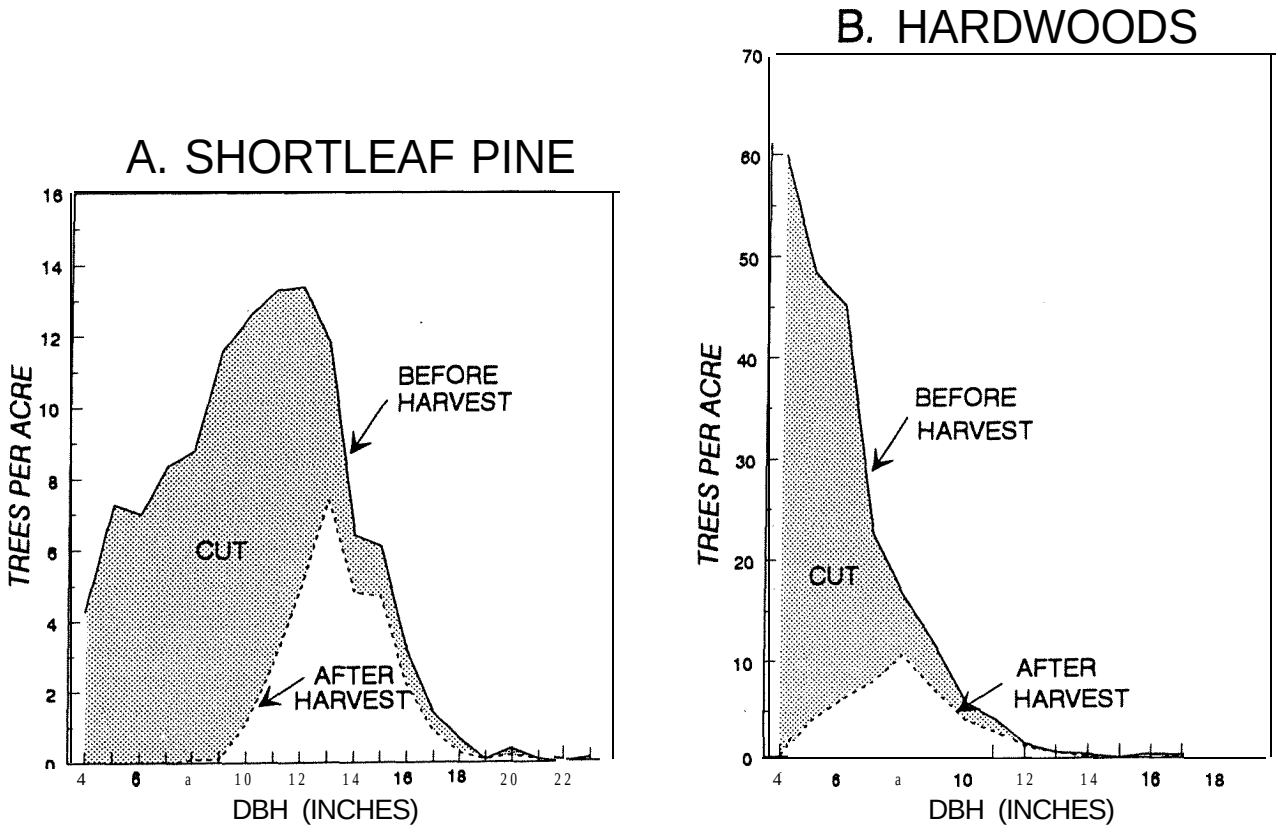


Figure 2.--Diameter distributions for shortleaf pine and hardwoods before and after the shelterwood regeneration cut.

Table 1.--Conditions in the shelterwood study before and after harvest.

