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PINE GROWTH AND PLANT COMMUNITY RESPONSE TO CHEMICAL vs. MECHANICAL SITE PREPARATION FOR ESTABLISHING LOBLOLLY AND SLASH PINE[1]

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Abstract—Chemical and mechanical site preparation methods were studied for establishing loblolly (*Pinus taeda* L) rind slash (*P. elliottii* var. *elliottii* Engelm.) pine following both integrated fuelwood-pulpwood harvesting and conventional whole-tree harvesting of pines and hardwoods In southern Alabama's Middle Coastal Plain. Revegetation was assessed in year 1, planted pines were measured afler years 2 and 5, and soil bulk density was examined. Site preparation treatments generally shifted the herbaceous component from grasses to forbs and blackberry (*Rubus* spp.). Afler integrated harvesting, mechanical and herbicide treatments performed equally well for loblolly pine, while disking treatments yielded greater fifth-year volumes than herbicide methods with slash pine. On conventional harvested sites, mechanical and chemical treatments performed equally well. Pine volumes were 10-fold greater within-windrows than that between windrows. A single disking treatment returned topsails to preharvest bulk densities.

INTRODUCTION

Over the past 3G years, a wide array of mechanical and chemical site preparation techniques have been developed for estabiishing loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* var. *elliottii* Engelm.) after harvesting short-wood and more recently, whole-trees. With the increased utilization of hardwoods for pulpwood and fuelwood, less woody biomass is left to be dealt with during site preparation. But with intensified harvesting comes increased logging traffic that can result in soil compaction (Gorden and others 1981, Miier and Sirois 1986, Slay and others 1987) and can hinder subsequent tree growth (Foil and Ralston 1967, Hatchell 1970, Lockaby and Vidrine 1984, Simmons and Ezell 1983, Tuttle and others 1988). Thus, there is an apparent need to redesign site preparation treatments to de-emphasize debris removal and enhance soil improvement treatments, while controlling competition (Morris and Lowery 1988).

This research is the site preparation phase of a multi-disciplinary investigation of harvesting and site preparation combinations and their efficiency and effects on subsequent stand development Prior reports have been made on the harvesting aspects (Franchi and others 1984, Miller and others 1985a, Miller and others 1987, Stokes and others 1984, Stokes and Watson 1986,Watson and others 1986,Watson and others 1987). The objective of this part of the investigation was to study the growth of loblolly and slash pine established following both integrated and conventional whole-tree harvesting In combination with several options of mechanical and chemical site preparation. We compared site preparation treatments that range from no soil amelioration with competition control (herbicides) to intensive soil tillage resulting in woody competition control (rootraking and/or disking) on both integrated and conventionally-harvested plots. Soils were sampled to examine bulk density changes with treatment Early plant community development was documented in the first growing season to assess competitive interferences, vegetative cover establishment, and floristic abundance.

METHODS

For this multidisciplinary investigation, two study areas (blocks) were established within 10 miles of each other on the Middle Coastal Plain in the southernmost part of Alabama (N 30" 15' W 87" 15') (Franchi and others 1984). Soils consisted of an Orangeburg fine sandy loam, 2-5% slope (siliceous, thermic Typic Kandiudult) and a Freemanville fine sandy loam, 2-5% slope (clayey. kaolinitic thermic Plinthic Kandiudult). 'Both series are well-drained upland soils with low fertility and organic matter; they both have fine sandy loam to loam surface horizons to a depth of 14-l 7 in. and clay or sandy clay loam B-horizons. The two soil series have site indices (SI,) of 85-90 for loblolly and slash pine. Topography was similar at both sites with gently sloping ground. Pre-harvest timber stands were 20- and 23-year-old slash pine plantations. Hardwoods greater

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than 4-in. d.b.h. comprised 8.5% of the total green tons per acre (Stokes and Watson, 1986).

