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Woody and herbaceous competition effects on the growth of naturally regenerated loblolly and shortleaf pines through 11 years *

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Application. Compared to plantation culture of southern pines, little information is available relative to the effects of herbaceous and woody nonpine competition on early growth of loblolly and shot-deaf pines (*Pinus taeda* L. and *P. echinata* Mill.) in naturally regenerated, even-aged stands in the southeastern U.S. At year 1 1, pine volumes were increased 27% by 5 years of woody competition control and 55% by 4 years of controlling herbaceous vegetation. Compared to no competition control, complete control of nonpine vegetation during the first 5 years after pine establishment doubled pine volume by age 11. Results of the present investigation represent unique standards of growth in naturally regenerated pine stands to which less-intensive operational treatments can be compared on similar sites in the Upper Coastal Plain of the southeastern U.S.

Abstract. Four levels of vegetative competition were used to quantify the growth of loblolly and shot-deaf pines (*Pinus taeda* L. and *P. echinatu* Mill.) in naturally regenerated, even-aged stands on the Upper Coastal Plain of southeastern Arkansas, USA. Treatments included: (1) no competition control, (2) woody competition control, (3) herbaceous competition control. and (4) total control of nonpine vegetation. After pines became established from natural seeding, herbicides were used to control herbaceous plants for 4 consecutive years and woody plants for 5 consecutive years. Even though 89% of crop pines on untreated check plots were free-to-grow 11 years after establishment, crop pines on vegetation control plots were larger ($P<0.001$) in mean dbh. total height, and volume *per tree.* From age 5 through 11 years, crop pine diameter growth increased on woody control plots and decreased on herbaceous control plots because of hardwood competition in the latter treatment. At age 11, cmp pine volume production averaged 207 m^3/ha on total control plots. 158 m^3/ha on herbaceous control plots. 130 m^3/ha on woody control plots. and 102 m^3/ha on untreated check plots.

Introduction

About 67% of pine stands in the southeastern United States originated from natural seedfall (USDA Forest Service 1988), and this method of regenera-

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tion continues to be important for perpetuating the species. If midstory and overstory hardwoods are controlled and there is an adequate pine seed source, natural pine regeneration is a viable alternative to artificial regeneration for restocking cutover sites (Baker and Murphy 1982). The lower costs associated with establishing natural pine regeneration can be particularly attractive to private, nonindustrial forest landowners (Cain and Bamett 1994a).

On cutover areas, natural regeneration of loblolly and shortleaf pines (*Pinus taeda* L. and *P. echinata* Mill.) is considered successful if density averages at least 3,706 seedlings/ha at the end of the first year of establishment or 1,730 stems/ha at the beginning of the third year (Grano 1967). Quadrat stocking (distribution) of these pine seedlings should range from 40% (Campbell and Mann 1973) to 60% (Trousdell 1963).

One long-term research study in the Upper Coastal Plain of the southeastem U.S. has shown that small clearcuts of about 2 ha will naturally regenerate with pines that seed in from bordering loblolly and shortleaf seed trees (Baker and Murphy 1982). By year 36, these regenerated clearcuts had developed into well-stocked stands of sawlog-size pines even with low-intensity site preparation and without followup control of competing vegetation. Even so, more recent studies indicate that competition control can substantially improve pine yields in natural stands during the first 5 to 6 years following pine establishment (Cain 1991, Cain and Bamett 1994b).

The present research was part of a region-wide (southeastern U.S.) investigation entitled Competition Omission Monitoring Project – COMP (Miller and Zutter 1987). Three objectives of that investigation are: (1) to establish a framework of growth response for loblolly pine relative to four competition regimes on major soil types across the region, (2) to compare the relative importance of herbaceous versus woody competition as they affect the early and long-term growth of loblolly pine on a wide range of sites, and (3) to identify the major herbaceous and woody competitors.

Of 14 study locations in that regional project. only the one reported here utilized natural pine regeneration. The others are studying planted loblolly pines. Because the present investigation relied entirely on natural seedfall, pines were allowed to invade the study area and no effort was made to control pine density during the first 5 years. This course of action was desirable so that population dynamics of the natural pines could be studied at four levels of competition. After 5 years, pines were hand-thinned to a density comparable to the planted pine installations (Miller et al. 1991).

During the first 5 years of this investigation, control of only woody competition did not improve pine growth compared to untreated checks; whereas, control of only herbaceous vegetation resulted in statistically significant increases in pine growth (Cain 1991). At age 5, total competition control produced significantly **more** pine volume compared to any other treatment. The focus of the present paper is to document the effect of these early competition control treatments on pine growth from ages 5 through 11 years. A second objective was to record the density and quadrat stocking of reinvading populations of natural pines and hardwoods, as well as the presence of herbaceous competitors at the end of 11 growing seasons.

Methods

Site description

The study is located within two 2-ha clearcuts located 90 m apart at 33” 02’ N mean latitude and 91” 56’ W mean longitude in southeastern Arkansas, USA. Before clearcutting, these areas contained uneven-aged stands of loblolly and shortleaf pines that ranged up to 71 cm diameter breast height (dbh) taken at 1.37 m, with about 247 merchantable-sized pines/ha and about 108 m^3/ha in sawlog volume. Hardwoods that were ≥ 3 cm diameter at groundline were stem injected with herbicide (Tordon® IO 1 R – 0.03 kg/L picloram and 0.12 kg/L 2,4-D) during summer 1980. Prescribed burning with backfires was done in March 1980 on one area and in January 1981 on the other area. Merchantable pines were harvested in spring 1981. In August 1983, before study installation, the 3-year-old thicket of hardwood sprouts, shrubs, brambles, and vines on both clear-cuts was mowed with a Hydro-ax@ to create a uniform vegetation height of about 0.8 m. During winter after mowing, the areas seeded naturally from mature pines that bordered the clearcuts. Natural pine seed production from the 1983-84 seed year averaged 2,470,000 potentially viable seeds/ha (Cam 1988) in accordance with a seed-cut test described by Bonner (1974).

