An 8-year field comparison of naturally seeded to planted container *Pinus* taeda, with and without release

Michael D. Cain and James P. Barnett

Abstract: A field study compared genetically improved, container loblolly pines (*Pinus taeda* L.) with naturally seeded loblolly pines through eight growing seasons on a cutover site in southern Arkansas, U.S.A. Measurement pines on 6 of 12 plots were released from woody and herbaceous competition within a 61-cm radius of each tree stem. On natural pine plots, only lst-year pine seedlings were selected for measurement based on quality standards and their spacing. Woody competition was controlled by hand cutting for 5 consecutive years, and herbaceous competition was controlled with herbicides for 4 consecutive years. Release treatments increased 8-year survival by 50% for natural pines and by 35% for planted pines. Greater gains (343–391%) in individual tree volumes were achieved within regeneration techniques, as a result of release, than were achieved with the two regeneration techniques. In addition, stand volume gains of 647% and 910% were achieved by planted and natural pines, respectively, as a result of release. Eight years after field establishment, stand volume index averaged 46% higher on planted plots than on natural plots. Degree of overtopping was a better predictor of pine performance than live-crown ratio.

Résumé : Des semis en récipients de pin à encens (*Pinus taeda* L.) génétiquement améliorés ont été comparés dans une Ctude au champ avec des semis régénérés naturellement durant huit saisons de croissance sur un parterre de coupe du sud de l'Arkansas, aux États-Unis. Dans 6 des 12 parcelles, les arbres qui allaient Ctre mesurés ont été dégagés de la compétition ligneuse et herbacée dans un rayon de 61 cm autour de la tige. Dans les parcelles de régénération naturelle, seuls des semis de première année ont été choisis en se basant sur des normes de qualité et sur l'espacement. La compétition ligneuse a été maîtrisée par coupe manuelle pendant 5 années successives et la compétition herbacée a été maîtrisée à l'aide d'herbicides pendant 4 années successives. Les traitements de dégagement augmentaient la survie après 8 ans de 50% pour la régénération naturelle et de 35% pour les plants reboisés. Des gains plus importants en volume individuel des tiges (343–391%) ont été obtenus par le dégagement à l'intérieur d'une méthode de régénération comparativement aux gains observés entre les méthodes de régénération. De plus, des gains en volume au niveau du peuplement de 647 et de 910% ont été obtenus respectivement pour les pins reboisés et naturels à la suite du dégagement. Huit ans après l'établissement, I'indice de volume du peuplement Ctait de 46% plus élevé dans les parcelles reboisées par rapport aux parcelles régénérées naturellement. Le degré de suppression Ctait un meilleur prédicteur de la performance des pins que le rapport de cime vivante.

[Traduit par la Rédaction]

Introduction

About 67% of the pine acreage in the southeastern United States originated from natural seedfall (USDA Forest Service 1988); consequently, this method of regeneration continues to be important for perpetuating the southern pines as a commercial resource. Even though forest landowners desire low-cost regeneration techniques, many of these landowners also prefer the advantages of artificial regeneration over natural regeneration and may attempt to reduce their establishment expenditures by outplanting improved pine seedlings where site conditions are less than optimum, such as areas with minimal, low-cost site preparation. Under those circumstances, landowners need to know the growth potential of improved pine seedlings as compared with natural pine regeneration when both are established on poorly prepared sites, with and without follow-up release.

The Upper Coastal Plain in the southeastern United States is the major physiographic subregion for growing southern pines, and loblolly pine (*Pinus taeda* L.) is the primary commercial species (Burkhart et al. 1987). Even though loblolly pine may be the dominant overstory species in naturally regenerated forests of the Upper Coastal Plain, the understory is generally occupied by a mixture of shade-tolerant hardwood trees, woody shrubs, and herbaceous vegetation (Cain 1985, 1988; Cain and Yaussy 1983).

If vigorous stands of southern pines are to be established and maintained with a competitive advantage over non-pine vegetation, proper cultural techniques must be implemented. Competition from both woody and herbaceous vegetation can severely limit available moisture, nutrients,

Received June 30, 1995. Accepted January 9, 1996.

M.D. Cain.[1] USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516, U.S.A.
J.P. Barnett. USDA Forest Service, Southern Research Station, Pineville, LA 7 1361-5500, U.S.A.

[1] Author to whom all correspondence should be addressed.

and sunlight, thereby resulting in considerable growth loss and high pine mortality in plantations (Gjerstad and Barber 1987) and naturally established stands (Cain 1991*a*). A critical stage in southern pine management occurs after a merchantable harvest because most hardwood species sprout prolifically from stumps and roots, and these sprouts can quickly overtop pine seedlings. This problem can be especially critical when minimal or no site preparation is used following harvest.

Historically, foresters have not considered herbaceous competition as a major impediment to the growth or survival of pines during the regeneration phase (Gjerstad and Barber 1987). However, studies on Upper and Lower Coastal Plain sites have indicated that during the first few years after field establishment, loblolly pines exhibit rapid growth and crown closure when herbaceous plants are eliminated in plantations (Nelson et al. 1981; Knowe et al. 1985; Miller et al. 1991) and in natural even-aged stands (Cain 1991*c*).

Because of the paucity of information on naturally seeded versus planted loblolly pines on the same site, our objectives in this investigation were (i) to compare survival and juvenile growth of loblolly pines established by natural seedfall with that of outplanted, container loblolly pines from a genetically improved seed source; (ii) to determine whether control of woody and herbaceous competition would result in a response difference within the two regeneration techniques; and (iii) to record the density and quadrat stocking of reinvading populations of natural pines and hardwoods, plus herbaceous competitors.

Methods

Site description

The study is located within a 2-ha clearcut in southern Arkansas, U.S.A., at 33°02′N and 91°56′W. Elevation of the area is about 40 m with nearly level topography. Soil is a Bude silt loam (Glossaquic Fragiudalf), and site index is 27 m at 50 years for loblolly pine (USDA 1979). The study area is typical of good sites for mixed stands of loblolly and shortleaf pines (*Pinus echinata* Mill.) growing in the West Gulf region, which includes the Coastal Plain west of the Mississippi River and extends to east Texas and southeast Oklahoma. Annual precipitation averages 140 cm with extremes being wet winters and dry autumns.