Harvesting Treatments

At both locations, three 20 ac harvesting plots (main plots) were established to test three harvesting methods for efficiency, recovery, and site preparation requirements (Watson and others 1986). At one location all three plots were contiguous and were within 1/8 mile of each other at the second location. One plot per block was harvested in a "conventional" manner. The conventional harvesting method removed all pine greater than 6 in. d.b.h. and hardwood sawlogs greater than 12 in. d.b.h. as whole-tree logs for pulpwood. Delimbing and toppings were done by chainsaws in the stand or at the deck after the trees had been processed through an iron gate. The tree length material was then skidded to the deck. This left 34-49% of the biomass of trees greater than 4 in. d.b.h. (measurement limit) on the site (Watson and others 1986).

The remaining two plots per location were harvested with intensive integrated methods leaving oniy 9-22% of the biomass on site (Watson and others 1986). With these integrated methods, pines and hardwoods below the merchantable standards fcr pulpwood (as used with the conventional harvest), were harvested for fuetwood using a one- or two-pass method. With the experimental one-pass method, both pulpwood and fuetwood were harvested simultaneously and separated by the machine operator. With the two-pass method, fuelwood was first removed so that it would not be crushed to the ground as occurs in a conventional system. With this procedure, it was necessary for the feller-buncher to carefully maneuver around the residual merchantable pulpwood trees during the first pass. All fue!wood trees were completeiy chipped on site as well as the tops and limbs of t!!e pu!pwood trees. Even though 8.5% more wood was recovered with the one-pass approach compared to the two-pass approach, no standing trees taller than about 8 ft remained on any integrated harvest blocks due to the heavy skidder traffic. The same rubber-tired feller-bunchers and grapp!e-skidders were used with all three harvesting methods. All harvesting took place in May-June, 1983.

Site Preparation Treatments

All study treatments are presented in Table 1. On each integrated-harvest main plot. site preparation sub-plots were 2.5 ac (165 x 660 ft) in size and 5 ac (330 x 660 ft) in size for check treatments (no site preparation). Disking treatments compared single- versus double-pass disking and whether disked for 1 or 2 years-four combinations. In each main plot, two sub-plots were single disked and two were double-disked in late-summer 1983. All disking treatments were performed with a D-4 double-gang, off-set, site preparation harrow. Double disking amounted to using the same disk-harrow and pulling it at right angles to the first single-disk pass. In 1984, one of the single disked and one of the double disked subplots per main plot were again disked using only a single pass. Tillage was about 6-10 in. deep, where stumps did not hinder disking depth. The two herbicide treatments were applied to sub-plots in 1984 after a year's regrowth (Table 1). Half of each sub-plot was planted to loblolly pine and half to slash pine by random assignment.

Table 1 .-Site preparation treatments tested on integrated and conventionally harvested sites.

Treatment	Treatment Explanation
Integrated Harvest of Fuelwood and Pulpwood	
Check	No site preparation
Single disk once	Single-disking. September 1983 + 1 year fallow before planting
Double disk once	Single-disking (perpendicular directions), September 1983 + 1 year fallow before planting
Single disk twice	Single-disking, September 1983 and again single-disking, August 1984
Double disk twice	Double-disking, September 1983 and again single-disking, August 1984
Herbicide early summer	1/2 GPA Tordon 101 + 1/2 GPA Garlon 4' applied in June 1984 + burning
Herbicide late summer	1 GPA Roundup + 1/4 GPA Garlon 4' applied in August 1984 + burning
Conventional Whole-tree Harvest of Pines and Hardwoods	
Windrowing: between[2] within	Shearing and rootraking into windrows, summer 1984 + burning
Windrow & double disk[2]	Shearing and rootraking into windrows and double-disking, summer 1984 + burning
Herbicide early summer	1/2 GPA Tordon 101 + 1/2 GPA Garlon 4' applied in June 1984 + burning

'Tordon 101. manufactured by DowElanco, is a mixture of 0.5 lb acid equivalent (ae) picloram and 2 lb ae 2,4-D per gallon in an amine formulation; Garlon 4, manufactured by DowElanco, is 4 lb ae triclopyr in an ester formulation; and Roundup, manufactured by Monsanto, is 3 lb ae glyphosate in an amine formulation.

[2]Pines planted between and within windrows were measured, but vegetation response was assessed only between windrows.