Soil series are Bude (Glossaquic Fragiudalf) and Providence (Typic Fragiudalf) silt loams (USDA 1979). These soils have a site index of about 27 m for loblolly pine at age 50 years. Elevation is about 40 m with nearly level topography. Annual precipitation averages 140 cm with seasonal extremes being wet winters and dry autumns. The study area is typical of productive sites for mixed stands of loblolly and shortleaf pines growing in the West Gulf region, which includes the Coastal Plain west of the Mississippi River and extends to East Texas and southeast Oklahoma.

Study design and treatments

Eight treatment plots were established within each 2-ha cleat-cut. Gross plots were 0.10 ha (3 1.7 m by 31.7 m) with 0.04-ha (20.1 m by 20.1 m) interior subplots for assessing pine growth. Treatments were replicated four times in a randomized, complete block design with blocking based on pretreatment stocking of pine regeneration. Each interior subplot contained 10 permanent 4-m^2 circular quadrats that were systematically established for obtaining natural pine and woody rootstock densities and quadrat stocking by size class, plus ocular estimates of percent vegetative ground cover.

Three competition control treatments were initiated during the 1984 growing season and were maintained along with an untreated check as follows:

1. Check *(CK).* No additional treatment of the woody or herbaceous components was made after mowing in 1983. Five years later, ground cover from herbaceous and woody nonpine vegetation averaged 78% and 38%, respectively (Cain 1991).
2. *Woody Control (WC).* Ail hardwoods, shrubs, and woody vines were controlled annually by single-stem treatments with a herbicide (10% Garlon® 4E – triclopyr) for the first 5 consecutive years. When this treatment series ended, ground cover averaged only 1% from woody nonpine vegetation but 92% from herbaceous vegetation (Cain 199 1).
3. *Herbaceous Control (HC).* Forbs, grasses, semiwoody plants, and vines were controlled annually using multiple applications of pre-emergent and post-emergent herbicides (Gust@ – sulfometuron at 0.26 kg a.i./ha, Vantage@ – sethoxydim at 0.84 or 1.68 kg a.i./ha, and/or 2% Roundup@-glyphosate) for the first 4 consecutive years. One year after this treatment series ended, ground cover averaged 38% from woody nonpine vegetation but only 7% from herbaceous vegetation (Cain 1991).
4. *Total Control (TC).* A combination of herbicides, as described in treatments 2 and 3, was used to control all nonpine vegetation. Woody plants were controlled for the first 5 consecutive years and herbaceous vegetation was controlled for the first 4 consecutive years. At the end of the 5-year treatment interval, ground cover from herbaceous and woody nonpine vegetation averaged 18% and 0%. respectively (Cain 1991).

Before spring of the 6th growing season, pines taller than 1.5 m were precommercially hand-thinned on all plots to a residual density of 1,235 crop pines/ha or 50 crop pines per 0.04-ha interior subplot. This density was comparable to pine densities being studied on the planted COMP installations. Hardwoods and shrubs were not cut. Thinning was done to facilitate the detection of pine growth differences that might be the result of competition from species other than pine. Crop pines were selected for retention according to their dominant or codominant crown class, spacing, and absence of obvious defects.

Across all plots, 90% of the crop pines were ioblolly and the other 10% were shortleaf.

Measurements and data analysis

Only measurements taken at ages 5, 7, 9, and 11 years are described here. Within each of ten **4-m^2 quadrats** per plot, all living pines were counted by size class (seedlings, saplings, or trees). Seedling-sized stems were < 1.5 cm dbh; sapling stems ranged from 1.5 to 8.9 cm dbh; and trees were $\geq$**9.0** cm dbh. For woody competition, dominant seedling-sized rootstocks and sapling stems were identified by species and all seedling-sized rootstocks and sapling stems were counted within each **4-m^2 quadrat** (Cain and Barnett 1996). A rootstock was comprised of either single or multiple stems (clump) of seedling size, which obviously arose from the same root system. In autumn, before leaf fall, percent ground cover from pines, hardwoods, and herbaceous competition (***i.e., grasses &*** sedges, forbs, vines, and semi-woody plants) was assessed within each **4-m^2 quadrat** by ocular estimation to the nearest 10%.

The following assessments and measurements were taken on surviving crop pines out of the 50 pines that were retained tier precommercial thinning on each **0.04-ha** interior subplot: free-to-grow status and dbh to an accuracy of 0.3 cm. Pines were judged as free-to-grow if their **terminal** leader was not overtopped by foliage of competing vegetation. Additional measurements were taken on a random sample of 25 crop pines out of the 50 per **0.04-ha** interior subplot: total height and crown height to an accuracy of 3 cm, and crown width to an accuracy of 3 cm at the widest axis and perpendicular to that axis.

Analysis of variance was used to evaluate treatment differences for all variables. Tree volumes were computed using equations developed by Farrar and Murphy (1988). Percent data were analyzed following **arcsine** square-root transformation. Orthogonal contrasts were used to partition mean differences among treatments as follows: (1) effects of no competition control versus competition control; (2) effects of controlling woody and herbaceous competition separately versus controlling both components; and (3) effects of controlling only woody competition versus controlling only herbaceous competition. On each **0.04-ha** interior subplot, the largest 247 crop pines/ha were segregated from the 1,235 crop pines/ha and measurements were analyzed separately to provide a better assessment of those pines that are likely to be grown to rotation. Treatment differences were judged significant a$\alpha \leq$**0.05** probability level.

