Woody and herbaceous competition effects on stand dynamics and growth of 13-year-old natural, precommercially thinned loblolly and shortleaf pines

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Abstract: Stand dynamics of naturally regenerated, even-aged, loblolly pines (Pinus *taeda* L.) and shortleaf pines (*P. echinata* Mill.) were examined on the Upper Coastal Plain of southeastern Arkansas, U.S.A., following four levels of competition control. Treatments included a check (Ck) with no competition control, woody control (WC), herbaceous control (HC), and total control (TC) of nonpine vegetation. After pines became established from natural seeding, herbicides were used to control herbaceous plants for four consecutive years and woody plants for five consecutive years. At age five, 1235 crop pines/ha were retained and al1 noncrop pines >1.5 m tal1 were precommercially hand thinned. Although 93% of crop pines on Ck plots were judged free-to-grow 13 years after establishment, crop pines on vegetation control plots were larger ($P \leq 0.001$) in mean diameter at breast height, total height, and volume per tree. From age 5 through 13 years, crop pine diameter growth increased on WC plots and decreased on HC plots because of hardwood competition in the latter treatment. At age 13, mean pine volume production was 48% greater ($P < 0.01$) on plots that received competition control than on Ck plots (160 $m^3 \cdot ha^{-1}$); TC resulted in 31% more ($P < 0.01$) volume (282 $m^3 \cdot ha^{-1}$) than the mean of WC and HC plots; and there was no difference ($P = 0.15$) between the latter two treatments.

Résumé : La dynamique de peuplements équiennes de pin à encens (Pinus *taeda* L.) et de pin jaune (*P. echinata* Mill.) issus de régénération naturelle a été étudiée sur la Haute Plaine Côtière du sud-est de l'Arkansas, aux États-Unis, à la suite de quatre niveaux de répression de la compétition. Les traitements incluaient un témoin sans répression de la compétition, une répression des espèces ligneuses, une répression des herbacées et une répression complete des espèces autres que les pins. Après l'établissement des pins par ensemencement naturel, des herbicides ont été utilisés durant quatre années consécutives pour réprimer la végétation herbacée et durant cinq années consécutives pour réprimer la végétation ligneuse. À 5 ans, 1235 pins d'avenir à l'hectare ont été retenus et tous les autres pins de plus de 1,5 m de hauteur ont été éliminés par une coupe précommerciale réalisée manuellement. Même si 93% des pins des parcelles témoins étaient jugés libres de croître 13 ans après l'établissement, les pins d'avenir des parcelles avec répression de la végétation présentaient en moyenne des diamètres à hauteur de poitrine, des hauteurs totales et un volume par arbre supérieurs ($P \leq 0{,}001$). De 5 à 13 ans, la croissance en diamètre des pins d'avenir a augmenté sur les parcelles avec répression de la végétation ligneuse et a diminué sur les parcelles où seule la végétation herbacée avait été réprimée, à la suite d'une compétition plus importante par les feuillus dans ce dernier cas. À 13 ans, la production moyenne en volume des pins sur les parcelles où un traitement avait été appliqué était de 48% supérieure ($P < 0{,}01$) par rapport aux parcelles témoins (160 $m^3 \cdot ha^{-1}$). L'élimination complete de la compétition a produit 31% plus de volume (282 $m^3 \cdot ha^{-1}$; $P < 0{,}01$) que la moyenne des parcelles ou seules les espèces ligneuses ou herbacées avaient été éliminées. Aucune différence n'a été decelée entre ces deux traitements ($P = 0{,}15$).

[Traduit par la Rédaction]

Introduction

Since most of the pine forests from which trees are being harvested in the southeastern United States originated from natural seedfall, this method of regeneration is still an important means of reforestation in that region (Dougherty and Duryea 1991). The major physiographic subregion for southern pines is the Upper Coastal Plain where loblolly and shortleaf pines (Pinus *taeda* L. and *Pinus echinata* Mill., respectively) predominate (Baker and Langdon 1990; Lawson 1990).

Even though loblolly and shortleaf pines are often principal components of the overstory in naturally regenerated forests of the Upper Coastal Plain, the understory is usually occupied by a dense mixture of shade-tolerant hardwood trees, woody shrubs, and herbaceous vegetation (Cain 198.5, 1988; Cain and Yaussy 1983). Concomitantly, when pines are commercially harvested in natural stands, the forest floor is often exposed to full sunlight, which promotes the invasion and proliferation of early successional vegetation (Cain 1991b). These herbaceous and woody plants can quickly overtop recently established natural pine seedlings and compete with larger pines for growing space, sunlight, soil moisture,

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and nutrients, thereby resulting in high mortality of pine regeneration (Cain 1991a) and growtb loss in pine saplings (Cain and Bamett 1996) and trees (Grano 1970).

An often-cited disadvantage for natural regeneration of southem pines is the inability to control density at the time of establishment (Bamett and Baker 1991). In the Upper Coastal Plain of the West Gulf Region, natural stands of loblolly and shortleaf pines can produce good seed crops (2 100 000 potentially viable seeds/ha) in 7 of 10 years (Cain 1993*a*). When these seeds are disseminated onto receptive sites, excessive pine density can result (Cain 1993b). In such situations, precommercial thinning is often recommended to shorten the rotation and reduce the risk of loss by fire, insects, diseases, and weather (Mann and Lohrey 1974).

The present study was conducted to investigate the interrelationships among woody and herbaceous competition components and to assess the impact of these components on establishment, survival, and growtb of naturally regenerated loblolly and shortleaf pines. During the first 5 years of this investigation, control of only woody competition did not improve pine growth compared with untreated checks, but total competition control and control of only herbaceous competition resulted in significant ($P < 0.05$) increases in pine growth (Cain 1991*c*). Also during the first 5 years, pines were allowed to invade study plots from natural seedfall, and no effort was made to control pine density. Before the sixth growing season, pines were precommercially hand thinned to a density of 1235 stems/ha to optimize future growth. The objective of this paper is to document the effect of these early competition control treatments and precommercial thinning on pine growth and stand dynamics from ages 5 through 13 years.

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, U.S.A. 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 leve1 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.

Before clear-cutting, 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 per hectare and about 108 $m^3 \cdot ha^{-1}$ in sawlog volume. Hardwoods that were ≥3 cm diameter at groundline were stem injected with herbicide (Tordon®[1] 101R: picloram, 0.03 kg/L, and 2,4-D, 0.12 kg/L) 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 clearcuts 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 this 1983-1984 seed year averaged 2 470 000 potentially viable seeds per hectare (Cain 1988).

Study design and treatments

Eight treatment plots were established within each 2-ha clearcut. Treatment plots were 0.10 ha (31.7 x 31.7 m) with 0.04-ha (20.1 x 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' 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 herbaceous or woody nonpine vegetation was made after mowing in 1983. Five years later, ground cover from herbaceous and woody nonpine vegetation averaged 78 and 38%, respectively (Cain 1991*c*).
(2) Woody control (WC): Al1 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 1991*c*).
(3) Herbaceous control (HC): Forbs, grasses, semiwoody plants, and vines were controlled annually using multiple applications of pre-emergent and post-emergent herbicides (Oust®: sulfometuron at 0.26 $kg \cdot ha^{-1}$; Vantage®: sethoxydim at 0.84 or 1.68 $kg \cdot ha^{-1}$; and (or) 2% Roundup®: glyphosate) for the first four consecutive years. One year after this treatment series ended, ground cover averaged 38% from woody nonpine vegetation but only 7% from herbaceous vegetation (Cain 1991c).
(4) Total control (TC): A combination of herbicides, as described in the WC and HC treatments, was used to control al1 nonpine vegetation. Woody plants were controlled for the first five consecutive years and herbaceous vegetation was controlled for the first four 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*c*).