On the two conventionally harvested main plots (20 ac each), half of each (10 ac) was randomly assigned either a mechanical treatment of rootraking into windrows or a herbicide treatment (Table 1). The mechanical-treated parts were halved again (5 ac) to compare disking versus no disking after windrowing and rootraking. Sub-plots were amply large to encompass the inter- and intra-windrow areas. Also, these sub-plots were further halved (2.5 ac) by random assignment and planted to the two pine species,

Operational herbicide treatments were tested-one that was normally applied in early summer and another for late summer-both with ground sprayers mounted on skidders (Table 1). The sprayer used in early summer had a manifold nozzle system and the one used in late summer had a duster nozzle (Miller and others 1985b). Total spray volume was 35 gallons per acre. Taller hardwoods on conventionally harvested areas treated with herbicides were controlled only by the soil activity of the herbicide and the burn.

All herbicide treatments and windrows were prescribed burned in October, 1984. Pines were machine planted in March 1985, using a 9 x 6 ft spacing or 807 trees/ac. Because of the late planting date, slash pine seedlings had started height growth, which combined with severe drought, resulted in poor survival. Also, because of !his study approach the one-year disking treatmens had a full year of regrowth before planting, which could simulate an operational delay.

Measurements

Non-pine vegetation was assessed in November (before frost) of the first growing season using systematically-located sample plots. Three 3 dusters of nested sample plots were positioned 1 00-ft apart across sub-plot centers per pine species. Percent cover was ocularly estimated for herbaceous growth-form components (grasses, forbs, semiwoody, and vines), blackberry (*Rubus* spp.), and gallberry (*Ilex glabra* L.) on 6 square 0.025-ac plots per sub-plot-2 per duster. Hardwood and shrub stems (besides gallberry) were counted by species and measured for total height (if greater than 2 ft) on 3 strip plots per subplot that were O.Ol-ac (6.6 x 66 ft)-1 per cluster.

Planted pines were measured after the second and fifth growing seasons using 0.05-ac circular measurement plots that were systematically located within subplots by pine species. Sample plot centers were randomly selected and positioned relative to the 6 permanent stakes marking vegetation sample plots. With loblolly pine, two pine measurement plots were established per subplot Because of low slash pine survival, 2-6 plots were required to obtain a sufficient number of measurement pines per sub-plot (an average of 44 trees per sub-plot). Ground line diameter (g.l.d.), d.b.h., and total height were recorded for pines. A pine volume index was calculated as g.l.d.^{2} x total height

Soils were sampled before and after harvest and after the first mechanical site preparation treatments. Samples were not collected after the second single disking or after herbicide treatments. Undisturbed cylindrical core samples (8.4 in.') were collected on a 200 x 200 ft grid at O-2 and 2-4 in. depths and resampied at approximately the same locations each time. Samples were oven-dried (105" C) for determining bulk density.

Experimental Design and Data Analysis

To test for differences in harvesting systems, an analysis of variance (ANOVA) of a split block design was used where blocks were locations, the three harvest methods were main plots, and site preparation treatments were sub-plots. Only fifth-year per-acre pine volume data from site preparation treatments common among all three harvest types were used, which were check and "herbicide early." Site preparation treatment differences were not specifically tested here since harvesting difference was the focus. The ANOVA source table was:

Source	df
Block (B)	1
Harvest method (H)	2
B x H	2 Error A
Site Prep Effect (SP)	1
SP x H	2
B x SP	1 }
B x H x SP	2 } Error B
Total	11

Since the harvest effect was not significant, harvest main plots were used as additional replications for a more powerful test of site preparation effects. The integrated and conventional harvest methods were analyzed separately. The ANOVA source table for the integrated methods was:

Source	df
Block (B)	1
Site Prep Effect (SP)	6
B x SP	6 }
Error	14 } Error
Total	27

The source table for the conventional harvested method has only 2 degrees of freedom for treatment. Prearranged orthogonal contrasts were used to examine differences in response to site preparation treatments for both harvest methods. Pine response for loblolly or slash pine were analyzed separately. Percent cover estimates were transformed using the arcsine square-root (Stee! and Torrie 1960) and averages were calculated and transformed back for reporting.

