Effects of Early Release on Natural Versus Container Loblolly Pines 12 Years After Field Establishment

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ABSTRACT: *Genetically improved, container loblolly pine (*Pinus taeda *L.) seedlings were compared to naturally established loblolly seedlings on a cutoverpine site. Crop pines on 6 of 12 plots were releasedfrom woody and herbaceous competition within a 2 ft radius of each stem. On release plots, woody competition was controlled by hand-cutting for 5 consecutive yr and herbaceous competition was controlled with herbicidesfor 4 consecutive yr ufterpine establishment. Competition control increased 12 yr survival by 68 percentage points for natural pines and by 47percentage points for planted pines. Twelve years afterfield establishment, mean-tree volume ofplantedpines was no different than that of naturally established pines. Nevertheless, volume gains of 150% to 200% were achieved within regeneration techniques as a result of release. South. J. Appl. For. 26(4):173–180.*

Key Words: Container pines, herbaceous competition, natural regeneration, *Pinus taeda* L., woody competition.

In the management of southern pines, harvesting exposes the forest floor to full sunlight, promoting the invasion of early successional species. Grasses, vines, shrubs, and hardwood trees often proliferate after well-stocked pine stands are cut. These herbaceous and woody plants can quickly overtop recently established pine seedlings and compete with them for growing space, sunlight, soil moisture, and nutrients. Under such conditions, shade-intolerant pine seedlings may linger in a suppressed state of growth for several years, and many eventually die. To counter these competitive circumstances on regenerated sites and thereby improve survival and growth of juvenile pines, release treatments have been recommended (Cain and Mann 1980, Clason 1984, Haywood 1986, Edwards and Miller 1988).

Since many private nonindustrial forest landowners desire low-cost regeneration techniques, they may attempt to reduce their establishment expenditures by outplanting improved seedlings where stand and site conditions are less than optimum. Governed by those circumstances, landowners need to know the growth-potential of improved pine seedlings as compared to natural pine regeneration when both are established following low-intensity site preparation.

When intensive treatments have been applied to control woody and herbaceous vegetation, substantial 5 yr growth gains were observed for planted loblolly pines (*Pinus taedu* L.) (Miller et al. 1991) and naturally seeded loblolly pines (Cain 1991 b). However, results from investigations in plantations are often not directly comparable with those from natural stands because of variations in site, competing species, and treatments.

Even though the benefits of release are well documented, there is little information on how naturally seeded and planted loblolly pines might respond to this silvicultural treatment when applied uniformly within the same research study. Our objectives were (1) to compare survival and growth of loblolly pines established by natural seedfall with that of outplanted, container loblolly pines from a genetically improved seed source; and (2) to determine if control of woody and herbaceous competition would result in a response difference within the two regeneration techniques. Container seedlings were chosen because they provide an efficient use of genetically improved seed, are quickly produced, and have an extended planting season (Barnett and Brissette 1986).

NOTE: Michael D. Cain can be reached at (870) 367-3464; Fax: (870) 367-1164; E-mail: mcain@fs.fed.us. James P. Barnett's e-mail is jpbarnett@fs.fed.us. This publication reports research involving herbicides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses must be registered by appropriate state and/or federal agencies before they can be recommended. Manuscript received April 24, 2001, accepted October 4, 2001.

Methods

Study Area

The investigation was initiated within a 5 ac clearcut on the Crossett Experimental Forest in southeastern Arkansas. Soil is a Bude silt loam (Glossaquic Fragiudalf) with a site index of 85 to 90 ft at 50 yr for loblolly pine.

Between 1934 and 1969, pines on the study area had been managed using single-tree selection. In that silvicultural system, the better pines were reserved from harvest during each cutting cycle until they attained a maximum diameter of 18 to 24 in. dbh. In the mid-l 980s, the site contained an overstocked, uneven-aged stand of loblolly and shortleaf pines (*Pinus echinata* Mill.) that were infested with southern pine beetles *(Dendroctonus frontalis* Zimm.). Trees were clearcut on about 5 ac in summer 1985 to salvage approximately 11,000 bfm/ac (Doyle scale) of pine sawlogs (>9.5 in. dbh) that were killed by the bark beetles.