Results and discussion

Average crop pine response to vegetation control

Of the 50 crop pines per 0.04-ha interior subplot (1,235 trees/ha) that were tagged for measurement at age 5, 98.5% **survived** through 11 years (Table 1). Treatment differences in survival were nonsignificant (P=0. 170). Crop pines on vegetation control plots averaged 11.42 m in height and were 17% taller (P<0.001) than those on untreated check (CK) plots (Table 1). Crop pines on total control (TC) plots averaged 10% taller (P<0.001) than the mean height of crop pines on woody control (WC) and herbaceous control (HC) plots. However, controlling only herbaceous competition during the first 4 years resulted in a 15% height gain (P<0.001) **over** pines on plots where only woody competition was controlled.

At 14.8 cm dbh, crop pines on vegetation control plots were 18% larger (P<0.001) than those on CK plots (Table I). Crop pines on TC plots averaged 2.0 cm larger (P-0.002) than the mean of crop pines on WC and HC plots. At 11 years, the gains in dbh from controlling just herbaceous competition or just woody competition were comparable (P-0.142). Obviously, residual hardwoods on HC plots had a negative impact on pine diameter growth during the last 6 years, but that trend was not apparent during the first 5 years of the study (Cain 1991). As the pines dominated the site on WC plots and shaded-out the herbaceous ground cover, pine growth increased in the absence of hardwood competition and declining herbaceous vegetation.

Differences in individual crop pine volumes among treatments were similar to differences in height and dbh at 11 years (Table 1). Pines on CK plots were smaller (P<0.001) than pines on vegetation control plots, and pines on TC plots outperformed (P<0.001) those on WC and HC plots. Because of a 1.5-m height advantage, crop pines on HC plots averaged 22% more (P-0.025) volume than crop pines on WC plots.

Although there was a statistically significant difference (P=0.005) between WC and HC plots in live-crown-ratios for crop pines, this variable averaged 54% or higher across all treatments (Table 1). Chapman (1953) suggested that live-crown ratio has little negative effect on pine growth until it drops below 40%.

Mean crown widths of crop pines on vegetation control plots averaged 0.6 m larger (P-0.007) than for crop pines on CK plots (Table 1). Total competition control resulted in a 0.6-m gain (P-0.009) in crown width compared to crop pines on WC and HC plots, but there was no difference (P-0.734) between these latter two treatments.

From 89% to 99% of surviving crop pines were free-to-grow in the autumn of 1994 (Table 1), with no differences (P-O. 137) in free-to-grow status among

Table 1. Treatment effects on the survival, mean size, and free-to-grow status of crop pines at age 11.

Vegetation control and orthogonal contrasts	Survival (%)	Height (m)	Dbh (cm)	Volume (m^3)	Live-crown ratio (%)	Crown width (m)	Free-to-Grow[1] (%)
1. Check	%	9.78	12.5	0.051	56	3.26	89
2. woody control	100	10.28	13.7	0.062	61	3.70	93
3. Herbaceous control	98	11.82	14.6	0.076	54	3.62	95
4. Total control	100	12.16	16.2	0.100	58	4.27	99
Mean square error	0.016	0.087	0.603	co.001	0.001	0.092	0.039
P > F	0.170	co.001	co.001	<0.001	0.020	0.008	0.137
				(Probabilities of a greater F-value)			
1 vs 2+3+4	0.051	<0.001	<0.001	<0.001	0.153	0.007	0.197
2+3 vs 4	0.592	<0.001	0.002	<0.001	0.675	0.009	0.059
2 vs 3	0.361	<0.001	0.142	0.025	0.005	0.734	0.488

[1] The terminal leader was not overtopped by foilage of competing vegetation,

treatments. Lack of overtopping competition is consistent with low mortality of crop pines and annual height growth that exceeded 0.9 m per year during the last 6 years.

In autumn 1994, at age 11, stand basal area in surviving crop pines ranged from 16 m^2/ha on CK plots to 27 m^2/ha on TC plots (Figure 1). Basal area of crop pines was 44% higher (*P*<0.001) on vegetation control plots compared to CK plots. Total control plots had 29% more (P-0.001) pine basal area than the mean of WC and HC plots, but there was no difference (*P*=0. 179) between the latter two treatments.

At the end of 11 growing seasons, standing volume of crop pines increased (*P*<0.001) by 62% with vegetation control versus no treatment (Figure 1). Total control plots averaged 63 m^3/ha more (*P*<0.001) than the mean of WC and HC plots. The gain of 28 m^3/ha from HC over WC was also important (P-0.040). Yields from CK and WC plots were somewhat less than the average volume expected on these sites, *i.e.*, 13 m^3/ha/yr, provided tree spacing is adequate for unrestricted growth (Grano 1969). Only TC plots produced more than 18 m^3/ha/yr through age 11. To maximize early volume production in precommercially thinned loblolly pine stands, a density of no more than

