RESPONSE OF SECOND-ROTATION SOUTHERN PINES TO FERTILIZER AND PLANTING ON OLD BEDS— FIFTEENTH-YEAR RESULTS

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Abstract-Two replicated site preparation studies were used to examine the effects of management on loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) growth-and-yield in a second rotation on silt loam soils. Treatments included no tillage, flat disking, bedding, and fertilization. After 15 growing seasons of the second rotation in study 1, loblolly pine and slash pine basal area and volume per acre were greater on burned-only plots than on plots mechanically site prepared 38 years earlier. In the first rotation, 15-year-old loblolly and slash pines had averaged 52 and 49 ft tall, respectively; in the second rotation the trees were only 40 and 46 ft tall. In study 2, slash pine responded to 88 lb per acre of phosphorus applied at the beginning of both rotations, but planting on l&year-old beds had no influence on slash pine growth 15 years later. Cross-rotation comparisons could not be made in study 2 because of age differences when measurements were taken between rotations.

INTRODUCTION

On poorly drained soils in the Southeastern Coastal Plain, pine seedlings have often been planted on beds to improve survival by increasing the volume of unsaturated soil available to roots during rainy periods (Pritchett and Gooding 1975). On west Gulf Coastal Plain silt loam sites where some soils are poorly drained, bedding can be a successful ameliorative treatment if soil depth to the winter water table averages < 1.5 ft (Haywood and others 1990). While the evidence supports bedding on only the most poorly drained sites, bedding is now being used on upland sites in the west gulf region.

Beds are a lasting topographic feature that can disrupt the natural drainage pattern on gently rolling west Gulf Coastal Plain silt loam soils (Haywood 1995). Surface water can pond and adversely affect tree development. Bedding may benefit tree growth through the first five growing seasons only to lose effectiveness by mid- or late-rotation (Derr and Mann 1977; Haywood 1983, 1995). Thus at the end of the rotation, what to do with the beds can be an issue. Should one plant on the old beds, level the site by knocking down the beds, or rework the beds before the next stand of trees is planted?

We studied two sites in central Louisiana to address the issue of whether or not to plant on old beds. At study 1, a second rotation of loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) trees was planted on beds created 22 years earlier (Haywood 1994). On study 2, a second rotation of slash pine trees was planted on beds created 16 years earlier (Tiarks and Haywood 1996). This paper reports on how planting on these old beds influenced growth-and-yield after 15 years of the second rotation. At study 1, we also were able to make 15-year height comparisons between the first and second rotations, but because of age differences when measurements were taken, cross-rotation comparisons could not be made for study 2. Earlier growth comparisons between rotations on one or both sites were made by Haywood (1994), Haywood and Tiarks (1995), and Tiarks and Haywood (1996). Soils and nutritional results for both studies were reported by Tiarks and Haywood (1996).

METHODS

Study Sites

The two study areas are located in Rapides Parish, LA, within 1 mi of each other. Study 1 is on Beauregard (fine-silty, siliceous, thermic Plinthaquic Paleudult) and Caddo (fine-silty, siliceous, thermic Typic Glossaqualf) silt loam soils; study 2 is on predominately Beauregard soil. These soils are acidic, have low natural fertility, can be highly productive with good management, and are common in flatwoods of the west Gulf Coastal Plain (Tiarks and Haywood 1996). The Caddo soil occurs on the lower parts of the level-to-slightly sloping landscape, is poorly drained, and may have a perched water table at or just below the surface during extended periods from December through February (Haywood and others 1990). The Beauregard occurs on slightly higher parts of the landscape, is moderately well drained, and has a winter water table between 1.5 and 2.3 ft. The two soils are very similar in surface horizon characteristics and response to site treatments, including fire and tillage.

On both sites, longleaf pine (*P. palustris* Mill.) and hardwoods were clearcut harvested in the 1920s. After harvesting, a cover of mostly grasses and scattered woody plants was maintained in open range by livestock grazing and periodic burning. Before plot establishment and tree planting, the areas were again cut to reduce woody vegetation.

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Study Establishment

Both studies were established in the 1960s to evaluate disking and bedding as mechanical site preparation methods. Study 1 was established to compare two pine species (loblolly and slash) and three site preparation treatments in a randomized complete block design with four blocks as replicates. Each of the 24 plots (2 pine species times 3 treatments times 4 blocks) measured 144 by 108 ft (0.36 ac). Row spacing was 8 ft, and seedlings were planted 6 ft apart within rows. Measurements were made on the central 10 rows of 10 trees per plot.