In April 1986, the entire area was treated with hexazinone at the rate of 3 lb a.i./ac in spots using herbicide spotguns on a 3 ft by 3 ft grid to control nonpine vegetation. Spot-treatment with hexazinone controlled the larger hardwoods but was less effective on seedling-sized hardwoods, shrubs, and herbaceous vegetation. A few residual hardwoods taller than 6 ft and not killed by hexazinone were basally injected with a 50% solution of glyphosate in summer 1987.

Study Design and Treatment

A completely randomized statistical design was used with three replications of four treatments: natural pine seedlings (N), natural pine seedlings plus release (NR), planted container pine seedlings (P), and planted container pine seedlings plus release (PR). The term "release" as used here refers to freeing a tree from immediate competition by eliminating vegetation that was overtopping or closely surrounding the subject tree within a 2 ft radius of the stem. Limbs of competing vegetation were cut whenever they overlapped with the crowns of released pines. For the purpose of this investigation, seedlings were stems less than 0.6 in. dbh, and saplings were greater than or equal to 0.6 in. but less than 3.6 in. dbh.

Each of 12 plots measured 93.3 ft by 93.3 ft with 63 ft by 63 ft interior subplots. Individual plots accommodated 121 planting spots for crop pines on a 9 by 9 ft spacing. The 49 crop pines on interior subplots were used as measurement trees. The selection of naturally established crop pines was based on seedling quality and spacing. The two regeneration techniques-natural and planted-were randomly assigned to each of six plots, and release treatments were randomly assigned within regeneration techniques.

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 source. The open-pollinated seeds were from a bulk orchard lot that had been collected in 1984 before the seed orchard was rogued. The expected genetic gain in yield at final harvest was about 5% over nursery-run stock.

In mid-September 1986, seeds for the planting stock were sown in Ray Leach Stubby Cells® filled with 1:1 peat-vermiculite medium. Greenhouse cultural treatments followed the guidelines described by Barnett and Brissette (1986). Because the seedlings were grown during winter months, development was slow, and the seedlings were about 26 wk old when outplanted in early April 1987. At the time of outplanting, pine shoot length averaged 0.38 ft and groundline diameter (gld) averaged 0. I in. The seedlings were considered small because the recommended shoot length of container loblolly pine seedlings is 0.5 to 0.7 ft at the time of outplanting (Barnett and Brissette 1986). April planting of these smaller than recommended container seedlings was to ensure that their initial size would be comparable to the natural pine seedlings that had just begun to germinate from seed.

Natural pine regeneration seeded onto the study area from the 1986-1987 (autumn through winter) seedcrop. An estimate of natural pine seed production was obtained from 2.2 ft^2 seed collection traps. One trap was placed 2 ft above ground at the center of each 0.2 ac plot. Seed counts were made weekly from October 1986 through February 1987. That seedcrop averaged over 300,000 seeds/ac, with 75% judged as potentially viable in accordance with a seed cut test described by Bonner (1974). The previous winter's seedcrop (1985-1986) was judged a failure with only 3,000 potentially viable seeds/ac (Cain 199 1 a). An average seedyearfor loblolly pine on these sites is expected to produce from 40,000 to 90,000 sound seedslac (Cain and Shelton 2001b).

In early summer 1987, 49 of the natural seedlings were selected as crop trees and tagged for identification on each of the six interior plots designated to monitor the growth of natural pine regeneration. The tallest first-year seedlings were most often chosen if their terminal buds were intact; however, other quality criteria included the presence of dark green needles and the absence of insects, disease, 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, crop 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 a 2 ft radius of preselected crop pines. Herbaceous vegetation was controlled with sulfometuron methyl and glyphosate within the same 2 ft radius. The cutting treatment was always applied before the herbicide treatment. Sulfometuron was the principal herbicide because of pine tolerance and was applied at 3.75 oz a.i./ac; glyphosate was applied at 0.68 lb a.i./ac. The herbicides were dispersed as water solutions at the rate of 11 gal/ac using backpack sprayers, and pines were shielded at the time of treatment. Glyphosate was included only in the third and fourth growing seasons to control broomsedge *(Andropogon virginicus* L.) which is resistant to sulfometuron. Some volunteer, natural pine seedlings became established within the 2 ft treatment radius after the first year of release but were not intentionally eliminated until the dormant season of the fourth year because they were so small as to be hidden within the broomsedge cover, which was not controlled until glyphosate was applied.