Before spring of the sixth growing season, pines taller than 1.5 m were precommercially hand thinned on all plots to a residual density of 1235 crop pines/ha or 50 crop pines per 0.04-ha interior subplot. This density was chosen to optimize pine volume production, as recommended by Lohrey (1977). Thinning was also 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 al1 plots, 90% of the crop pines were loblolly and the other 10% were shortleaf. Hardwoods and shrnbs were not cut during thinning.

Measurements and data analysis

Only measurements taken at ages 5, 7, 9, ll, and 13 years are described here. Within each of ten 4-m' quadrats per plot, al1

[1] 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. The use of trade or firm names is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1. Treatment effects on the survival, mean size, and free-to-grow status of crop pines at age 13 in southeastern Arkansas, U.S.A.

Vegetation control and orthogonal contrasts	Survival (%)	Height (m)	DBH (cm)	Volume (m^3)	Live-crown ratio (%)	Crown width (m)	Free to grow (%)
1. Check	94	11.35	14.6	0.082	50	3.91	93
2. Woody control	98	11.80	15.8	0.097	53	4.33	94
3. Herbaceous control	97	13.14	16.5	0.112	48	4.06	97
4. Total control	99	13.54	17.8	0.136	52	4.64	100
Mean square error	0.036	0.084	0.550	<0.001	<0.001	0.083	0.032
	0.480	<0.001	0.002	<0.001	0.024	0.026	0.157
Probabilities of a greater *F* value for orthogonal contrasts							
1 vs. 2+3+4	0.186	<0.001	0.001	<0.001	0.224	0.027	0.191
2+3 vs. 4	0.455	KO.001	0.006	<0.001	0.255	0.034	0.078
2 vs. 3	0.864	<0.001	0.221	0.079	0.006	0.226	0.442

[a]Foliage of competing vegetation was not touching and did not cover the terminal leader of crop pines.

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 ≥9.0 cm DBH. At 5, 7, and 9 years, each woody rootstock was identified by species and size class within individual quadrats. At ll and 13 years, only dominant woody seedling-sized rootstocks and sapling stems were identified by species, but al1 seedling-sized rootstocks and sapling stems were counted within each 4-m’ quadrat. 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 and sedges, forbs, vines, and semiwoody 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 after precommercial thinning on each 0.04-ha interior subplot: free-to-grow or overtopped status and DBH to an accuracy of 0.3 cm. Pines were judged as overtopped if the foliage of competing vegetation was touching or covered the pine’s terminal leader; otherwise, the crop pines were judged as free-to-grow (Cain and Barnett 1996). Additional measurements were taken on a random sample of 25 crop pines 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 or linear regression were used to evaluate treatment effects. Tree volumes were computed using equations developed by Farrar and Murphy (1988). Percent data were analyzed following arcsine square-root transformation. In analysis of variance, orthogonal contrasts were used to partition mean differences among treatments as follows: (i) effects of no competition control versus competition control; (*ii*) effects of controlling woody and herbaceous competition separately versus controlling both components; and (iii) 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 1235 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 at $\alpha = 0.05$ probability level.

Results and discussion

Pine response to competition control

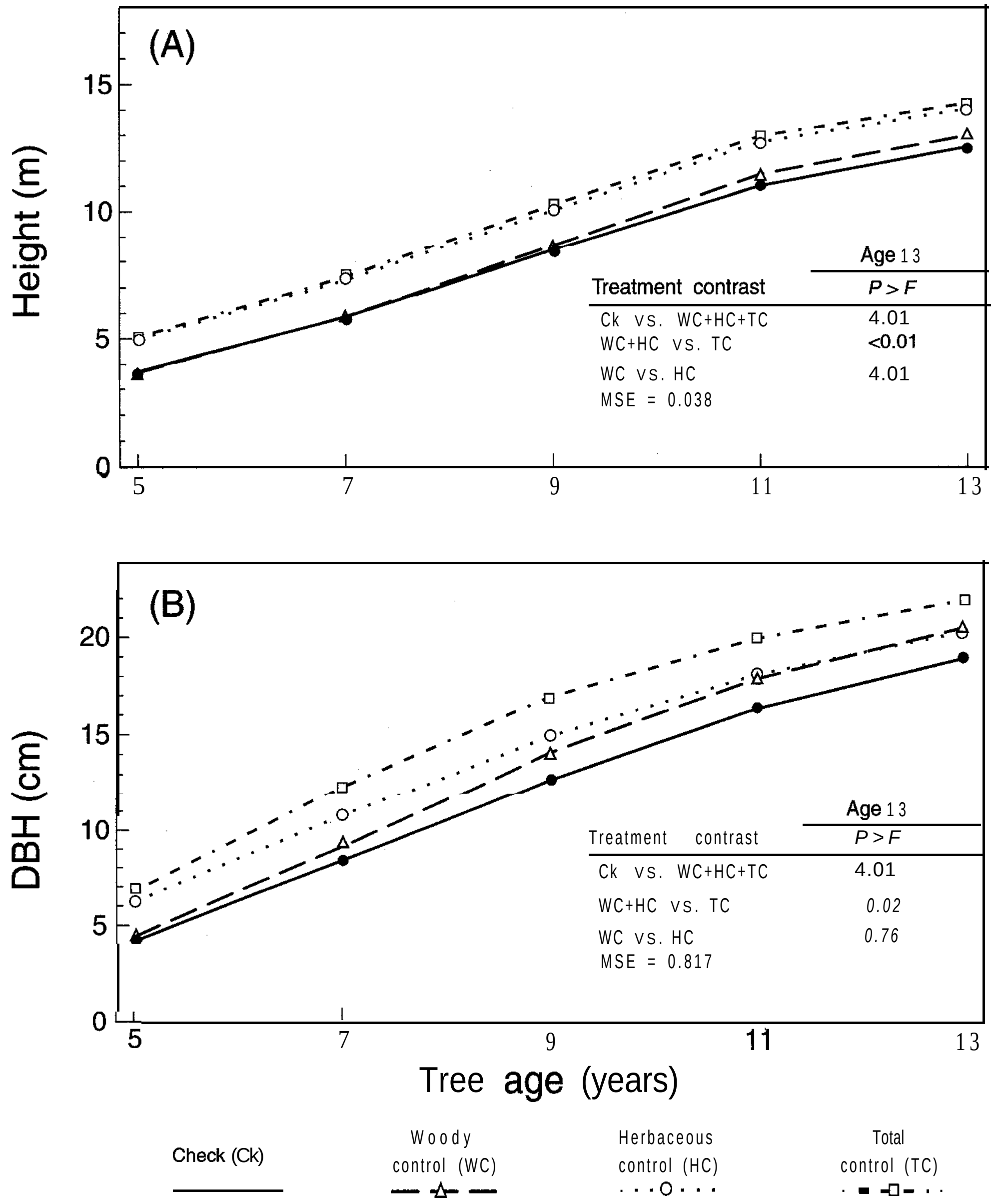
Precommercial thinning at age 5 equalized density of the natural pine component across al1 treatments and was desirable in this investigation to facilitate the detection of pine growth differences that might result from interspecific competition. A residual density of 1235 trees/ha was consistent with published recommendations for achieving maximum volume production from precommercial thinning of southern pines (Mann and Lohrey 1974).

