Eleventh-Year Response of Loblolly Pine and Competing Vegetation to Woody and Herbaceous Plant Control on a Georgia Flatwoods Site

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ABSTRACT. *Through 11 growing seasons, growth of loblolly pine* (Pinus taeda *L.) increased after control of herbaceous, woody, or both herbaceous and woody vegetation (total control) for the first 3 yr after planting on a bedded site in the Georgia coastal flatwoods. Gains in stand volume index from controlling either herbaceous or woody vegetation alone were approximately two-thirds that from controlling both types of vegetation. Pine response through age 11 was approximately equal for herbaceous control alone and woody control alone, whereas, response through age 5 was greater with control of only herbaceous vegetation. The impact of woody vegetation should continue to have a strong effect on pine growth through midrotation because of its continued development. This is in contrast to herbaceous weeds that have greatly decreased in abundance since age 6. South. J. Appl. For. 22(2):88–95.*

Significant progress has been made in developing herbicide prescriptions for woody plant control in the coastal flatwoods region of the southeastern United States. Good to excellent control can be obtained for most major species (Shiver et al. 1991, Lauer and Glover 1993). As forest managers evaluate the use of herbicides to control woody and herbaceous plants, there is an increased need to understand the potential long-term response from such control. Large short-term response from control of both woody and herbaceous vegetation from the time of planting on flatwoods sites has been noted for both loblolly (*Pinus taeda* L.) and slash (*Pinus elliottii* Engelm.) pines (McKee and Wilhite 1988, Swindel et al. 1988, Colbert et al. 1990, Shiver et al. 1990, and Dalla-Tea and Jokela 1991). Because herbicide treatments may be applied to control primarily herbaceous, primarily woody, or both types of competing vegetation, there exists the need to assess the relative importance of effects of the vegetation type controlled. A central question is whether the sum of gains in pine growth from controlling individual vegetation types is equal to the gain when controlling both types. Thus, are the effects additive, or more or less than additive? Understanding stand dynamics, with and without competing vegetation of either or both types, is also needed.

As a part of the region-wide Competition Omission Monitoring Project (COMP) (Miller et al. 1991, Miller et al. 1995), a single location was established in the coastal flatwoods of Georgia. Objectives of COMP are to compare the relative importance of effects of woody versus herbaceous vegetation on the short- and long-term growth of loblolly pine and to document dynamics of associated vegetation. This article summarizes response of loblolly pine through 11 growing seasons on the Georgia flatwoods site as influenced by woody and/or herbaceous vegetation control. The abundance of competing herbaceous and woody vegetation is also examined as an aid to understanding pine response over the 11 yr period.

Reasons for focusing on results from this single COMP site are: (1) its uniqueness among the other locations in terms of the type of site-lower coastal plain flatwoods-and dominant form of woody vegetation—shrubs— and (2) the opportunity to provide a more detailed examination of both short- and long-term dynamics than would be possible if all

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COMP study locations were being summarized. As the data are from only one location, and might be considered by some individuals as a case study, results will be discussed in reference to findings from similar and more recently established studies on flatwoods sites.

Methods

Study Site

The study is located in the lower coastal plain flatwoods in southeastern Georgia near the town of Pembroke. The area is in the Lower Coastal Plains Province, Atlantic Coast Flatlands Region, Upper Terraces Subregion using the physiographic classification system developed by Pehl and Brim (1985). Soils are predominantly of the Mascotte series (sandy, silicaceous, thermic Ultic Haplaquods), which are strongly acidic (pH 4.3). Such soils fall within CRIFF soil group C, being poorly drained to somewhat poorly drained spodosols with an argillic horizon (Fisher and Garbett 1980). The water table is within 18 in. of the surface for 1 to 4 months during the year, which may limit rooting volume. Site index, base age 25, is 58 ft based on age 11 mean dominant heights on the no control treatment and the site index curves of Borders (1994). The site had been occupied by a 6-yr-old bedded slash pine plantation that burned in a wildfire and subsequently was windrowed and rebedded in 1983. Improved first-generation loblolly pine seedlings (1-O stock) were operationally planted at a 7 ft x 11 ft spacing during the winter of 1983-1984. Seedlings averaged 0. 11 in. in diameter at the groundline and 0.67 ft in height following planting.