Measurements and Data Analysis

After the first year of field establishment, crop-tree heights were taken to the nearest 0.1 ft, and groundline diameters (gld) were measured to the nearest 0.04 in. Total heights and gld's were remeasured, using the same degree of precision, on all surviving crop pines at the end of the third, fifth, sixth, and eighth growing seasons. At each inventory, dbh measurements were taken to 0.1 in. on all crop pines that were taller than 4.5 ft. At age 12, dbh measurements were taken on all surviving crop pines, and a random sample of 1.5 crop pines per plot (30% sample) was used for measurement of total height as well as height-to-live-crown and crown width to 0.1 ft. Crown widths were measured at the widest axis and perpendicular to that axis. Crop-pine volumes were computed from height and dbh equations developed by Clark and Saucier (1990). All surviving crop pines were judged as free-to-grow if the terminal leader was not overtopped by foliage of competing vegetation. If pines were overtopped, then the competing species was recorded.

Estimates of natural pine and woody rootstock densities and quadrat stocking were obtained from an inventory of nine temporary 0.001 ac circular quadrats (10% sample) that were systematically located on each interior plot. Rootstocks consisted of either single or multiple stems (clump) of seedling size which obviously arose from the same root system. Volumes for the population of all merchantable-sized pines (≥3.6 in. dbh) were computed from number of trees by 1 in. dbh classes according to local volume tables (Farrar et al. 1984). Cubic-foot volumes were converted to cords (cd) based on 76 ft^3/cd (Grano 1969). Percent ground cover for vegetative components was visually estimated to the nearest 10% within each 0.001 ac sample quadrat.

Analyses of variance (ANOVA) for acompletely randomized design were used to evaluate treatment effects (a = 0.05). Data in percent were analyzed following arcsine square-root transformation. Homogeneity of treatment variances was tested by Levene's test (Levene 1960), and in all analyses the assumption of homogeneity of variance was met. To test for interactions, data were analyzed as a factorial design with one factor being method of establishment (natural versus planted) and the other factor being competition control (release versus no release). All interactions were nonsignificant at a = 0.05; therefore data are presented as one-way ANOVAs and orthogonal contrasts were used to partition mean differences among treatments as follows: Natural (N) vs. Natural Release (NR); Planted (P) vs. Planted Release (PR); and N+NR vs. P + PR.

Results and Discussion

Pine Response to Treatments

After 12 growing seasons, release treatments had improved survival of crop pines by 68 percentage points on naturally regenerated plots ($P < 0.01$) and by 47 percentage points on planted plots ($P < 0.01$) (Table 1). There was no difference in pine survival between the two regeneration techniques ($P = 0.29$). High mortality of nonreleased crop pines during early years after field establishment was the result of dense shading from overtopping vegetation, primarily American beautyberry (*Callicarpa americana* L.) and Japanese honeysuckle (*Lonicera japonica* Thunb.).

On nonreleased plots, 38% of crop pines that were still alive after 12 yr were overtopped on natural pine plots and 21% were overtopped on planted pine plots (Table 1). Of those species that were recorded as overtopping surviving crop pines on nonreleased plots, all were natural loblolly pines with the exception of 11% overtopping by Japanese honeysuckle on planted plots. Through 8 yr, 80% of overtopping species on nonreleased plots were either hardwoods or Japanese honeysuckle, and only 20% of overtopping species were pines (Cain and Barnett 1996).

Even with rather high mortality of crop pines on plots with no release, quadrat stocking of all pines averaged 52% or better across plots, and there were no significant differences ($P > 0.05$) in pine stocking within or between regeneration techniques. On released plots, 94% of naturally established crop pines and 95% of planted crop pines were judged as free-to-grow, and there was no difference ($P = 0.08$) in the free-to-grow status of natural versus planted crop pines (Table 1).

Table 1. Status of loblolly pine crop trees 12 yr after establishment on a cutover site in southeastern AR.