At age 13, crep-pine survival ranged from 94% on Ck plots to 99% on TC plots and was one of only two variables not affected ($P > 0.05$) by competition-control treatments (Table 1). Excellent survival of crop pines through 13 growing seasons was attributed to their free-to-grow status, which averaged 293% with no differences ($P = 0.157$) among competition control treatments (Table 1). Low pine mortality and lack of overtopping by competing vegetation, especially on untreated Ck plots, was attributed to a uniform reduction in vegetative ground cover by mowing the study areas in August 1983, just before a better-than-average natural pine seed crop was disseminated onto the site. When site preparation does not coincide with pine seeding, competing vegetation on these sites can overtop natural pine regeneration resulting in mortality rates of 50% within 8 years after pine establishment (Cain and Bamett 1996). On good sites (site index >26 m for loblolly pine at 50 years) as occurs here, there is continuous reinvasion by both woody and herbaceous vegetation even with intensive competition control (Cain and Yaussy 1983, 1984).

During the first 5 years of this investigation, pine growth differences among competition control treatments were consistent with those achieved in loblolly pine plantations (Miller et al. 1991), where competing vegetation was controlled in a manner similar to the present study. Although pine growth averaged higher where there was total control of competing vegetation in these studies at year 5, controlling only herbaceous competition was more important for enhancing pine growth than controlling only woody nonpine competition. Through age 5, significant ($P < 0.05$) gains were achieved in pine height growth and DBH growth for herbaceous control versus woody control (Cain 1991*c*).

After 13 growing seasons, crop pines on vegetation control plots averaged 12.83 m in height (Table 1) and were 13% taller ($P < 0.001$) than those on untreated Ck plots. Crop pines on TC plots averaged 9% taller ($P < 0.001$) than

Fig. 1. Growth trends in (A) height and (B) DBH for the largest 247 crop pines/ha from age 5 through 13 by competition control treatments.

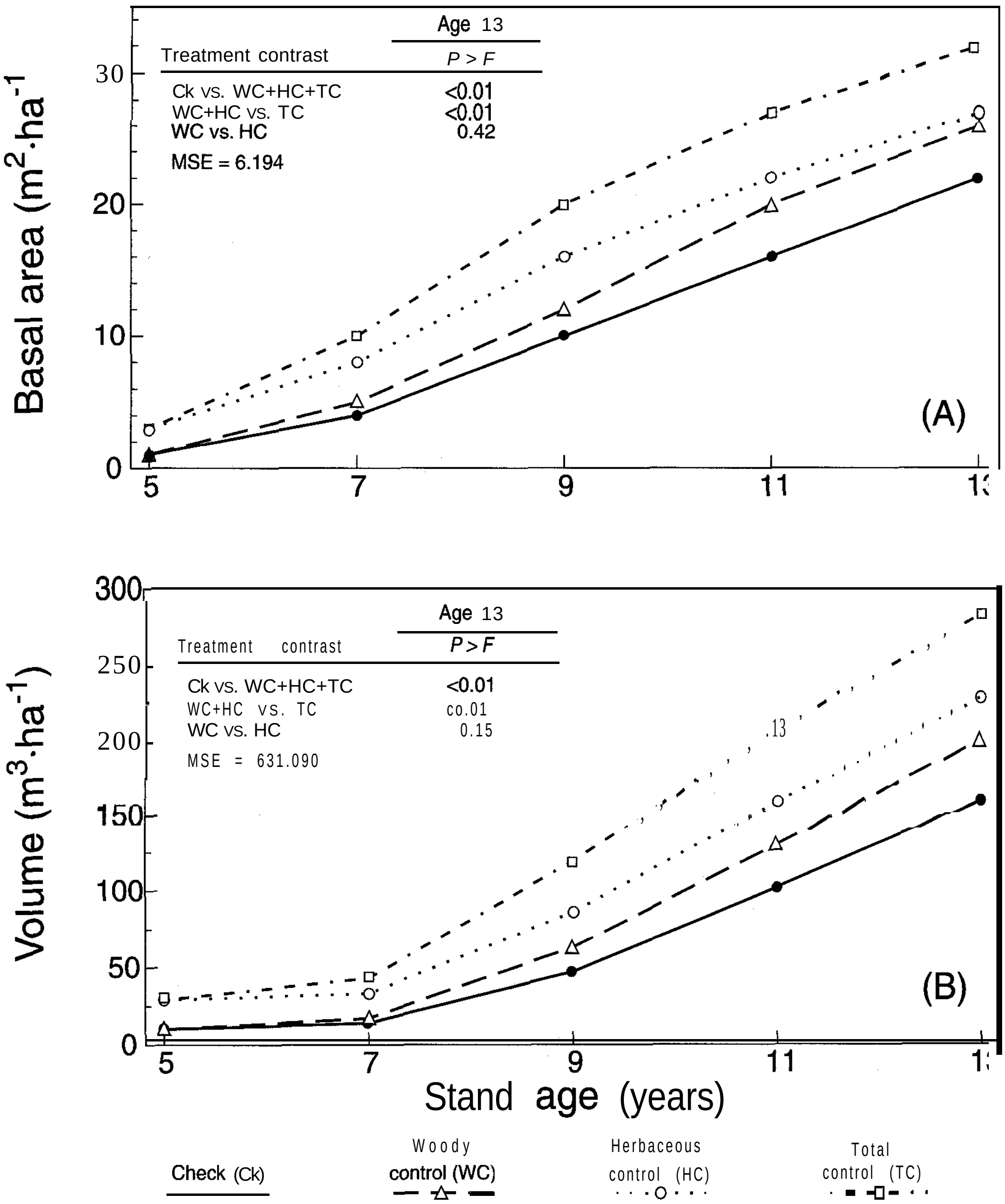


the mean height of crop pines on WC and HC plots. Also, controlling only herbaceous vegetation during the first 4 years after pine establishment resulted in an 11% height gain ($P < 0.001$) over pines on plots where only woody competition was controlled. Annual height growth was excellent and averaged 20.9 m across al1 treatments.

Height growth trends among treatments for the largest 247 crop pines/ha were similar at ages 5 and 13 years (Fig. 1). At age 13, dominant pines were taller ($P < 0.01$) on competition control plots compared with Ck plots, pines on TC plots were taller ($P < 0.01$) than the mean of those on WC and HC plots, and control of only herbaceous competition produced taller ($P < 0.01$) pines than control of only woody competition (Fig. 1). These gains in height for dominant pines on HC and TC plots during the last 8 years were the equivalent of a 2-year height growth advantage over those on WC and Ck plots.

Treatment differences in pine DBH were consistent with those for height at age 5; that is, controlling only herbaceous competition was superior to controlling only woody competition (Cain 1991*c*). Yet, as hardwood competitors increased in size from age 5 to 13 on HC plots, there was a concomitant decrease in pine DBH growth. At 16.7 cm DBH, crop pines on competition control plots were 14% larger ($P = 0.001$) than those on Ck plots, and crop pines on TC plots averaged 10% larger ($P = 0.006$) than the mean of crop pines on WC and HC plots (Table 1). Residual hardwoods on HC plots caused a decline in pine DBH growth during the last 8 years, but that trend was not apparent at age 5 (Cain 1991*c*). With crown closure from age 5 to 13 years, pines on WC plots began to shade out herbaceous competition, which in turn resulted in an increase in pine DBH growth in the absence of a hardwood component. Consequently, by age 13, gains in pine DBH from controlling only

Fig. 2. Periodic trends in crop pine (A) basal area and (B) volume production by competition control treatments during 8 years after precommercial thinning to 1235 pines/ha.



