PLANT COMMUNITY RESPONSES TO SOIL DISTURBANCE AND HERBICIDE TREATMENTS OVER 10 YEARS ON THE TEXAS LTSP STUDY

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Abstract—Determining how anthropogenic disturbances affect site productivity through bioassays requires a complete understanding of both overstory and understory vegetation. This study was installed in 1997 to determine how soil compaction and intensive harvesting affected the inherent site productivity of pine stands on the western boundary of loblolly pine's (*Pinus taeda* L.) natural range. We measured the plant communities at ages 5 and 10 on plots receiving a factorial combination of three levels of soil compaction and three levels of organic matter removal at harvest. Soil compaction had little impact on plant communities. Intensive harvesting, especially when the forest floor was removed, greatly reduced pine survival and growth and somewhat reduced woody understory growth, while increasing herbaceous understory growth. The reduction in woody understory biomass did not improve pine growth because forest floor removal reduced soil fertility and water content, which affected the pines in addition to the understory vegetation.

INTRODUCTION

The North American Long-Term Soil Productivity (LTSP) study was created to determine how forest management affected the long-term productivity of a site (Powers and others 1990). The most consistent finding across the 62 locations of the core LTSP study and across the many affiliate installations has been the large and sustained positive impact of noncrop vegetation control on forest productivity (Powers and others 2004). Seldom if ever has the total aboveground biomass of the nontreated plots been equal or greater than the plots receiving competition control. Although soil compaction has reduced tree growth on some heavy textured soils, it has also led to increased growth on several sites. The increased growth on some sites has been attributed to increased water holding capacity (Gomez and others 2002), but also to the indirect control of noncrop vegetation (Stagg and others 2006). Intensive organic matter removals have not consistently reduced productivity but they have reduced productivity on inherently low nutrient soils through induced nutrient deficiencies (Scott and others 2007). A final lesson that has emerged from synthesizing the overall LTSP project has been that various site-specific anomalies in site type, treatment installation, or post-treatment events have at times overshadowed the main treatments in their effect on measured productivity.

An excellent example of this effect was observed on the Mississippi plots at age 10, which are dominated in the understory by inkberry (*Ilex glabra* L.), a very persistent and dense-growing woody species that is difficult to control even with herbicides. On these sites, planted loblolly pine (*Pinus taeda* L.) productivity was 21 percent greater on the plots that had been compacted compared to uncompacted plots, apparently due to reduced understory biomass on those plots (Stagg and Scott 2006). The compaction effect was apparent whether herbicides were applied or not; chemical vegetation control was not 100 percent effective on understory biomass and was greater on compacted plots compared to the noncompacted plots. Since the soil was loamy and had a moderate initial bulk density, it was not likely that the compaction increased pine growth through increased soil water holding capacity as found on the loose sands in California (Gomez and others 2002).

The Texas LTSP sites provide a unique environment to test how differences in site and soil conditions may alter the relationships between soil compaction, organic matter removal, chemical vegetation control, and planted tree productivity. Accordingly, the objectives of this study were to determine how organic matter removal, soil compaction, and chemical vegetation control affected understory plant abundance and growth over the first 10 years since plantation establishment, and how any differences in understory dynamics affect planted loblolly pine dynamics.

MATERIALS AND METHODS

Study Sites

The study site is located in the Davy Crockett National Forest in Trinity County, TX. The soil is a Kurth series, which is in the fine-loamy, siliceous, semiactive, thermic family of oxyaquic glossudalfs. A relatively thick (0.5-m) sandy loam surface caps a deep clay loam subsoil. This series is moderately well drained, forming in loamy clay sediments in uplands (Steptoe 2003). The preharvest stand was a well-stocked, naturally regenerated, even-aged loblolly and shortleaf (*P. echinata* Mill.) pine stand with a few scattered longleaf pines (*P. palustris* Mill.) and associated upland hardwoods, such as oaks (*Quercus* spp.) and sweetgum (*Liquidambar styraciflua* L.). The site had received prescribed burns at 3- to 5-year intervals during the previous rotation, although the site had not been burned for 10 years prior to the establishment of the LTSP study.