Study Design and Plot Layout

A randomized complete block design was used with 5 blocks of 4 plots each for a total of 20 treatment plots. Blocks were arranged in increasing distance from a pond, and thus increasing drainage. Treatment plots were approximately 0.25 ac in size (10 rows by approximately 100 ft). Interior measurement plots for pines and hardwoods were centered within each treatment plot and were approximately 0.1 ac (6 rows by approximately 66 ft).

Treatments

Treatments following site preparation included: (1) no control, (2) woody control alone, (3) herbaceous control alone, and (4) woody and herbaceous control, referred to hereafter as total control. The no control treatment received no herbicide treatments following windrowing and rebedding of the site following the wildfire. Woody and herbaceous treatments were applied during each of the first three growing seasons. Woody control was accomplished via backpack foliar sprays of triclopyr (Garlon 48, 5% solution in water) to hardwood and shrub foliage (arborescent and nonarborescent species) in June of each growing season, with an additional treatment in late summer of the first year. Herbaceous control included: (1) annual pre-emergent applications of sulfometuron (Oust@, 4-6 oz product/ac), and (2) directed sprays of glyphosate (Roundup@, 2% solution in water) applied twice the first year and once the following 2 yr to control herbaceous weeds emerging during the summer. Applications were made to all appropriate treatment plots at each specified time. Vines and semiwoody plants such as erect blackberry (*Rubus* spp.) were included in the herbaceous component.

Measurements

Pines were measured annually for height from age 1 through 11 and for dbh from age 3 through age 11. Approximately 50 trees were measured within each pine measurement plot. A volume index was calculated for each pine as follows: $dbh^2 * height/3$, where both dbh and height are in feet. The presence of fusiform rust on the stem was also noted for each tree. Mean total height and dbh, stocking or density in trees/ac, stand basal area, stand volume index, and percent of trees with fusiform rust on the stem were computed for each measurement plot for use in statistical analyses.

In September of the first through fifth, eighth, and eleventh growing seasons, woody rootstocks were counted by species and height class on each of three 11 ft by 15 ft competition measurement plots (CMPs) within each interior measurement plot. Height classes were in 1 ft intervals from 1 through 12 ft and in 5 ft intervals thereafter. Rootstock density, sum of rootstock heights, and mean rootstock height werecalculated separately for arborescent and nonarborescent woody groups. Species in the nonarborescent group included: low gallberry (*Ilex glabra* [L.] Gray), fetterbush and staggerbush *(Lyonia* spp.), sparkleberry/blueberries *(Vaccinium* spp.), and yaupon *(Ilex vomitoria* Ait.).

Plant cover was ocularly estimated in September of the first through eighth, and eleventh growing seasons. Each CMP was divided in half to yield two 7.5 ft by 11 ft subplots and cover estimated on each of these subplots. Cover estimates were made of crop pines and competing woody and herbaceous vegetation. Herbaceous cover was described further by estimating cover of grass and grass-likes (including sedges and rushes), forbs, vines, and semiwoody components. Cover of prevalent herbaceous genera (>15% cover or three most abundant genera) were also noted on each subplot. Cover of nonarborescent and arborescent components of woody vegetation was estimated beginning in year five. Mean percent cover of each type of vegetation was determined for each plot from estimates on each of the six subplots. An index of crown volume (ft^3/ac) of both arborescent and nonarborescent woody vegetation was made by calculating mean cover in square feet per acre [(percent cover/100) x 43560 ft^2/ac] and multiplying by mean rootstock height (ft).

During the dormant seasons following the fifth, eighth, and eleventh growing seasons, stems of all arborescent rootstocks exceeding 4.5 ft were recorded by species, dbh class (0.5 in. classes: 0.1, 0.5, 1.0, 1.5, 2.0, etc.) and height class within each interior measurement plot. Stand basal area of arborescent hardwoods was calculated for each plot.

