Reprinted from the May 1985 *Southern Journal of Applied Forestry*, Vol. 9 No. 2

Site Preparation and Phosphorus Application Alter Early Growth Of Loblolly Pine

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ABSTRACT. Loblolly pine (Pinus taeda) *was grown on three sites with a series of site preparation treatments and differential applications of herbicide to determine the impact of site preparation on early growth and nutrition of trees without the interaction of woody competition. The study sites were poorly, somewhat poorly, and moderately well-drained soils of the lower Atlantic Coastal Plain in South Carolina. One year after planting, treatments of no fertilizer, phosphorus, potassium, and phosphorus plus potassium were applied to each site preparation plot. Five years after planting, the tallest pines (12 to 15 feet) were on plots that had received the most expensive and most intensive treatment (bedding, phosphorus fertilizer, and a small amount of herbicide), but growth was good (10 to 13 feet) on plots that had received the least expensive and least intensive treatment as well (preparation with hand tools, no fertilizer, and a larger amount of herbicide). Growth was poorest (7 to 10 feet) on plots that had been rootraked and had received a medium amount of herbicide. Foliar nutrient data also indicated that rootraking was site degrading.*

We report here the effects on loblolly pine growth of mechanical site preparation, herbicide application, and fertilizer treatments for three drainage classes on sites in the lower Coastal Plain in South Carolina. Most mechanical site preparation causes changes in both soil and competing vegetation. However, the design of past site preparation studies does not allow for differentiation of responses to vegetation or soil changes, or some combination of the two. In this study, plots were brought to approximately the same low level of woody competition by applying herbicide. The effects of site preparation on soil and on tree growth are thus free of the confounding effects of woody competition. This approach results in a better understanding of the response of pines to various methods of mechanical site preparation and should help managers determine the most effective treatment to be used on an operational basis.

METHODS

Study Areas

Three study areas were established on the Francis Marion National Forest in South Carolina. The sites had never been under cultivation and before harvest and replanting supported merchantable stands of 50- to 70-year-old loblolly and longleaf pines (*P. palustris*) with dense hardwood understories. The areas represent three soil drainage classes common to the lower Coastal Plain: (1) a poorly drained Bethera soil (Typic Paleaquult, clayey mixed thermic); (2) a somewhat poorly drained Wahee soil (Aeric Ochraquult, clayey mixed thermic); and (3) a moderately well-drained Goldsboro soil (Aquic Paleudult, fine-loamy siliceous thermic).

These soils are acid, have imperfect internal drainage, and are low in fertility—at least by agronomic standards. Their A horizons are approximately 6 in thick, and most of their nutrients and organic matter are within 4 in of the soil surface (Table 1). Such low fertility makes these sites ideal for the study of site preparation effects, because a removal from or a concentration of nutrients on the planting site is likely to be reflected in the growth rate.

Experimental Design

Following timber harvest, rectangular 1-acre site preparation plots were established on each study area in a randomized block design with two replications. Each plot had four subplots randomly assigned treatments of no fertilizer, phosphorus, potassium, or phosphorus plus potassium fertilizer. Each subplot was divided into two ⅛-acre sub-subplots, which were hand planted to seed orchard stock of inherently rapid growth rate or to nursery-run stock of average growth rate. These sub-subplots contained four rows (spaced 10 ft apart) of 10 planting positions (spaced 6 ft apart) surrounded by a border of one or two rows of isolation trees of nursery-run stock.

Site Preparation Treatments

Six site preparation treatments, ranked in order of increasing costs (costs of the early 1970s as presented in Table 2) were compared:

(1) Fell with chain saws and hand tools all stems of more than 1 in of diameter remaining after timber harvest;
(2) Shear with a K-G blade all stems remaining after harvest;
(3) Shear, bed (excluded from the somewhat poorly drained site);
(4) Shear, rootrake debris into windrows;
(5) Shear, rootrake debris into windrow, disk twice;
(6) Shear, rootrake debris into windrows, bed.