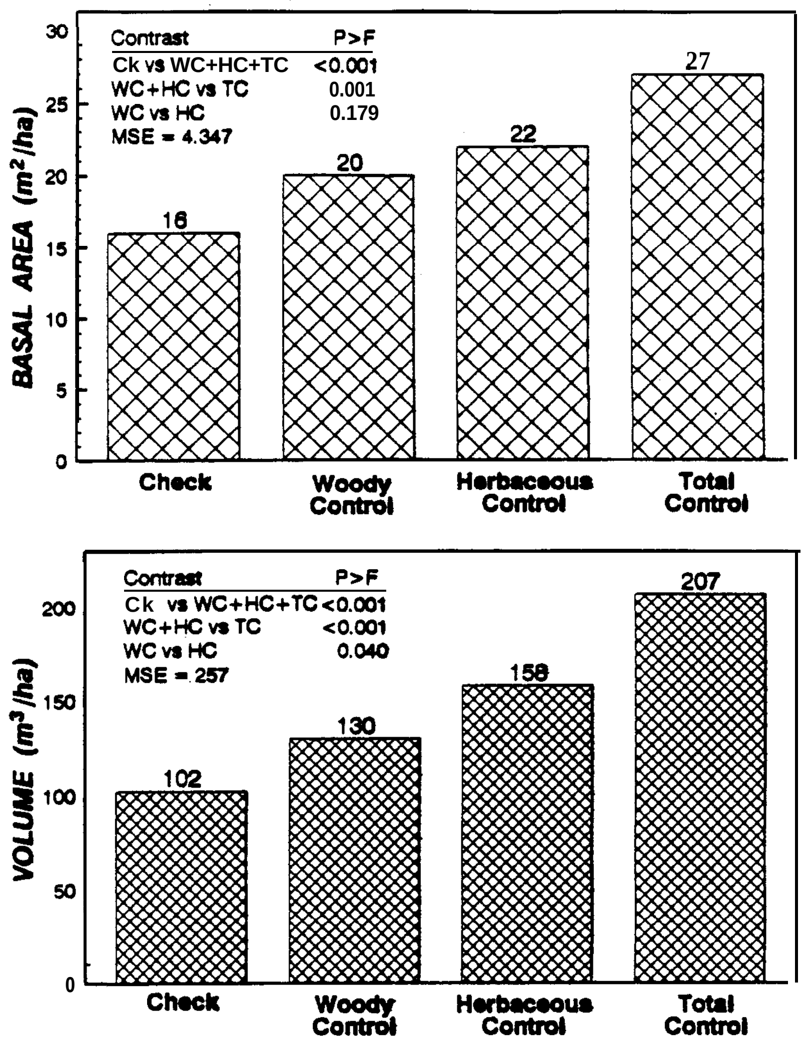
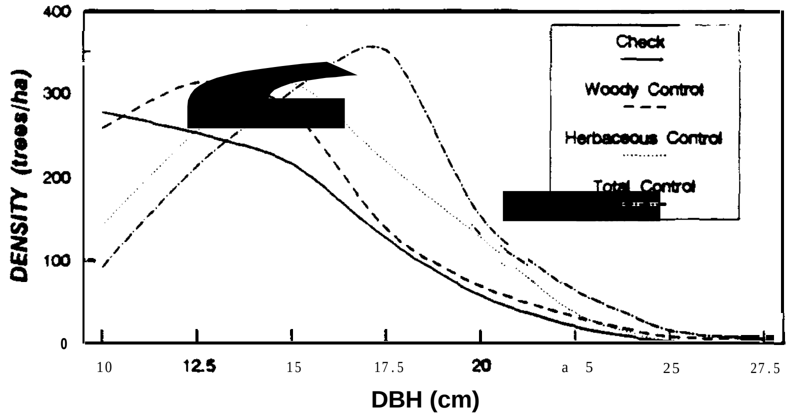


Figure 1. Stand basal area and volume in surviving crop pines at age 11 by vegetation control technique.

1,350 trees/ha has been reported as optimum (Lohrey 1977). Consequently, somewhat higher volumes might have been achieved in the! present study with a residual pine density that exceeded 1,235 trees/ha following precommercial thinning at age 5.

The highest density for merchantable-sized crop pines occurred in the 10-cm and 12.5-cm dbh classes on CK and WC plots, respectively (Figure



Vegetation control	Trees/ha by 2.5-cm DBH classes							
	10	12.5	15	17.5	20	22.5	25	27.5
Check	278	253	222	124	56	19	0	0
Woody Control	259	321	290	130	68	31	6	6
Herbaceous Control	142	259	327	216	130	31	0	0
Total Control	93	216	303	377	142	62	12	6

Figure 2. Diameter **distributions** for merchantable-sized crop pines at age 11 by vegetation control technique.

2). On HC and TC plots, most dominant pines occurred in the 15-cm and 17.5-cm dbh classes, respectively. The proportion of surviving crop pines that achieved merchantability within 11 years was as follows: CK (80.3%), WC (90.0%), HC (91.3%). and TC (98.1%). Only WC and TC plots had sawlog-sized pines (>24 *cm* dbh) at 11 years (Figure 2). Normality of dbh was more pronounced with HC and TC as exhibited by the well-defined peaks in Figure 2.

Response of largest 247 *crop pines/ha to vegetation control*

At 1 I years, the 247 largest crop pines/ha averaged 1.2 m taller than the mean of all crop pines. These 247 trees/ha were also 1.2 m taller ($P<0.01$) on vegetation control plots as compared to those on CK plots (Figure 3). Controlling only herbaceous vegetation during the first 4 years resulted in a similar 1.2-m height gain ($P<0.01$) by age 11 when compared to plots where only woody vegetation was controlled for 5 years.

Mean dbh's for the 247 largest crop pines/ha ranged from 15.5 cm on CK plots to 19.0 cm on TC plots (Figure 3). Vegetation control resulted in a 16%