Twenty-seven 0.2-ha study plots were established in a split-plot, randomized complete block design (RCBD). The general plot layout is a 3 × 3 factorial arrangement of organic matter removal and soil compaction. Following harvest, main plot treatment applications and planting, each plot was split in half. On half of each main plot, the understory vegetation community was allowed to recover naturally. On the other half,

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the understory was intended to be controlled chemically to create a virtual planted pine monoculture.

Treatments

The compaction treatments of the LTSP study consisted of no compaction (C0), moderate (C1), and severe (C2) compaction. No equipment traffic was allowed during harvest on the C0 plots; only foot traffic was allowed. The trees were removed by chainsaw felling and lifting the logs off of each plot with a log loader or crane. The C1 and C2 compaction plots were logged by normal logging methods, which consisted of chassis-mounted shears and grapple skidders, although no repetitive trafficking was allowed on these plot treatments. Prior to harvesting, the compaction treatments were applied by towing a pneumatic-tire roadbed compactor with a crawler tractor over the designated plots. The roadbed compactor had a rolling width of 1.52 m. The ballast in the roadbed compactor was adjusted to meet the requirements of the treatment. Field trial tests determined that a load of 3.0 mt was required to initiate soil compaction in the Kurth soil series. The severe load was set at 6.4 mt and the moderate load was set as a logarithmic average between these two points or 3.6 mt. To ensure complete coverage and uniform compaction, each plot received three passes in one direction and then three more passes in a perpendicular direction for a total of six passes.

The organic matter removal treatments consisted of a bole-only harvest (BOH), a whole-tree (aboveground) harvest (WTH), and a whole-tree harvest followed by the removal of the forest floor (WTFF). Following the compaction and organic matter removal treatments the study plots were hand planted with containerized loblolly pine seedlings from 10 known families on a 2.5- by 2.5-m spacing. Four annual applications of glyphosate (3.9 L/ha each) were applied to the pine-only half of each main treatment plot beginning in the middle of the fourth growing season.

Measurements

Prior to harvesting, the understory biomass was destructively sampled within five randomly placed 1-m^2 square sampling areas and separated by lifeform (woody or herbaceous). The understory was collected, oven dried, and weighed. All understory species <7.62 cm in diameter at breast height (d.b.h.) were collected, but the biomass was not separated by species. Percent cover by species was determined visually along six 30.5-m transects per plot.

At age 5, understory vegetation biomass (woody and herbaceous) was collected from four randomly placed 1.56-m^2 sample areas on each subplot, but was separated only by lifeform, not species.

A more intense understory vegetation biomass measurement was made at age 10. All woody understory species <1.37 m tall were clipped, bagged, and tallied by species and number of stems in each of three 6.25-m^2 sampling areas on each subplot. All woody understory species >1.37 m tall were tallied by species, height, and number of stems per rootstock within three 56-m^2 sampling areas randomly located within each study plot. Plot level biomass was determined from these measurements using biometric equations developed from the LTSP installations and other nearby forests (Scott and others 2006).

Data Analysis

The study was analyzed as a split-plot RCBD with three replicate blocks using analysis of variance (ANOVA) (repeated measures for understory biomass) and an alpha of 0.1. Interaction terms were statistically insignificant unless otherwise stated. When interaction terms were significant, the least-squares means were sliced by each effect in the interaction. When the ANOVA showed a significant model, the means were separated with the Ryan-Einot-Gabriel-Welsch multiple range test (SAS Institute 1999).

RESULTS AND DISCUSSION

Initial planted pine survival was very good following the first growing season after planting, averaging 93 percent across all plots. Survival was not affected by compaction or intensive organic matter removal in the first growing season (table 1). About 40 percent of the planted trees died in the second growing season, and survival averaged 51 percent across all plots. Few trees died following the second growing season, and overall survival through age 10 was 46 percent (data not shown). Neither compaction nor WTH had an impact on survival compared to uncompacted or BOH, but removing the forest floor reduced survival to only 34 percent. In fact, two WTFF plots had such poor initial survival (<20 percent), they were replanted and failed again and were not included in the calculations.