Treatment 1, requiring hand tools only, is the control for comparing changes in soil properties caused by tractors and their implements in the other five treatments. Treatment 1 also is the least expensive of the six treatments. Treatment 2 is similar to Treatment 1 except that a blade mounted on a tractor was used rather than hand tools.

Table 1. Chemical and physical properties of the A1 horizons of study sites 1 year after planting and before application of fertilizer.

Soil property and depth in inches	Poorly drained site	Somewhat poorly drained site	Moderately well- drained site
Total N (*ppm*)			
0–2	2301[1]	2169	1355
2–4	758	677	768
4–6	391	464	528
Available P (*ppm*)			
0–2	15.3	6.0	17.9
2–4	6.0	2.7	9.0
4–6	3.8	1.3	5.5
Exchangeable K (*ppm*)			
0–2	27	31	27
2–4	12	0	16
4–6	8	0	12
Exchangeable Ca (*ppm*)			
0–2	396	608	266
2–4	78	138	44
4–6	40	94	18
Exchangeable Mg (*ppm*)			
0–2	58	76	40
2–4	14	26	11
4–6	10	26	7
Organic matter (%)			
0–2	7.7	11.5	5.4
2–4	3.4	4.2	3.5
4–6	1.8	3.2	2.5
Sand (%)			
0–2	50	49	82
2–4	55	47	83
4–6	50	39	80
Clay (%)			
0–2	13	12	8
2–4	15	17	8
4–6	16	22	11
pH			
0–2	4.4	4.8	4.9
2–4	4.5	4.9	5.0
4–6	4.7	4.9	5.0

[1] Values are averages from plots site prepared with hand tools, hence soils were not distributed by heavy equipment.

Treatment 3 improves drainage and Treatment 4 leaves a cleaner site for pine establishment. Both treatments include one more operation than Treatment 2.

The double disking of Treatment 5 mixed the surface soil and was intended to restore porosity to soils compacted by the tractors. The rootraking of Treatment 6 resulted in better-packed and higher (1 ft versus ½ ft) beds than Treatment 3. Treatments 5 and 6 include one more operation than Treatment 4.

Rootraking in Treatments 4, 5, and 6 was done carefully, so very little of the forest floor or mineral soil was windrowed with the logging debris.

The poorly drained and moderately well-drained study sites received all six site preparation treatments and were prepared and planted on a different schedule from the somewhat poorly drained site:

Operation	*Somewhat poorly drained site*	*Poorly and moderately well-drained sites*
Preharvest burn	Dec. 1968	Apr. 1972
Overstory removal	Jan. 1969	Aug. 1972
Hand tool preparation	Feb. 1969	Sept. 1972
Postharvest burn	Feb. 1970	Oct. 1972
Mechanical preparation	July 1970	Nov. 1972
Herbicide spraying	Sept. 1970	—
Pine planting	Feb. 1971	Feb. 1973
Herbicide spraying	Aug. 1972	June 1973

The somewhat poorly drained site was prepared and planted 2 years before the other two sites, so different weather conditions are undoubtedly responsible for some of the differences reported. However, weather records through 5 years after planting in this study do not appear to contain any departures from normal conditions great enough to significantly affect differences between the earlier and later plantings.

A formulation of the herbicide 2, 4, 5-T (2, 4, 5-trichlorophenoxy acetic acid) containing 4 lb ae/gallon of concentrate was used to control the woody vegetation. Although 2, 4, 5-T is no longer available, this has little effect on the value of this study, for the purpose of the herbicide was to bring plots to the same level of woody competition rather than to evaluate a particular herbicide. Some details of the 2, 4, 5-T treatments will be reported because they might be useful to forest managers using available herbicides.

For the preplanting herbicide treatment, which was applied only on the somewhat poorly drained site, one part 2, 4, 5-T concentrate was mixed with

Table 2. Cost per acre (1970s) of site preparation and fertilization treatments.