Analysis

Analysis of variance (ANOVA) appropriate for a 2^2 factorial randomized complete block design was utilized to examine the data. Percent cover values were transformed using the arcsine square root transformation prior to analysis. Statistical tests were made of the main effects of woody

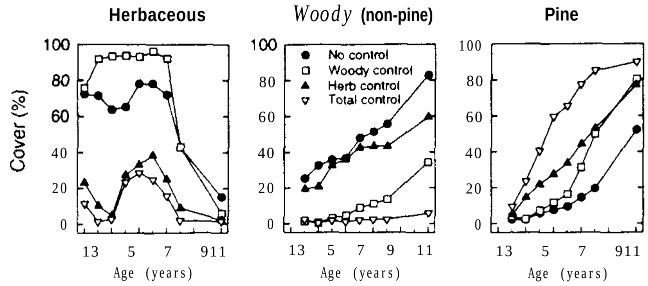

Figure 1. Cover of herbaceous, total woody (nonpine), and loblolly pine through 11 growing seasons by vegetation control treatment.

treatment (average of woody control and total control versus average of no control and herbaceous control), herbaceous treatment (average of herbaceous control and total control versus average of no control and woody control), and their interaction. Differences were considered statistically different at a significance level of $P = 0.05$. When the interaction between woody treatment and herbaceous treatment was significant, treatment means were separated using Tukey's HSD test ($P = 0.05$). References in the text to effects of woody treatment or herbaceous treatment will refer to tests of main effects from the ANOVA, whereas references to no control, woody control alone, herbaceous control alone, or total control will refer to the four treatments within the study design. Presentation of results of statistical analysis of data will largely be limited here to eleventh year data as results have been-reported elsewhere following the first and second (Milleret al. 1987), third (Zutter 1988), fourth (Zutter 1990), and fifth growing seasons (Zutter 1990, Miller et al. 1991).

Results

Competing vegetation

Herbaceous cover averaged less than 20% on all treatments at age 11, having commenced declining at age 6 from 96, 78, 38, and 25% on no control, woody control alone, herbaceous control alone and total control treatments (Figure 1). This decline in herbaceous cover coincided with pine and woody cover (canopy) development (Figure 1). Herbaceous cover on plots receiving herbaceous control continued to be significantly lower following cessation of herbaceous treatments following year three (Table 1) (Miller et al. 1991). Herbaceous cover did resurge immediately **following** cessation of herbicide treatments on herbaceous control alone and total control treatments, but only to one-third to one-half of no control and woody control alone treatments. Bluestem grasses (*Andropogon* spp.) accounted for most of this recovery. Absence of woody vegetation on woody control alone treatments led to an increased herbaceous cover of 15 to 20% during years two through seven (Figure 1). Thus, control of one type of competing vegetation (woody) was compensated for by an increase in another type (herbaceous).

Herbaceous cover on the no control treatment has been dominated by grasses since age 1 (Miller et al. 1987, Zutter 1988, Zutter 1990). Panicums (*Panicum* spp.) and bluestems were the dominant grasses during the first two growing seasons (Miller et al. 1987), with wiregrass (*Aristida* spp.) and bluestems becoming the predominant grasses by the eleventh year, having covers of 6 and 3%, respectively.

Cover of total woody, arborescent woody, and nonarborescent woody vegetation at age 11 remained significantly lower as a result of earlier woody control treatments (Table 1). Total woody and nonarborescent woody cover, but not arborescent cover, were also lower where herbaceous plants had been controlled. This was not true at age 5 when woody cover levels were nearly identical between no control and herbaceous control alone treatments, and between woody control alone and total control treatments (Figure 1). Since age 5 woody cover development has been slower where herbaceous control treatments were applied (i.e., herbaceous control alone and total control).

Cover of nonarborescent woody vegetation has been two to three times that of arborescent woody cover since the separate cover calls began at age 5 (Figure 2). Effects of treatment on crown volume index at age 11 followed similar trends to that for cover (Table 1), except that crown volume values were more similar in magnitude between arborescent and nonarborescent woody vegetation due to the greater average height of arborescent species (Table 2). Both cover and crown volume index convey the relative importance

Table 1. Mean competing plant cover by type and crown volume index of arborescent (arb.) and nonarborescent (nonarb.) woody vegetation by treatment after 11 growing seasons; and tests of effects of treatment of woody vegetation, herbaceous vegetation and the interaction.

Treatments and	Cover				Crown volume index	
statistical contrasts	Herbaceous	Total woody	Arb. woody	Non-arb. woody	Arb. woody	Non-arb. woody
	(%)				(ft^3/ac × 10^{-3})	
No control	15	83	20	77	5.80	7.42
Woody control	6	34	4	31	0.61	2.61
Herb control	2	60	24	44	5.94	5.08
Total control	2	6	1	5	0.09	0.36
	(Probability > F-value)					
Contrasts[1]						
Woody (W)	0.139	<0.001	<0.001	<0.001	<0.001	<0.001
Herb (H)	0.008	<0.001	0.947	<0.001	0.826	<0.001
W × H	0.215	0.493	0.108	0.880	0.704	0.927

[1] Test of woody treatment main effect: (woody control + total control)/2 vs. (no control + herb control)/2; test Of herb treatment main effect: (herb control + total control)/2 vs. (no control + woody control)/2; test of woody treatment x herb treatment interaction (W × H): (no control + total control)/2 vs.(woody control + herb control)/2.