The poor survival of planted pines in the second growing season appeared to be due largely to rainfall patterns. Rainfall was normal following planting until autumn of the first growing season (data not shown). From November through January, the site received almost twice the normal rainfall, creating overly wet conditions for good root growth. This was followed by extremely dry conditions in the early part of the second growing season, and wet conditions in the latter part of the second growing season. These periods of wetness and dryness likely inhibited early root growth through increased soil strength when the soil was dry and low aeration when the soil was wet. While the original hypothesis of the LTSP study proposed that compaction would exacerbate these types of effects through increasing soil strength and reducing aeration (Greacen and Sands 1980), compaction had no impact on survival at the Texas sites. Some sandy sites have benefited from compaction by increasing soil water holding capacity, but the Texas sites showed no improvement in survival or growth that could be attributed to improved water-holding capacity. It's possible that while water-holding capacity may have been improved, which would have improved root growth and survival during the droughty months, the corresponding decrease in macroporosity would have hindered root growth and survival during the wet months.

Woody understory biomass was unaffected by compaction at age 10 (fig. 1), even though the C1 plots had only about one-third the biomass at age 5 and grew from just over 2 mt/ha to about 8 mt/ha. Herbaceous biomass was unaffected by compaction

Table 1—Planted loblolly pine initial survival and 10-year mean height and d.b.h. response to three levels of compaction and harvest intensity and two levels of herbicide application on a sandy soil in east Texas

	Levels of compaction			Harvest intensity			Herbicide application	
	C0	C1	C2	BOH	WTH	WTFF	H0	H1
Survival (%)								
Year 1	95 a	92 a	92 a	94 a	92 a	91 a	93[a]	N/A
Year 2	50 a	57 a	46 a	64 a	56 a	34 b	51	N/A
Height (m)								
Age 5	3.8 a	3.8 a	3.8 a	4.1 a	3.8 b	3.5 c	3.8 a	3.8 a
Age 10	9.5 a	9.6 a	9.7 a	10.0 a[b]	9.7 a	8.9 b	9.5 a	9.7 a
D.b.h. (cm)								
Age 5	5.0 a	5.0 a	5.1 a	5.5 a	5.0 b	4.4 c	4.8 b	5.2 a
Age 10	12.9 b	13.0 b	13.5 a	13.8 a	13.2 b	12.2 c	12.8 b	13.5 a

N/A = not applicable; C0 = no compaction; C1 = moderate compaction; C2 = severe compaction; BOH = bole-only harvest; WTH = whole-tree harvest; WTFF = whole-tree and forest floor harvest; H0 = hand-felled, bole-only harvest; H1 = high-production, whole-tree harvest.

[a] Statistics were not performed for survival differences between herbicide treatments because those treatments had not yet been implemented.

[b] The compaction by organic matter removal by herbicide interaction term was significant, but was caused by one specific treatment combination and not in any discernible pattern.