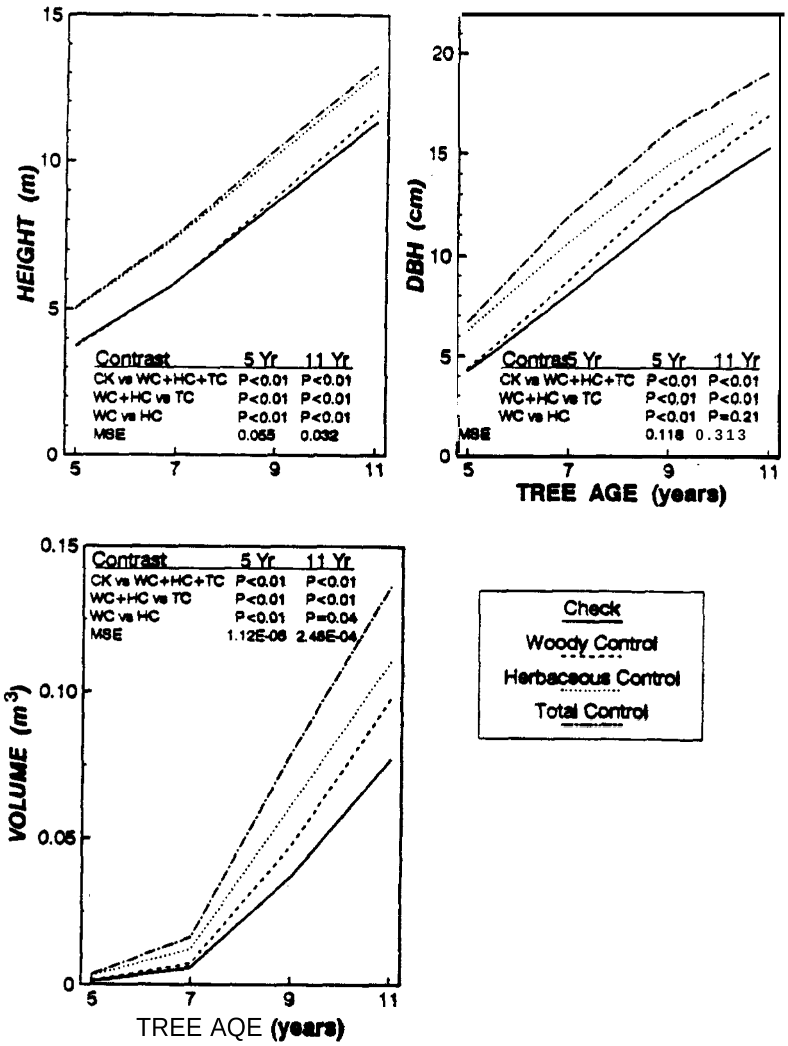


Figure 3. Growth trends in dbh. height, and volume for the largest 247 crop pines/ha from age 5 through age 11 by vegetation control technique.

gain ($P<0.01$) in dbh for these 247 largest trees/ha compared to CK pines. The diameter growth gain($P<0.01$) that was achieved by age5 from controlling herbaceous vegetation rather than woody vegetation (Figure 3) had declined to nonsignificance (P-0.21) by age 11, as hardwoods negatively impacted pine diameter growth on HC plots. So, the negative effect from hardwoods was more apparent for pine dbh growth than for pine height growth through the first 11 years.

For the 247 largest crop pines/ha, volume growth gains increased from age 5 to 11 years on competition control treatments compared to CK plots (Figure 3). On competition control plots, dominant pines had the equivalent of from 1 to 2 yearsgrowth advantage over dominants on untreated plots at age 11. Through 11 years, volume growth achieved by dominant pines on TC plots remained superior ($P<0.01$) to the mean of those on WC and HC treatments. Even with reduced pine dbh growth on HC plots from age 9 to 11 years (Figure 3), mean volumes for these dominant pines still favored (P-0.04) HC over WC at age 11.

Pine population size structure

Pine density in autumn 1994 averaged 4,881 stems/ha with the majority of stems in the seedling size class (Table 2). This was because pines taller than 1.5 m were precommercially thinned at the end of the fifth growing season (1988), leaving only 1,235 crop pines/ha on all treatments. Because of a mineral-soil seedbed and lack of nonpine competition which facilitated pine establishment from natural seedcrops, density of pine seedlings on TC plots averaged 5,000 stems/ha more ($P<0.001$) *than* on the other three treatments (Table 2). In the absence of a catastrophic disturbance to crop pines, this abundance of pine seedlings on TC plots makes no positive contribution to even-aged management. At age 11, there were no important differences among treatments in orthogonal contrasts with regard to the density of pine saplings (P-0.242) or trees (P-0.269). From an operational standpoint, pine densities on untreated CK plots exceeded the minimum recommended (1,730 stems/ha) for successful natural regeneration of clearcut areas.

Based on quadrat stocking (a measure of plant distribution), there were treatment differences in the pine seedling and sapling populations (Table 2), but these differences were considered unimportant because all treatments were adequately stocked with merchantable-sized pines, With 40% stocked quadrats, WC plots had less (P-0.043) stocking of merchantable-sized pines compared to the other three treatments; but all treatments had at least 1,235 crop pines/ha. Therefore, lower quadrat stocking on WC plots simply reflects less uniform spatial distribution of the crop pines. A dense ground cover of herbaceous vegetation on WC plots during the early years of this study probably contributed to clumping of pines, but only where microsites were most favorable for pine establishment. Since the minimum acceptable quadrat stocking of natural pine regeneration on clearcut areas is 40% to 60%. all treatments were adequately stocked with pines after 11 growing seasons. Consequently, intensive competition control was not a prerequisite to achieving ample natural pine regeneration on these sites.

Table 2. Pine population density and quadrat stocking at stand age 11.

Vegetation control and orthogonal contrasts	Density: Seedlings[2]	Saplings[3]	Trees[4]	Quadrat stocking[1]: Seedlings[2]	Saplings[3]	Trees[4]
	(stems/ha)			(%)		
1. Check	803	556	1,545	17.5	17.5	60.0
2. Woody control	2,286	865	1,236	47.5	27.5	40.0
3. Herbaceous control	185	62	1,545	7.5	2.5	57.5
4. Total control	7,413	1,544	1.483	87.5	20.0	57.5
Mean square error	940,249	923,315	56.021	0.030	0.020	0.015
P > F	<0.001	0.242	0.269	<0.001	0.146	0.084
	(Probabilities of a greater F-value)					
1 vs 2+3+4	0.002	0.641	0.389	0.005	0.943	0.205
2+3 vs 4	<0.001	0.099	0.538	<0.001	0.597	0.214
2 vs 3	0.014	0.267	0.098	0.007	0.030	0.043

[1] Based on the presence of at least one seedling-, sapling-, or tree-sized pine per 4-m^2 quadrat and 10 systematically spaced quadrats per interior plot.
[2] Stems < 1.5 cm dbh.
[3] Stems 1.5 cm to 8.9 cm dbh.
[4] Stems ≥9.0 cm dbh.