Treatments and orthogonal contrasts	Survival	Free-to-grow*	Total height (ft)	Dbh (in.)	Volume (ft^3)	Crown width (ft)	Live-crown ratio (%)
	(%)						
	12th yr means						
Natural (N)	22	62	28.3	3.4	1.0	6.1	40
Natural release (NR)	90	94	35.9	5.2	2.5	10.1	46
Planted (P)	41	79	28.8	3.7	1.1	6.5	41
Planted release (PR)	88	95	37.4	5.9	3.3	10.8	44
N+NR	56	78	32.1	4.3	1.8	8.4	43
P+PR	64	87	33.1	4.8	2.2	8.6	42
Mean square error	0.0151	0.0083	5.3604	0.0912	0.2360	1.2481	0.0013
	Probabilities of a greater F-ratio						
N vs NR	<0.01	co.01	<0.01	<0.01	<0.01	<0.01	0.08
P vs PR	co.01	<0.01	co.01	co.01	co.01	<0.01	0.37
N + NR vs P + PR	0.29	0.08	0.47	0.02	0.18	0.73	0.71

* Free-to-grow status of surviving crap pines.

As a result of competition control, mean height of crop pines at 12yr had increased ($P<0.01$) by 7.6 ft on natural pine plots and by 8.6 ft on planted pine plots (Table 1). The 1 ft height difference between natural and planted pines was nonsignificant ($P = 0.47$).

Release also resulted in dbh gains ($P < 0.01$) that averaged 53% for natural pines and 59% for planted pines (Table 1). Twelve years after field establishment, planted pines were 12% larger ($P = 0.02$) in dbh compared to natural pines. Release was required to produce naturally regenerated crop pines with a mean dbh of merchantable size (23.6 in.) within 12 yr. Although nonreleased planted pines attained a mean dbh of 3.7 in., that was possible only because the smaller planted pines died from suppression by overtopping species.

With release, mean volume per tree increased ($P < 0.01$) by 150% on natural pine plots and by 200% on planted pine plots (Table 1). There was no difference ($P= 0.18$) in volume per tree between naturally regenerated pines and planted pines.

Within each regeneration technique, crown widths of released pines averaged 1.5 times greater ($P < 0.01$) than the width of nonreleased pines, but there was no difference ($P = 0.73$) in mean crown widths between natural and planted pines (Table 1). Live-crown ratios for surviving crop pines averaged about 43% with no differences ($P > 0.05$) within or between regeneration techniques (Table 1). According to Baker and Langdon (1990), diameter growth of individual loblolly pines generally increases as crown surface area and crown ratio increase, with optimal diameter growth in trees with at least 40% live-crown ratio. Consequently, greater crown surface area for pines on released plots versus those without release most likely contributed to improved pine growth rather than live-crown ratio.

To better assess treatment efficacy, it is often desirable to look at how the tallest 100 trees/ac respond. For these pines, growth in height and dbh through age 12 was better ($P < 0.01$) with release than without, and differences generally increased with time (Figure 1). Similar trends were apparent for gld growth through 8 yr. For both regeneration techniques, gains from release of these dominant pines were equivalent to a growth advantage of 3 yr for height and 5 yr for dbh. At 12 yr, dominant planted pines had larger ($P = 0.04$) dbh's than dominant natural pines, but mean heights were not different ($P = 0.12$) between regeneration techniques.

Diameter distributions for the largest 100 crop pine trees/ac at age 12 are illustrated in Figure 2. Released pines in both regeneration techniques were approaching chip-n-saw size (7.6 in. dbh) (Dicke and McCreight 1999), whereas most nonreleased pines were still at the lower threshold of pulpwood size classes (3.6-7.5 in. dbh).

Basal areas for the population of all merchantable-sized pines (crop and noncrop) ranged from 50 ft^2/ac on planted plots with no release to 142 ft^2/ac on planted plots with release (Figure 3), and the difference was significant ($P < 0.01$). Although natural release plots had 1.8 times as much basal area in merchantable-sized pines as natural plots with no release, the difference was not significant ($P = 0.11$). Natural pines accounted for 74% and 37% of merchantable pine basal area on planted and planted release plots, respectively.

At age 12, density of merchantable-sized pines averaged 414 trees/ac on natural plots and 474 trees/ac on natural release plots. Planted plots had the fewest pines of merchantable size at 296 trees/ac, and 67% of those pines were of natural origin. Only 26% of merchantable-sized pines on planted release plots seeded naturally, and mean density for these planted and natural pines averaged 592 merchantable-sized trees/ac.