Differences are considered significant at the 0.05-probability level, but probabilities of a Type I error are presented for contrasts to permit the reader to judge significance. Certain other near-significant contrasts are discussed with their probabilities presented. Soil bulk densities were analyzed using paired-t tests between harvested and site prepared soils to pre-harvest conditions. Differences here are considered significant at the 0.10-probability level.

RESULTS AND DISCUSSJON

Site Preparation Influence on Herbaceous Plants and Gallberry

The common plant species that were identified during the first-year following site preparation are listed by component growth-form in Table 2. Table 3 contains the means of cover and woody stem numbers and sizes for both the integrated and conventional harvested sites. Revegetation was rapid; herbaceous cover exceeded 85% on all treated areas except those treated by windrowing with disking after conventional harvest, which averaged 62%. This latter treatment also resulted in considerable woody plant suppression compared to the other treatments on the conventional harvest Complete or near-complete (> 0.2% cover) first-year control of gallberry was achieved by all treatments except single disking once. Gallberry was the pdncipal shrub component in these forests prior to harvesting.

After integrated harvesting, total herbaceous cover was slightly less on treated plots compared to none site prepared checks (93% vs. 99%). less cn mechanical treatments compared to herbicides (91% vs. 99%). and less on single disking twice compared to single disking once (86% vs. 97%) (Table 4). Forbs were significantly decreased by the repeated single disking.

Site preparation treatments reduced grass and gallberry cover and enhanced forb and rubus cover. Mechanical treatments had 39% less grass cover than herbicide applications but 26% more blackberry cover. Grasses have been shown to be severe competitors to planted pines (Miller 1987, Morris and others 1989). Grasses were less (probability of 6%) with Roundup + Garion treatments compared to Tordon + Garion. Tordon + Garion treatments resulted in the greatest grass cover on both the integrated and conventional harvested plots. The semiwoody st. john's wort was completely controlled with the early-summer treatment with Garlon + Tordon.

Table 2.—Common species identified on study area: the first year.

Common Names	Scientific Names
Hardwoods	
black cherry	*Prvnus serotina* Ehrh.
blackgum	*Nyssa sylvatica* Marsh.
dogwood	*Cornus florida* L.
oak, southern red	*Quercus falcata* Michx.
oak, water	*Q. nigra* L.
persimmon	*Diospyros virginiana* L
red maple	*Acer rubrum* L.
sassafras	*Sassafras albidum* Nutt
sweetbay magnolia	*Magnolia virginiana* L.
sweetgum	*Liquidambar styraciflua* L.
Shrubs	
am. beautyberry	*Callicarpa americana* L.
blueberry	*Vaccinium elliottii* Chapman
gallberry	*Ilex glabra* L.
plum	*Prunus* spp.
privet	*Ligustrum sinense* Lour.
southern bayberry	*Myrica cerifera* L
sumac, smooth	*Rhus gtabra* L.
sumac, winged	*R. copallina* L.
yaupon holly	*Ilex vomitoria* Ait.
Semiwoody	
blackberry	*Rubus* spp.
jersey tea	*Ceanothus amaricanus* L.
st john's wort	*Hypericum* spp.
Grasses	
broomsedge	*Andropogon virginicus* L.
panicum grass	*Panicum* spp.
pindand threeawn	*Aristida stricta* Michx.
Forbs	
asters	*Aster* spp.
common ragweed	*Ambrosia artemisiifolia* L
dogfennel	*Eupatorium capillifolium* Lam.
goldenrod	*Solidago* spp.
goldenweed	*Polypremum procumbens* L.
pokeweed	*Phytolacca americana* (Tourn.) L.
poorjoe	*Diodia teres* Walt
three-seeded mercury	*Acatypha* spp.
Fern	
bracken fern	*Pteridium aquilinum* (L.) Kuhn.
Vines	
grape	*Vitis rotundifolia* Michx.
greenbrier	*Smilax* spp.
japanese honeysuckle	*Lonicera japonica* Thumb.
morningglory	*Ipomoea* spp.
trumpet creeper	*Campsis radicans* L.
yellow jasmine	*Gelsemium sempervirens* (L.) Ait.

Table J.-Mean herbaceous cover and woody competition by component in late summer of the first growing season after planting by harvest and site preparation regime.