Property	Before	cut	After
	----------Shortleaf Pine----------		
d.b.h.-inches	10.8	9.6	13.6
Trees per acre	117	89	28
Basal area-ft^2/acre	74	46	28
Total volume-ft^3/acre	2,000	1,200	800
Pulpwood-ft^3/acre	520	430	90
Sawtimber-bd ft Scribner/acre	7,400	3,800	3,600
	----------Hardwoods[1/]----------		
d.b.h.-inches	6.5	5.8	8.5
Trees per acre	181	139	42
Basal area-ft^2/acre	41	25	16
Total volume-ft^3/acre	990	580	410
Percent red oaks	23	21	22
Percent white oaks	69	67	76
Percent others	8	12	2

[1/] After cut values for pine-hardwood shelterwood only.

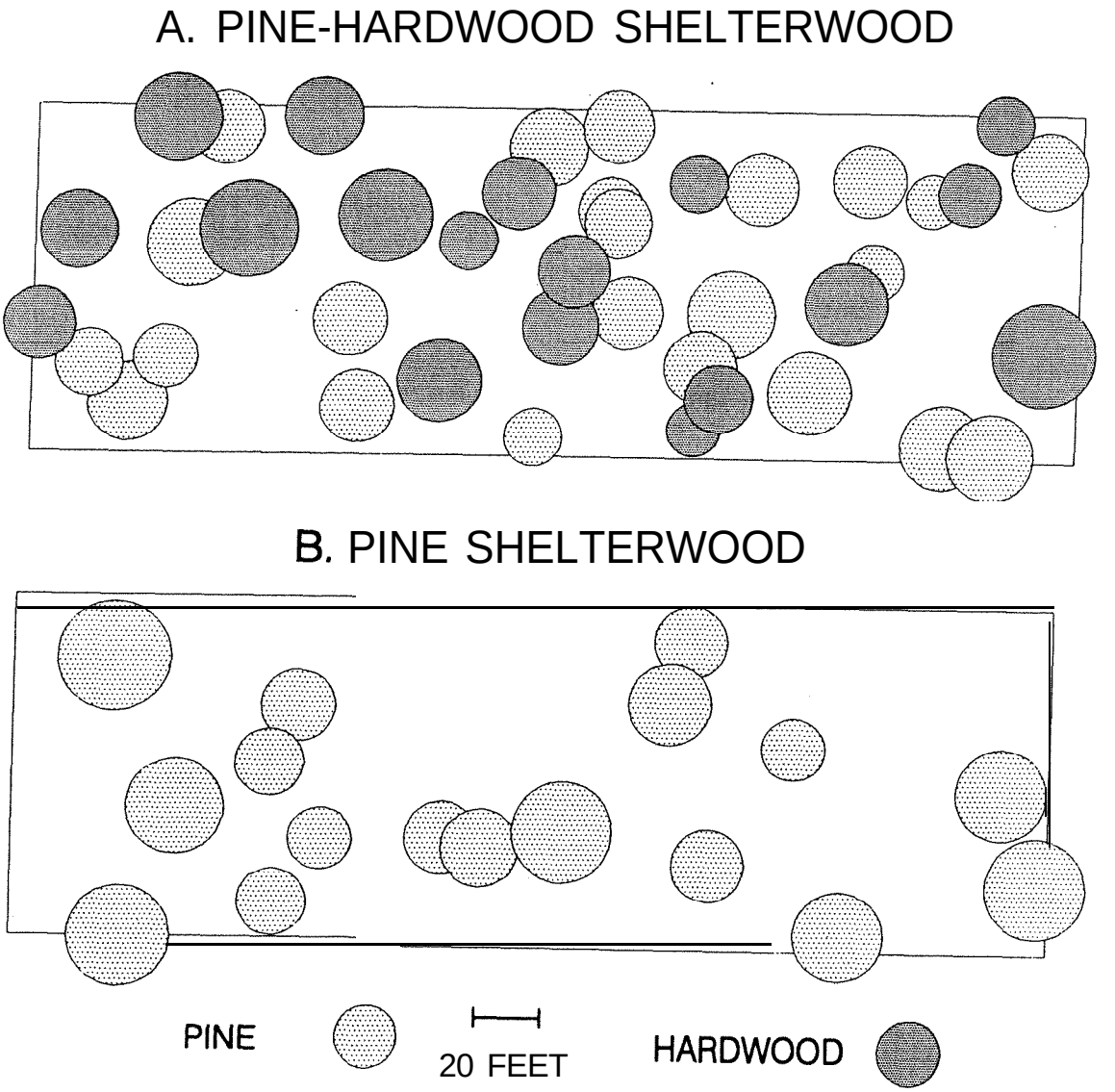


Figure 3.--An overhead *view* of two typical subplots. The width of each symbol represents crown diameter and is drawn to scale.

season after harvest. Most of the pine seedlings were established from the 1989/90-seed crop, which averaged 170,000 sound seeds per acre in the nearby uneven-aged study. However, most of the seedlings from this seed crop were destroyed by the subsequent logging activity in the shelterwood. The 1990/91-seed crop was generally a failure.

Some components of the understory vegetation responded to the overstory treatments during the first growing season after harvest (Table 3). Grass and forbs had more coverage in the pine-only shelterwood, undoubtedly a response to the higher light intensities and the lower demands on soil moisture. During the first growing season after harvest, total coverage almost doubled over preharvest levels in the pine-only shelterwood, while the pine-hardwood shelterwood increased by about one-quarter.

The success or failure of the tested treatments will not be *fully* assessed until the fifth year after harvest.

Table 2.--Milacre stocking (percent) and density (number per acre) of pine and oak seedlings at the end of the first growing season after harvest.