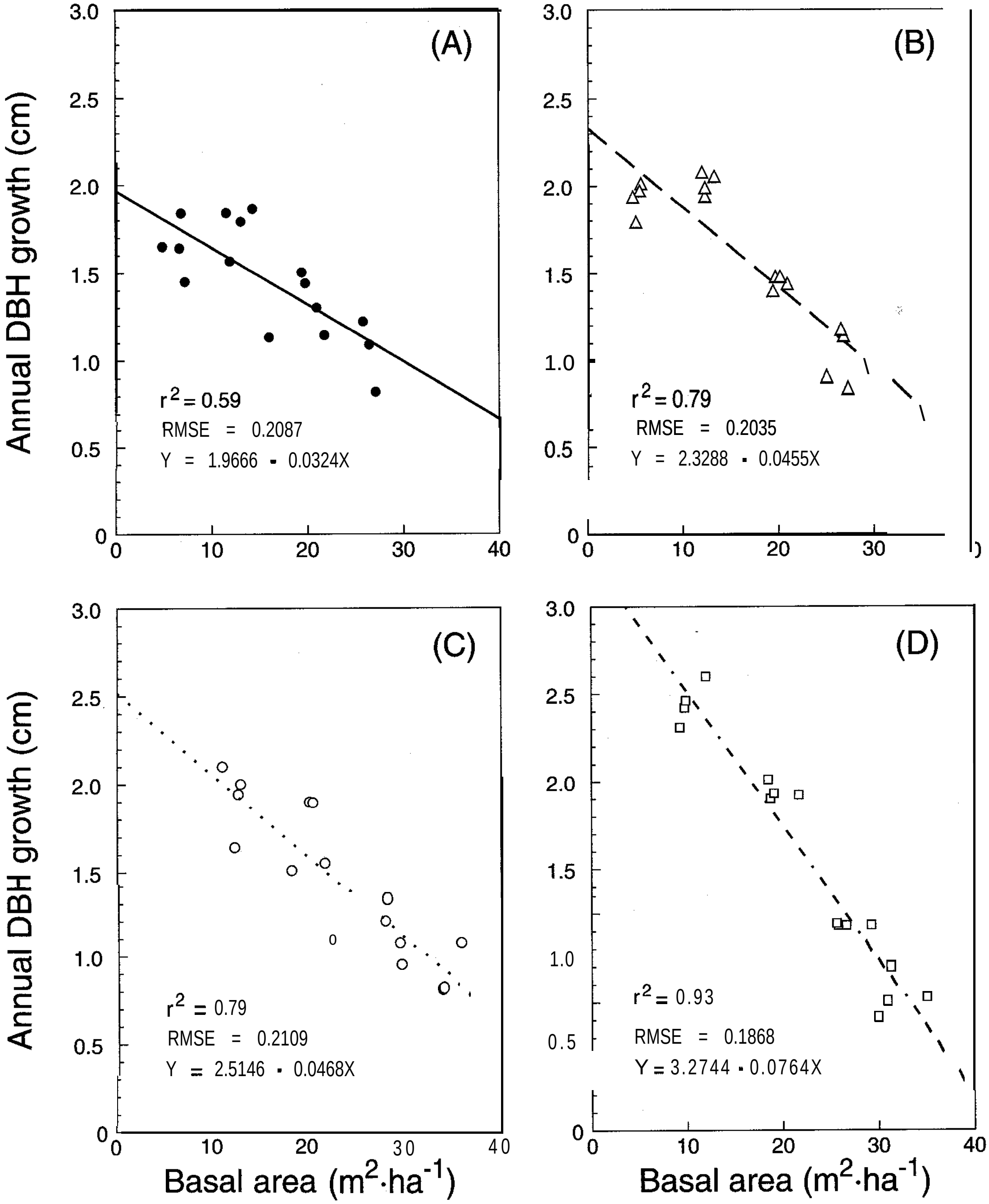
woody competition or only herbaceous competition were comparable (P = 0.221).

At age 5, treatment differences in DBH for the largest 247 crop pines/ha paralleled height differences (Fig. 1). However, gains in pine diameter growth achieved from controlling only herbaceous competition began to decline by age 7, while diameter growth for dominant pines began to increase where only woody competition was controlled. By age 13, mean DBHs for these dominant pines did not differ (P = 0.76) between WC and HC treatments (Fig. 1). At 13 years, dominant pines on TC plots had achieved an equivalent of about a 3-year gain in DBH growth over dominant check pines, while on HC and WC plots the DBH growth advantage for dominant pines was equivalent to about 2 years over untreated checks.

For individual crep-pine volumes, Ck plots had smaller pines ($P < 0.001$) than competition control plots, and crop pines on TC plots continued to outperform ($P < 0.001$) those on WC and HC plots (Table 1). Even though crop pines on HC plots were taller ($P < 0.001$) than those on WC plots, the lack of DBH differences (P = 0.221) resulted in similar (P = 0.079) volumes per tree at 13 years.

Live-crown ratios for crop pines on WC plots averaged five percentage points larger (P = 0.006) than those on HC plots at age 13, but the mean for this variable was 48% or better across al1 treatments (Table 1). According to Chapman (1953), the negative effects of reduced live-crown ratios on loblolly pine growth tend to occur only after the ratio drops below 40%. Crown widths for pines on competition control plots averaged 0.4 m greater (P = 0.027) than those on Ck

Fig. 3. Annual DBH growth of surviving crop pines relative to total pine and hardwood basal area from age 5 tbrough 13 years by competition control treatments: (A) check, (B) woody control, (C) herbaceous control, (D) total control.



plots. There was also a 0.4-m gain (P = 0.034) in crown width by pines on TC plots compared with the mean of WC and HC plots, with no difference (P = 0.226) between the latter two treatments.

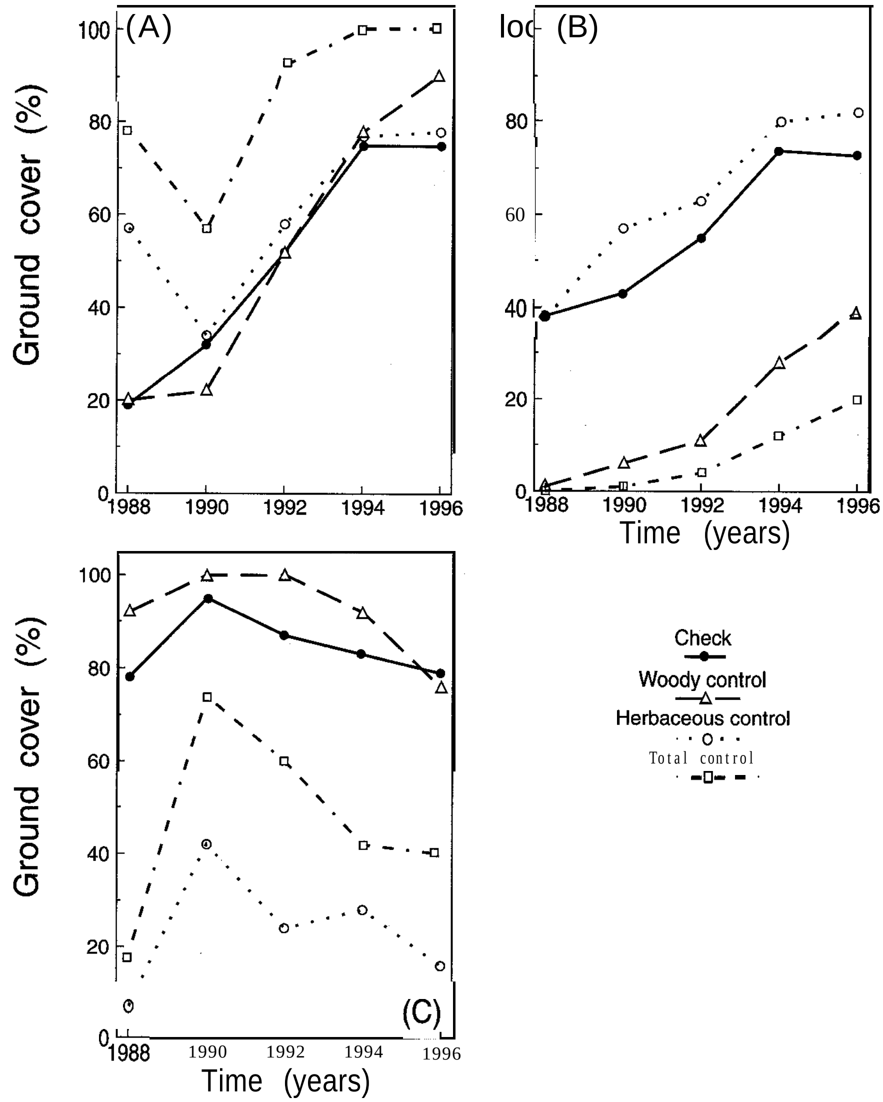
Stand dynamics

At age 5, crep-pine basal area averaged 1 $m^2 \cdot ha^{-1}$ on Ck and WC plots as compared with 3 $m^2 \cdot ha^{-1}$ on HC and TC plots (Fig. 2). Volume production showed similar trends among treatments at age 5, with Ck and WC plots averaging 10 versus 29 $m^3 \cdot ha^{-1}$ on HC and TC plots (Fig. 2).