From the mid-1930s to the mid-1960s, pines on the study area had been intensively managed using single-tree selection, thereby eliminating the poorest trees and retaining the best for saw-log production and natural seeding (Reynolds 1969). In the mid-1980s, the site contained an overstocked, uneven-aged stand of loblolly and shortleaf pines that were infested with southern pine beetles (*Dendroctonus frontalis* Zimm.). Trees were clear-cut in summer 1985 to salvage approximately 132 m^3/ha of pine saw logs that were killed by the bark beetles. In April 1986, the entire study area was treated with hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione)[2] at the rate of 3.4 kg active ingredient (a.i.)/ha using herbicide spotguns on a 0.9 X 0.9 m grid to control nonpine vegetation. Spot treatment with hexazinone controlled the larger hardwoods but was less effective on small hardwoods, shrubs, and herbaceous vegetation. A few residual hardwoods taller than 2 m and not killed by hexazinone were injected with a 50% solution of water and glyphosate (N-(phosphonomethyl)glycine) (0.24 kg a.i./L) in summer 1987.

Study design and treatment

A completely randomized statistical design was used with three replications of four treatments: natural seedlings, natural seedlings plus release, planted container seedlings, and planted container seedlings plus release. Container seedlings were chosen for planting because they provide an efficient use of genetically improved seed, are quickly produced, have an extended planting season (Barnett and Brissette 1986), and provide an opportunity to compare the growth of small, planted seedlings with the growth of seedlings from a current year's natural seed crop.

The term release as used in this study refers to freeing a tree from immediate competition by eliminating vegetation that was overtopping or closely surrounding the tree within a 61-cm radius of the stem (Ford-Robertson 1971). Limbs of competing vegetation were cut whenever they overlapped with the crowns of released pines.

Each treatment plot measured 28.4 X 28.4 m (0.08 ha) with 19.2 X 19.2 m (0.04 ha) interior subplots. Individual plots accommodated 121 planting spots on a 2.7 X 2.7 m spacing, with 49 measurement (crop) pines on the interior subplot. The four treatments were randomly assigned to 12 established plots, resulting in three replications of each treatment.

Loblolly pine seeds for the container stock were obtained from the Kisatchie National Forest Seed Orchard in central Louisiana, but the original clone selections were from a northern Louisiana area. The open-pollinated seeds were from a mixed orchard lot that had been collected in 1984 before the seed orchard was rogued, and had an expected genetic volume gain of about 5% over nursery-run stock.

In mid-September 1986, seeds for the planting stock were sown in Ray Leach Stubby Cells@ filled with a 1:1 peat-vermiculite medium. Greenhouse cultural treatments followed the guidelines described by Barnett and Brissette (1986). Because the seedlings were grown during the winter months, development was slow and the stock was about 26 weeks old when outplanted in early April 1987. Outplanting was done at this time to coincide with the emergence of natural pine seedlings. Shoot length averaged 11.6 cm and groundline diameter (GLD) averaged 2.5 mm. The seedlings were considered small because the recommended shoot length for outplanting container loblolly pine seedlings is 15-20 cm (Barnett and Brissette 1986). The general rule for southern pine planting stock is that the higher the morphological grade, or the larger the seedling, then the better will be the survival and growth (Wakeley 1954). Although smaller than recommended, container seedlings in the present investigation had a distinct size advantage at the time of outplanting when compared with natural regeneration that had just begun to germinate from seed.

[2] Discussion of pesticides in this paper is not a recommendation of their use and does not imply that uses discussed here are registered by appropriate State and (or) federal agencies.

Natural pine regeneration seeded onto the study area from the 1986-1987 seed crop. An estimate of natural pine seed production was obtained from 0.2-m' seed collection traps. One trap was placed 0.6 m above ground at the center of each 0.08-ha plot. Seed counts were made weekly from October 1986 through February 1987. That seed crop averaged over 740 000 seeds/ha, with 75% judged as potentially viable in accordance with a seed-cutting test described by Bonner (1974). The previous winter's seed crop (1985-1986) was judged to be a failure, with only 7400 potentially viable seeds per hectare (Cain 1991*b*). An average seed year for loblolly pine is expected to produce from 74 000 to 198 000 viable seeds per hectare (Baker and Langdon 1990).

In early summer 1987, 49 of the lst-year natural seedlings were selected as measurement trees and tagged for identification on each of the six interior subplots that had been randomly assigned to monitor the growth of natural pine regeneration. The tallest Ist-year natural seedlings were most often chosen as measurement trees if spacing was at 2.7 X 2.7 m intervals and their terminal buds were intact; however, other quality criteria included the presence of dark green needles and the absence of insects, disease, forking, or mechanical damage. A total of 294 natural pine seedlings and 294 planted pine seedlings were tagged for measurement. All other natural pine seedlings were left undisturbed.

Beginning in the 1987 growing season, measurement pines were released from woody and herbaceous competition on three planted plots and on three naturally seeded plots. Woody vegetation was hand cut with machetes, below pine height, within the 61-cm radius of preselected pines. Herbaceous vegetation was controlled with sulfometuron (methyl 2-[[[[(4,6-dimethyl-2-pyrimidinyl)-amino]carbonyl]-amino]sulfonyl]benzoate) and glyphosate within the same 61-cm radius. In this study, herbaceous vegetation included all forbs, grasses, herbs, sedges, semiwoody plants, and woody vines. The cutting treatment was always applied before the herbicide treatment. Sulfometuron was the principal herbicide because of pine tolerance and was applied at 0.26 kg a.i./ha; glyphosate was applied at 0.76 kg a.i./ha. The herbicides were mixed in water and applied at 103 L/ha using backpack sprayers. Pines were shielded at the time of treatment. Glyphosate was included only in the 3rd and 4th years to control broomsedge grass (*Andropogon virginicus* L.), a major competitor that is resistant to sulfometuron (Neary et al. 1984).

During the first growing season, only one cutting treatment and one herbicide treatment were used. Two cutting treatments were needed in the second, third, and fourth growing seasons. Herbicides were applied twice in the second and third growing seasons but only once during the fourth season. In the fifth growing season, a single cutting treatment was used without herbicide.

Measurements and data analysis

After the first, third, fourth, and fifth growing seasons, tree heights were measured to an accuracy of 3.0 cm, and GLDs were measured to 1.0 mm on all survivors of the original 49 measurement pines per interior subplot. At ages 6 and 8 years, GLDs were recorded to an accuracy of 0.3 cm, and heights were measured to 3.0 cm. Volume index was calculated as (total height) X $(\mathrm{GLD})^2$. Through age 5, DBHs were measured to 1.0 mm on pines that were 1.5 m in height or taller; the degree of precision for DBH measurements was 0.3 cm at ages 6 and 8 years. At ages 5, 6, and 8 years, height to live crown was measured to 3.0 cm on all surviving measurement pines, and crown widths were measured to 3.0 cm at the widest axis and perpendicular to that axis but only on a random sample of 15 measurement pines per plot.