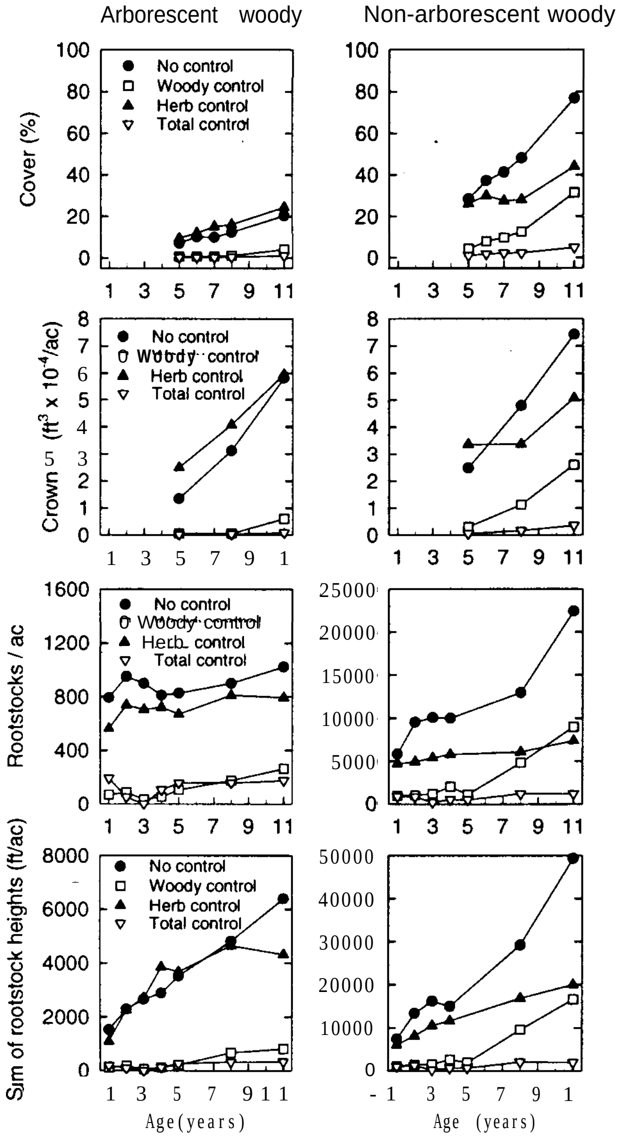

Figure 2. Cover, **crown volume index, rootstock density, and sum of rootstock heights per acre of competing arborescent and nonarborescent woody vegetation through 11 growing seasons by vegetation control treatment.**

nonarborescent shrubs may have in coastal flatwoods plantations. Over the first 11 years, low gallberry, blueberry, and fetterbush plus staggerbush comprised an average of 73, 15, and 9% of nonarborescent rootstock density, respectively, and 75, 13, and 10% of sum of nonarborescent rootstock heights/ac, respectively.

Patterns among treatments in age 11 rootstock density and sum of rootstock heights of arborescent and nonarborescent woody vegetation were similar to those noted for cover and crown volume (Table 2). Woody control treatments resulted in not only fewer rootstocks, but those that were present were significantly shorter (Table 2). Arborescent and nonarborescent rootstocks at age 11 were approximately 3 ft and 1 ft shorter, respectively, with woody treatment. No increases in mean rootstock height were noted with herbaceous control treatments. Increases over time for cover and crown volume of arborescent woody plants in the absence of woody control (i.e., no control and herbaceous control alone treatments) are primarily a result of increased size of rootstocks as the density has changed little and sum of rootstock heights/ac has increased greatly since age 1 (Figure 2). However, density of nonarborescent woody plants on the no control treatment quadrupled from age 1 to age 11, whereas density on the herbaceous control alone treatment increased by only one-half. This helps to explain the more rapid increase in cover and crown volume of nonarborescent woody plants on no control treatments (Figure 2).