Operation	Treatment 1 hand tools	Treatment 2 shear	Treatment 3 shear-bed	Treatment 4 shear-rootrake	Treatment 5 shear-rootrake-disk	Treatment 6 shear-rootrake-bed
	Dollars					
Preharvest burn[1]	1	1	1	1	1	1
Fell nonmerchantables[2]	13	—	—	—	—	—
Postharvest burn[1]	1	1	1	1	1	1
Shear	—	26	26	26	26	26
Bed	—	—	21	—	—	21
Rootrake into windrows	—	—	—	23	23	23
Disk twice[3]	—	—	—	—	16	—
Apply herbicide[4]	28	19	12	16	9	9
Triple superphosphate[5]	10	10	10	10	10	10
Total cost	53	57	71	77	86	91

[1] Costs were estimated on the basis of large burns under similar conditions.
[2] Felling trees with hand tools required 3.5 hours per acre at $3.59 per hour for labor.
[3] Disking twice required 1.5 hours per acre, operating cost of tractor was $6 per hour, and operator was paid $4.45 per hour.
[4] Dollar values are higher here than in the last column of Table 3 because cost of the preplanting herbicide treatment on the somewhat poorly drained site has been averaged in also.
[5] Cost of fertilizer only; labor costs not recorded.

9 parts water and applied with a backpack mistblower at 3 gallons per acre to all plots. The concentrate cost $7.55 per gallon, labor received $3.59 per hour, and 0.7 acre was treated per hour, resulting in a treatment cost of $4.78 per acre.

For the postplanting treatments, woody vegetation was cut with axes and machetes and the stumps were sprayed with a mixture of 1 part concentrate to 39 parts water. Generally, the more intensive the mechanical site preparation treatment had been, the less woody vegetation remained, and the fewer gallons of herbicide had to be sprayed (Table 3). Fewer gallons were sprayed after planting on the somewhat poorly drained site because it had also received the preplanting mist blowing.

Our plans called for spraying or mowing the competing woody plants and herbs as necessary throughout the first 5 years after planting. All measurement trees appeared to remain free-to-grow after the first postplanting spraying, however, so no further competition control measures were taken.

Fertilizer Treatments

Analyses of soil and pine foliar samples collected during the first growing season on the somewhat poorly drained site indicated possible phosphorus (P) and potassium (K) deficiencies. Consequently, within each plot on this site, the four subplots were randomly assigned no fertilizer, P at the rate of 50 lb/a applied as triple superphosphate (46% P_2O_5), K at the rate of 100 lb/a applied as muriate of potash (60% K_2O), and the combination of P and K. These granular fertilizers were broadcast by hand in early May of the second growing season.

The same fertilizers were applied at the same rates on the other two sites so that statistical comparisons of fertilizer effects among all three study sites would

Table 3. Amount of mixture[1], time, and costs[2] per acre of the 2, 4, 5-T treatments applied after planting.

	Amount applied in gallons			Application time in hours			Cost in dollars			
	Site			Site			Site			
	Poorly drained	Somewhat poorly drained	Moderately well-drained	Poorly drained	Somewhat poorly drained	Moderately well-drained	Poorly drained	Somewhat poorly drained	Moderately well-drained	Average of all sites
Hand tools	17.5	5.0	14.0	6.5	9.5	5.0	26.64	35.04	20.59	27.42
Shear	7.0	4.0	11.0	3.0	7.0	4.0	12.09	25.89	16.44	18.14
Shear-bed	10.5	—	3.5	4.5	—	1.5	18.14	—	6.04	12.09
Shear-rootrake	10.0	2.0	8.5	4.0	3.5	4.0	16.25	12.94	15.96	15.05
Shear-rootrake-disk	3.0	2.5	4.5	1.0	3.5	2.0	4.16	13.03	8.03	8.41
Shear-rootrake-bed	4.0	1.5	4.0	2.0	2.0	2.0	7.94	7.46	7.94	7.78

[1] Mixture consisted of 1 part 2, 4, 5-T concentrate to 39 parts water.
[2] Costs were based on $7.55 per gallon for the 2, 4, 5-T concentrate and $3.59 per hour for labor.

be possible. The fertilizers were applied on these two sites in late April of the second growing season.