There is an average minimum cut per acre that makes a product attractive to potential buyers. This minimum standard varies across the South, but generally is no lower than 5 cd/ac for pulpwood (Dennington et al. 1986). By including naturally established pines on planted plots, all treatments had sufficient volumes in merchantable-sized trees to support a commercial thinning at 12 yr. Natural pines of merchantable size accounted for 76% of the volume on planted plots and 39% of the volume on planted release plots. Standing pine volumes ranged from about 10 cd/ac on natural and planted plots with no release to 37 cd/ac on planted plots with release (Figure 3). The only statistically significant difference ($P = 0.02$) in cubic-foot volume was between planted and planted release treatments. By leaving approximately 200 crop trees/ac for future growth after 12 yr, a landowner could have conceivably harvested about 8 cd/ac of pine pulpwood on nonreleased plots and from 18 to 28 cd/ac on natural release and planted release treatments, respectively.

According to Grano (1969), loblolly pines on these sites should yield 1.5 to 2 cd/ac/yr, provided tree spacing is adequate for unrestricted growth from the start. Without release, the pine population averaged less than 1 cd/ac/yr in the present study. With release, pulpwood volume production through 12 yr equaled the expected upper threshold on natural plots and exceeded it by 54% on planted plots.

In addition to merchantable-sized pines, there was a substantial number of naturally established pine saplings on all plots after 12 yr. Although density of these saplings ranged from 200 to 1,000 stems/ac across treatments, mean differences were statistically nonsignificant ($P = 0.16$).

Adequate density and quadrat stocking of pine regeneration was achieved by natural seeding across this 5 ac clearcut without the benefit of intensive site preparation. Although survival was only 22% for natural pines selected as future crop trees following their establishment, the high density of natural pines resulted in adequate stocking of merchantable-sized trees that could have supported an operational harvest at 12 yr. One long-term research study, located less than 0.5 mile from the present investigation, showed that small clearcuts of about 5 ac will naturally regenerate with pines that seed in from bordering loblolly and shortleaf pine seed trees and will develop into well-stocked stands of sawlog-sized pines even with low-intensity site preparation and minima1 control of competition (Cain and Shelton 2001a). Nevertheless, pine yields through age 12 were favored substantially in the present study by release treatments.

Competing Vegetation

After 12 growing seasons, hardwood trees (>3.5 in. dbh) averaged fewer than 40 stems/ac, and none were larger than 6 in. dbh. Nonpine woody competitors were principally in the