Stand basal area of arborescent woody vegetation remained lower at age 11 as a result of woody treatments (Table 2). Even without woody treatments, arborescent basal area is still low, averaging less than 3 ft^2/ac on no control and herbaceous control alone treatments. There was no significant increase in arborescent basal area with herbaceous control at age 11, whereas there had been a significant increase of 1 .O ft^2/ac noted at age 5 (Miller et al. 1991). Redbay (*Persea borbonia* L.) was the dominant arborescent species, comprising over 90% of rootstock density, sum of rootstock heights, and stand basal area at all evaluation dates (ages 5, 8, and 11).

Table 2. Mean arborescent (arb.) and nonarborescent (nonarb.) woody rootstock density, sum of rootstock heights and mean rootstock height and arborescent stand basal area by treatment after 11 growing seasons; and tests of effects of treatment of woody vegetation, herbaceous vegetation, and the interaction.

Treatments and	Rootstock density		Sum of rootstock heights		Mean rootstock height		Basal area
statistical contrasts	Arb. woody	Non-arb. woody	Arb. woody	Non-arb. woody	Arb. woody	Non-arb. woody	Arb. woody (ft^2/ac)
	(no./ac)		(ft/ac)		(ft)		
No control	1,021	22,440	6,389	49,350	6.3	2.2	2.3
Woody control	264	8,976	810	16,562	3.1	1.8	0.1
Herb control	792	7,374	4,312	20,011	5.4	2.7	2.8
Total control	176	1,197	334	1,918	1.9	1.6	0.0
	(Probability > F-value)						
Contrasts[1]							
Woody(W)	0.002	<0.001	<0.001	<0.001	<0.001	0.002	<0.001
Herb (H)	0.371	<0.001	0.237	<0.001	0.229	0.621	0.528
W × H	0.687	0.054	0.450	0.071	0.530	0.069	0.391

[1] Test of woody treatment main effect: (woody control + total control)/2 vs. (no control + herb control)/2; test of herb treatment main effect: (herb control + total control)/2 vs. (no control + woody control)/2; test of woody treatment × herb treatment interaction (W ×H): (no control + total control)/2 vs.(woody control + herb control)/2.

Pine Response

Although treatments had pronounced effects on levels of both woody and hetbaceous vegetation, no differences were noted in pine density among treatments at age 11 (Table 3), with density ranging only from 508 to 525 trees/ac. No effect of treatments on density was also noted at age 5 (Miller et al. 1991). Growing season rainfall for the first 2 yr after planting was near average.

Competing vegetation has had a substantial effect on average pine height, dbh, stand basal area, and stand volume index at age 11 (Table 3). Effects of the woody and herbaceous treatment were each significant for all four pine response variables. However, for dbh and stand basal area, the treatment interaction was also statistically significant. In general, largest gains were achieved by controlling only one vegetation type, either woody or herbaceous, with additional gain from controlling the other vegetation type, to give total control, being about half as much. In other words, the gain from controlling both vegetation types was less than *additive* or less than the sum of gains from controlling each type individually. Eleven-year gains from woody control alone or herbaceous control alone were nearly identical in magnitude for a given response variable, 6.7 ft vs. 6.9 ft for height, 0.9 in. vs. 0.9 in. for dbh, 28 ft^2/ac vs. 28 ft^2/ac for stand basal area, and 608 ft^3/ac vs. 622 ft^3/ac for stand volume index. Additional gains from controlling the other vegetation type averaged only 2.7 ft in height, 0.3 in. in dbh, 12 ft^2/ac in stand basal area, and 304 ft^3/ac in stand volume index. The incidence of stem fusiform rust increased with control of either herbaceous and woody vegetation, with an additive effect when both components were controlled (Table 3).

The differences due to treatment differ greatly from that noted at age 5 in two respects (Figure 3). First, response to herbaceous and woody treatments were additive following the fifth growing season (Miller et al. 1991). Secondly, response from herbaceous control alone was greater than that from woody control alone at age 5, whereas by age 11 response was equal for the two treatments (Figures 3 and 4). Gains in height over no control as a result of herbaceous control alone changed little from age 5 to age 11, 7.2 ft to 6.9 ft, while gains with woody control alone increased from 3.2 ft to 6.7 ft. Dbh gain decreased with herbaceous control alone and increased slightly with woody control alone over the 6 yr period. Gains in stand basal area and stand volume index for herbaceous control alone increased from age 5 to age 11, but did not increase as much as for woody control alone.