At 13 years, competition control treatments averaged 29% more (P < 0.01) basal area than Ck plots (22 $m^2 \cdot ha^{-1}$) (Fig. 2). Basal area on TC plots (32 $m^2 \cdot ha^{-1}$) also exceeded (P < 0.01) the mean on WC and HC plots (26.5 $m^2 \cdot ha^{-1}$), but there was no difference (P = 0.42) between the latter two treatments.

By age 13, mean stand volume (Fig. 2) on competition control plots averaged 48% higher ($P < 0.01$) than on Ck plots (160 $m^3 \cdot ha^{-1}$). Total competition control resulted in a 32% volume gain ($P < 0.01$) over the mean of WC and HC treatments (214 $m^3 \cdot ha^{-1}$), between which no difference ($P = 0.15$) was found. According to Grano (1969), loblolly pine on these sites should produce from 13 to 18 $m^3 \cdot ha^{-1}$ per year. By age 13 in the present investigation, pine volume production on Ck plots approached the expected lower threshold at

Fig. 4. Percent ground cover for (A) natural pines, (B) woody nonpine species, and (C) herbaceous species relative to the method of competition control and time since competition control ended. Control of herbaceous competition ended after the 1987 growing season, and control of woody competition ended after the 1988 growing season.



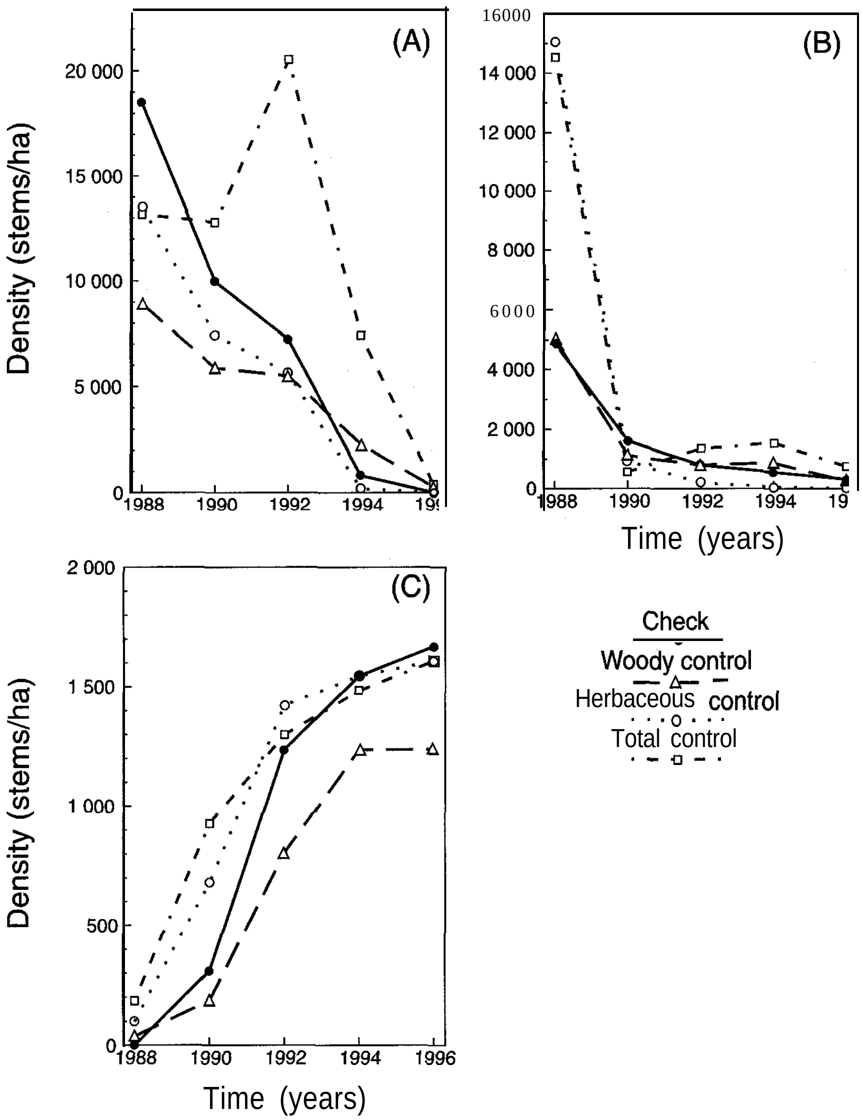
12 $m^3 \cdot ha^{-1}$ per year; WC and HC volumes fell within the expected range at 15 and 18 $m^3 \cdot ha^{-1}$ per year, respectively; and volume production on TC plots (22 $m^3 \cdot ha^{-1}$ per year) exceeded the expected upper threshold by 22%.

As stand basal area in pines and hardwoods increased from age 5 to 13 years, there was a consistent decline in crop pine DBH growth across all treatments (Fig. 3). From age 11 to 13 years, annual DBH growth of crop pines averaged about 1.0 cm on Ck and WC plots, 0.9 cm on HC plots, and 0.8 cm on TC plots. Reduced pine DBH growth on TC plots is attributed to intraspecific competition as indicated by 100% crown closure from pines (Fig. 4) that had been achieved by age 11 (1994).

Ocular estimates of ground cover are indicative of changes in stand structure through time. From 1988 (age 5) to 1990 (age 7), there was a substantial reduction in percent ground cover from natural pines on TC and HC plots (Fig. 4) as a result of precommercial thinning. Pine ground cover was not reduced during that time on Ck and WC plots because pines were smaller and fewer in number compared with TC and HC plots (Cain 1991*c*). As pine crowns began to close, pine cover increased in all competition control treatments from age 7 through age 13 (Fig. 4). On TC plots, there was an influx of additional pine seedlings (Fig. 5) from seed-bearing pines that bordered the study areas because the exposed mineral soil on those plots provided an excellent seedbed. But these shade-intolerant seedlings did not survive through 13 years. The beneficial effect of precommercial thinning is illustrated by the substantial increase in density of tree-size pines (29.0 cm DBH) across all treatments during the next 8 years (Fig. 5).

Between year 5 (1988) and 13 (1996), ground cover from woody nonpine species increased from 40% to a mean of 78% on Ck and HC plots (Fig. 4). At year 5, both WC and TC plots had no observable ground cover from woody nonpine species, but within 8 years, ground cover from these plants averaged 39% on WC plots and 20% on TC plots. With more than 22 000 rootstocks/ha, density of seedling-sized rootstocks on Ck plots far surpassed the numbers on competition control treatments at year 5 (Fig. 6). During the

Fig. 5. Periodic trends in density of natural pine components ((A) pine seedlings, (B) pine saplings, and (C) pine trees) relative to the method of competition control and time since control ended. Control of herbaceous competition ended after the 1987 growing season, and control of woody competition ended after the 1988 growing season. Before the 1989 growing season, pines taller than 1.5 m were precommercially thinned to 1235 stems/ha.