Data Collection and Analyses

At the end of the first growing season and before fertilizer application, 10 soil cores were taken from each sub-subplot (from the bedded portions of the bedded sub-subplots) and divided into segments of 0–2, 2–4, 4–6 in in depth. Segments from the same depth were composited by sub-subplots, dried, and crushed to pass through a 10-mesh screen. Total nitrogen (N) was determined by Kjeldahl analysis; available P was determined with Bray P-2 extractant; and exchangeable bases were extracted with normal ammonium acetate. Soil pH was measured with a glass electrode in a 1:1 soil-water mixture; mechanical analysis was accomplished by the Bouyoucos hydrometer method; and organic matter was determined by wet digestion.

At the end of each of the first five growing seasons, foliage from at least 10 trees on each subplot was collected, dried for 24 hours at 158°F, and ground to pass through a 40-mesh screen. Nitrogen content was determined by Kjeldahl analysis. For analysis of the other macronutrients, 1 gram of plant material was dry ashed at 842°F for 2 hours and taken up in 0.3-normal nitric acid. Phosphorus was determined by the molybdovanadate procedure, and K, calcium (Ca), magnesium (Mg), and sodium (Na) by atomic absorption.

Tree heights and survival were measured soon after planting and annually thereafter for 5 years.

Statistical Analyses

Data for each study area were subjected to analysis of variance for a completely randomized design with split-split plots. Differences within site preparation, fertilization, and genotype treatments were tested for statistical significance at the 0.05 level by Duncan's multiple range test.

Variables tested were height and percent survival of trees; total N, available P, exchangeable bases, and organic matter content of soils; and major nutrients of pine foliage.

Table 4. Effects of site preparation treatments on selected soil properties on three sites 1 year after planting.

	Poorly drained site[1]			Somewhat poorly drained site			Moderately well-drained site		
	Depth of soil in inches			Depth of soil in inches			Depth of soil in inches		
Treatments	0–2	2–4	4–6	0–2	2–4	4–6	0–2	2–4	4–6
					Total N (ppm)				
1. Hand tools	2301 A	758 A	391 A	2169 A	678 C	464 B	1355 A	768 A	528 ABC
2. Shear	2082 AB	910 A	563 A	2244 A	859 BC	527 B	674 B	373 B	247
3. Shear-bed	1626 AB	1481 A	1109 A	—	—	—	629 B	668 A	599 A
4. Shear-rootrake	1626 AB	724 A	340 A	2364 A	936 BC	636 B	1254 A	729 A	489 BC
5. Shear-rootrake-disk	1491 AB	1153 A	787 A	1612 AB	1121 B	652 B	509 B	542 AB	472 C
6. Shear-Rootrake-bed	820 B	952 A	864 A	1235 B	1594 A	1253 A	520 B	621 AB	565 AB
					Available P (ppm)				
1. Hand tools	15.3 A	6.0 AB	3.8 B	6.0 A	2.7 AB	1.3 B	17.9 A	9.0 A	5.5 A
2. Shear	11.6 B	5.5 B	3.5 B	3.8 A	1.6 B	1.1 B	9.0 B	5.2 A	3.9 A
3. Shear-bed	6.9 CD	5.9 B	4.4 B	—	—	—	8.1 B	8.8 A	7.2 A
4. Shear-rootrake	10.3 BC	5.8 B	3.7 B	4.7 A	2.3 AB	1.6 B	11.4 B	6.3 A	4.3 A
5. Shear-rootrake-disk	6.9 CD	6.4 AB	4.8 B	2.9 A	2.5 AB	2.3 AB	6.6 B	6.0 A	4.1 A
6. Shear-rootrake-bed	6.4 D	7.7 A	7.3 A	3.0 A	4.1 A	3.2 A	7.4 B	7.2 A	6.8 A
					Exchangeable Ca (ppm)				
1. Hand tools	132 A	78 B	40 A	608 AB	139 B	94 B	266 AB	44 B	18 D
2. Shear	142 A	166 AB	152 A	558 AB	177 B	102 B	280 A	121 A	56 C
3. Shear-bed	134 A	370 A	286 A	—	—	—	168 AB	184 A	128 A
4. Shear-rootrake	98 A	85 B	52 A	768 A	272 AB	214 AB	158 AB	50 B	16 D
5. Shear-rootrake-disk	130 A	287 AB	240 A	496 AB	311 AB	216 AB	192 AB	159 A	84 BC
6. Shear-rootrake-bed	70 A	190 AB	178 A	356 B	492 A	314 A	128 B	140 A	116 AB
					Organic matter (% by weight)				
1. Hand tools	7.7 A	3.4 A	1.8 C	11.5 AB	4.2 B	3.2 B	5.4 A	3.5 AB	2.5 AB
2. Shear	7.0 A	3.9 A	2.1 BC	11.5 AB	5.6 AB	4.1 B	3.5 B	2.4 B	1.3 B
3. Shear-bed	5.1 AB	5.2 A	4.1 AB	—	—	—	3.2 B	3.1 AB	2.7 A
4. Shear-rootrake	6.1 AB	3.3 A	1.7 C	13.0 A	5.8 AB	4.8 AB	6.0 A	4.2 A	2.6 A
5. Shear-rootrake-disk	5.8 AB	4.4 A	2.3 BC	7.8 C	6.1 AB	4.2 B	2.7 B	2.5 B	1.8 B
6. Shear-rootrake-bed	4.0 B	4.7 A	4.5 A	6.7 BC	9.4 A	7.8 A	3.1 B	3.6 AB	3.1 A