Overstory Treatment	Pine Seedlings		Oak Seedlings[1/]	
	Stocking	Density	Stocking	Density
Pine only	36	680	38	760
Pine-hdws	35	550	46	690

[1/] Excludes blackjack oak.

Table 3.--Horizontal coverage (percent) of species groups in the understory before and one growing season after harvest.

Overstory Treatment	Species Group					Total Coverage[1/]
	Grass	Forbs	Vines	Shrubs	Hardwoods	
	Before Harvest					
Average	3	0.5	6	10	4	22
	First Growing Season After Harvest					
Pine only	11	10	6	4	10	40
Pine-hdws	5	2	5	8	8	27

[1/] Total coverage may not equal the sum of species groups because of multiple occupancy.

LIST OF PARTICIPANTS
SHORTLEAF PINE REGENERATION WORKSHOP

October 29-31, 1991

Dan Andries
Southern Forest Exp. Station
P.O. Box 5500
Pineville, LA 71360
(318) 473-7216

Francis E. Attaway
Ozark-St. Francis Nat. Forest
Rt. 4, Box 14A
Marianna, AR 72360
(501) 295-5278

James B. (Jim) Baker
Southern Forest Exp. Station
P.O. Box 3516
Monticello, AR 71655
(501) 367-3464

James (Jim) Barnett
Southern Forest Exp. Station
P.O. Box 5500
Pineville, LA 71360
(318) 473-7216

Garner Barnum
Arkansas Forestry Commission
P.O. Box 4523
Asher Station
Little Rock, AR 72214
(501) 664-2531

John Brissette
Southern Forest Exp. Station
P.O. Box 5500
Pineville, LA 71360
(318) 473-7243

Stephen (Steve) Browder
Ozark National Forest
P.O. Box 427
Jasper, AR 72641
(501) 446-5122

Mark A. Burge
US Forest Service
P.O. Box 76
Ozark, AR 72949
(501) 667-2191

William A. (Bill) Busch
US Forest Service
4 Whitney Lane
Clarksville, AR 72830
(501) 754-8076

Gezahegne Bushra
Oklahoma State University
Forestry Dept., Ag. Hall 011
Stillwater, OK 74078
(405) 744-3710

Larry Caughern
Deltic Farm & Timber Co., Inc.
P.O. Box 129
Ola, AR 72853
(501) 489-5223