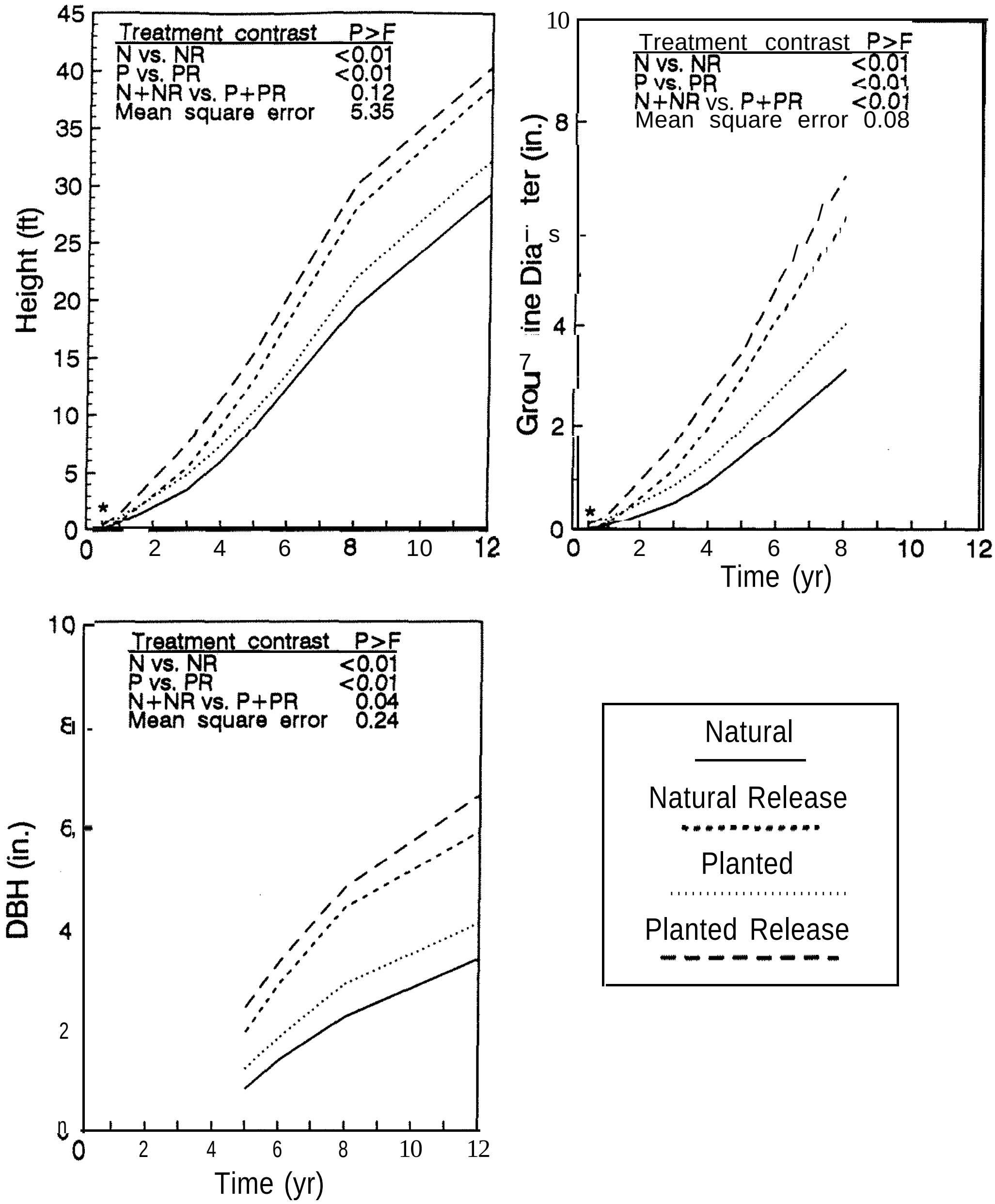

Figure 1. Growth trends through 12 yr for the tallest 100 loblolly pine crop trees/ac by regeneration technique, with and without release. Asterisk (*) denotes the time of outplanting. Treatment contrasts represent results at 12 yr for height and dbh and results at 8 yr for groundline diameter. N = Natural, P = Planted, and R = Release.

seedling and sapling size classes. Hardwood seedlings averaged about 3,000 rootstocks/ac, with no differences ($P > 0.05$) among treatments (Table 2). These seedling-sized stems were well distributed across the plots with 87% quadrat stocking. Across all treatments, *Callicarpa americana* L. and *Ilex opaca* Ait. were the two predominant species of seedling size, occurring on more than 50% of stocked quadrats.

Sapling-sized hardwoods averaged about 1,400 stems/ac with 70% stocking, and there were no differences ($P > 0.05$) within or between regeneration techniques for either density or stocking (Table 2). The predominant sapling-sized hardwood species occurring on 10% or more of stocked quadrats included: sassafras (*Sassafras albidum* [Nutt.] Nees) with from 15% to 26% stocking across all four treatments; American holly (*Ilex opaca* Ait.) with 11% and 18% stocking on natural and natural release plots, respectively; water oak (*Quercus nigra* L.) with 11% and 22% stocking on natural release and planted plots, respectively; and sweetgum (*Liquidambar styraciflua* L.) and red maple (*Acer rubrum* L.) with 15% and 11% stocking, respectively, on planted release plots. If the main stem is cut or broken near groundline during reproduction cutting operations, most of these hardwood species have the ability to produce multiple sprouts, thereby increasing their competitive influence on pine regeneration. For example, within 3 yr after low-intensity hardwood control treatments were applied on a low-quality forest site (site index of 64 ft for shortleaf pines at 50 yr) in northwest Arkansas,