Measurement pines were judged as overtopped if the foliage of competing vegetation was touching or covered the pine's terminal leader; otherwise the measurement pines were judged as free-to-grow. If a crop pine was overtopped, then the overtopping species was recorded. Estimates of natural pine and woody rootstock densities and quadrat stocking were obtained from an inventory of nine nonpermanent 4-m^2 circular quadrats (10% sample) that were systematically located on each of the 12 interior plots. The dominant (tallest) natural pine seedling (<1.5 cm DBH) or sapling (1.5-8.9 cm DBH) on each quadrat was judged as being free-to-grow or overtopped. On each quadrat, species were identified for dominant nonpine seedling-sized rootstocks and sapling-sized stems that exhibited the most ground coverage compared with other species. Rootstocks consisted of either single or multiple stems (clump), which obviously arose from the same root system. Species nomenclature follows Little (1979).

Analysis of variance for a completely randomized design was used to evaluate treatment effects on crop pine survival and free-to-grow status, as well as on density and quadrat stocking of the population for natural pines and competing vegetation. Growth and size of measured pines were first subjected to analysis of covariance, with measures of 1st-year size as the covariates. Since the covariates proved to be nonsignificant (a >0.05), all variables were reanalyzed by analysis of variance.

Percent values for survival, quadrat stocking, and free-to-grow condition were compared following arcsine square root transformation. Treatment differences were tested by orthogonal contrasts as follows: (i) natural versus natural–release; (ii) planted versus planted-release; and (iii) natural plus natural-released versus planted plus planted-released. All analyses were carried out at the $\alpha \leq 0.05$ probability level.

Results

Pine response to treatments

After eight growing seasons, release treatments had improved survival of crop pines by 50% on naturally regenerated plots (P = 0.0002) and by 35% on planted plots (P = 0.0034). These differences were apparent by 1989, within the first 3 years after field establishment (Fig. 1). During the first 6 years, survival of nonreleased pines tended to follow a parallel course between regeneration techniques, but survival of natural pines declined by 24% between years 6 and 8; yet after 8 years there was no difference in crop pine survival between the two regeneration techniques (P = 0.9837).

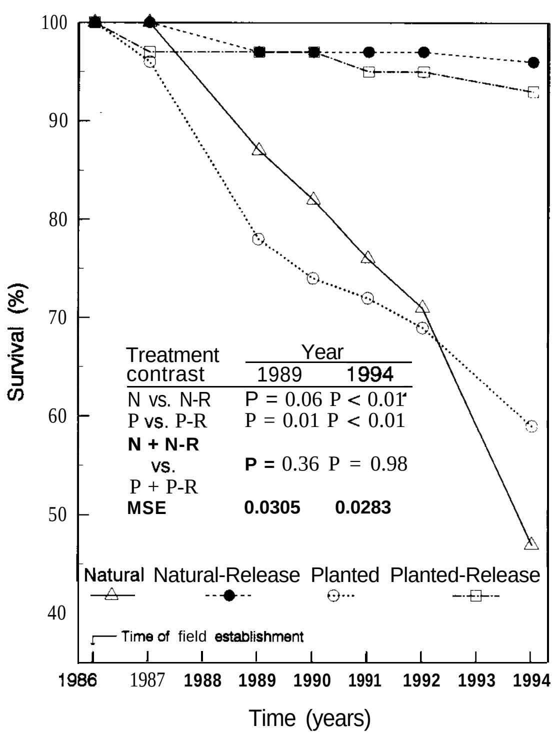
Of those nonreleased pines that were still alive after 8 years, less than 40% were judged as free-to-grow (Table 1). On these nonreleased plots, free-to-grow pines

Table 1. Status of surviving crop pines 8 years after field establishment.

Regeneration technique[a]	Total height (m)	DBH (cm)	Volume index (m^3)	Crown width (m)	Live-crown ratio (%)	Free-to-grow (%)
			8th-year means			
N	**4.32**	**3.47**	**0.0230**	1.26	44	38
N-R	7.02	8.08	0.1129	2.34	59	84
P	4.64	4.65	0.0373	1.31	50	33
P-R	7.60	9.50	0.1651	2.47	59	79
N + N-R	5.67	5.77	0.0680	1.80	52	61
P + P-R	6.12	7.08	0.1012	1.89	54	56
MSE	0.1621	0.3710	3.04×10^{-4}	0.0334	2.98×10^{-6}	0.0212
			Probabilities of a greater *F*-value[b]			
N vs. N-R	0.0001	0.0001	0.0002	0.0001	0.0001	0.0010
P vs. P-R	0.0001	0.0001	0.000 1	0.0001	0.0019	0.0013
N + N-R vs. P + P-R	0.0882	0.0059	0.0108	0.3889	0.0706	0.4316

[a]N, natural; N-R, natural plus release; P, planted; P-R, planted plus release. MSE, mean square error.
*The probability of obtaining a larger F-ratio under the null hypothesis with orthogonal contrasts.

Fig. 1. Periodic trends in survival of crop pines, by regeneration technique, during 8 years after field establishment.



exhibited better GLD growth and better height growth through 8 years than pines that were overtopped, regardless of the regeneration technique (Fig. 2). Within 3 years after the final release treatment was applied, 16% of survivors on released natural plots and 21% of survivors on released planted plots had become overtopped (Table 1), which indicated rapid closure of the release zone.

After eight growing seasons, release resulted in a 62% height gain (P = 0.0001) for natural pines and a 64% height gain (P = 0.0001) for planted pines (Table 1). Although the mean height of natural pines averaged 0.4 m less than that of planted pines, the difference was not statistically significant (P = 0.0882).