[1] Within each site-depth-nutrient category, values followed by the same letter do not differ significantly at the 0.05 level.

RESULTS AND DISCUSSION

Soil Properties

Results of the analyses of soil samples indicated some general trends (Table 4). At the 0–2 in soil depth on all sites, total N, available P, and percent organic matter generally were lower for the five treatments requiring tractor power than for the hand tool treatment. Exchangeable Ca levels tended to be reduced as site preparation intensity increased. Mixing soil from the less fertile 2–6 in depth with the surface 2 in by tractor operation is probably responsible for these results.

At the 4–6 in depth, amounts of N, P, Ca, and organic matter generally were higher for the bedded treatments than for the other four treatments across all three sites. The cause was probably the action of the bedding harrow, which concentrates topsoil into the beds and mixes the fertile surface 2 in of this topsoil into the 4–6 in layer.

At the 2–4 in depth of the bedded treatments, P was generally higher than in the 0–2 and 4–6 in depths, again probably due to the action of the bedding harrow. On the four nonbedded treatments, soil properties of the 2–4 in depth almost always were intermediate between those of the 0–2 and the 4–6 in depths, much as found on nonprepared sites.

Unexpectedly, the surface 6 in of the sheared and rootraked plots on the two better drained sites had a significantly higher percentage of organic matter than some of the other treatment plots. Possibly this percentage was higher for these plots before treatment than for other plots, for rootraking organic debris from an area should not increase the organic matter in its mineral soil.

Foliar Nutrients

By the end of the first growing season (before fertilizer application), the shear-rootrake and shear-rootrake-disk treatment plots had the lowest percentages of foliar N, P, and Ca (Table 5). These treatments resulted in significantly lower amounts than either the hand-tool or one of the bedded treatments for: foliar N on all three sites, foliar P on somewhat poorly and moderately well-drained sites, and foliar Ca on the moderately well-drained site.

Analyses of foliage at the end of the second through fifth growing seasons indicated that the application of P at the beginning of the second growing season corrected any deficiency in that nutrient through the fifth growing season. These analyses also showed differences among site preparation treatments in amounts of N, P, and Ca that were similar to, but smaller than, the differences found at the end of the first growing season. Therefore, the results of these later analyses will not be presented.

