EIGHTEEN-YEAR RESPONSE OF SLASH PINE TO WET-WEATHER HARVESTING AND SITE PREPARATION ON A POORLY DRAINED SILT LOAM SOIL IN LOUISIANA

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Abstract—Physical disturbances to soil resulting from forest management operations may reduce tree survival and growth, but responses are soil-, species-, and disturbance-specific. We studied wet-weather harvesting, shearing, root-raking, disking, and phosphorus fertilization on a poorly drained flatwoods site in Louisiana. Slash pine survival was improved by wet-weather harvesting, but 18-year growth responses were not affected by any physical disturbances due to the inherently poor physical properties of soils on the site. Fertilization increased volume at age 18 by 47 percent, and the effect was still increasing.

INTRODUCTION

Foresters and others have been concerned for decades about potential risks to long-term soil productivity caused by mechanized equipment-based soil physical disturbances. Many short-term and some long-term studies have been conducted in the South over the past 40 years, and negative harvesting impacts on soil properties have been well documented (Miller and others 2004, Miwa and others 2004).

Few studies of severe soil disturbance have resulted in clear, well-documented losses in soil productivity as measured by tree-growth reductions. Some studies have been confounded with other effects, such as weed competition or adequate experimental control (Morris and Miller 1994). Some recent studies that have controlled for many of these factors have not found growth losses following soil compaction (Scott and others 2004) or wet-weather logging (Eisenbies and others 2004).

Responses to soil disturbances can be partially explained in terms of soil properties and processes. Soil physical disturbances (compaction, rutting, churning) may cause increased soil strength, reduced porosity, reduced infiltration and aeration, and reduced root growth (Miller and others 2004, Miwa and others 2004). The most severe disturbances occur not when a soil is at the water content most conducive to compaction but at water contents at or above the liquid limit, which is the water content at which soil becomes fluid. At soil water contents above the liquid limit, static and shear forces cause the soil to become viscous and flow. In this state, soil porosity is not lost due to the incompressibility of saturated soil, although pore size distributions may change (Miwa and others 2004).

Tree root growth may be reduced by loss of aeration, increased soil strength, or altered hydrology. The relative impact of soil disturbance on any given soil depends on the specific soil properties and the type of disturbance. In soils with adequate internal drainage, the loss of soil porosity and structure may increase soil strength and reduce aeration, causing reduced root growth. Soils with well-graded textures may be especially prone to damage by puddling, which causes crusting and cementation. In imperfectly drained soils, however, the loss of soil structure caused by rutting and churning may not have discernible effects on drainage and tree growth. Thus, some soil deleterious compaction effects can be avoided by logging during dry times when soil strengths are high enough to support machinery or during wet times when the soil will flow; but we do not yet know which sites will respond negatively to each type of disturbance. Physical soil preparation, such as disking, ripping, and bedding, may help restore soil physical properties, but the efficacy of each method on each soil type is not known.

An additional problem with determining whether soil disturbances and site preparation practices have lasting effects on productivity is that early results are not always indicative of later results (Tiarks and others 1998). Tree growth responds to soil treatments quite differently in some cases before canopy closure, when intraspecific competition and each tree must establish roots in a small area, and after canopy closure, when individual trees are better established and competition becomes more interspecific.

We designed this study to determine if severe soil disturbances would reduce long-term soil productivity on a poorly drained flatwoods soil in southwest Louisiana, what level of mechanical site preparation would be needed to restore productivity, and if fertilization had an interactive effect with soil physical disturbance. We also wanted to determine how responses have changed or not changed over 18 years of stand development.

MATERIALS AND METHODS

Study Sites

The study site is located in the West Bay Management Area in Allen Parish, LA, which is on the West Gulf Coastal Plain and in the flatwoods physiographic region. The soil is a poorly drained Caddo silt loam (fine-silty, siliceous, active, thermic Typic Glossaqualfs) interspersed by about 10 percent moderately well drained Messer silt loam (coarse-silty, siliceous, superactive, thermic Haplic Glossudalfs) pimple mounds.

The preharvest stand was a 40-year-old slash pine (*Pinus elliotti* Engelm.) plantation with little understory vegetation.