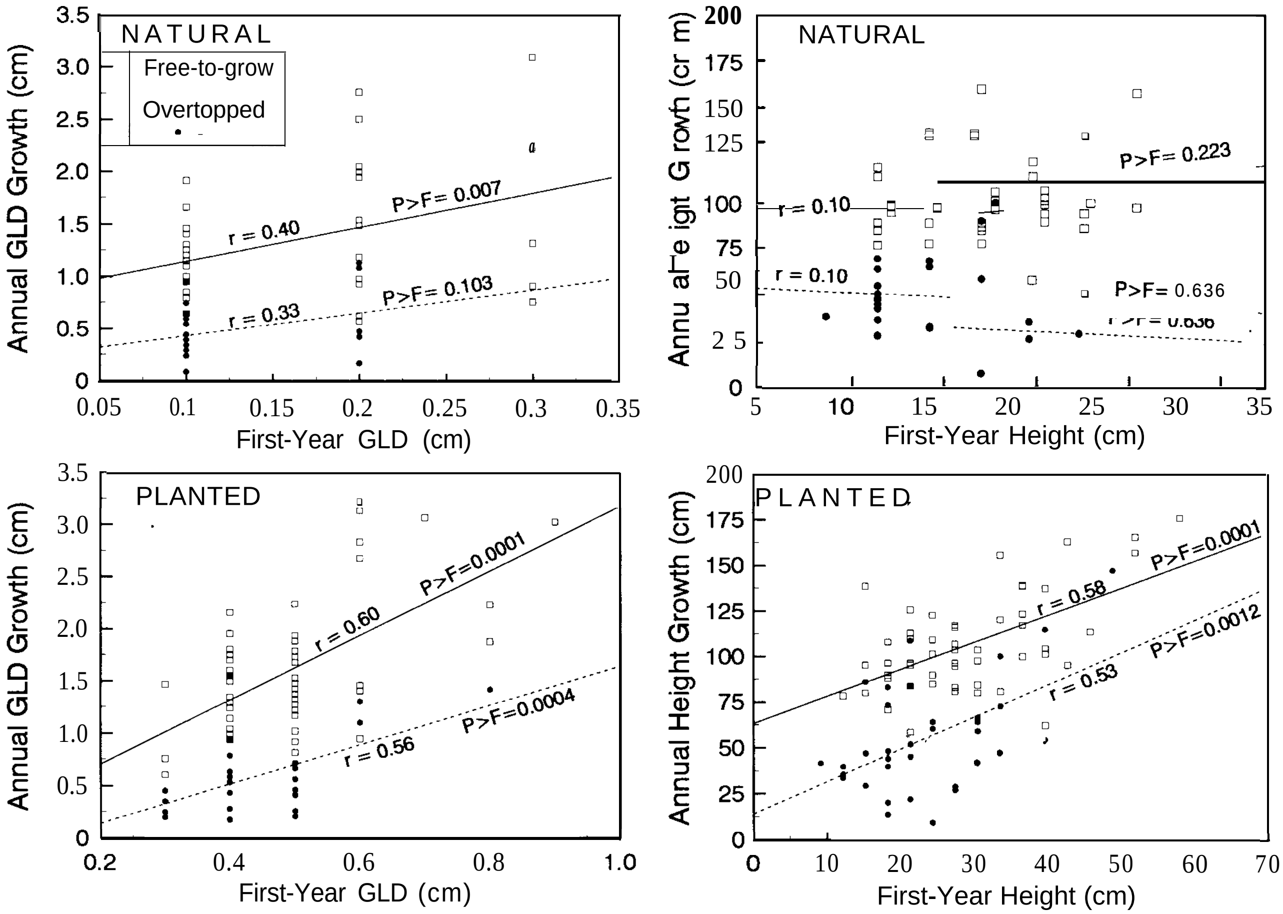
Both natural pines and planted pines exhibited a positive and statistically significant diameter growth response (P = 0.0001) to release treatments (Table 1). At age 8, gains in DBH from release averaged 133% on natural plots and 104% on planted plots. Planted pines were 23% larger (P = 0.0059) in DBH than natural pines.

Mean differences in volume index per tree between release treatments averaged 0.09 m^3 (P = 0.0002) on natural pine plots and 0.13 m^3 (P = 0.0001) on planted pine plots (Table 1). Planted pines had 49% more (P = 0.0108) volume than naturally regenerated pines.

Crown widths of released pines averaged 86% larger (P = 0.0001) than nonreleased pines on natural plots and 89% larger (P = 0.0001) on planted plots, with no difference (P = 0.3889) between natural and planted pines (Table 1). With release, live-crown ratios ranged from 9% to 15% larger ($P < 0.002$) for planted and natural pines, respectively, but there was no difference (P = 0.0706) between the two regeneration techniques (Table 1).

High mortality of nonreleased crop pines plus slow growth of survivors contributed to significantly less (P = 0.0001) basal area and volume production at the stand level when compared with released pines, regardless of the regeneration technique (Fig. 3). Eight years after establishment, planted pines averaged 36% more (P = 0.0211) basal area (m^2/ha) and 46% more (P = 0.0269) volume (m^3/ha) as compared with natural pines.

Fig. 2. Relationships between periodic annual increment of crop pines through 8 years and lst-year seedling size by free-to-grow status and regeneration technique on plots where pines were not released.



The tallest 247 crop pines per hectare

To better assess treatment efficacy, the response of the tallest 247 trees/ha was examined. For these pines, periodic growth in height, GLD, and volume index was better ($P < 0.01$) with release than without, and differences increased through 8 years (Fig. 4). Within 2 years of field establishment, growth of dominant released natural pines surpassed that of dominant planted pines where there was no release (Fig. 4). However, as a group, planted pines outperformed naturally regenerated pines by averaging about 1 year's growth more in height, GLD, and volume during the first 8 years.

Diameter distributions for these dominant pines are illustrated in Fig. 5 at age 8. The majority of released pines in both regeneration techniques were well past the lower threshold for pulpwood size, i.e., >8.9 cm in DBH. In contrast, only a few nonreleased dominant pines had attained pulpwood size during the same time; most averaged from 4 to 8 cm in DBH.

Density and quadrat stocking of the natural pine population

Nine years after site preparation, density of natural pine regeneration averaged over 7000 stems/ha (Table 2). Natural pines of sapling size, which will become the crop trees, accounted for 70% of total pine density, but only 9% of those saplings were dominants (i.e., 7.6 cm DBH class). Natural pine densities tended to average higher on plots without release because natural pines were rogued within the 61-cm treatment radius on release plots.

Quadrat stocking for natural pine regeneration exceeded 30% for seedlings and was greater than 40% for saplings (Table 2). Statistical significance was generally unimportant among treatments because the lower values for density and quadrat stocking are within the ranges (40–60% quadrat stocking with 1700 trees/ha) recommended for successful natural regeneration of loblolly pine in even-aged stands (Trousdell 1963; Grano 1967; Campbell and Mann 1973).

From this natural pine population, 44% of the dominant pines were judged as free-to-grow on natural plots, and 20% were free-to-grow on planted plots (Table 2). The lower free-to-grow percentage on planted plots was due to overtopping of the dominant natural pines by planted pines.

Competing vegetation

Nine years after site preparation, seedling-sized, woody, nonpine species had an average density exceeding 10 000 rootstocks/ha, and sapling-sized hardwoods averaged over 6500 stems/ha (Table 3). Quadrat stocking averaged

Fig. 3. Stand basal area and volume index for surviving crop pines, by regeneration technique, at age 8.