Percentages of K and Mg were not affected by site preparation treatments on any of the sites on any of the five sampling dates. At the end of the first growing season, K averaged 0.542, 0.440, and 0.459% dry weight of foliage for the moderately well-drained, the somewhat poorly, and the poorly drained sites, respectively, and Mg averaged 0.125, 0.130, and 0.107%, respectively.

Survival and Growth

Five years after planting, survival was high and varied little among treatments or sites. Survival differences among some treaments and treatment interactions were statistically significant, but none was of practical importance. Heights did vary somewhat more as shown in the table on page 108:

Table 5. Effects of site preparation treatments on amount of nutrients in pine foliage 1 year after planting and before application of the fertilizer, ranked by increasing cost

Treatment	Poorly drained site	Somewhat poorly drained site	Moderately well- drained site
	Percent dry weight of foliage		
		N	
1. Hand tools	1.71 A[1]	1.12 AB	1.80 A
2. Shear	1.67 A	1.04 ABC	1.68 BC
3. Shear-bed	1.80 A	—	1.73 AB
4. Shear-rootrake	1.42 B	0.91 BC	1.28 D
5. Shear-rootrake-disk	1.39 B	0.88 C	1.61 C
6. Shear-rootrake-bed	1.81 A	1.25 A	1.72 AB
		P	
1. Hand tools	0.090 A	0.114 A	0.116 A
2. Shear	0.086 A	0.100 AB	0.108 AB
3. Shear-bed	0.073 A	—	0.106 B
4. Shear-rootrake	0.070 A	0.095 AB	0.082 C
5. Shear-rootrake-disk	0.058 A	0.086 B	0.089 C
6. Shear-rootrake-bed	0.072 A	0.112 A	0.101 B
		Ca	
1. Hand tools	0.341 A	0.291 A	0.314 A
2. Shear	0.332 A	0.272 A	0.302 A
3. Shear-bed	0.324 A	—	0.321 A
4. Shear-rootrake	0.245 A	0.252 A	0.222 B
5. Shear-rootrake-disk	0.232 A	0.234 A	0.299 A
6. Shear-rootrake-bed	0.381 A	0.309 A	0.338 A

[1] Within each site-nutrient category, values followed by the same letter do not differ significantly at the 0.05 level.

Treatment of Site	*Percent survival*	*Height in feet*
Hand tools	88	11.5
Shear	90	11.3
Shear-Bed	93	13.4
Shear-rootrake	91	8.7
Shear-rootrake-disk	93	10.2
Shear-rootrake-bed	94	14.3
No fertilizer	92	11.0
Phosphorus	92	11.7
Potassium	91	11.2
Phosphorus plus potassium	91	11.9
Nursery-run stock	91	11.0
Seed-orchard stock	91	11.9
Poorly drained site	91	10.0
Somewhat poorly drained site	91	12.0
Moderately well-drained site	92	12.5

At planting, the seed-orchard stock averaged 0.06-ft taller than the nursery-run stock—a small but statistically significant difference. By age 5, the seed-orchard stock had increased its height advantage to 0.9 ft, and the difference was still significant.

Trees fertilized with P were significantly taller by 1 ft than unfertilized trees on the somewhat poorly drained site. No other differences in fertilizer treatments were statistically significant, but the results suggested that P increased growth on all three sites and that K did not. Therefore, data for all treatments with P were combined, as were all treatments with P (Figure 1).

Heights differed little between the hand tool and the shear treatment, but the shear-rootrake treatment reduced growth 2 to 4 ft. Following shear-rootraking with disking resulted in heights similar to those of the shear treatment on the moderately well-drained site but appeared to further reduce growth on the other two sites. Disking plus fertilization appeared to recover the height lost by rootraking on the moderately well-drained and the somewhat poorly drained sites but not on the poorly drained site. On all three sites, the bedding treatments resulted in the best growth—a 2- to 4-ft height advantage over the hand-tool treatment.