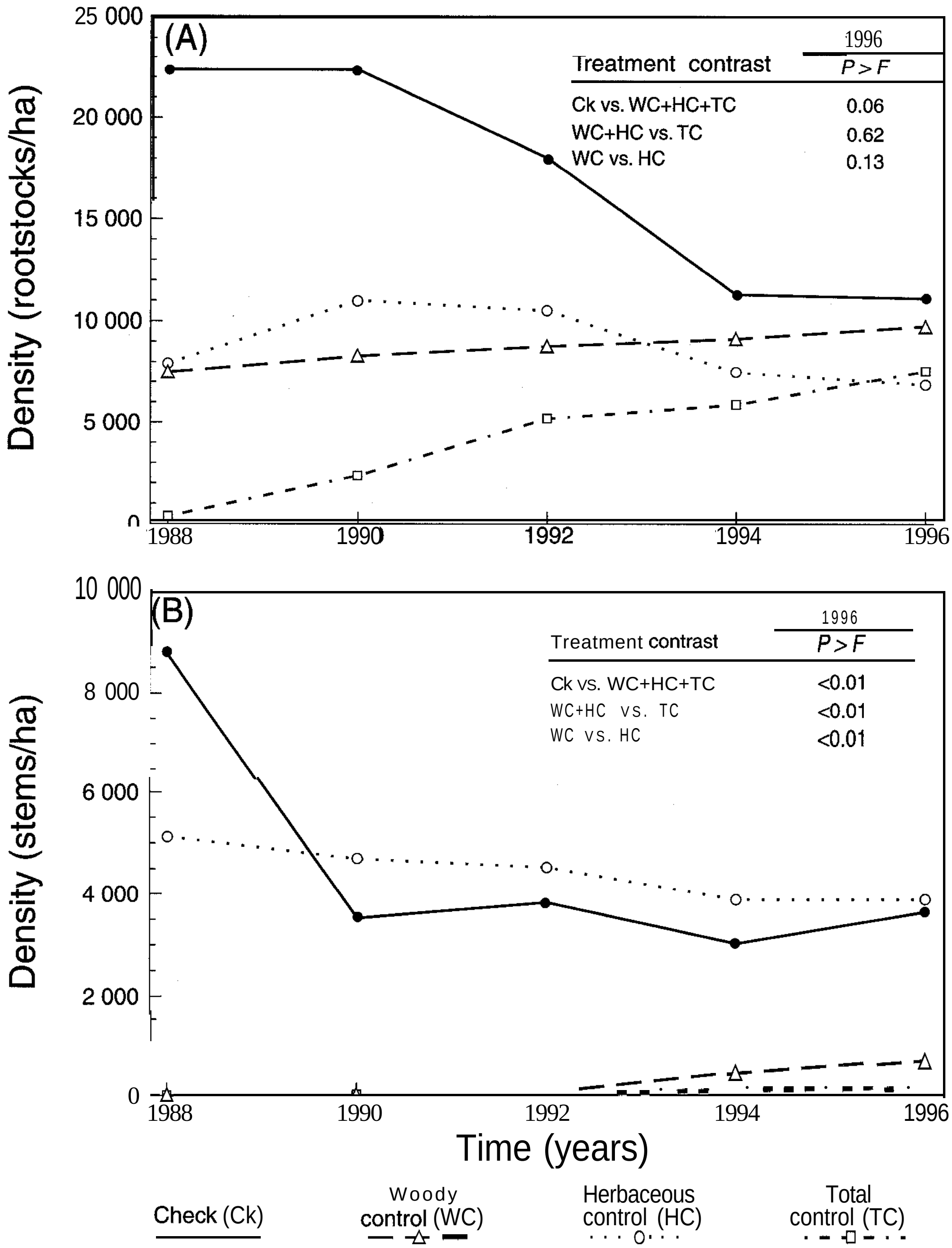


next 8 years, density of seedling-sized rootstocks declined on Ck plots and HC plots due to mortality of shade-intolerant species as a result of crown closure by the dominant pines and hardwoods. By year 13, there were no important differences ($P > 0.05$) among treatments in numbers of seedling-sized hardwood species, and density averaged about 8800 rootstocks/ha (Fig. 6).

There was a steeper decline in density for hardwood saplings on Ck plots compared with HC plots between 1988 and 1990 (Fig. 6), which was attributed to hardwood mortality caused by vines (principally *Lonicera japonica* Thunb., *Smilax* spp., and *Vitis* spp.). In an assessment of growth rates for the larger hardwood saplings 9 years after their development from stump sprouts, hardwood crowns had vine infestations that averaged 94% on Ck plots compared with only 29% on HC plots (Cain 1995). Within 4 years after woody control treatments ended on WC and TC plots, hardwoods of sapling size began to appear on those plots, but averaged <700 stems/ha at 13 years (Fig. 6) with only 18% quadrat stocking. In contrast, density of hardwood saplings averaged >3500 stems/ha with 64% quadrat stocking at year 13 on Ck and HC plots where woody nonpine vegetation had not been controlled.

Ground cover from herbaceous vegetation increased in al1 treatments between 1988 and 1990 (Fig. 4) because precommercial pine thinning resulted in more open stand conditions, which was conducive to the proliferation of these shade-intoleraut plants. As ground cover from crop pines and woody plants increased through time, there was a concomitant decrease in ground cover from herbaceous vegetation. At year 13, herbaceous ground cover averaged about 80% on Ck and WC plots, 40% on TC plots, and 16% on HC plots (Fig. 4). Vines were the most prolific herbaceous vegetation on WC and Ck plots where vine cover averaged from 70 to 80%, respectively, at year 13 (Fig. 7). After precommercial pine thinning, grasses, forbs, and semiwoody