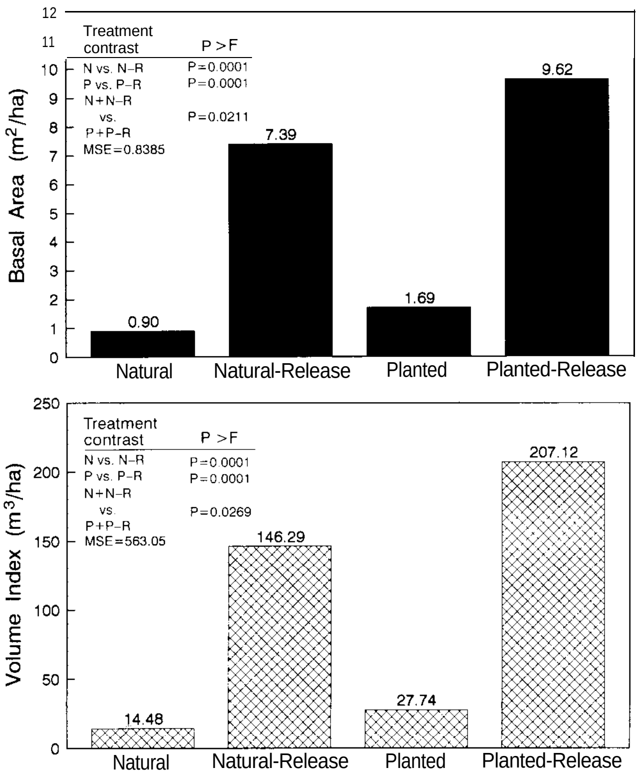
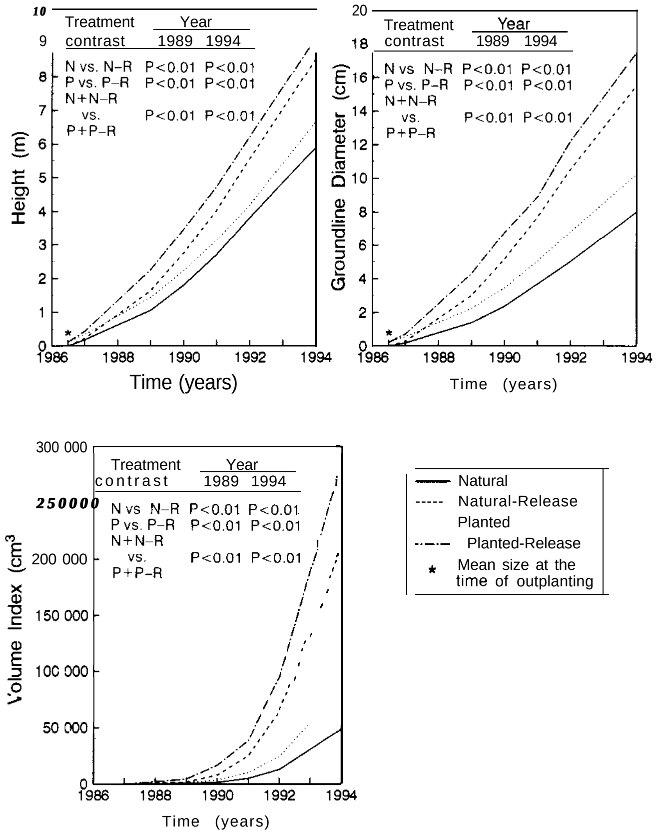


Fig. 4. Periodic growth trends for the tallest 247 pines/ha by method of release and regeneration technique.



98% for seedling-sized hardwoods and 84% for sapling-sized hardwoods (Table 3). Mean differences within and between regeneration techniques were unimportant and statistically nonsignificant ($P > 0.05$).

Herbaceous ground cover ranged from 60% to 78%, with no significant differences ($P > 0.05$) within or between regeneration techniques (Table 3). An exotic vine (*Lonicera japonica* Thunb.) and an indigenous, semiwoody species (*Rubus* spp.) were the most prevalent forms of herbaceous vegetation.

The dominant, nonpine, woody species of sapling size included at least 1.5 trees and 3 shrubs (Table 4). Species richness within the four regeneration techniques ranged from 8 woody species on planted plots to 10 woody species on both natural and natural-release plots. The 6 most frequently occurring woody species of sapling size were *Sassafras albidum* (Nutt.) Nees (21.3%); *Cornus florida* L. (16.6%); *Acer rubrum* L. (8.3%); *Liquidambar styraciflua* L. (8.3%); *Ilex opaca* Ait. (6.5%); and *Quercus nigra* L. *(6.5%).*

After eight growing seasons, at least 12 woody species were recorded as overtopping the crop pines (Table 5). Crop pines were most often overtopped by other natural pines that had become established during the winter of 1985-1986, after the area was clear-cut. Because of a seed-crop failure that winter, these overtopping pines were poorly distributed across the site and were few in number. For nonpine species, *Liquidambar styraciflua*, *Acer rubrum*, *Lonicera juponica,* and *Callicarpa americana* L. were the most troublesome in terms of overtopping the crop pines.

These species of woody and herbaceous plants are typically found in association with loblolly and shortleaf pines throughout the southeastern United States. They have been identified as prevalent on regenerated pine sites in east-central Alabama, south Georgia, central Louisiana, and southwest Mississippi (Miller and Zutter 1987).

Discussion

Eight years after field establishment, planted container pines averaged 49% larger in volume index per tree than naturally regenerated pines. Similar gains have been reported between container loblolly pines and spot-seeded loblolly pines on a Coastal Plain site in central Louisiana through age 15 (Haywood and Bamett 1994). In that study, a cutover pine site was prepared with a rolling-drum chopper and two prescribed burns. Because of those rather intensive treatments, there was no need for follow-up release.

Several studies have demonstrated that lst-year control of herbaceous vegetation can increase growth of planted loblolly pines (Knowe et al. 1985; South and Barnett 1986; Wittwer et al. 1986; Creighton et al. 1987; Zutter et al. 1987). Since plantation culture is often preceded by intensive site preparation, a single treatment to control herbaceous vegetation may be sufficient. However, on good sites (site index > 85 ft (1 ft = 0.3048 m) for loblolly pine at 50 years), as in the present study, there is rapid reinvasion by both woody and herbaceous vegetation even with intensive competition control (Cain and Yaussy 1983;

Table 2. Status of natural pine regeneration 9 years after site preparation.