Treatments	Herbaceous Component Cover: Total herbaceous cover	grass	forbs	semiwoody	vines	rubus	Gallberry cover	Shrubs: stems per acre	Shrubs: sum of heights	Hardwoods: stems per acre	Hardwoods: sum of heights
	percent							no.	ft	no.	ft
Integrated Harvest											
Check	99.3	83.8	3.7	0.2	0.3	1.3	6.7	1071	3188	958	3537
Single disk once	97.1	51.8	14.3	0.7	0.5	20.9	0.8	496	1254	329	1242
Double disk once	93.6	36.1	7.9	0.9	0.2	42.4	0.1	742	2108	196	763
Single disk twice	86.4	34.6	4.7	0.4	0.1	24.0	0.0	125	313	108	338
Double disk twice	85.7	26.1	8.5	0.4	0.5	24.8	0.0	254	725	125	375
Herbicide early	99.3	88.7	9.4	0.0	0.0	0.2	0.0	229	571	242	692
Herbicide late	98.4	63.2	16.2	0.8	0.1	3.2	0.1	204	558	429	1408
Conventional Harvest											
Windrow: between'	92.7	26.1	13.2	1.2	0.4	36.4	0.0	500	1150	580	1940
Windrow • double disk'	61.7	8.2	3.7	0.3	0.1	37.5	0.0	313	900	300	747
Herbicide early	92.7	57.3	14.8	1.8	0.0	7.8	0.2	683	1185	566	1625

[1] Vegetation assessments were only made between windrows.

Table 4.–Orthogonal contrasts showing the probability of a greater F-value (upper value) and contrasted group means (lower value) for herbaceous cover, cover growth-form components, and gallberry cover.

Treatment	Total herbaceous cover	Herbaceous component cover: grass	forbs	semiwoody	vines	rubus	Gallberry cover
Integrated Harvest							
Check/	0.0218	0.0054	0.0431	0.3590	*0.6901*	0.0218	*0.0009*
Treated	99.3/93.4	83.8/50.1	3.7/10.2	o.zo.5	0.3/0.4	1.3/19.3	6.8/0.2
Mechanical/	0.0007	0.0002	0.1703	0.2048	*0.0869*	*0.0001*	0.8626
Chemical	90.7/98.8	37.2/76.0	8.9/12.8	0.6/0.4	0.3/0.1	28.011.7	0.2/0.1
Single disk/	0.4014	0.2583	0.8211	0.8994	*0.6913*	0.2764	*0.5950*
Double disk	91.7/89.7	43.2131.1	9.5/8.2	0.6/0.6	0.3/0.4	22.5133.6	0.4/0.1
Single disk once/	0.0154	0.2680	0.0373	0.5724	0.3178	0.8134	0.2744
Twice	97.1186.4	51.7134.6	14.3/4.7	0.7/0.4	0.5/0.1	20.9/24.0	0.8/0.0
Double disk once/	0.1113	0.4844	0.8886	0.2443	0.4589	*0.2379*	0.7228
Twice	93.6185.7	36.1/26.1	7.9/8.5	0.9/0.4	0.2/0.5	42.4t24.8	0.1/0.0
Herbicide early/	0.6086	0.0565	0.1917	0.0119	0.6653	*0.3948*	0.8365
Late	99.3/98.4	88.7/63.2	9.4/6.2	0.0/0.8	0.0/0.1	0.2/3.2	0.010.1
Conventional Harvest							
Mechanical/	0.3127	0.0830	0.4544	0.3478	*0.0933*	0.1824	0.2585
Chemical	77292.7	17.1/57.3	8.5/14.8	0.7/1.8	0.3/0.0	36.9i7.8	0.0/0.2
Windrow/	0.1422	0.2613	*0.3329*	0.3808	0.1351	*0.9638*	0.9054
Windrow+ Double disk	92 7/617	26.1/8.2	13.2/3.7	1.2/0.3	0.4/0 1	36.4/37.5	0.0/0.0

After conventional harvest, the same general trends were evident of more grass cover with chemical treatments (8% probability level) and more rubus cover with mechanical treatments (18% probability level) as found with integrated harvesting. Gallberry was effectively eliminated during the first-year with windrowing in this test.