Discussion

Results from this study illustrate both direct and indirect effects that controlling one type of vegetation can have on other vegetation types in the flatwoods. In addition to the positive response of pines to woody plant reduction, herbaceous vegetation also responded positively during the first 7 yr (Figure 1). Lauer and Glover (1995) also noted a positive response of herbaceous vegetation to woody control on a flatwoods site in Florida, and Miller et al. (1991) noted a similar response for all 13 COMP locations for the first 5 yr. On this study site, cover and crown volume index of nonarborescent vegetation at age 5 were not affected by herbaceous treatment, but by age 11 they were significantly lower with herbaceous treatment (Figure 2). This decline is likely due to a reduction in resources available to nonarborescent woody vegetation as a result of increased pine size resulting from herbaceous treatment (Table 3, Figure 3). Light reaching nonarborescent species in the understory was certainly reduced with herbaceous treatment. Pine cover with herbaceous treatment averaged from 16% greater at age 3 (18% vs. 2%), increased to 35% greater at age 8 (69% vs. 34%), and then decreased to 28% greater at age 11 (94% vs. 66%) compared to no herbaceous treatment (Figure 1). Dalla-Tea and Jokela (1991) noted photosynthetically active radiation (PAR) intercepted by 6-yr-old slash or loblolly pine canopies on a flatwoods site in Florida to be twice as great in stands receiving total vegetation control compared to no control, approximately 60% vs. 30%. respectively, during the growing season.

Increases in herbaceous and woody vegetation following cessation of herbicide treatments illustrates the resiliency of the populations of each group of plants on this flatwoods site.

Table 3. **Mean density, height, dbh, stand basal area, stand volume index, and incidence of fusiform rust on the stem of loblolly pines by treatment after 11 growing seasons; and tests of effects of treatment of woody vegetation, herbaceous vegetation, and the interaction.**

Treatments and statistical contrasts	Density (trees/ac)	Height (ft)	Dbh[1] (in.)	Basal area[1] (ft^2/ac)	Volume index (ft^3/ac)	Incidence of stem fusiform rust (%)
No control	525	30.4	4.3 b	57 b	786	4
Woody control	513	37.1	5.4 a	85 a	1,394	7
Herb control	508	37.3	5.4 a	85 a	1,408	11
Total control	513	39.9	5.7 a	97 a	1,705	16
	(Probability > F-value)					
Contrast[2]						
Woody (W)	0.611	<0.001	<0.001	<0.001	<0.001	0.031
Herb (H)	0.304	<0.001	<0.001	<0.001	<0.001	<0.001
W × H	0.303	0.076	0.010	0.044	0.128	0.667

[1] Treatment means separated using Tukey's HSD test when the interaction between woody and herb treatment was significant. Means in the same column followed by the same letter are not significantly different by Tukey's HSD test (P = 0.05).

[2] Test of woody treatment main effect: (woody control + total control)/2 vs. (no control + herb control)/2; test of herb treatment main effect: (herb control + total control)/2 vs. (no control + woody control)/2; test of woody treatment × herb treatment interaction (W × H): (no control + total control)/2 vs. (woody control + herb control)/2.

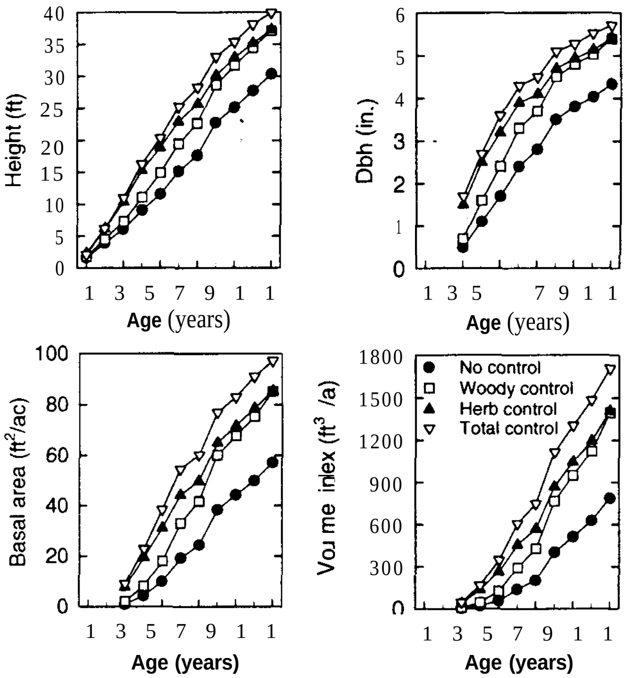

Figure 3. Mean loblolly pine height, dbh, stand basal area, and stand volume index through 11 growing seasons by vegetation control treatment.