Study 2 was established as a randomized complete block split-plot design. There were three main effect site preparation treatments and four blocks as replicates. Only slash pine was planted at study 2. Each of the 12 main plots (3 treatments times 4 blocks) was split into 4 subplots that were 70 by 72 ft (0.12 ac), and to which fertilizer treatments were applied. Row spacing was 10 ft and seedling spacing 6 ft. Tree measurements were made on the center three rows of eight trees per subplot. In both studies, blocking was based on surface drainage.

In study 1, site preparation treatments were: (1) burn-only, all plots were burned in 1960; (2) burn-disk, following burning, some plots were treated with an offset disk harrow once in the fall of 1960 and again in July 1961 to control established grasses; and (3) burn-disk-bed, following burning and disking, technicians created beds averaging 20 in. tall from furrow to crest-before settling-in September 1961 by making two passes with a bedding harrow. The beds were 10 in. tall after 17 years and 8 in. tall after 33 years. The bare-root, 1-O loblolly and slash pine seedlings were obtained from a Louisiana State nursery. The seedlings were graded and hand planted on the appropriate plots in February 1962. The plots were thinned during the 13th growing season (Haywood 1983) and control burned at least once in the first rotation.

In study 2, the three site preparation treatments were: (1) burned only, (2) disked only, and (3) bedded only. The plots were established in the fall of 1967. The fertilizer treatments applied to one of four subplots in each main plot were: (1) no nutrient amendment, (2) 88 lb per acre of phosphorus (P) as triple superphosphate, (3) 1,000 lb per acre of lime, and (4) a combination of P and lime. The amendments were applied after the burning but before mechanical site preparation so the P and lime were mixed into the soil only on the disked or bedded plots. However, incorporation of P fertilizer is unnecessary on these soils (Shoulders and Tiarks 1980). In February 1969, slash pine seedlings similar in quality to those used in study 1 were hand planted in study 2.

Tiarks and Haywood (1996) outlined all of the treatment applications and dates soil and plant samplings were done for both studies and rotations. In 1983, both studies were clearcut harvested. Logging equipment was not allowed on the plots. After harvest, both study sites were broadcast burned to reduce logging residue and facilitate planting the next year. The disked or bedded plots were not retreated mechanically, so the influence of only the initial site preparation treatments could be evaluated during the second rotation.

In February 1984, the plots on both sites were hand planted with the same species of pine as were planted in the first rotation. Seedlings were obtained from a Louisiana State nursery and were similar in quality and probably better genetically to those used in the first rotation. The seedlings were planted at the original spacing between stumps in the original planting rows.

During the first rotation, grasses were initially the principal competitors with the pine trees, although woody competitors were present at both study sites. During the second rotation, all plots in study 1 were rotary mowed yearly between the rows of pine trees to control the size of woody competitors. Woody vegetation within planted rows was cut down during the eighth growing season. The plots were control burned 10 years after planting.

In study 2, the competition was allowed to change in response to the treatments so no competition control was applied to any of the plots. Where no P had been applied, the competition was mostly grasses in both rotations, but on plots that had received P, the amount of woody competition gradually increased during the first rotation and was much greater in the second.

The lime applied to the first rotation of study 2 had no effect on pine growth (Tiarks 1983), so that treatment was replaced with a nitrogen (N) application of 50 lb per acre applied as ammonium nitrate in the beginning of the eighth growing season of the second rotation. The rate of N was based on pine response to N on nearby Beauregard soils (Shoulders and Tiarks 1983).

Measurements

After 15 growing seasons, total heights were measured with a clinometer, and a diameter tape was used to measure diameter at breast height (d.b.h.). Outside bark total stem volumes were calculated for loblolly (Baldwin and Feduccia 1987) and slash (Lohrey 1985) pines.

Management Effects on Growth Comparisons

At study 1, a thinning of the 13-year-old stands in the first rotation did not affect the total height curve for either species. Therefore, height comparisons could be made between the first and second rotation stands at age 15 years. However, thinning nullified comparing diameter, basal area, or volume differences between rotations after age 10 (Haywood and Tiarks 1995). Nevertheless, pine variables could be compared among treatments at the end of the second rotation.

At study 2, pine beetle (*Dendroctonus* spp. and *Ips* spp.) infestations during the second rotation nullified the usefulness of the diameter, basal area, and volume estimates after age 10 years. Height comparisons between rotations were also not possible past age 10 because of differences in ages when measurements were taken between rotations (Tiarks 1983). However, tree heights could be compared among treatments at the end of the second rotation.