Steven (Steve) Cole
Ouachita National Forest
P.O. Box 255
Mt. Ida, AR 71957
(501) 767-0264

Jack P. Davis
Ozark National Forest
Rt. 1, Box 36
Hector, AR 72843
(501) 284-2044

Roger W. Dennington
USFS, Region 8
1720 Peachtree Rd. NW
Atlanta, GA 30367
(404) 347-7205

Jim Dixon
Ozark National Forest
P.O. Box 427
Jasper, AR 72641
(501) 446-5122

Jim Donham
International Paper Co.
602 North Hutchinson
Pine Bluff, AR 71602
(501) 247-3101

Phil Dougherty
Southeast. Forest Exp. Station
P.O. Box 12254
Research Triangle Park, NC
27709
(919) 549-4012

Kathryn Duncan
Ouachita National Forest
P.O. Box 369
Glenwood, AR 71943
(501) 356-4186

Howard Freerksen
US Forest Service
P.O. Box 511
Paris, AR 72855
(501) 963-3076

James (Jim) Gates
Kisatchie National Forest
P.O. Box 5500
Pineville, LA 71360
(318) 473-7195

James C. (Jim) Geisler
Cooperative Extension Service
P.O. Box 390
Little Rock, AR 72203
(501) 671-2000

David L. (Dave) Graney
Southern Forest Exp. Station
726 West Maple St.
Fayetteville, AR 72701
(501) 521-5695

Stephen W. (Steve) Hallgren
OSU Forestry Department
910 S. Stanley
Stillwater, OK 74074
(405) 744-6805

Floyd Hickam
Arkansas Forestry Commission
Baucum Nursery
1402 Highway 391 North
North Little Rock, AR 72117
(501) 945-3345

Kevin Hickie
Arkansas Forestry Commission
P.O. Box 100
Camden, AR 71701
(501) 836-7385

Henry Hicks
Ouachita National Forest
P.O. Box 2255
Waldron, AR 72958
(501) 637-4174

Lauri Hogeboom
Ouachita National Forest
P.O. Box 255
Mount Ida, AR 71957
(501) 867-2101

Rick Horton
International Paper Co.
Box 23
Bluff City, AR 71722
(501) 685-2562

Roy Jansson
US Forest Service
P.O. Box 76
Ozark, AR 72949
(501) 667-2191

Harold Johnson
Ouachita National Forest
P.O. Box 2255
Waldron, AR 72958
(501) 637-4174

Larry Kile
Sabine National Forest
P.O. Box F
Hemphill, TX 75948
(409) 787-3870

Johnny R. Kiser
US Army Corps of Engineers
Lake Ouachita Field Office
P.O. Box 4
Mtn. Pine, AR 71956-0004
(501) 767-2101

Robert N. (Bobby) Kitchens
USFS, Region 8
1720 Peachtree Rd. NW
Atlanta, GA 30367
(404) 347-4039

Clark W. Lantz
USFS, Region 8
1720 Peachtree Rd. NW
Atlanta, GA 30367
(404) 347-3554

Brian Lockhart
Univ. Ark. - Monticello
P.O. Box 3468
Monticello, AR 71655
(501) 460-1052

James L. (Jim) McConnell
USFS, Region 8
1720 Peachtree Rd., Suite 816
Atlanta, GA 30367
'(404) 347-4045

Cynthia (Lynn) McDonald
Sabine National Forest
101 s. Bolivar
San Augustine, TX 75972
(409) 275-2632

John McGilvray
Southern Forest Exp. Station
P.O.Box 5500
Pineville, LA 71360
(318) 473-7216

J. Kenneth Meeks
US Army Corps of Engineers
Lake Greeson Field Office
Rt. 1, Box 48B
Murfreesboro, AR 71958-9720
(501) 285-2151

John G. Mexal
Dept. of Agronomy & Horticulture
New Mexico State University
Box 3530
Las Cruces, NM 88003
(505) 646-3325