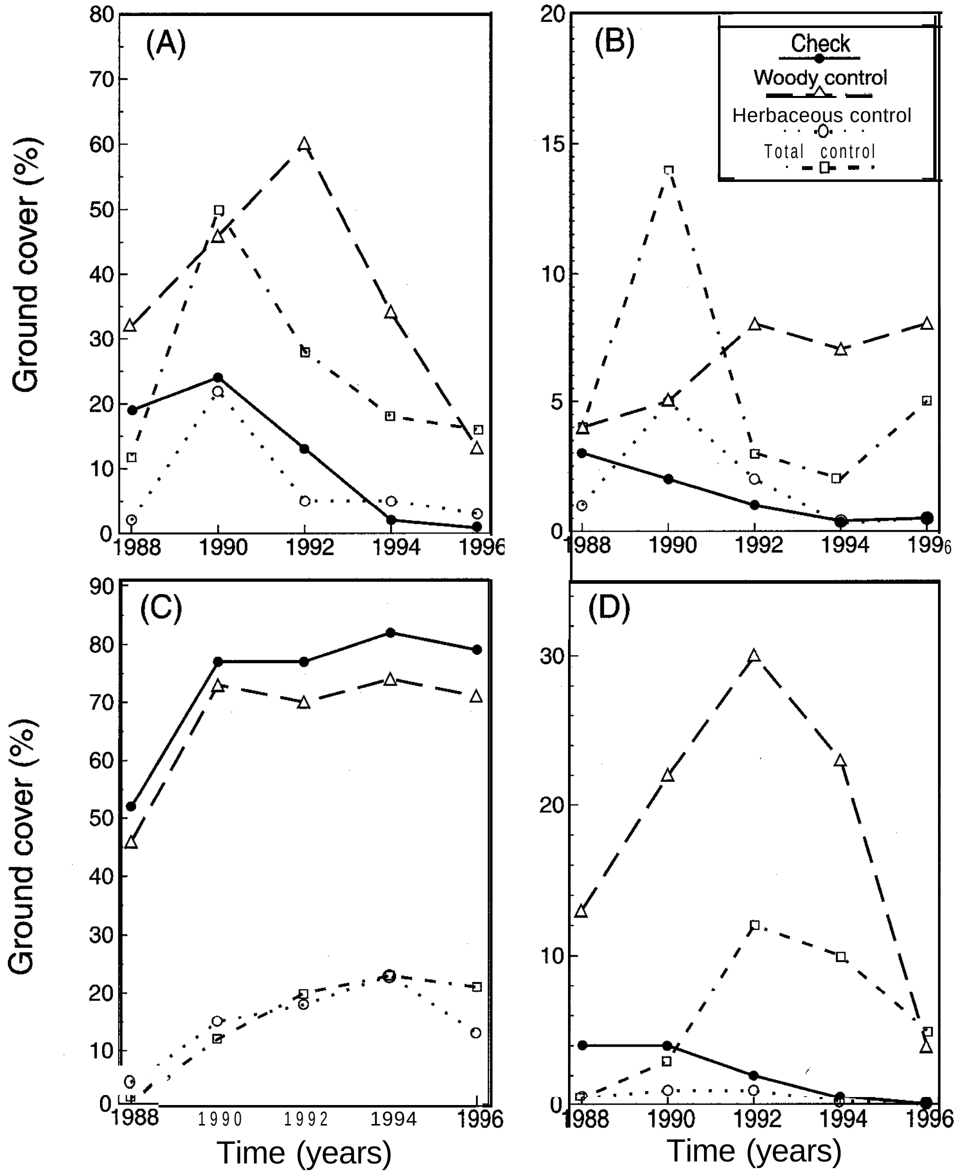
Fig. 6. Periodic trends in density of woody nonpine vegetation ((A) seedling-sized rootstocks, and (B) sapling-sized stems) following termination of woody competition control in 1988.



plants had substantial short-term gains in ground cover on TC and WC plots (Fig. 7) where hardwood cover was minimal (Fig. 4). Except for a fluctuating component of forbs on WC and TC plots from 1992 through 1996, ground cover from forbs in other treatments, as well as grasses and semi-woody plants in al1 treatments exhibited a consistent decline to <20% by year 13 (Fig. 7) as they were shaded out by crown closure from pines and hardwoods.

During the first 4 years after woody control ended, *Acer rubrum* L., *Cornus florida* L., *Ilex opaca* Ait., and *Sassafras albidum* (Nutt.) Nees were the predominant arborescent hardwood species across all treatments (Fig. 8). *Sassafras* is classified as intolerant of shade, whereas the other three species are classified as shade tolerant (Cain and Shelton 1995). For *Acer rubrum* and *Ilex opaca,* rootstock numbers tended to increase through time. The substantial 4-year gain in *Acer* rootstocks on TC plots is attributed to wind-disseminated seeds from surrounding stands, whereas *Ilex* gains on TC plots are attributed to sprouts from surviving root systems. Rootstock dynamics for *Cornus* and *Sassafras* were less consistent. For example, on Ck and HC plots where woody competition was not controlled, both *Cornus* and *Sassafras* decreased in numbers or remained the same from 1988 to 1992. On WC and TC plots with woody competition control, the general trend was for these latter two species to increase in numbers.

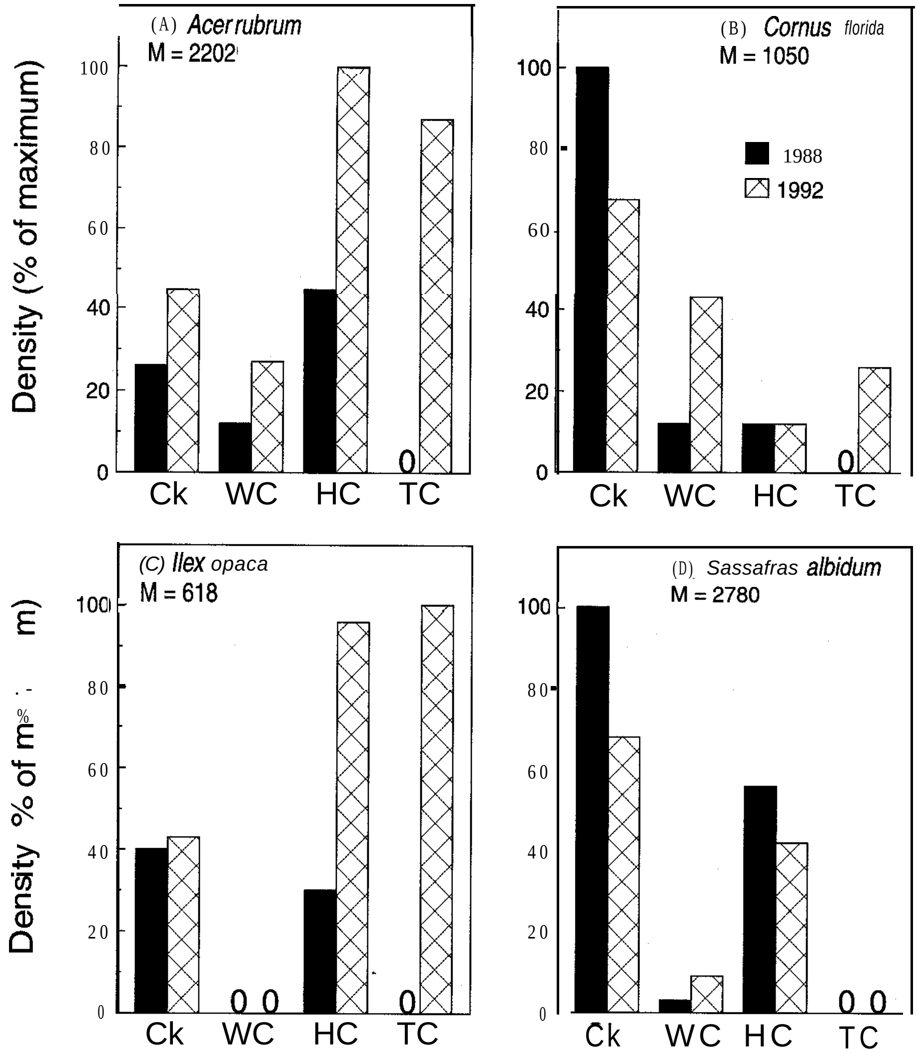
Fig. 7. Percent ground cover for herbaceous vegetation ((A) grasses, (B) forbs, (C) vines, and (D) semiwoody plants) relative to competition control treatments and time since herbaceous competition control ended in autumn 1987.



For nonarborescent shrubs, *Callicarpa americana* L. was the most prolific species, averaging >10 700 rootstocks/ha in 1988 on Ck plots (Fig. 9). By 1992, this species had declined in numbers on all treatments except TC plots. For woody nonarborescent competitors, *Rhus* spp., and *Vaccinium* spp. were the second and third most prevalent genera, averaging >5000 rootstocks/ha on Ck plots in 1988. Because of shade intolerance, *Rhus* numbers declined by 1992 on Ck and HC plots where hardwoods were not controlled, yet increased in density on both WC and TC plots to about 700 rootstocks/ha. *Vaccinium* had substantial rootstock numbers on WC plots in 1988 because they were of small size, generally <0.6 m tall, and difficult to find within the dense grasses and vines on WC plots during the treatment phase. Although woody competitors were not targeted for control on HC plots between 1984 and 1988, the discrepancy in rootstock numbers between Ck and HC plots for these four genera in 1988 suggests that many woody plants were susceptible to herbicides or were inadvertently treated with herbicides while controlling herbaceous vegetation on HC plots.