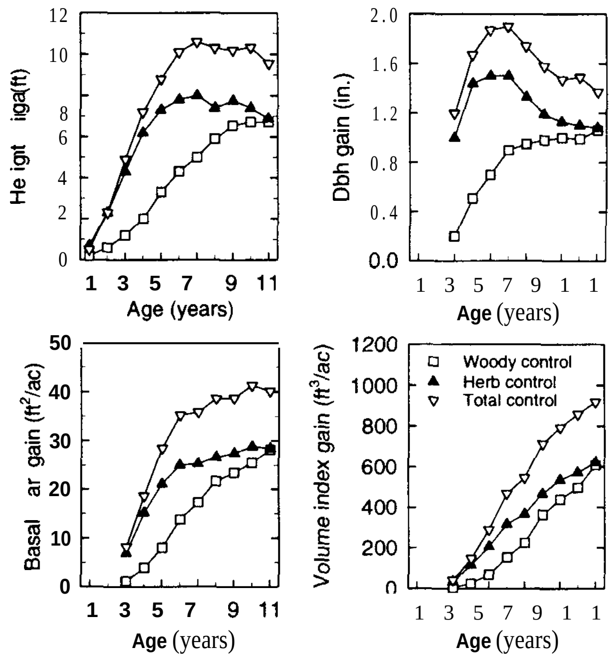

Figure4. Gain in mean loblolly pine height, dbh, stand basal area, and stand volume index over no control treatment through 11 growing seasons by vegetation control treatment.

Thus, these intensive control treatments only resulted in suppression. This is mostly attributed to a reinvasion of the plots by both groups of vegetation, because earlier control was successful. The size of the treated plots, 0.25 ac, may have facilitated invasion from adjacent untreated areas. Since grass seed are primarily wind-dispersed and the woody plant seeds are primarily bird-dispersed, reinvasion can occur over considerable distances. There was, however, little development of woody plants on total control plots, because of the significant pine canopy development by age 7 (Figure 1).

Operational herbicide treatments are applied for only one or two growing seasons and are generally less effective in controlling woody or herbaceous plants than control obtained from repeated treatments in this study (Zutter et al. 1986, Lauer 1991, Yeiser and Barnett 1991, Lauer and Clover 1993). Thus, increases in cover of each plant group over the years following operational treatments in the flatwoods might be expected to be more rapid and potentially greater in magnitude than forrepeated research treatments (Zutteret al. 1986, Lauer and Clover 1995). Response of pine to treatment should also be somewhat smaller when treatment duration is shortened. Creighton et al. (1987) and Lauer et al. (1993) noted lower response to 1 versus 2 yr of herbaceous control. However, Lauer and Clover (1995) did not notice any difference between first year shrub control and annual shrub control in effects on 5 yr slash pine height or dbh, possibly due to the low levels of shrubs on both treatments through the fifth year. The degree to which recolonization of vegetation, especially woody plants, may limit long-term growth potential in the flatwoods is uncertain. However, vegetation present in midrotation flatwoods stands following bedding and planting may reduce growth by as much as 0.2 to 0.5 cords/ac/yr (Oppenheimer et al. 1989).

Differences between no control and total control treatments in this study are comparable to that noted on studies including similar treatments and located on spodosols in the flatwoods. At age 8, Shiver et al. (1990) noted increases of approximately 8.5 ft in height and 1.5 in. in diameter for slash pine receiving complete vegetation control versus no control following chopping, burning, and bedding. In this study, loblolly pine on total control treatments had an increase of 10.3 ft in height and 1.6 in. in diameter over no control at age 8 (Figure 3). Colbert et al. (1990) noted continued, complete vegetation control following planting on chopped and bedded sites to result in increases of 7.9 ft and 5.9 ft in height and 1.9 in. and 1.5 in. for loblolly pine and slash pine, respectively, at age 4. In this study, loblolly pine receiving total control increased 7.2 ft in height and 1.7 in. in dbh over no control at age 4 (Figure 3).