Site Preparation Influences on Woody Stems

On integrated harvest plots. number and size of shrub (other than gallberry) and hardwood stems were fewer and shorter *on* the treated plots than check plots (Table 5). In general, mechanical treatments were more effective in controlling hardwood regrowth than herbicide treatments, although sizable reductions in shrubs by herbicides were non-significant Probabilities at the 6% level indicate a consistent reduction in hardwoods with single disking for 2 years compared to single disking once.

On conventionally harvest plots, no significant differences were evident in shrubs and hardwoods due to treatments. As expected, there were more and larger hardwoods following conventional harvest than evident on integrated harvested areas (see means for mechanical/chemical contrasts)

Site Preparation Influences on Pine Growth

For both harvesting methods. seedling stocking (trees/ac) for loblolly pine in the second year ranged from 563 to 875, while survival of the late-planted slash pine ranged from 167 to 607, excluding within-windrow areas (Table 6 and 7). Stocking decreased by a maximum of only 10% for all loblolly treatments from years 2-5. while there was up to a 36% decrease for slash pine. This relatively high mortality is at least partially due to the occurrence of record dry years in the second and third growing seasons (1986 and 1987).

Table 5.–Orthogonal contrasts showing the probability of a greater F-value (upper value) and contrasted group means (lower values) for woody components.

Treatment	Shrubs stems per acre	Shrubs sum of heights	Hardwoods stems per acre	Hardwoods sum of heights
		Integrated Harvest		
Check/ Treated	**0.0010** 1071/342	***0.0010*** 3188/922	**0.0001** 9581240	0.0001 3538/809
Mechanical/ Chemical	0.2353 405/218	0.2768 1098/568	0.0414 190/339	0.1a63 681/1065
Single disk/ Double disk	0.3153 315/496	0.2814 796/1402	0.484 1 219/163	0.5106 7901573
Single disk once/ Twice	0.1432 504/125	0.2264 1279/313	0.0617 329/108	0.0620 1242/338
Double disk once/ Twice	0.0663 7381254	0.0957 20791725	0.5092 200/1 25	0 . 3 9 7 0 7701375
Herbicide early/ Late	0.934 1 2291208	0.9958 5701567	**0.0946** 2421437	0.1186 692/1 438
		Conventional Harvest		
Mechanical I Chemical	0.3010 4071683	0.3026 1025/1 183	0.6821 440/566	0.7776 1344/1625
Windrow I Windrow + Double disk	0.5030 500/3 13	**0.7295** 1150/900	**0.4598** 580/300	0.3581 19401747

Table 6.--Loblolly pine: mean stocking, size, and volume per tree and per acre in the second- and fifth-year by harvest and site preparation regime.

Treatment	Second Year stocking	g.l.d.	height	volume index[1] per tree	volume index[1] per acre	Fifth Year stocking	g.l.d.	d.b.h.	height	volume index[1] per tree	volume index[1] per acre
	no./ac	in.	ft	ft^3	ft^3/ac	no.	in.	in.	ft	ft^3	ft^3/ac
				Integrated	*Harvest*						
Check	563	0.48	2.1	0.004	2.3	517	2.4	1.2	9.3	0.5	241
Single disk once	677	0.56	2.3	0.007	5.0	627	2.5	1.4	10.0	0.5	325
Double disk once	657	0.54	2.2	0.006	3.7	657	2.8	1.6	10.5	0.7	425
Single disk twice	760	0.72	2.3	0.011	8.5	687	3.3	1.9	12.1	1.0	707
Double disk twice	875	0.81	2.6	0.016	13.5	795	3.3	1.9	12.0	1.0	813
Herbicide early	707	0.71	2.6	0.012	8.6	650	3.1	1.7	11.4	0.9	601
Herbicide late	673	0.67	2.3	0.009	6.5	615	3.1	1.7	11.4	0.9	570
				Conventional	*Harvest*						
Windrow: between	663	0.50	1.9	0.004	2.8	607	2.5	1.3	9.3	0.5	303
within	800	1.77	5.6	0.143	114.8	790	5.5	3.9	18.8	4.3	3374
Windrow + double disk	717	3.73	2.2	0.0; 1	7.5	683	3.2	1.9	11.8	0.9	646
Herbicide early	725	0.77	3.0	0.01 7	12.2	673	3.2	2.0	12.6	1.0	678

[1] Volume index = g.l.d.^{2} x ht

Table 7.-Slash pine: mean stocking, size, and volume per tree and per acre in the second- and fifth-year by harvest and site preparation regime.