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Treatments

The experimental design was a split-plot randomized complete block design with four blocks. The main-effects plots were rectangular, 0.45-ha in size, and split into two equal halves. The measurement plots were the interior 0.05-ha of each half. We installed six main-effects treatments, which comprised two soil conditions at the time of harvest and four site preparation treatments in different combinations. The treatments were:

1. Dry weather logging (DRYH-ONLY). The plots were logged in the summer of 1979 when the soil was dry enough to support logging equipment with little compaction or surface disturbance. The woody residue on these plots was burned.
2. Dry weather logging followed by shearing (DRYH-SHEAR). Logging was done at the same time as Treatment 1. The plots were sheared in the fall of 1979.
3. Wet-weather logging (WETH-ONLY). The plots were logged in January-March 1979 when the soil water content ranged from above field capacity to nearly saturated, so compaction and rutting effects by the skidders were maximized. The woody residue on these plots was burned.
4. Wet weather logging followed by shearing (WETH-SHEAR). Logging was done at the same time as Treatment 3. The plots were sheared in the fall of 1979.
5. Wet weather logging followed by shearing and rootraking (WETH-RAKE). This treatment was the same as Treatment 4, except the areas were rootraked following shearing.
6. Wet weather logging followed by shearing, rootraking, and flat disking (WETH-DISK). After logging, shearing, and rootraking (same as Treatment 5), the plots were flat disked.

The split-plot treatments were fertilizer applications of 0 and 56 kg ha^{-1} of phosphorus (P) applied as triple superphosphate (0-46-0) in a small circle around each tree. The rate of fertilizer was 0.154 kg $tree^{-1}$ and was applied in May 1980.

All woody vegetation 6.4 cm or larger in diameter remaining on the plots was injected with Tordon 101 (picloram and 2,4-D) in the summers of 1980 and 1981.

Planting

Uniform grades 1 and 2 slash pine seedlings were hand planted at 2- by 3-m spacing February 11-13, 1980. Because overall survival at the end of the first growing season was only 61 percent, all missing and dead trees were replaced.

Measurements

Total height of each tree in the measurement plot was measured at 1, 3, 5, 9, and 13 years following treatment, and the height of every 10^{th} tree was measured at 18 years following treatment. Diameter at breast height of each tree in the measurement plot was measured at 5, 9, 13, and 18 years following treatment. At age 18 years, tree heights were estimated by height-diameter relationships developed from the sampled heights. Individual tree volumes were determined by equations developed by Lohrey (1985) and summed by measurement plot for stand volume estimates.

Data Analysis

Initial survival was analyzed with analysis of variance and orthogonal contrasts. The stand volume data were analyzed with a repeated measures analysis of variance and orthogonal contrasts to elucidate the individual effects over time. For all comparisons, $\alpha = 0.05$ was used. When the F-test indicated significant treatment differences, the Student-Newman-Keuls multiple comparisons test was used to separate the means. All statistical analysis was performed on SAS (SAS Institute 2000).

RESULTS

Survival

Initial survival was low across all treatments and averaged only 61 percent after one full growing season. When all treatments were compared, only the WETH-SHEAR and WETH-RAKE treatments had significantly greater first-year survival than the DRYH-ONLY treatment (fig. 1). All other treatments were similar, and the fertilizer treatment and the fertilizer by treatment interaction had no significant effect. Because of this poor survival, all dead and missing trees were replanted after the first growing season. At age 3 years, the overall survival had improved to 86 percent. All treatments were similar at age 3 years.

Orthogonal contrasts were used to elucidate the various effects at ages 1 and 3 years. At age 1 year, the time of logging had the only significant effect (table 1). Wet-weather harvesting improved initial survival from 53.7 percent on the dry-harvested plots to 64.9 percent. Shearing, rootraking, disking, and fertilization had no effect, and there were no significant interactions between the time of logging and shearing and between physical treatments and fertilization. At age 3 years, after the poor survival was supplemented by replanting, the time of logging had no significant influence on survival, but shearing improved survival from 82.8 to 87.8 percent (table 1). No other treatment or interaction was significant.