Table l-For study 1, mean total height, d.b.h., and outside-bark volume and stand density, basal area, and yield for 15-year-old loblolly and slash pines after the second rotation

Pine species and site preparation treatments[a]	Total height	D.b.h.	Volume per tree	Number per acre	Basal area	Total volume
	feet	*In.*	*Ft³*	*Count*	*Ft²/ac*	*Ft³/ac*
Loblolly pine						
(1) Burn-only	40.1	5.8	4.2	737	144	3,102
(2) Burn-disk	40.2	5.9	4.2	696	136	2,894
(3) Burn-disk-bed	39.4	5.6	3.9	669	122	2,568
Means	39.9	5.8	4.1	701	134	2,855
			Prob > F-value			
Treatments (trt)	.806	.478	.392	.256	.035	.068
Linear contrasts						
Trt 1 vs. trt 2+3	.803	.763	.426	.139	.033	.058
Trt 2 vs. trt 3	.560	.257	.271	.488	.073	.125
Error mean square	3.056	.060	.148	2,717.382	80.375	66,973.974
Slash pine						
(1) Burn-only	45.9	6.2	5.4	635	137	3,402
(2) Burn-disk	45.8	6.3	5.7	556	124	3,067
(3) Burn-disk-bed	45.6	6.1	5.1	585	119	2,912
Means	45.7	6.2	5.4	592	127	3,127
		Prob > F-value				
Treatments (trt)	.959	.682	.723	.549	.029	.017
Linear contrasts						
Trt 1 vs. trt 2+3	.838	.927	1.000	.325	.012	.008
Trt 2 vs. trt 3	.851	.404	.440	.687	.356	.247
Error mean square	2.493	.202	1.050	9,718.988	50.174	29,138.913
Combined species analysis						
			Prob > F-value			
Species	< .001	.012	.001	.004	.060	.020
Treatments (trt)	.837	.402	.478	.246	.001	.004
Linear contrasts						
Trt 1 vs. trt 2+3	.770	.948	.767	.099	.001	.003
Trt 2 vs. trt 3	.610	.185	.245	.977	.048	.078
Species times trt interaction	.959	.956	.899	.764	.615	.787
Error mean square	3.549	.131	.591	6,123.717	75.993	64,910.527

[a] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

Table P-For study 1, comparison of total height between the first and second rotations for 15-year-old loblolly and slash pine

Rotations and site preparation treatments[a]	Total height	
	Loblolly pine	Slash pine
	······· Feet ·········	
First rotation		
(1) Burn-only	50.6	48.7
(2) Burn-disk	53.4	48.6
(3) Burn-disk-bed	52.6	50.4
Second rotation		
(1) Burn-only	40.1	45.9
(2) Burn-disk	40.2	45.8
(3) Burn-disk-bed	39.4	45.5
	Prob > F-value	
Rotation	< .001	.007
Main effect error mean square	3.034	1.690
Treatment	.217	.673
Rotation times treatment interactions	.184	.459
Subplot effect error mean square	2.419	3.126

[a] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

Data Analysis

For study 1, treatment and species comparisons for per pine d.b.h., height, and volume, as well as stand stocking, basal area, and yield after the second rotation were made by analyses of variance using randomized complete block design models (a = 0.05) (Steel and Torrie 1980). Fifteenth year height comparisons were made between the two rotations by analysis of variance using a split-plot-in-time model with rotation as the main plot effect and site preparation as the subplot effect (Haywood and Tiarks 1995). For study 2, pine height results were analyzed by a split-plot randomized complete block design model with site preparation as the main plot and P and N fertilization as the subplot effects (a = 0.05) (Steel and Torrie 1980). We also report probabilities > F-value (Prob) of over 5 percent but < 15 percent because natural variation is always an issue in field studies regardless of the care taken to reduce it (Peterman 1990, Thomas 1997) and this added information may be of interest to the reader.

RESULTS

In study 1, 15-year-old loblolly pine basal area per acre was significantly greater on the burned-only plots (144 ft^2 per acre) than on the two mechanical treatments (129 ft^2 per acre) (table 1). Yield was greater on the burned-only plots (3,102 ft^3 per acre) than on the two mechanical treatments (2,731 ft^3 per acre) at Prob = 0.06. Bedding as a secondary treatment following flat disking further reduced loblolly pine basal area (122 ft^2 per acre) and volume (2,568 ft^3 per acre) compared to flat disking alone (136 ft^2 per acre and 2,894 ft^3 per acre) at Prob = 0.07 and 0.12, respectively.

Fifteen-year-old slash pine basal area and yield were both significantly greater on the burned-only plots (137 ft^2 per acre and 3,402 ft^3 per acre) than on the two mechanical treatments (122 ft^2 per acre and 2,989 ft^3 per acre) (table 1). There were no important differences in slash pine growth-and-yield between the two mechanical treatments.

When the two pine species were compared, the 15-year-old slash pine had significantly greater total height, d.b.h., and volume per tree than loblolly pine after two rotations (table 1). There were significantly fewer slash pine than loblolly pine, but the slash pine stands (3,127 ft^3 per acre) still had greater yields than the loblolly pine stands (2,855 ft^3 per acre).