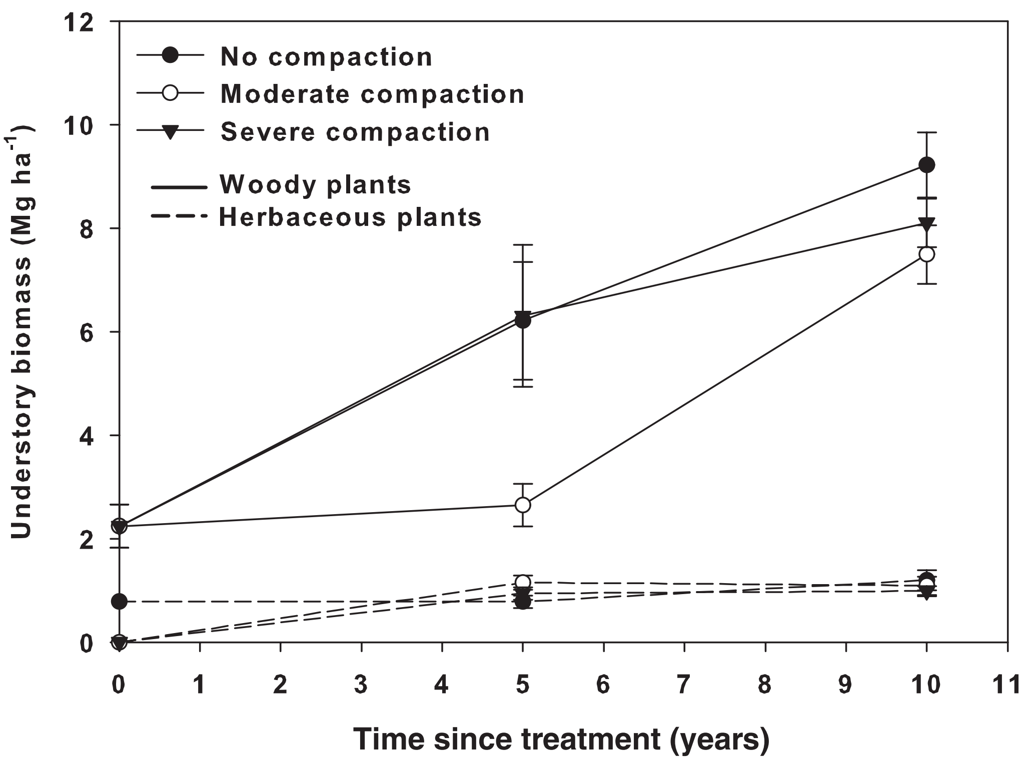

Figure 1—Woody and herbaceous understory biomass response to three levels of experimentally applied soil compaction in loblolly pine plantations. Time 0 years refers to preharvest conditions.

at either age, and averaged about 1 mt/ha from age 5 through age 10. These results are in contrast to the results found on the Mississippi LTSP sites, where soil compaction reduced overall understory biomass by 66 percent at age 5 years, and at age 10 years the understory biomass on the C1 plots was the same as on the C0 plots, but remained 40 percent less on the C2 plots (Stagg and Scott 2006). The compaction treatments on the Texas sites were effective in increasing soil bulk density, but not to exceptionally high levels; both the C1 and C2 treatments increased bulk density of the surface 10 cm, from 1.18 to 1.33 mt/m^3 (Scott and others 2004). Thus, the change in bulk density and concomitant increase in soil strength and decrease in macroporosity may have been too slight to affect root growth and water relations.

Similarly, compaction had little impact on planted pine growth at age 5 or 10, even though the trees on the C2 plots were about 0.5 cm greater in d.b.h. than the trees on the C0 and C1 plots at age 10 (table 1). In Mississippi, pine growth increased in proportion with the decrease in understory biomass (Stagg and Scott 2006). Stagg and Scott (2006) did not find evidence of soil improvement caused by compaction; the compaction apparently acted as a vegetation control treatment. Since understory biomass was not affected by compaction in Texas at age 10, it was not surprising that tree growth was also largely unaffected. The slight increase in d.b.h. on the C2 plots may have been due to differences in understory biomass; woody understory biomass was lower, although not statistically significant, on the C2 plots (fig. 1). It is unclear why the understory was reduced by compaction in Mississippi but not in Texas at age 10. In general, the understory composition was quite similar between the two sites except for the dominant understory species. The Texas sites were dominated by yaupon (*I. vomitoria* Aiton), while the Mississippi sites were dominated by inkberry. Although both yaupon and inkberry are hollies, it is possible that inkberry is more susceptible to reduced sprouting and growth caused by direct crushing than yaupon.