Comparion of regeneration techniques"	Seedlings				Saplings					
	Density		Quadrat stocking'		Density		Quadrat stocking[b]		Free-to-grow'	
	Stems/ha	P >F	%	P >F	Stems/ha	P >F	%	P >F	%	P >F
N	1 922		41		9 518		74		44	
vs.		*0.917*		*0.888*		*0.024*		1.000		1.000
N-R	1 830		37		3 844		74		44	
P	3 112		63		4 942		56		26	
vs.		0.200		0.094		0.178		0.295		0.400
P-R	1 922		33		1 922		41		15	
N + N-R	1 876		39		6 681		74		44	
vs.		0.318		0.406		0.055		0.021		0.026
P + P-R	2 517		32		3 432		48		20	
MSE	1 086 551		0.0407		6 263 302		0.0286		0.0262	

"See footnote *a* in Table 1.

"Based on the presence of at least one natural pine seedling or sapling per 4-m' quadrat and nine systematically spaced quadrats per interior plot.

'Percent of stocked 4-m' quadrats in which the tallest natural pine seedling or sapling was not overtopped by nonpine vegetation

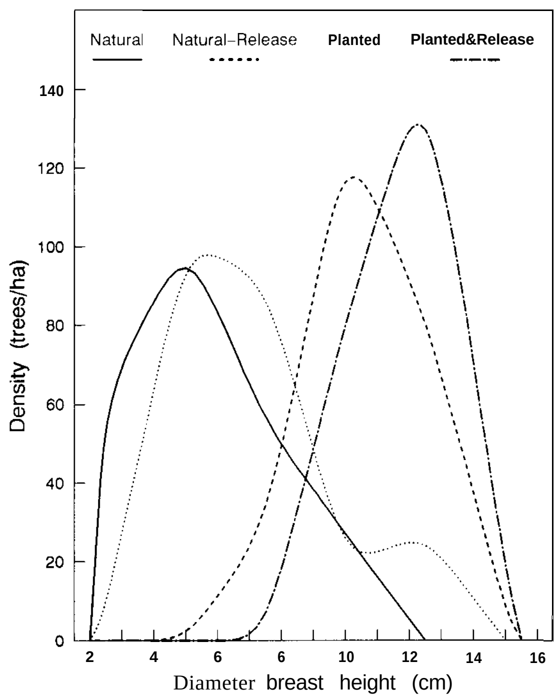
Cain 1991a). Concomitantly, Tiarks and Haywood (1986) concluded that when controlling herbaceous vegetation within a 1.14-m radius of planted loblolly pines, treatment was necessary for the first 4 years after pine establishment to ensure maximum pine growth.

Growth gains that were achieved from container seedlings compared with natural seedlings in the present investigation were most likely the result of the cumulative influence of larger initial size at the time of field establishment, the enhanced nutrient status of the growth medium that was used in the containers, and a genetic effect.

Greater gains (343–391%) in individual tree volumes were achieved within regeneration techniques, as a result of competition control, than were achieved between the two regeneration techniques. Concomitantly, compared with the mean height of crop pines at age 6 (Cain and Barnett 1994*b*), released pines in both regeneration techniques had a 2-year height gain over nonreleased pines by age 8. These gains were unexpected given that only 18% of the land area was subjected to competition control. The treatment area was in accordance with the recommendation by Dougherty and Lowery (1991): "From an environmental standpoint, it is important to treat the smallest area needed to provide the desired response."

Barnes et al. (1990) found that rates of sulfometuron ranging from 0.10 to 0.42 kg a.i./ha could reduce the root growth of loblolly pine seedlings, especially during a dry planting season; however, they concluded that the negative effects of sulfometuron on pine root growth were small in comparison with the positive effect of weed control. Pines that were released from woody and herbaceous competition within a 61-cm radius in the present study had better survival and exhibited more vigor (i.e., larger crowns) than those that were not released. Also, mean differences in pine size, which were achieved as a result of release,

Fig. 5. Diameter distributions for the tallest 247 pines/ha by method of release and regeneration technique at age 8.



increased through 8 years. Growth gains from released pines have been attributed to increased soil moisture, nutrient availability, and light intensity (Zutter et al. 1986).

Larocque and Marshall (1993) proposed that the onset of competition could be assessed by observing recession of live-crown ratio in *Pinus resinosa* Ait. They found that crown recession was easier to measure than growth variables.

Table 3. Status of nonpine vegetation 9 years after site preparation.

Comparison of regeneration techniques[a]	Seedling-size woody vegetation				Sapling-size woody vegetation				Herbaceous ground cover	
	Density		Quadrat stocking[b]		Density		Quadrat stocking[b]			
	Rootstocks/ha[c]	P >F	%	P >F	Stems/ha	P>F	%	P >F	%	P >F
N	*8 0.54*		*93*		*6 315*		*70*		*61*	
vs.		*0.288*		*0.195*		*0.675*		*0.673*		*0.938*
N-R	10 159		100		5 766		85		60	
P	12 996		100		7 688		93		78	
vs.		0.252		1.000		0.309		0.329		0.412
P-R	10 708		100		6 315		85		71	
N + N-R	9 106		96		6 040		78		60	
vs.		0.069		0.347		0.313		0.327		0.070
P + P-R	11 852		100		7 002		89		74	
MSE	5 138 252		0.0201		2 393 331		0.07 13		0.0156	

[a]See footnote a in Table 1.
[b]Based on the presence of at least one seedling-size woody rootstock or one sapling-size woody stem per 4-m[2] quadrat and nine systematically spaced quadrats per interior plot.
[c]A rootstock consisted of either single or multiple stems (clump) of seedling size, that obviously arose from the same root system.

Table 4. Percentage of dominant, nonpine, woody species in the sapling size class 9 years after site preparation.

Species[a]	Regeneration technique			
	Natural	Natural-release	Planted	Planted-release
Trees				
Acer rubrum L.	7.4	7.4	18.5	0.0
Aralia spinosa L.	0.0	7.4	0.0	0.0
Carya spp.	3.7	0.0	0.0	0.0
Cornus florida L.	7.4	14.8	22.2	22.2
Diospyros virginiana L.	0.0	3.7	0.0	0.0
Ilex opaca Ait.	18.5	3.7	3.7	0.0
Liquidambar styraciflua L.	7.4	3.7	11.1	11.1
Nyssa sylvatica Marsh.	0.0	0.0	3.7	0.0
Prunus americana Marsh.	0.0	0.0	0.0	3.7
Prunus serotina Ehrh.	3.7	3.7	0.0	3.7
Quercus falcata Michx.	0.0	0.0	0.0	3.7
Quercus nigra L.	3.7	7.4	11.1	3.7
Quercus stellata Wangenh.	0.0	0.0	3.7	0.0
Quercus velutina Lam.	0.0	3.7	0.0	0.0
Sassafras albidum (Nutt.) Nees	11.1	29.6	18.5	25.9
Shrubs				
Callicarpa americana L.	3.7	0.0	0.0	3.7
Rhus copallina L.	0.0	0.0	0.0	7.4
Vaccinium spp.	3.7	0.0	0.0	0.0
Missing[b]	29.7	14.9	7.5	14.9
Total	100.0	100.0	100.0	100.0

[a]Sapling-size stems that exhibited the most crown cover compared with other species on sample quadrats.
[b]Percentage of sample quadrats on which there were no woody, nonpine species of sapling size.