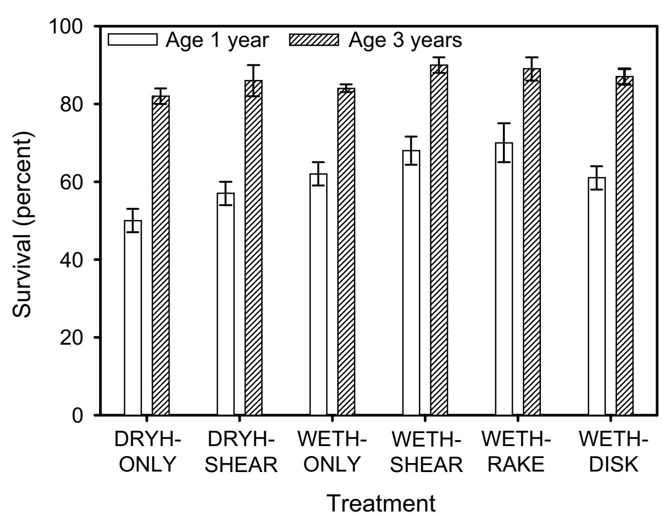

Figure 1—Early survival of slash pine in soils impacted by harvesting and site preparation on a flatwoods site in Louisiana. Age 3 years results include trees replanted after the first growing season. The treatment abbreviations indicate the type of harvest (dry vs. wet) and site preparation (only = no mechanical site preparation, shear = shearing site preparation, rake = rootraking following shearing, and disk = flat disking following shearing and rootraking).

Table 1—Early survival of slash pine (percent) in soils impacted by harvesting and site preparation on a flatwoods site in Louisiana

	First-year survival (%)			Third-year survival (%)		
Treatment comparison	A[a]	B	P>F[b]	A[a]	B	P>F[b]
Dry (A) vs. wet logging (B)	53.7	64.9	0.01	83.8	86.9	0.16
No shearing (A) vs. shearing (B)	56.1	62.5	0.12	82.8	87.8	0.03
No rootraking (A) vs. rootraking (B)	59.3	65.5	0.08	85.3	88.1	0.14
No disking (A) vs. disking (B)	69.8	61.2	0.14	89.2	87.0	0.46
Not fertilized (A) vs. fertilized (B)	61.7	60.9	0.78	84.9	87.6	0.17

[a] Within each year numbers in the A column represent survival for the A treatments and numbers in the B column represent survival for the B treatments.
[b] The P-values were determined from preplanned orthogonal contrasts for the physical site treatments and from the type III F-test for the fertilizer treatments.

Volume Growth

At age 18 years, stand volume averaged 213 m^3 ha^{-1}. Stand volumes were similar for all soil physical treatments (fig. 2). Fertilization increased volume production by 47 percent and was a significant factor at every age sampled. The unfertilized plots averaged 172.3 m^3 ha^{-1}, while the fertilized plots averaged 253.8 m^3 ha^{-1}. The interaction between the physical treatments and fertilization was not significant.

Orthogonal contrasts revealed that at age 18 none of the individual or interaction effects (wet or dry logging, shearing, rootraking, disking, and the logging and shearing interaction) were significant at $\alpha = 0.05$ (table 2). Shearing increased volume by 13 percent but was not significant at $\alpha = 0.05$.

Because the treatments imposed variable survival after the first year and therefore different numbers of trees were replanted, we analyzed the volume of the original trees at age 18 years to ensure that the replanting did not affect our interpretations. The only difference in treatment effect between the total stand volume (original + replanted trees) and the original trees only was the shearing effect. Shearing improved growth of the original trees significantly (*P* < 0.0234), while only marginally (*P* < 0.0524) for all trees. Otherwise, the interpretations were not different for any effect.