Both woody and herbaceous understory biomass were also largely unaffected by harvesting treatment. Although the understory woody biomass on the WTFF plots was about 37 percent lower than the biomass on the BOH plots (fig. 2), this difference was not significant. In contrast, the herbaceous biomass declined slightly from age 5 to 10 on the BOH and WTH plots but doubled on the WTFF plots due to the higher light availability on these plots that had poor pine survival and poor woody biomass colonization. Several areas on these plots had open areas up to about 0.08 ha in size with little if any woody cover of any sort. Forest floor removal may have removed some of the seed source for many of the woody species, but it is unclear why, after 10 years, these areas have not been colonized by woody plants.

Planted pine height was about 1 m less on the WTFF plots compared to the BOH or WTH plots at age 10, and d.b.h. was 0.6 and 1.6 cm less on the WTH and WTFF plots, respectively, than on the BOH plots at age 10, and the relative differences among treatments were similar at age 5 (table 1). This difference in pine response to competition between the Texas and Mississippi sites was probably due to the mechanism by which the treatments controlled the vegetation. In Mississippi,

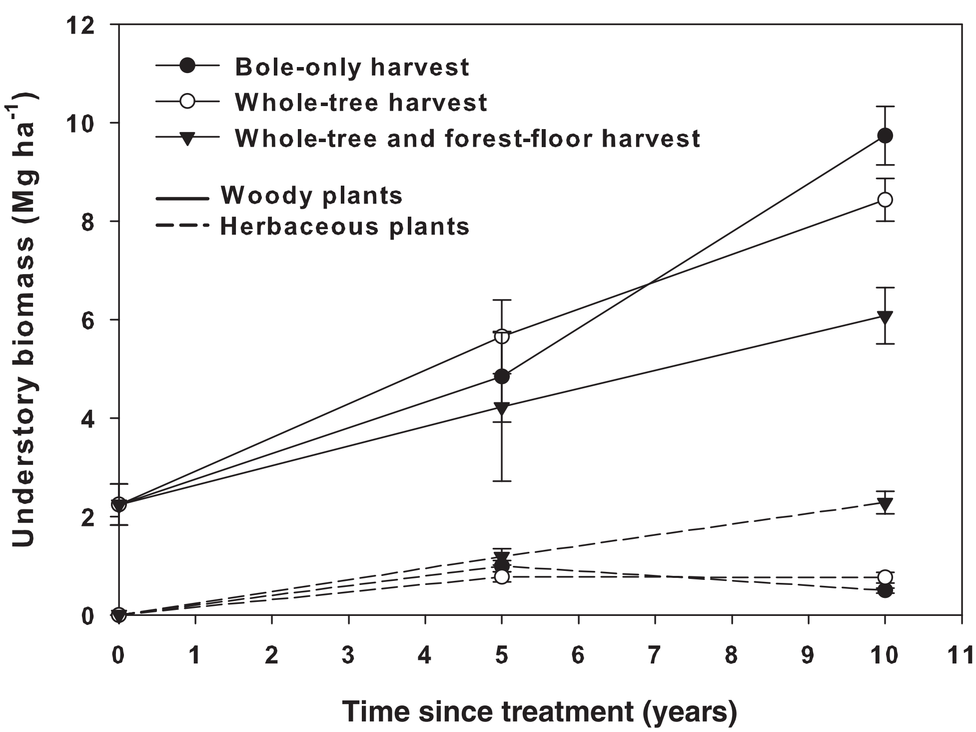

Figure 2—Woody and herbaceous understory biomass response to three levels of harvest intensity. Time 0 years refers to preharvest conditions.

the control mechanism was likely the direct impact of compaction against the vegetation. In Texas, the WTH and forest floor removal had much less of a direct impact against the understory vegetation, but instead probably affected its growth through organic matter and nutrient removal.