Table 5. Percentage of surviving overtopped crop pines, by competing species, 8 years after field establishment.

Overtopping species	Regeneration technique			
	Natural	Natural-release	Planted	Planted-release
Trees				
Acer rubrum L.	12.0	10.0	14.3	23.1
Cornus florida L.	16.0	0.0	5.6	0.0
Ilex opaca Ait.	4.0	0.0	11.4	0.0
Liquidambar styraciflua L.	4.0	30.0	2.9	30.8
Pinus spp.”	20.0	30.0	20.0	7.7
Prunus serotina Ehrh.	0.0	0.0	2.9	0.0
Quercus falcata Michx.	0.0	0.0	2.9	0.0
Quercus nigra L.	4.0	0.0	14.3	0.0
Sassafras albidum (Nutt.) Nees	0.0	10.0	2.9	23.1
Shrubs				
Callicarpa americana L.	20.0	10.0	14.3	0.0
Vaccinium spp.	4.0	0.0	0.0	0.0
Vines				
Lonicera japonica Thunb.	16.0	10.0	8.5	15.3
Total	100.0	100.0	100.0	100.0

“Advance regeneration from naturally established *Pinus echinata* Mill. or *Pinus taeda* L.

However, in the present investigation, nonreleased crop pines that were alive at age 6, but dead at age 8, had live-crown ratios that averaged 43%, which was similar to the mean of crop pines that survived to age 8 on natural plots (Table 1). Since 86% of the pines that died in this study between 1990 and 1994 were overtopped by competing vegetation, that criterion appears to be a better measure of competitive influence for loblolly pine regeneration than live-crown ratio.

Release treatments imposed within a 61-cm radius of 1500 pines/ha had little negative impact on density or quadrat stocking of woody vegetation, because treatments were restricted to only 18% of the plot area. High density of seedling-sized woody rootstocks can be partially attributed to the fact that hexazinone does not control *Callicarpa americana* (McLemore 1983), the most common seedling-sized rootstock at year 8. Quadrat stocking of this shrub ranged from 56% on natural-release plots to 70% on planted plots. Spot treatments for pine release can be more advantageous for some forest landowners than bands or total control treatments because more vegetation is retained to stabilize soil, reduce visual offensiveness, maintain species diversity, and provide food and cover for wildlife (Yeiser and Barnett 1991).

Adequate density and quadrat stocking of pine regeneration was achieved by natural seeding across a 2-ha clearcut without the benefit of intensive site preparation. Although only 44% of the dominant natural pine saplings were judged as free-to-grow after 8 years in the absence of release, the high density of free-to-grow saplings (>4000/ha on natural plots) did not indicate a need for release. Since many of these volunteer pines are likely to become crop trees, they might be viewed as increased stocking rather than as additional competition (Fredericksen et al. 1991).

Natural regeneration of loblolly pines is still a viable alternative to artificial regeneration and is especially desirable for landowners who prefer a low-cost establishment technique. In an economic comparison of natural and planted pine regeneration, Dangerfield and Edwards (199 1) concluded that natural loblolly regeneration is financially competitive with clearcut and plant silviculture. Costs for regeneration and subsequent release during the first 5 years of the present investigation have been previously reported by Cain and Barnett (1994*a*, 1994*b*).

Precommercial thinning of natural loblolly pine regeneration has been recommended when density exceeds 12 300 stems/ha (Mann and Lohrey 1974). To maximize early volume production in loblolly pines, a density of no more than 18.50 trees/ha has been reported as optimum (Lohrey 1977). Since dominant pine saplings (7.6 cm DBH class) averaged <500 stems/ha across all plots in the present study at 8 years, precommercial thinning would not be justified.

This study has shown that container loblolly pines can be outplanted on cutover sites in the Upper Coastal Plain following minimal preparation. However, in the absence of follow-up release on good sites, high mortality and poor growth can be expected from these planted pines. When planting loblolly pine container stock on an operational basis, the recommendation is to use seedlings that have a higher morphological grade than those that were outplanted in the present investigation (Barnett 1991).

References

Baker, J.B., and Langdon, O.G. 1990. Loblolly pine (*Pinus taeda* L.). *In* Silvics of North America, Vol. 1. Conifers. *Edited by* R.M. Burns and B.H. Honkala. U.S. Dep. Agric. Agric. Handb. 654. pp. 497–512.

Barnes, A.D., Zedaker, S.M., Feret, P.P., and Seiler, J.R. 1990. The effects of sulfometuron on the root growth of loblolly pine. New For. 3: 290–295.

Barnett, J.P. 199 1. Effects of morphological grade on field performance of container-grown southern pine seedlings. In Proceedings of the 6th Biennial Southern Silvicultural Research Conference. Edited by S.S. Coleman and D.G. Neary. USDA For. Serv. Gen. Tech. Rep. SE-70. pp. 94-96.

Barnett, J.P., and Brissette, J.C. 1986. Producing southern pine seedlings in containers. USDA For. Serv. Gen. Tech. Rep. so-59.

Bonner, F.T. 1974. Seed testing. *In* Seeds of woody plants in the United States. *Edited by C.S.* Schopmeyer. U.S. Dep. Agric. Agric. Handb. 450. pp. 136–152.

Burkhart, H.E., Glover, G.R., and Sprinz, P.T. 1987. Loblolly pine growth and yield response to vegetation management. In Forest vegetation management for conifer production. *Edited by* J.D. Walstad and P.J. Kuch. John Wiley & Sons, New York. pp. 243-27 1.

Cain, M.D. 1985. Long-term impact of hardwood control treatments in mature pine stands. USDA For. Serv. Res. Pap. SO-214.

Cain, M.D. 1988. Hardwood control before harvest improves natural pine regeneration. USDA For. Serv. Res. Pap. SO-249.

Cain, M.D. 1991*a*. Five-year response of natural loblolly and shortleaf pine regeneration to release treatments. USDA For. Serv. Res. Pap. SO-265.

Cain, M.D. 199 1 *b*. Importance of seedyear, seedbed, and overstory for establishment of natural loblolly and shortleaf pine regeneration in southern Arkansas. USDA For. Serv. Res. Pap. SO-268.