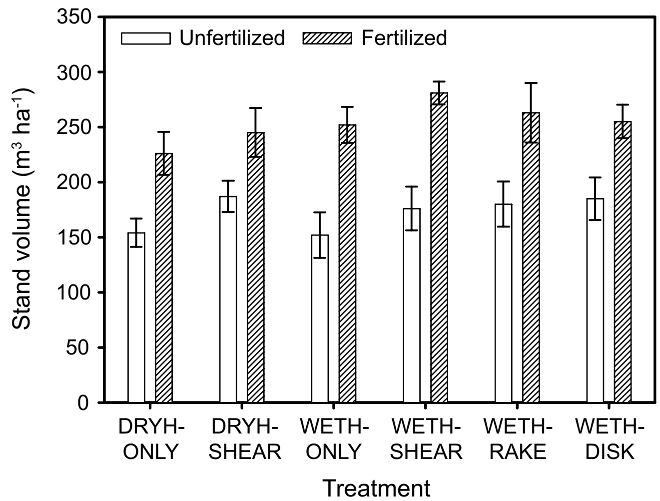

Figure 2—Eighteen-year slash pine volume response to soil physical disturbances and fertilization on a flatwoods site in Louisiana. Error bars represent one standard error. The treatment abbreviations indicate the type of harvest (dry vs. wet) and site preparation (only = no mechanical site preparation, shear = shearing site preparation, rake = rootraking following shearing, and disk = flat disking following shearing and rootraking).

Table 2—Eighteen-year volume production of slash pine in soils impacted by harvesting and site preparation on a flatwoods site in Louisiana

	Volume		
Treatment comparison	A[a]	B	P>F[b]
	- - - - *m^3/ha* - - - - -		
Dry (A) vs wet logging (B)	203.1	215.2	0.3421
No shearing (A) vs. shearing (B)	196.1	222.2	0.0524
No rootraking (A) vs. rootraking (B)	209.3	220.9	0.2931
No disking (A) vs. disking (B)	221.7	219.9	0.9200
Not fertilized (A) vs. fertilized (B)	172.3	253.8	0.0001

[a] Numbers in the A column represent volume for the A treatments and numbers in the B column represent volume for the B treatments.
[b] The P-values were determined from preplanned orthogonal contrasts for the physical site treatments and from the type III F-test for the fertilizer treatment.

Similarly, the soil physical treatments had little effect on volume growth throughout the development of the stand. The time of logging (wet vs. dry logging) had no effect on volume at any age (fig. 3). Shearing marginally increased (as defined by $\alpha = 0.10$) volume at ages 5, 13, and 18 (fig. 4). Rootraking increased volume growth by 47 percent at age 5 years, but this effect was absent at age 8 and thereafter (fig. 5). Disking had no effect on volume growth at any age (fig. 6). Fertilization increased volume production significantly at every age measured (fig. 7).

The repeated measures analysis revealed that the soil physical treatment effects were not different through time, although the fertilization effect was significantly different ($P < 0.0001$) through time. Fertilization continued to increase the growth rates through age 18 (fig. 7). The fertilization x soil physical treatment x age interaction was not significant. The individual effects, as estimated by contrasts, changed little through time. The time of logging x age, disking x age, and time of logging x shearing x age interactions were not significant. The shearing x age ($P < 0.0765$) and rootraking x age ($P < 0.0834$) interactions were marginally significant.

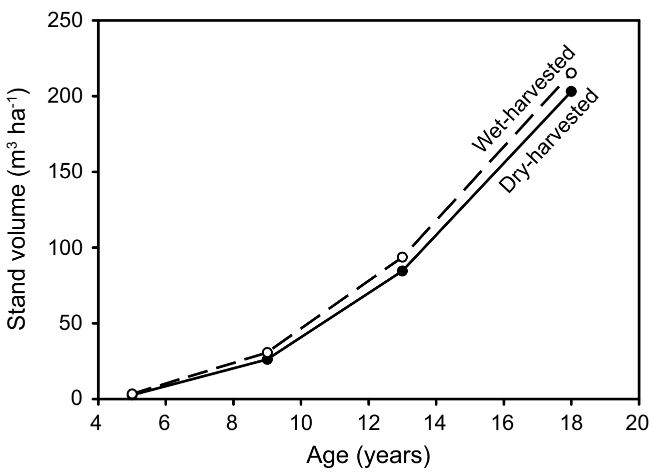

Figure 3—Slash pine volume response to wet and dry soil conditions at harvest on a flatwoods site in Louisiana.