Nonpinc competition

In autumn 1994, density of woody, nonpine competition averaged 8,448 rootstocks/ha for the seedling size class and 1,869 stems/ha for the sapling size class (Table 3). Even with intensive control of woody vegetation using herbicides for 5 consecutive years (1984-l 988), woody species had reinvaded both WC and TC plots by year 11, resulting in comparable seedling densities (P-0.133) among treatments. Quadrat stocking of these seedling-sized woody rootstocks averaged 85% or higher, also with no differences (P-0.526) among treatments. The increasing densities of woody rootstocks on TC and WC plots, during the 6 years since the last treatment, are indicative of natural plant succession on disturbed sites.

As would be expected, WC plots and TC plots had the fewest woody stems of sapling size at the end of 11 growing seasons, averaging 433 stems/ha or less (Table 3). In contrast, there were over 3,000 hardwood saplings/ha on CK and HC plots. Quadrat stocking of sapling hardwoods on TC plots and on WC plots averaged 15% or less as compared to an average of 58% stocked quadrats for hardwood saplings on CK and HC plots.

After 11 growing seasons, percent ground cover from pines averaged 10 percentage points less (P-0.041) on CK plots (75%) compared to treated

Table 3. Population status of nonpine woody vegetation, 11 years after mowing and 6 to 7 years after further competition control ended.

Vegetation control and orthogonal contrasts	Seedling-size[1]		Sapling-size[2]	
	Density (rtstk/ha)[3]	Quadrat stocking[4] (%)	Density (stems/ha)	Quadrat stocking[4] (%)
1. Check	11,305	97.5	3,027	60.0
2. Woody control	9,143	90.0	433	15.0
3. Herbaceous control	7,475	85.0	3,892	57.5
4. Total control	5,869	95.0	124	5.0
Mean square error	8,951,863	0.115	821.383	0.071
P > F	0.133	0.526	0.001	0.017
	(Probabilities of a greater F-value)			
1 vs 2+3+4	0.055	0.283	0.016	0.026
2+3 vs 4	0.216	0.444	0.005	0.069
2 vs 3	0.451	0.520	<0.001	0.034

[1] Rootstocks taller than 15 cm but < 1.5 cm dbh.
[2] Stems 1.5 cm to 8.9 cm dbh.
[3] A rootstock (rtstk) was comprised of either single or multiple stems (clump) of seedling size. which obviously arose from the same root system.
[4] Based on the presence of at least one seedling-size woody rootstock or one sapling-size woody stem per 4-m^2 quadrat and 10 systematically spaced quadrats per interior plot.

plots (85%) (Table 4). Likewise, TC plots averaged22 percentage points more ($P<0.001$) pine coverage than occurred on WC or HC plots, and there was no difference (P-0.859) between the latter two treatments. Ground coverage from nonpine woody vegetation was lowest($P<0.001$) on WC and TC plots (Table 4), where that component was controlled during the first 5 years of this investigation.

For herbaceous vegetation, ground coverage at 11 years also reflected the type of vegetation control that was applied during the first 4 years of this study. Check plots and WC plots had 83% and 92% herbaceous ground coverage, respectively (Table 4), which was more ($P<0.001$) than occurred on HC (28%) or TC (42%) plots. The most prevalent herbaceous invaders were grasses, vines (principally Japanese honeysuckle [*Lonicera japonica* Thunb.]), and semi-woody plants (principally blackberry canes [*Rubus* spp.]). In all four treatments, vines accounted for the greatest ground coverage from herbaceous species. Pines and hardwoods served as trellises for the vines, which often cut into the boles and deformed the crowns. At 11 years, there was no visual evidence that pines had recovered from defects or deformities

Table 4. Ground coverage by woody and herbaceous vegetation at stand age 11.

Vegetation control and orthogonal contrasts	Pine	Woody nonpine	Herbaceous				
			Grass	Forbs	Vines	Semi-woody[1]	Total[2]
	(%)[3]						
1. Check	75.2	73.5	1.6	0.4	82.2	0.5	82.6
2. Woody control	77.8	27.6	33.6	7.4	74.0	23.3	91.8
3. Herbaceous control	76.8	80.4	5.0	0.3	22.9	0.2	28.2
4. Total control	99.8	12.0	17.7	1.6	22.6	10.4	42.2
Mean square error	0.034	0.028	0.012	0.002	0.061	0.006	0.046
P>F	0.002	<0.001	0.008	0.175	0.002	0.008	<0.001
	(Probabilities of greater F-values)						
1 vs 2+3+4	0.041	0.002	0.022	0.350	0.004	0.042	0.016
2+3 vs 4	<0.001	0.001	0.766	0.440	0.063	0.788	0.050
2 vs 3	0.859	<0.001	0.004	0.061	0.005	0.003	<0.001

[1] In this investigation, semi-woody plants were principally blackberries (*Rubus* spp.).
[2] Total for herbaceous ground cover does not equal the sum of individual components because of multiple layers.
[3] Percent ground cover was determined by ocular estimation. Each value represents a mean from forty 4-m^2 quadrats.

caused by vines in earlier years. Consequently, on sites where vines are a problem, some type of vine control is probably justified.

The most prevalent woody species of seedling size was American beautyberry (*Callicarpa americana* L.), which was dominant on 40% of all quadrats that were inventoried (Table 5). The second most prevalent nonpine woody rootstock was *Vuccinium* spp., occurring on 14% of quadrats. These data are consistent with Miller et al. (1995) who studied 13 pine plantations across the southeastern U.S. and found that, of woody species occurring most frequently 8 years after site preparation, *Vuccinium* spp. and *Callicarpa americana* ranked second and fourth, respectively.