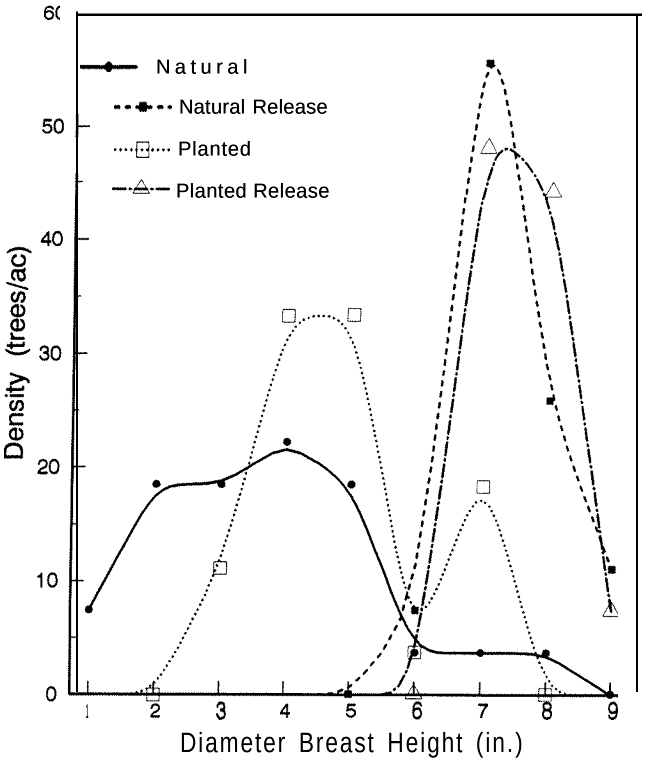

Figure 2. Smoothed curves for diameter distributions of the largest 100 loblolly pine crop trees/ac at 12 yr by regeneration technique, with and without release.

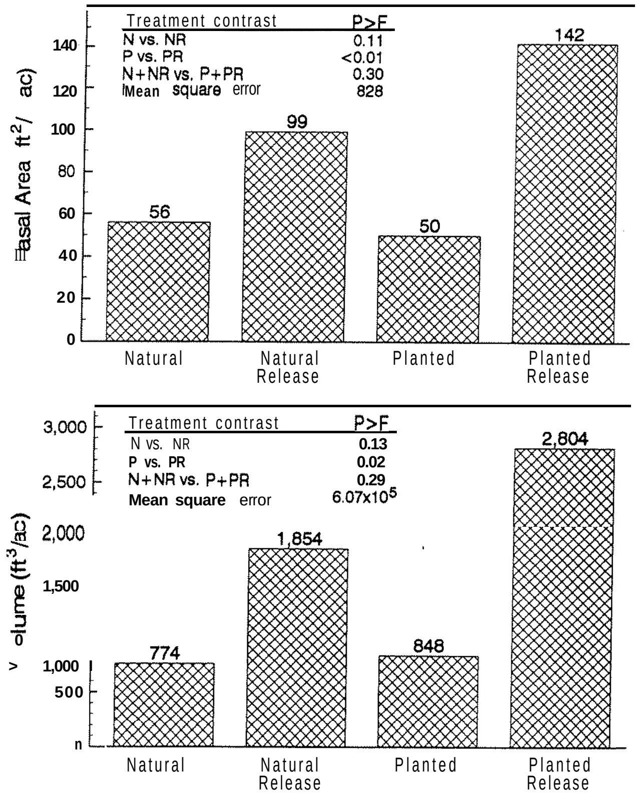

Figure 3. Basal area and volume production of all merchantable-sized loblolly pine trees (crop and noncrop) through 12 yr by regeneration technique, with and without release. In treatment contrasts, N = Natural, P = Planted, R = Release.

ground cover from submerchantable hardwood sprouts averaged 38% on plots where hardwoods were manually cut compared to 12% on plots where hardwoods were injected with herbicide (Cain 1995).

At 12 yr, ground cover from woody nonpine competitors averaged 70% for arborescent hardwoods and 26% from nonarborescent shrubs, and differences among treatments were nonsignificant ($P > 0.05$). Ground cover from herbaceous species (forbs, grasses, vines, and semiwoody plants) ranged from 53% on planted plots with no release to 69% on planted release plots (Table 2), and the difference between those two treatments was significant ($P = 0.05$). The most prolific herbaceous plants were vines with more than 50% ground cover across all plots. Cover from herbaceous species tends to decline as pine canopies close because most herbaceous plants are shade intolerant. But vines have a distinct advantage over other herbaceous vegetation because they are not restricted to the forest floor. Vines attach to trees and climb into the canopy where they are exposed to partial sunlight which sustains their presence even in closed stands. The predominant vines in the present study were *Lonicera japonica* Thunb. and *Smilax* spp.