Heights did not differ significantly among treatment interactions, except for the interaction of fertilization and genotype on the poorly drained site. There, seed-orchard stock fertilized with P averaged 1.6 ft taller than did nonfertilized nursery-run stock.

Growth-Nutrient Relationships

Bedded Plots.—The two bedding treatments ranked first and second in the amounts of N, P, Ca, and organic matter at 4–6 in soil depths on the somewhat poorly and moderately well-drained sites (Table 4). On the poorly drained site, the bedding treatments ranked first and second in the amounts of N and organic matter and first and third in the amounts of P and Ca in their 4–6 in soil depths. Growth on beds tended to be negatively correlated with nutrient amounts at the 0–2 and 2–4 in depths, because bedding tends to invert the top 8 in of soil, burying the fertile topsoil and bringing the less fertile subsoil to the surface.

Trees on beds tended to have higher percentages of N and Ca in their foliage, but not significantly higher than trees on the hand tool-prepared plots. Foliar P for beds was lower—significantly so on the moderately well-drained site—than for hand tool-prepared plots. Perhaps faster growth on the beds tended to dilute nutrient concentrations in the pine foliage.

Haines and Pritchett (1965) found that better pine growth on beds was correlated with greater concentrations of organic matter and nutrients in the soil. McKee and Shoulders (1970) found that the higher the bed and the greater the distance from the top of the bed to the water table, the better the pine growth. Probably the better growth on beds in this study is due to a combination of higher amounts of nutrients and organic matter in the soil plus improved soil aeration.

Rootraked plots.—The shear-rootrake treatment ranked low in pine heights (Figure 1) and in foliar nutrients (Table 5), but appeared to differ little from the hand tool-prepared treatment in soil nutrients (Table 4). Possibly because of repeated soil compaction by tractors during harvesting, shearing, and windrowing, pine seedlings were not able to take up nutrients from the soil of shear-rootrake plots as well as from the other plots.

Disked Plots.—The shear-rootrake-disk treatment resulted in taller pines (Figure 1) and higher percentages of foliar nutrients (Table 5) than the shear-rootrake treatment on the moderately well-drained site but not on the other two sites. Results of the soil analyses (Table 4) revealed nothing that correlated with these growth and foliar data, although it should be noted that the soil analyses did not measure N mineralization, which probably was increased by disking. Another possible explanation is that disking improved growth on the moderately well-drained site by reducing the soil compaction caused by tractor operations but decreased growth on the more poorly drained sites by puddling the surface soil.

CONCLUSIONS AND RECOMMENDATIONS

Percent survival of the planted loblolly pines has remained high through 5 years after planting and has been little affected by site preparation treatment, fertilizer treatment, planting stock, or site.

The seed orchard stock averaged almost 1 ft taller than the nursery-run stock after 5 years. This growth