When site treatments were compared with both pine species in the analyses, basal area and yield were both significantly greater on the burned-only plots (141 ft^2 per acre and 3,252 ft^3 per acre) than on the two mechanical treatments (125 ft^2 per acre and 2,860 ft^3 per acre) (table 1). Bedding after flat disking significantly reduced pine basal area (121 ft^2 per acre) compared to flat disking alone (130 ft^2 per acre). It also resulted in less yield (2,740 ft^3 per acre) when compared to flat disking (2,981 ft^3 per acre) at Prob =

Table 3-For study 2, comparison of total height of 15-year-old slash pine after the second rotation

Site preparation treatments	P	N[a]	Total height
	-- *Lb/ac* --		*Feet*
(1) Burn-only[b]	0	0	50.0
	0	50	48.6
	88	0	53.3
	88	50	54.2
(2) Burn-disk[b]	0	0	46.2
	0	50	47.3
	88	0	51.9
	88	50	48.8
(3) Burn-bed'	0	0	47.3
	0	50	44.1
	88	0	48.8
	88	50	49.4
			Prob > F-value
Treatment			.284
Main effect error mean square			46.053
Phosphorus			< .001
Nitrogen			.278
Phosphorus times nitrogen interaction			.681
Treatment times phosphorus interaction			.833
Treatment times nitrogen interaction			.834
Subplot error mean square			7.127

[a] Lime was applied at 1,000 lb per acre in the first rotation only. The N fertilizer treatment was applied only in the second rotation at the beginning of the eighth growing season.

[b] The study area was broadcast burned before planting the second rotation of pines, but the mechanical site treatments were not reapplied at the beginning of the second rotation.

0.08. There were no significant species-by-treatment interactions.

Both pine species were significantly taller in the first rotation (table 2), as reported at younger ages by Haywood (1994) and Haywood and Tiarks (1995). Loblolly and slash pines averaged 52 and 49 ft tall in the first rotation and 40 and 46 ft tall in the second, respectively. There were no rotation-by-treatment interactions.

In study 2, P fertilization significantly increased slash pine total height. The fertilized 15-year-old slash pines averaged 51 ft and the unfertilized pines averaged 47 ft (table 3). Nitrogen fertilization and mechanical site preparation did not significantly influence slash pine total height. There were no significant interactions.

DISCUSSION

At study 1, mechanical site preparation in the early 1960s adversely affected loblolly and slash pine basal area and yields 38 years later, and planting on old beds also adversely affected the productivity of loblolly pine but not slash pine. At study 2, slash pine was also not adversely affected by planting on old beds.

Interestingly, loblolly pine is more responsive to planting on newly created beds than slash pine on silt loam soils in the west Gulf Coastal Plain (Haywood and others 1990). Perhaps as the beds become smaller due to erosion of the crown and filling of the furrow, loblolly pine no longer enjoys the benefit of better drained soil for root growth compared to flat areas, although the negative effects of bedding on surface drainage remain (Haywood 1995). These effects may limit loblolly pine growth more than slash pine growth (Haywood and others 1990).

Also, where pine roots tended to concentrate in the beds, the trees might have drawn down nutrient reserves during the first rotation. On silt loam soils in the west Gulf Coastal Plain, loblolly pine is more sensitive to P deficiencies than slash pine (Tiarks and Shoulders 1982). A differential reduction in nutrients in the beds versus the flat areas may partly explain why loblolly pine did less well on old beds than slash pine.

Loblolly pine was somewhat more productive than slash pine at the end of the first rotation at study 1 (Haywood 1983), but the opposite was true in the second rotation (table 1). Indeed, we report a general decline in height growth for both pine species in the second rotation at study 1. Because loblolly pine needs more P on poorly drained soils than slash pine (Tiarks and Shoulders 1982), and as P is lost in harvesting and burning, a more severe growth decline occurs for loblolly pine than for slash pine (Haywood and Tiarks 1995). Planting on old beds worsens this.

Fertilization is a way to improve growth or to overcome nutrition deficiencies on Paleudult soils (Haywood and Tiarks 1990, Jokela and others 2000) and at study 2, P fertilization significantly increased slash pine yields in the first rotation (Tiarks 1983) as well as total height in the second rotation (table 3). Based on these results, we recommend P be applied to Paleudult soils at the beginning or early in the rotation on intensively managed southern pine plantation sites. Bedding is not recommended on somewhat poorly drained and better drained sites because it is usually ineffective and can create long-term management problems (Derr and Mann 1977, Haywood 1995, Haywood and others 1990). Where old beds are found, they should be either leveled or recreated and P fertilizer applied before planting loblolly pine.

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