Species richness of dominant seedling-sized rootstocks averaged 9 on CK plots, 13 on WC plots, 9 on HC plots, and 10 on TC plots. It is noteworthy that plots which received the most intensive treatments for controlling woody vegetation had the greatest variety of dominant woody species within 6 years after treatments ended. On southern pine sites, reinvasion of intensively controlled woody species is usually attributed to soil seed banks (Haywood 1994), root sprouts (Reynolds 1956), and seed dissemination by animals (Halls 1977) and wind (Krugman et al. 1974).

Table 5. Species composition of dominant seedling-sized[1] woody rootstocks as a Percent of total stems, 6 years after woody plant control ended.

Species	Check	Woody control	Herbaceous control	Total control	Species mean
	(%)				
Acer rubrum	2.5	2.5	7.5	22.5	a.8
Callicarpa americana	50.0	27.5	45.0	37.5	40.0
Carya SQQ.	0.0	0.0	2.5	0.0	0.6
Cornus florida	0.0	5.0	0.0	5.0	2.5
Crataegus SQQ.	2.5	2.5	0.0	0.0	1.2
Ilex opaca	2.5	0.0	0.0	12.5	3.8
1. vomitoria	0.0	0.0	5.0	0.0	1.3
Liquidambar styraciflua	0.0	2.5	0.0	0.0	0.6
Morus rubra	0.0	5.0	2.5	0.0	1.9
Ostrya virginiana	0.0	5.0	0.0	0.0	1.2
Prunus serotina	0.0	2.5	0.0	2.5	1.3
Prunus SQQ.	0.0	2.5	0.0	0.0	0.6
Quercus alba	0.0	0.0	0.0	2.5	0.6
Q. *falcata*	7.5	0.0	5.0	2.5	3.8
Q. nigra	0.0	0.0	2.5	0.0	0.6
Q. stellata	2.5	2.5	0.0	0.0	1.2
Rhamnw caroliniana	0.0	0.0	0.0	2.5	0.6
Rhus copallina	5.0	7.5	0.0	5.0	4.4
Sassafras albidum	7.5	2.5	2.5	0.0	3.1
Vaccinium SQQ.	17.5	22.5	12.5	2.5	13.8
Missing[2]	2.5	10.0	15.0	5.0	8.1
Totals	loo.0	100.0	100.0	100.0	100.0

[1] Rootstocks taller than 15 cm but < 1.5 cm dbh that exhibited the most ground cover on each of forty 4-m^2 quadrats per vegetation control treatment.
[2] Percent of 4-m' quadrats on which no seedling-sized woody rootstocks were observed.

For dominant sapling-sized hardwood stems, red maple (*Acer rubrum* L.) and water oak (*Quercus nigra* L.) were most prevalent, occurring on 5% to 6% of quadrats inventoried across all treatments (Table 6). In the regional study of woody plants on cutover pine sites, Miller et al. (1995) found that *Quercus nigra* and *Acer rubrum* ranked second and sixth, respectively, as the most frequently recurring arborescent species, 8 years after site preparation. In the present investigation, flowering dogwood(*Cornus florida* L.) was the most prominent species of sapling size (15% quadrat stocking) on CK plots. On WC and TC plots, respectively, 85% to 95% of sample quadrats had no hardwoods of sapling size (Table 6) because woody stems were intensively controlled for the first 5 of 11 years.

Table 6. Species composition of dominant sapling-sized[1] woody stems as a percent of total stems, 6 years after woody plant control ended.

Species	Check	Woody control	Herbaceous control	Total control	Species mean
	(%)				
Acer rubrum	2.5	0.0	17.5	0.0	5.0
Callicarpa americana	0.0	2.5	2.5	2.5	1.9
Carya spp.	5.0	0.0	0.0	0.0	1.2
Cornus florida	15.0	0.0	0.0	2.5	4.4
Crataegus spp.	2.5	2.5	0.0	0.0	1.2
Ilex opaca	5.0	0.0	2.5	0.0	1.9
1. vomitoria	2.5	0.0	0.0	0.0	0.6
Liquidambar styraciflua	2.5	0.0	2.5	0.0	1.3
Morus rubra	0.0	0.0	2.5	0.0	0.6.
Nyssa sylvatica	5.0	0.0	2.5	0.0	1.9
Prunus serotina	2.5	5.0	0.0	0.0	1.9
Quercus falcata	0.0	0.0	10.0	0.0	2.5
Q. nigra	7.5	0.0	15.0	0.0	5.6
Q. stellata	0.0	0.0	2.5	0.0	0.6
Rhus copallina	7.5	2.5	0.0	0.0	2.5
Sassafras albidwn	2.5	2.5	0.0	0.0	1.3
Missing[2]	40.0	85.0	42.5	95.0	65.6
Totals	100.0	100.0	100.0	100.0	100.0

[1] Stems 1.5 cm to 8.9 cm dbh that exhibited the most ground coverage on each of forty 4-m^2 quadrats per vegetation control treatment.
[2] Percent of 4-m^2 quadrats on which no sapling-sized woody stems were observed.

Management implications

Even on plots without competition control, density of merchantable-sized pines and quadrat stocking of those same pines were above the levels recommended for successful natural regeneration of loblolly and shortleaf pines on clearcut areas. Also, 89% of crop pines on CK plots were judged as free-to-grow at the end of 11 growing seasons. Therefore, successful natural pine regeneration of the clearcuts in this study was not dependent on annual control of herbaceous or woody competition from a practical point-of-view. The presence of vines on crop pines contributed to substantial defects in the form of deformed crowns and crooked boles and stems. Therefore, vine control is probably warranted on sites where vines are abundant.

Even though herbicide applications for the first 4 to 5 years after pine establishment did much to control competing vegetation, the site was reinvaded by as many as 13 dominant species of woody plants, plus herbaceous vegetation, and natural pine regeneration within [illegible] years after treatments ceased. These data suggest that concerns over potential loss of plant species richness resulting from the silvicultural use of herbicides are not well grounded.