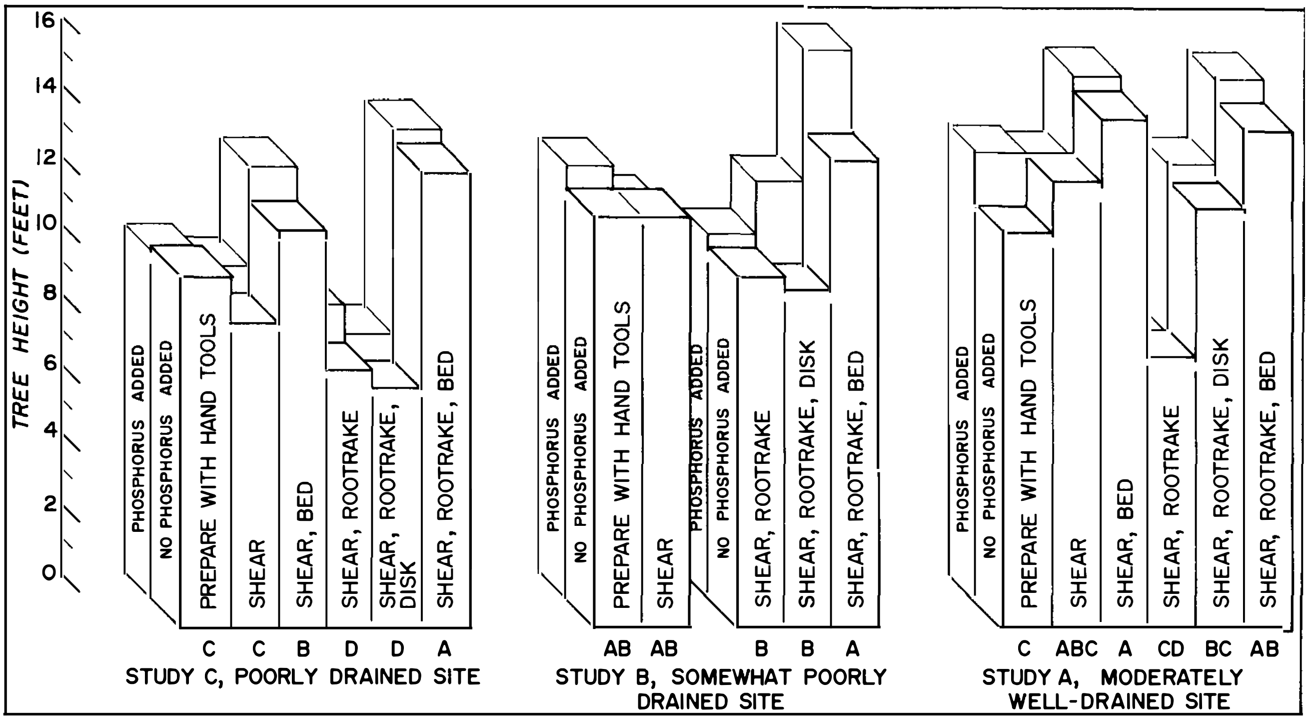

Figure 1. Compared with site preparation by hand tools and with no fertilizer, tree heights 5 years after planting tended to be unchanged by shearing, decreased by rootraking, and increased by phosphorus application, bedding, or improved drainage. Within each site, with fertilizer treatments combined, site preparation treatments designated by the same letter do not differ significantly at the 0.05 level.

advantage is about what would be expected, considering that the seed orchards had not yet been rogued of their slower-growing families at the time seed was collected for the planting stock for these studies.

Bedding increased growth more than phosphate application did, but bedding cost more than fertilization. The most expensive treatment, Treatment 6 with fertilizer, resulted in the fastest growth. However, the most inexpensive treatment, Treatment 1 without fertilizer, resulted in growth that probably would be acceptable to most forest managers.

It should be noted that herbicide treatments probably increased survival and overall growth by eliminating woody sprout competition. The increase was most on the less intensively prepared plots, for those received the most herbicide. Thus, a comparison of growth on the $91 intensive mechanical-low herbicide treatment with growth on the $51 hand tool-high herbicide treatment is valid. It would not be valid to ascribe growth or survival advantages to increasing intensities of mechanical treatments while ignoring herbicide effects.

Five years is too early in the rotation to predict which of the various treatments will be the most cost effective. The early growth advantage from the concentration of nutrients by bedding may not last through the rotation. Results with slash pine (*P. elliottii*) suggest that the height advantage of bedding diminishes after age 17 (Wilhite and Jones 1981). The growth data and the foliar nutrient data from this study strongly indicate that rootraking is site degrading. Also, treatments involving tractors, because they mix the fertile surface soil to greater depths and compact the soil, might eventually prove to be site degrading.

These early results suggest that forest managers eliminate windrowing of logging debris whenever possible and minimize site preparation operations requiring tractors. Excellent discussions on the causes, amelioration, and avoidance of forest site degradation during harvesting and site preparation operations can be found in Tippin (1978).

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