Release treatments imposed within a 2 ft radius of 606 pines/ac had little negative impact on density and quadrat stocking of woody vegetation because treatments were restricted to only 18% of the plot area. Spot treatments for pine

Table 2. Hardwood and herbaceous vegetation assessments 12 yr after establishment of planted and natural loblolly pines on a cutover site in southeastern AR.

Treatments and orthogonal contrasts	Hardwood seedlings Density (rootstocks/ac)	Hardwood seedlings Stocking* (%)	Hardwood saplings Density (stems/ac)	Hardwood saplings Stocking* (%)	Ground cover Hardwoods (%)	Ground cover Shrubs (%)	Ground cover Herbaceous (%)
Natural (N)	3,185	89	1,704	63	73	28	61
Natural release (NR)	2,111	85	1,037	63	58	22	59
Planted (P)	3,630	93	1,555	74	72	33	53
Planted release (PR)	2,630	82	1,444	78	76	21	69
Mean square error	99.07 x 10^4	0.0893	26.4 x 10^4	0.0280	0.0230	0.0139	0.0078
	Probabilities of a greater F-ratio						
N vs NR	0.22	0.84	0.15	1.00	0.21	0.49	0.78
P vs PR	0.25	0.45	0.80	0.70	0.82	0.19	0.05
N + NR vs P + PR	0.43	0.81	0.67	0.15	0.30	0.80	0.86

* A quadrat was stocked if it contained at least one hardwood seedling or hardwood sapling.

release are often more advantageous than bands or total control treatments because more vegetation is left to stabilize soil, reduce visual offensiveness, and provide food and cover for wildlife (Yeiser and Barnett 1991). In an evaluation of spot size for controlling herbaceous vegetation to improve the growth and survival of recently planted loblolly pines, Dougherty and Lowery (1991) noted that from an environmental standpoint it was important to treat the smallest area needed to provide the desired response. In this study, the desired response from release was to improve pine growth as compared to trees with no release. It appears that a treatment area of 12.6 ft^2/tree accomplished that objective.

Treatment Cost

The cost for release treatments was the same for both planted and natural seedlings in this investigation (Cain and Barnett 1994). Consequently, cost differences between regeneration techniques were for establishment. Using 1998 cost data (Dubois et al. 1999) at 12 yr, pine seedlings averaged $35/thousand for bareroot stock in the South, and planting costs averaged $38/ac on cutover Coastal Plain sites following less than intensive site preparation. Therefore, establishment costs in 1998 for planted seedlings would have exceeded that of natural regeneration by about $62/ac when planting on an 8 by 8 ft spacing.

Management Implications

Pines that were released from woody and herbaceous competition within a 2 ft radius exhibited more vigor and better growth than those that were not released, regardless of the regeneration technique. Release resulted in pine volume gains of three times that which occurred on nonreleased plots. Costs associated with 5 yr of intensive competition control on small plots are not operationally feasible. However, chemical release may be operationally achieved by ground application with backpack sprayers. According to Dubois et al. (1999), the 1998 cost of such treatments across Coastal Plain and Piedmont sites in the South was $60/ac.

In this investigation, natural regeneration of loblolly pines was found to be a viable alternative to planting and is especially desirable for private nonindustrial forest landowners who often prefer a low-cost establishment technique. During the first 8 yr, planted container stock outperformed pines of natural origin (Cain and Barnett 1996); yet after 12 yr, there were no differences ($P > 0.05$) in total volume production between the two regeneration techniques. Lack of volume differences was attributed to the high mortality of planted crop pines on nonreleased plots and the abundance of naturally seeded pines which tended to balance total volume production.

Data from this investigation suggest that container loblolly pines from a genetically improved seed source can be outplanted on areas with minimal site preparation and will equal or exceed the growth of naturally established pine regeneration, but high mortality may occur on productive sites-site index greater than 90 ft at 50 yr for loblolly pines. To maximize survival as well as the growth potential of genetically improved planting stock on good sites, some degree of herbaceous and woody competition control appears to be justified during the first few years after pine establishment. A delay in release of established pines may not produce desired results because competitors that are established earlier than loblolly pines can cause greater reductions in growth than if they are established at the same time (Mitchell et al. 1999). Also, when using loblolly pine container stock on an operational basis, the recommendation is to outplant seedlings that are larger than were used in the present investigation (Barnett 1991).

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