Early gains in pine diameter growth that were achieved from controlling only herbaceous vegetation as compared to controlling only nonpine woody vegetation began to disappear after age 7 and were no longer statistically significant at age 11. Consequently, control of herbaceous competition was most beneficial for pine growth up to about 7 years, but continued growth enhancement for pines required the control of hardwood competitors. This was evident by the fact that hardwood saplings (>3,800/ha) contributed to the decline in pine diameter growth on HC plots. Because 95% of crop pines on HC plots were free-to-grow, early gains in height growth persisted for pines in that treatment (1.5 m through age 11) when compared to crop pines on WC plots.

Compared to untreated plots, 4 years of total competition control did result in a gain of about 2.4 m in height and 3.7 cm in dbh for all crop pines after 11 growing seasons. Consequently, volumes averaged about 207 m^3/ha in merchantable-sized pines on plots where all nonpine competition was controlled as compared to about 102 m^3/ha where the only treatment was precommercial thinning of pines at age 5.

Historically and operationally, control of only woody competition has been given priority in southern pine management because, in the absence of disturbance, pines can be displaced by more aggressive shade-tolerant hardwoods, as documented in old-field succession (Oosting 1956). In that same successional process, pines become established coincidentally with herbaceous vegetation and usually dominate the site within a few years. Yet, this investigation has shown that herbaceous vegetation can substantially reduce pine growth during the first 11 years after pine establishment. Three of the four competition levels tested in this study represent previously undocumented standards of pine growth in naturally regenerated stands of loblolly and shortleaf pines to which less-intensive operational treatments can be compared on Coastal Plain sites in the southeastern U.S.

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References

Baker, J.B. and Murphy, PA. 1982. Growth and yield following four reproduction cutting methods in loblolly-shortleaf pine stands – a case study. South. J. Appl. For. 6: 66-74.

Bonner, ET. 1974. Seed testing, pp. 136152. In: Seeds of Woody Plants in the United States. USDA, Washington, DC. Agric. Handb. 450.

Cain, M.D. 1988. Hardwood control before harvest improves natural pine regeneration. USDA For. Serv., South. For. Exp. Sta., New Orleans, LA. Res. Pap. SO-249.6 p.

Cain, M.D. 1991. The influence of woody and herbaceous competition on early growth of naturally regenerated loblolly and shortleaf pines. South. J. Appl. For. 15: 179–185.

Cain, M.D. and Barnett, J.P. 1994a. 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. 1994b. Importance of release for naturally seeded and planted container loblolly pines on a cutover site. Tree Planters' Notes 45(4): 128-136.

Cain, M.D. and Barnett, J.P. 1996. An I-year field comparison of naturally seeded to planted container *Pinus taeda*, with and without release. Can. J. For. Res. 26: 1237-1247.

Campbell, T.E. and Mann. W.F., Jr. 1973. Regenerating loblolly pine by direct seeding, natural seeding, and planting. USDA For. Serv., South. For. Exp. Sta., New Orleans, LA. Res. Pap. SO-84.9 p.

Chapman, H.H. 1953. Effects of thinning on yields of forest-grown longleaf and loblolly pines at Urania, La. J. For. 5 1: 16-26.

Farrar, R.M.. Jr. and Murphy, PA. 1988. A versatile volume-defining function for natural loblolly pine trees. USDA For. Serv., South. For. Exp. Sta., New Orleans, LA. Res. Pap. SO-243.9 p.

Grano. C.X. 1967. Growing loblolly and shortleaf pine in the Midsouth. USDA, Washington. DC. Farmers' Bull. 2102.27 p.

Grano, C.X. 1969. Precommercial thinning of loblolly pine. J. For. 67: 825-827.

Halls. L.K. (Ed) 1977. Southern fruit-producing woody plants used by wildlife. USDA For. Serv., South. For. Exp. Sta., New Orleans, LA. Gen. Tech. Rep. SO-16.235 p.

Haywood, J.D. 1994. Seed viability of selected tree. shrub, and vine species stored in the field. New For. 8: 143-154.

Krugman, S.L.. Stein, W.I. and Schmitt, D.M. 1974. Seed biology, pp. 5–40. In: Seeds of Woody Plants in the United States. USDA, Washington, DC. Agric. Handb. 450.

Lohrey, R.E. 1977. Growth responses of loblolly pine to precommercial thinning. South. J. Appl. For. 1: 19-22.

Miller, J.H. and Zutter, B. 1987. A region-wide study of loblolly pine seedling growth relative to four competition levels after two growing seasons. pp. 581-591 In: Proc. Fourth Bienn. South. Silvic. Res. Conf., USDA For. Serv., Southeast. For. Exp. Sta.. Asheville, NC. Gen. Tech. Rep. SE-42.

Miller, J.H., Zutter, B.R., Zedaker, S.M., Edwards, M.B., Haywood, J.D. and Newbold, R.A. 1991. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. South. J. Appl. For. 15: 169-179.

Miller, J.H.. Zutter. B.R., Zedaker, S.M., Edwards, M.B. and Newbold. R.A. 1995. Early plant succession in loblolly pine plantations as affected by vegetation management. South. J. Appl. For. 19: 109-126.

Oosting. H.J. 1956. The study of plant communities. 2nd ed. W.H. Freeman, San Francisco. 440 p.

Reynolds. R.R. 1956. Upland hardwoods in south Arkansas pine stands-aerial or underground fifth column? J. For. 54: 585-586.

Trousdell. K.B. 1963. Loblolly pine regeneration from seed - what do site preparation and cultural measures buy? J. For. 61: 441444.

USDA. 1979. Soil survey of Ashley County, Arkansas. USDA Soil Conserv. Serv. and For. Serv. in cooperation with Ark. Agric. Exp. Sta. 92 p. and maps.

USDA, Forest Service. 1988. The South's fourth forest: alternatives for the future. USDA For. Serv.. Washington, DC. For. Resour. Rep. 24. 512 p.