Cain, M.D. 1991*c*. The influence of woody and herbaceous competition on early growth of naturally regenerated loblolly and shortleaf pines. South. J. Appl. For. **15**(4):179–184.

Cain, M.D., and Barnett, J.P. 1994*a*. Five-year field comparison of naturally regenerated *Pinus taeda* L. to genetically improved container stock, with and without release. New For. 8: 123–141.

Cain, M.D., and Barnett, J.P. 19946. Importance of release in a 6-year evaluation of naturally seeded and planted container loblolly pines on a cutover site. Tree Plant. Notes, **45**(4): 128-136.

Cain, M.D., and Yaussy, D.A. 1983. Reinvasion of hardwoods following eradication in an uneven-aged pine stand. USDA For. Serv. Res. Pap. SO-188.

Campbell, T.E., and Mann, W.F., Jr. 1973. Regenerating loblolly pine by direct seeding, natural seeding, and planting. USDA For. Serv. Res. Pap. SO-84.

Creighton, J.L., Zutter, B.R., Glover, G.R., and Gjerstad, D.H. 1987. Planted pine growth and survival responses to herbaceous vegetation control, treatment duration, and herbicide application technique. South. J. Appl. For. **11**(4): 223-227.

Dangerfield, C.W., Jr., and Edwards, M.B. 1991. Economic comparison of natural and planted regeneration of loblolly pine. South. J. Appl. For. **15**(3): 125-127.

Dougherty, P.M., and Lowery, R.F. 1991. Spot-size of herbaceous control impacts loblolly pine seedling survival and growth. South. J. Appl. For. **15**(4):193–199.

Ford-Robertson, F.C. *(Editor)*. 1971. Terminology of forest science, technology, practice and products. The multilingual forestry terminology series No. 1. Society of American Foresters, Washington, D.C.

Fredericksen, T.S., Allen, H.L., and Wentworth, T.R. 199 1. Competing vegetation and pine growth response to silvicultural treatments in a six-year-old Piedmont loblolly pine plantation. South. J. Appl. For. **15**(3): 138-144.

Gjerstad, D.H., and Barber, B.L. 1987. Forest vegetation problems in the South. In Forest vegetation management for conifer production. *Edited by* J.D. Walstad and P.J. Kuch. John Wiley & Sons, New York. pp. 55-75.

Grano, C.X. 1967. Growing loblolly and shortleaf pine in the midsouth. U.S. Dep. Agric. Farmers' Bull. 2102.

Haywood, J.D., and Barnett, J.P. 1994. Comparing methods of artificially regenerating loblolly and slash pine: container planting, bareroot planting, and spot seeding. Tree Plant. Notes, **45**(2): 63–67.

Knowe, S.A., Nelson, L.R., Gjerstad, D.H., Zutter, B.R., Glover, G.R., Minogue, P.J., and Dukes, J.H., Jr. 1985. Four-year growth and development of planted loblolly pine on sites with competition control. South. J. Appl. For. 9(l): 1 l-15.

Larocque, G.R., and Marshall, P.L. 1993. Evaluating the impact of competition using relative growth rate in red pine (*Pinus resinosa* Ait.) stands. For. Ecol. Manage. 58: 65-83.

Little, E.L., Jr. 1979. Checklist of United States trees (native and naturalized). U.S. Dep. Agric. Agric. Handb. 541.

Lohrey, R.E. 1977. Growth responses of loblolly pine to precommercial thinning. South. J. Appl. For. l(3): 19-22.

Mann, W.F., Jr., and Lohrey, R.E. 1974. Precommercial thinning of southern pines. J. For. 72: 557–560.

McLemore, B.F. 1983. Four formulations of hexazinone for controlling hardwoods in pine stands. Proc. South. Weed Sci. Soc. 36: 212–217.

Miller, J.H., and Zutter, B. 1987. Region-wide study of loblolly pine seedling growth relative to four competition levels after two growing seasons. *In* Proceedings of the 4th Biennial Southern Silvicultural Research Conference. *Edited by* D.R. Phillips. USDA For. Serv. Gen. Tech. Rep. SE-42. pp. 581–591.

Miller, J.H., Zutter, B.R., Zedaker, S.M., Edwards, M.B., Haywood, J.D., and Newbold, R.A. 199 1. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. South. J. Appl. For. **15**(4):169–179.

Neary, D.G., Conde, L.F., and Smith, J.E. 1984. Effects of sulfometuron methyl on six important competing species in coastal plain flatwoods. Proc. South. Weed Sci. Soc. 37: 193–199.

Nelson, L.R., Pedersen, R.C., Autry, L.L., Dudley, S., and Walstad, J.D. 198 1. Impacts of herbaceous weeds in young loblolly pine plantations. South. J. Appl. For. **5**(3): 153-158.

Reynolds, R.R. 1969. Twenty-nine years of selection management on the Crossett Experimental Forest. USDA For. Serv. Res. Pap. SO-40.

South, D.B., and Barnett, J.P. 1986. Herbicides and planting date affect early performance of container-grown and bareroot loblolly pine seedlings in Alabama. New For. 1: 17-27.

Tiarks, A.E., and Haywood, J.D. 1986. *Pinus taeda* L. response to fertilization, herbaceous plant control, and woody plant control. For. Ecol. Manage. 14: 103-I 12.

Trousdell, K.B. 1963. Loblolly pine regeneration from seed — what do site preparation and cultural measures buy? J. For. 61: 441-444.

USDA. 1979. Soil survey of Ashley County, Arkansas. USDA Soil Conservation Service and Forest Service, in cooperation with Arkansas Agricultural Experiment Station, Washington, D.C.

USDA Forest Service. 1988. The South's fourth forest: alternatives for the future. USDA For. Serv. For. Resour. Rep. 24.

Wakeley, P.C. 1954. Planting the southern pines. USDA For. Serv. Agric. Monogr. 18.

Wittwer, R.F., Dougherty, P.M.. and Cosby, D. 1986. Effects of ripping and herbicide site preparation treatments on loblolly pine seedling growth and survival. South. J. Appl. For. **10**(4): 253-257.

Yeiser, J.L., and Barnett, J.P. 1991. Growth and physiological response of four shortleaf pine families to herbicidal control of herbaceous competition. South. J. Appl. For. **15**(4): 199–204.

Zutter, B.R., Clover, G.R., and Gjerstad, D.H. 1986. Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. For. Sci. 32: 882-899.

Zutter, B.R., Glover, G.R., Gjerstad, D.H. 1987. Vegetation response to intensity of herbaceous weed control in a newly planted loblolly pine plantation. New For. 4: 257-27 1.