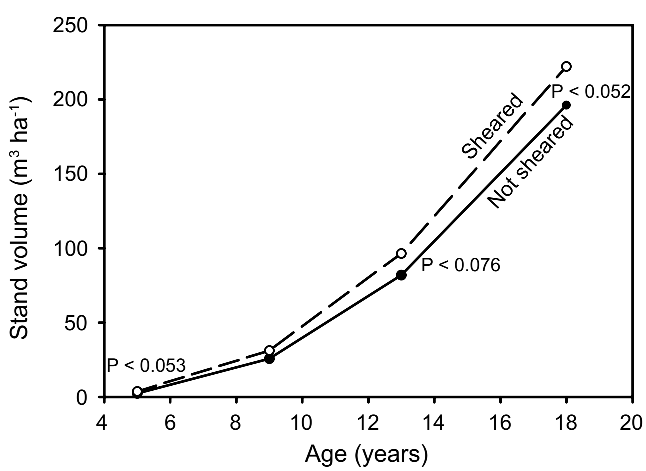

Figure 4—Slash pine volume response to burning vs. shearing site preparation on a flatwoods site in Louisiana. *P* values were determined from preplanned orthogonal contrasts.

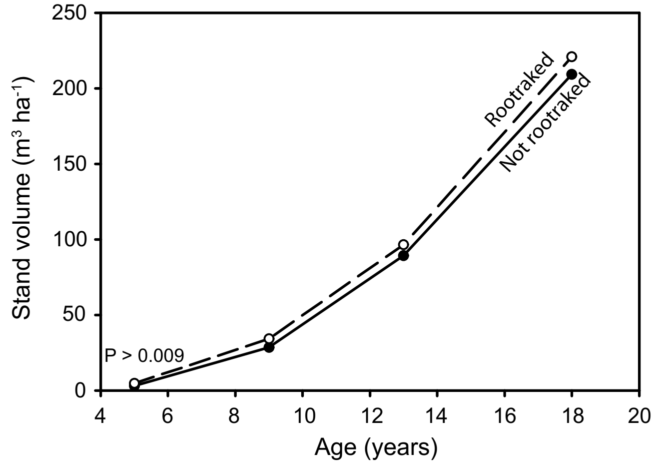

Figure 5—Slash pine volume response to rootraking following shearing on a flatwoods site in Louisiana. *P* values were determined from preplanned orthogonal contrasts.

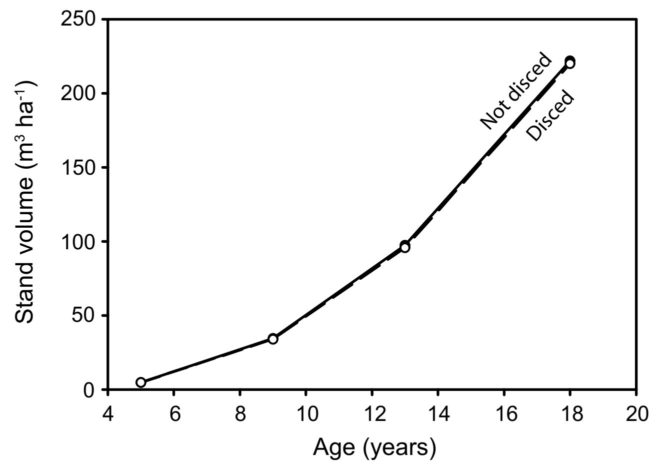

Figure 6—Slash pine volume response to disking following shearing and rootraking on a flatwoods site in Louisiana.

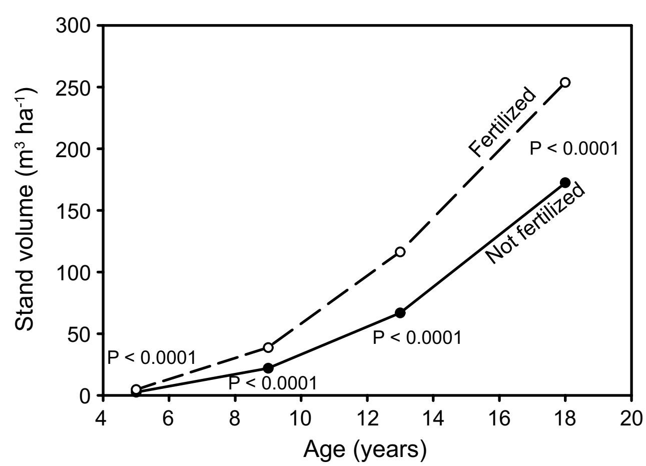

Figure 7—Slash pine volume response to fertilization on a flatwoods site in Louisiana.