Carl D. Minehart
US Forest Service
P.O. Box 1008
Russellville, AR 72801
(501) 968-2354

Bobby Morphew
Ouachita National Forest
P.O. Box 369
Glenwood, AR 71943
(501) 356-4186

Allan Murray
Arkansas Forestry Commission
Baucum Nursery
1402 Highway 391 North
North Little Rock, AR 72117
(501) 945-3345

Larry Nance
Arkansas Forestry Commission
P.O. Box 10
Greenbrier, AR 72058
(501) 679-3584

Scott Noble
Oklahoma State University
Forestry Department
Stillwater, OK 74078
(405) 744-7061

William T. Price
Ouachita National Forest
P.O. Box 459
Danville, AR 72833
(501) 495-2844

Michael (Mike) Regan
Ozark National Forest
Rt. 1, Box 36
Hector, AR 72843
(501) 284-3150

Robert M. (Bob) Rhodey
Ozark-St.Francis National For.
P.O. Box 1279
Mt. View, AR 72560
(501) 269-3228

Justin Ridenhour
Ouachita National Forest
P.O. Box 2255
Waldron, AR 72958
(501) 637-4174

Jim H. Roberson
Ouachita National Forest
P.O. Box 459
Danville, AR 72833
(501) 495-2844

Frank A. Roth, II
University of Arkansas
Rt. 3, Box 258
Hope, AR 71801
(501) 777-9702

Thomas (Tom) Rothwell
Missouri Dept. of Conservation
P.O. Box G
Eminence, MO 65466
(314) 226-3616

Elaine Sharp
Ouachita National Forest
P.O. Box 1270
Hot Springs, AR 71902
(501) 321-5325

Michael G. (Mike) Shelton
Southern Forest Exp. Station
P.O. Box 3516
Monticello, AR 71655
(501) 367-3464

Bob Smiley
Sabine National Forest
P.O. Box F
Hemphill, TX 75948
(409) 787-3870

0. D. Smith
Ozark-St.Francis National For.
Box 1008
Russellville, AR 72801
(501) 968-3287

William (Allen) Smith
Ouachita National Forest
1039 Hwy. 10 North
Perryville, AR 72126
(501) 889-5176

Vernon Speers
Ouachita National Forest
P.O. Box 189
Jessieville, AR 71949
(501) 984-5313

Russell Standingwater
US Forest Service
Hwy. 71N, Box 220
Mena, AR 71953
(501) 394-2382

Charles Stangle
Southern Forest Exp. Station
2500 Shreveport Hwy.
Pineville, LA 71360
(318) 473-7216

Glen Stepp
US Forest Service
Hwy. 71N, Box 220
Mena, AR 71953
(501) 394-2382

Charles Studyvin
U.S. Forest Service
Box 255
Mt. Ida, AR 71957
(501) 867-2101

Mary Anne Sword
Southern Forest Exp. Station
P.O. Box 5500
Pineville, LA 71360
(318) 473-7216

Chris Tinnell
US Forest Service
Rt. 1, Box 36
Hector, AR 72843
(501) 284-3150

Jack Voeller
Ozark National Forest
Box 190
Clarksville, AR 72830
(501) 754-2864

William D. (Bill) Walker
Ouachita National Forest
Box 1270
Hot Springs, AR 71902
(501) 321-5202

Vicki M. Weindel
US Forest Service
P.O. Box 511
Paris, AR 72855
(501) 963-3076

September Wilhelm
Ozark-St.Francis National For.
1709 S. Glenwood
Russellville, AR 72801
(501) 284-3150

Robert F. (Bob) Wittwer
Dept. of Forestry
Oklahoma State University
Stillwater, OK 74074
(405) 744-5478

Jimmie L. Yeiser
Univ. Ark. - Monticello
P.O. Box 3468
Monticello, AR 71655
(501) 460-1052

Ray Yeluerton
US Forest Service
P.O. Box 369
Glenwood, AR 71943
(501) 356-4186

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