Previous research has shown that across seven soil types from Mississippi to Texas, site productivity loss caused by intensive harvesting (WTH or WTFF) is directly related to soil phosphorus content (Scott and others 2007). The Kurth soils in Texas had the lowest soil P content of the seven soil series studied. Thus, it is likely that the additional removal of nutrients, especially P, by the WTH and forest floor removal reduced pine growth. In addition, following the second growing season the sites experienced a 4-year drought that may have reduced the ability of the woody plants to expand or invade into the open areas. Grasses and other herbaceous plants were able to competitively invade these open areas. The removal of the forest floor may also have exacerbated the drought stress on these plots by removing the mulch effect normally provided by an intact forest floor which again would likely favor herbaceous plants over woody species.

Herbicides had much less of an effect on either understory biomass or on pine tree growth at the Texas sites than expected or in comparison to similar studies. By age 5, the herbicide treatments had been applied twice; once during the fourth and once during the fifth growing seasons. Woody understory biomass was reduced from 6.4 to 3.6 mt/ha by the herbicide applications, while herbaceous biomass was reduced from 1.3 to 0.6 mt/ha (fig. 3) at age 5. After age 5, two more applications were made; one each in the sixth and seventh growing seasons. At age 10, woody understory biomass was essentially unaffected by the additional herbicide treatments. The difference between the treated and untreated subplots at age 10 (2.7 mt/ha) was the same as at age 5 (2.8 mt/ha). The herbaceous understory was no longer different between the treatments at age 10. Planted pines were significantly but only slightly taller and larger in d.b.h. on the plots receiving herbicide treatment compared to untreated plots at age 5 or 10 years (table 1). Although the herbicides reduced woody understory biomass, the early drought and poor soil fertility conditions hindered the ability of the pines to take advantage of the reduction in competition.

Woody species composition changed dramatically from preharvest to age 10. Prior to harvest, American beautyberry (*Callicarpa americana* L.) was the most dominant species in the understory, followed by yaupon and sweetgum. Various oaks, mostly southern red oak (*Q. falcata* Michx.), cherrybark oak (*Q. pagoda* Raf.), water oak (*Q. nigra* L.), and white oak (*Q. alba* L.) and wax myrtle [*Morella cerifera* (L.) Small] composed the other common species. Neither compaction nor any of the organic matter removal treatments affected the composition of the major woody species (data not shown). The herbicide applications reduced the biomass and relative dominance of American beautyberry, sweetgum, oaks, and wax myrtle, but more than doubled the relative dominance of yaupon (fig. 4). Apparently, because of their relatively low susceptibility to glyphosate, the herbicide treatments