DISCUSSION

Many studies on soil compaction and wet-weather logging have focused on skid trails and logging decks but have not reported whether an overall area has been negatively impacted, e.g., Lockaby and Vidrine (1988) and Hatchell (1981). In this study we assessed the entire plot. Only 2.7 percent of the area of wet-weather logged plots remained undisturbed, while > 50 percent was characterized by moderate or severe compaction and rutting (Tiarks 1990). The dry-weather logged plots had no visually detected soil disturbance. Therefore, this study was a good test of the overall effects of harvest-induced soil physical disturbance on site productivity.

Survival

Initial survival was poor across all plots, partly due to a mild to severe drought in the area from July 1980 through July 1982, which averaged -2.74 on the Palmer Drought Severity Index (National Climatic Data Center 2005). The only significant treatment effect in the first year was higher survival in the wet-weather harvested plots. The dry-weather harvesting did not take place until July, which increased the probability of insect damage (Tiarks 1990). After replanting, the survival at age 3 years was affected only by shearing, which improved survival. Although woody competition was controlled by injected herbicides, brushy competition was reduced by shearing better than the burning on the nonsheared plots. These results are in contrast to those of several other studies (Miwa and others 2004) in which survival was reduced by compaction, rutting, and other soil disturbances. However, those studies were conducted on coarse-textured or adequately drained soils. This study was conducted on a medium-textured (silt loam) soil with little internal drainage but dry soil conditions during late summers.

Volume

Volume growth was unaffected by both soil disturbance caused by harvesting and site preparation method. Wet-weather logging had no impact on volume growth at any age through age 18 years. The growth patterns were not diverging, even after canopy closure. Mechanical site preparation (shearing, shearing + root raking, shearing + root raking + disking) had no effect on volume growth compared to burning. Shearing had marginal impacts at ages 5, 13, and 18 years, but this effect was likely due to its control of brush competition.

The lack of response to any soil physical disturbance indicates that for this soil, which had little internal drainage and little macroporosity prior to harvest, soil physical disturbances during very wet conditions did not impact soil productivity. Further, the site preparation treatments had little impact, largely because they did not affect soil properties limiting growth. These results are similar to those found in other studies. Aust and others (1995) found that soils with inherently low soil physical quality had less impact from wet-weather logging than soils with better initial soil properties.

Other site preparation treatments may have been beneficial, such as bedding, although bedding studies in the West Gulf Coastal Plain have not shown similar improvements in growth as in the Atlantic Coastal Plain (Derr and Mann 1977, Haywood 1980), or with slash pine compared to loblolly pine (*P. taeda* L.) (Cain 1978). Heavier surface textures in the West Gulf Coastal Plain reduce the ability of bedding to increase aeration, because wet conditions are maintained in the surface through capillary action. Further, early increases in growth due to bedding in this region have not been maintained, possibly due to low soil fertility (Tiarks and Haywood 1996).

Volume growth was significantly improved by P fertilization, which was not surprising. Several studies in similar soils have found P fertilization to be required on the moderately to severely P-deficient soils in the West Gulf Coastal Plain (Haywood and Burton 1990, McKee 1973, Tiarks 1983). The fertilizer effect was no more significant on the wet-weather logged plots, indicating the soil physical disturbance did not restrict rooting volume.

CONCLUSIONS

Soil physical disturbances caused by wet-weather logging and mechanical site preparation had no negative effects on early survival and no effect on 18-year volume growth of slash pine on a poorly drained flatwoods site in southwestern Louisiana. The lack of effect was not due to a lack of disturbance; the wet-weather-logged plots were moderately to severely disturbed across the majority of the area. However, the soils were medium-textured, had little inherent macroporosity or drainage, and were inherently infertile. Soil physical disturbance did not likely change these factors, so slash pine growth was unaffected. Similarly, mechanical site preparation had little effect, because the forms of site preparation, i.e., shearing, root-raking, and disking, did not improve the soil physical characteristics. Tree growth was substantially improved by P fertilization on this inherently infertile site. This study indicates that while soil physical disturbances may reduce the long-term productivity of some sites, moderate to severe physical disturbances may not negatively impact soils with inherently poor soil physical properties.

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