For seedling-sized rootstocks at year 13, *Acer rubrum* was the dominant tree species and *Callicarpa americana* was still the dominant shrub, averaging 11 and 44%, respectively of total rootstocks across all treatments. In the sapling size-classes, *Quercus nigra* L. was the dominant woody species with 6% of total stems across treatments, while *Quercus falcata* Michx., *Acer rubrum*, *Cornus florida*, and *Rhus* spp. averaged 4% each of total saplings. In 1996, 8 years after woody control treatments ended, 73% of quadrats on WC plots and 92% of quadrats on TC plots had no stems of sapling size, indicating slow growth of the reinvading hardwood

Fig. 8. Change in density for the four most prevalent arborescent hardwood species ((A) red maple, (B) flowering dogwood, (C) American holly, and (D) sassafras) after woody competition control ended in 1988. Density is expressed as a percentage of maximum (*M*) rootstocks per hectare for each species. Ck, check; WC, woody control; HC, herbaceous control; TC, total control.



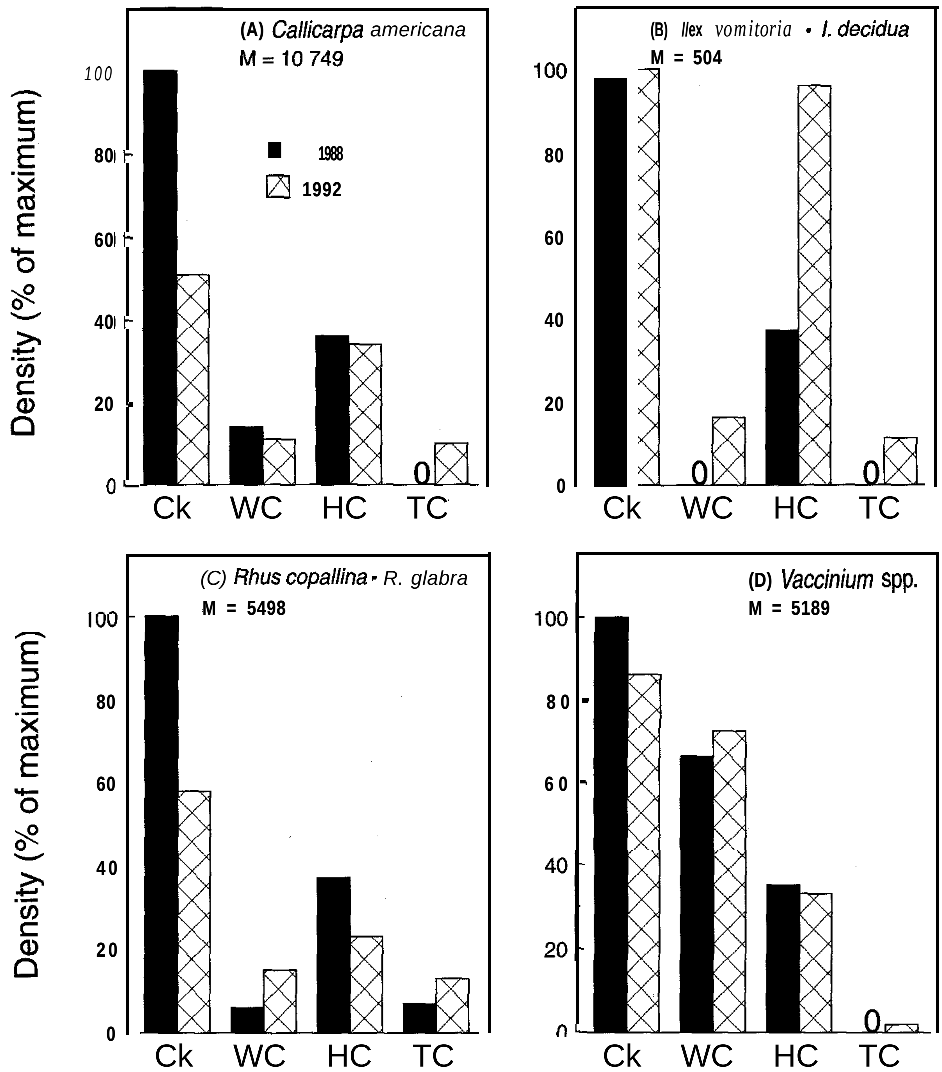
component under a pine canopy that averaged 90–100% cover on WC and TC plots, respectively (Fig. 4). Also, no tree-size hardwoods (>8.9 cm DBH) occurred on any sample quadrats, regardless of treatment, through year 13.

Summary and conclusions

During the first 13 years of this investigation, 4 years of controlling only herbaceous competition after pine establishment significantly ($P < 0.01$) enhanced pine height growth when compared with 5 years of controlling only woody competition. Similar trends were apparent between these treatments when mean DBHs were compared at year 5. But around year 7, hardwood competition on HC plots began to exert a negative influence on pine DBH growth while lack of hardwood competition on WC contributed to an increase in pine DBH growth as crown closure from pines began to shade out herbaceous competition. By year 13, DBH differences between these two treatments were unimportant ($P = 0.22$). After 13 growing seasons, pines on plots that received total competition control were taller ($P < 0.01$) and larger in DBH ($P < 0.01$) when compared to the means for pines on plots receiving only herbaceous control or only woody control. Although mean pine volume production across competition control treatments surpassed ($P < 0.01$) that of untreated checks through 13 years, the effect was not additive but synergistic (i.e., total control of competing vegetation resulted in greater pine volume production than the sum of woody control or herbaceous control taken independently). Moreover, at the stand level, total competition control resulted in pine volume gains equivalent to 3-year's growth on check plots.

Using competition control treatments similar to the present investigation, Zutter and Miller (1998) studied the response of planted loblolly pines to 3 years of woody and herbaceous competition control on a bedded, Lower Coastal Plain flatwoods site in Georgia. They found that ll-year pine-volume gains from controlling both vegetation types were less than additive or less than the sum of gains from controlling each type individually. However, 8-year results from a compilation of the Competition Omission Monitoring Project (Zutter et al. 1995) installations throughout the

Fig. 9. Change in density for the four most prevalent nonarborescent genera ((A) American beautyberry, (B) yaupon and deciduous holly, (C) shinning and smooth sumac, and (D) huckleberry) after woody competition control ended in 1988. Density is expressed as a percentage of maximum (*M*) rootstocks per hectare for each genera. Ck, check; WC, woody control; HC, herbaceous control; TC, total control.



southeastern United States produced more than additive volume growth gains from planted loblolly pines when woody and herbaceous treatments were combined on those sites where hardwood densities were high.

In old-field succession (Oosting 1956), pines become established coincidentally with herbaceous vegetation but usually dominate the site within a few years. In that same successional process, pines can be displaced by more aggressive shade-tolerant hardwoods in the absence of disturbance. Consequently, control of only woody competition has historically been given priority in southern pine management. Yet, this investigation has shown that herbaceous competition was more detrimental to pine growth than nonpine woody competition during the first 10 years after pine establishment on this highly productive site. Concomitantly, the presence of seed-bearing pines in combination with competition control often results in dense stands of pine regeneration, which may necessitate precommercial thinning to reduce intraspecies competition. Results of this investigation represent unique standards of previously undocumented, potential growth of pines in response to four levels of competition control in naturally regenerated loblolly and shortleaf pine stands on the Upper Coastal Plain. Even though less-intensive competition control treatments and precommercial thinning treatments are applied operationally in natural pine stands throughout tbe southeastern United States, results from the present investigation suggest that a combination of such treatments could maximize pine volume production.

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