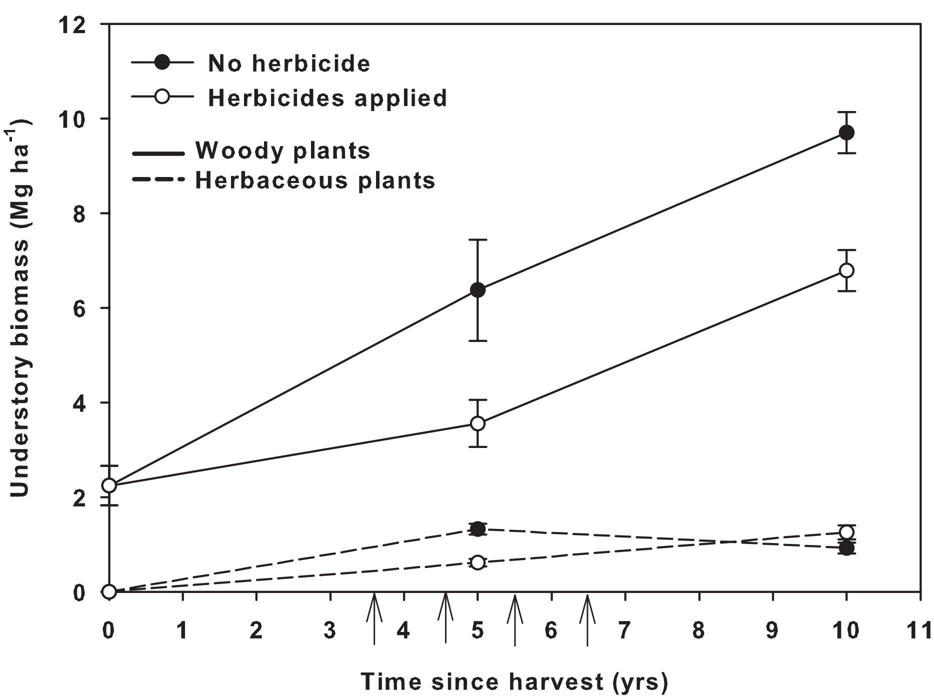

Figure 3—Woody and herbaceous understory biomass response to four applications of herbicide (glyphosate) in loblolly pine plantations. Arrows indicate approximate dates of application. Time 0 years refers to preharvest conditions.

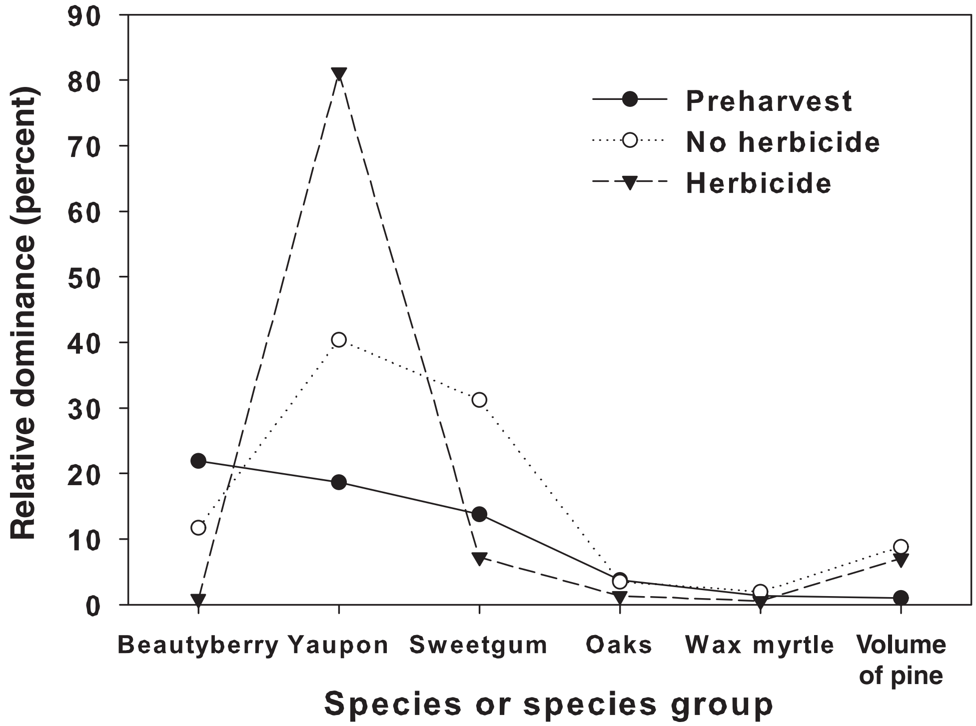

Figure 4—Relative dominance of the six most dominant woody species or species groups across the Texas LTSP sites before treatments and at age 10 years following two vegetation control treatments (no treatment and herbicide).

essentially provided a chemical release to both loblolly pine and yaupon.

CONCLUSIONS

This study found that in contrast to other LTSP sites, compaction had little impact on the understory or overstory vegetation, while both organic matter removal and herbicide treatments did affect the vegetation. Intensive organic matter removal reduced the growth of planted pine even where woody understory biomass was somewhat reduced by the treatments. The poor soil moisture conditions that developed due to both very low and very high rainfall during the second growing season likely caused the poor pine survival, but treatments such as whole-tree and forest floor removal that further reduced soil fertility on these infertile sites caused further declines in pine tree growth. These results support caution when harvesting to leave the forest floor and slash scattered on site on soils with limited nutrients.

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