Trends in patterns of pine response over the 11 yr growth period can be explained to a large extent by considering the quantity and developmental patterns of competing vegetation (Figure 5). Mean herbaceous cover,

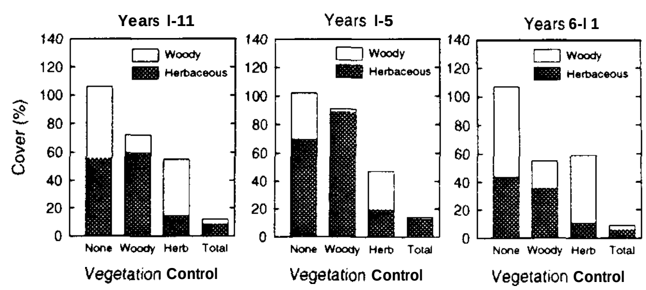

Figure 5. Mean cover of competing woody and herbaceous vegetation through 11 growing seasons, through the first 5 growing seasons, and from 6–11 growing seasons by vegetation control treatment.

woody cover, and summed values of herbaceous and woody cover over the 11 yr period, as well as during the first 5 and last 6 yr were the lowest with the total control treatment and hence pine response was the greatest. Pine response with no control was the lowest throughout the 11 yr, with woody cover and summed woody and herbaceous cover being the greatest during the first 5 yr, the last 6 yr, and over the entire 11 yr period.

During the first 5 yr, summed woody and herbaceous cover on the herbaceous control alone treatment was second lowest only to total control. The resulting pine growth response was slightly less in magnitude to that with total control but greater than that with woody control alone. Similar pine response for woody control alone and herbaceous control alone treatments by year 11 can be explained by comparing the quantity and composition of competing vegetation over years 6 through 11. The overall quantity of competing vegetation (summed woody and herbaceous cover) was similar during years 6 through 11; however, a greater proportion of cover was comprised of woody vegetation on the herbaceous control alone treatment (Figure 5). Lauer and Clover (1995) observed that for similar levels of cover, woody vegetation had greater effects on pine response than herbaceous vegetation on a site in the Florida flatwoods. The increasing stature of both arborescent and nonarborescent woody plants would appear to be resulting in an increasing detrimental influence on the pines.

The annual or frequent measures performed in this research permit a detailed view of the temporal dynamics of competition and pine growth on this flatwoods site. It is evident that the growth dynamics of the pines remain altered by suppression of competing vegetation that occurred in the first 3 yr. A residual influence is not surprising because early control treatments have strongly influenced competition levels of both woody and herbaceous vegetation through age 11. Probably more importantly, early vegetation control is known to rapidly increase leaf area of loblolly pine (Zutter et al. 1986, Colbert et al. 1990) and thus photosynthesis rates per unit area of land surface. Over the next few years, pine volume on all vegetation control treatments should be expected to continue to increase over the no control treatment (Figure 4). In addition, pine volume on the woody control alone treatment should be expected to surpass that on the herbaceous control alone treatment.

Implications for Managers

At least through age 11, the greatest increase in pine growth on this flatwoods site was a result of controlling both herbaceous and woody plants. However, controlling herbaceous plants or woody plants singly achieved two-thirds of that maximum. Although herbaceous control alone resulted in the greatest response during the first five years of growth, control of woody vegetation in the flatwoods appears to enhance pine growth the most in the long-term based on trends over the last six years in the present study and findings by Lauer and Clover (1995) on a similar site.

Woody plant establishment, and to a lesser degree, herbaceous re-establishment. began immediately after the 3 yr of intensive control treatments ceased. This should make managers aware that woody plant regrowth and herbaceous re-establishment will probably occur to varying degrees following any intensity of treatment on flatwoods sites. The presence of understory woody regrowth will likely continue to influence pine volume growth through midrotation and beyond.

Development patterns of the pines, herbaceous plants, and woody plants were observed to be strongly interrelated on this flatwoods site. Early control of only the herbaceous plants increased the development of the woody species, including pines, hardwoods, and shrubs. Similarly, when woody plants were controlled early, herbaceous cover was increased. As the pine canopy developed, it decreased herbaceous plant cover and retarded the growth of woody plants. The degree of influence by pine canopy development will depend on planting density and survival, as well as other cultural treatments such as fertilization. Thus, the density and speed of pine canopy development will have a long-term influence on woody and understory plant associates, and possibly as significant an effect as the direct effect resulting from herbicide applications.

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