Treatment	Second Year stocking	g.l.d.	height	volume index[1] per tree	volume index[1] per acre	Fifth Year stocking	g.l.d.	d.b.h.	height	volume index[1] per tree	volume index[1] per acre
	no./ac	in.	ft	ft^3	ft^3/ac	no.	in.	in.	ft	ft^3	ft^3/ac
				Integrated	*Harvest*						
Check	167	0.61	2.1	0.007	1.3	161	2.5	1.4	9.1	0.5	75
Single disk once	401	0.71	2.1	0.009	3.7	317	3.0	1.7	10.2	0.8	230
Double disk once	393	0.70	2.3	0.010	3.6	330	2.9	1.7	10.2	0.7	235
Single disk twice	431	0.93	2.4	0.019	8.0	424	3.4	2.0	11.4	1.1	445
Double disk twice	607	0.95	2.6	0.02 1	11.9	389	3.6	2.1	11.9	1.2	483
Herbicide early	276	0.88	2.6	0.023	8.7	251	3.0	1.8	9.7	0.8	223
Herbicide late	415	0.82	2.2	0.014	3.9	284	3.1	1.9	10.4	0.8	197
				Conventional	*Harvest*						
Windrow: between	5 10	0.73	2.2	0.011	5.1	447	2.8	1.6	9.5	0.6	258
within	800	2.00	5.4	0.166	133.1	800	5.4	3.7	17.9	3.9	3141
Windrow + double disk	480	0.96	2.5	0.021	9.5	447	3.4	2.3	12.1	1.1	473
Herbicide early	304	0.89	2.8	0.02 1	6.7	286	3.1	1.8	10.6	0.8	235

[1] Volume index = g.l.d.^{2} x ht

On the conventionally harvested plots, fifth-year per-acre volumes for loblolly after windrow-disking and after herbiciding were twice as much as that found between windrows without disking (Table 6). For slash pine following conventionai harvest, fifth-year per-acre volume in the windrow-disked treatment was 83% greater than in windrowed-only plots (Table 7). Because of low survival, per-acre volumes of the herbicide treatment were comparable to windrowed-alone. It is unclear whether the high mortality with slash pine on herbicide treated plots was attributable to residual Tordon toxicity, which warrants further testing. For both pine species, volumes per-acre within windrows were over 10 times greater than those between windrows where disking was not used, indicating the usual concentration of site resources in windrows (Morns and others 1983).

After integrated harvesting, stocking and volume were greater on site prepared treatments compared to none-treated checks for both loblolly and slash pine (Table 8). Mechanical treatments produced more slash pine volume and greater stocking in year 5, while there were no differences between mechanical and chemical treatments with loblolly pine. No differences between mechanical and chemical treatments were significant because tree growth for chemical treatments fell between those for 1 and 2 years of disking, resulting in similar means. Single disking for 2 years produced significantly larger volumes for both pines by the fifth year than 1 year of single disking. The same was true for double-disking twice compared to once, except lobloliy pine stocking was also improved. Both herbicide treatments produced similar growth of loblolly pine. For the herbicide treatments with slash pine, the

Table 8.--Orthogonal contrast showing the probability of a greater F-value (upper value) and the contrast group means (lower values) for stocking and volume index per acre for both loblolly and slash pines.

	Loblolly				Slash			
	Second Year		Fifth Year		Second Year		Fifth Year	
Treatment	Stocking	Vol Index	Stocking	Vol Index	Stocking	Vol Index	Stocking	Vol Index
				Integrated Harvest				
Check/	0.0017	0.0396	0.0032	0.0052	0.0211	0.0123	0.0019	0.0041
Treated	563/725	2.3f7.6	5171672	2411574	1671421	1.3/6.6	161/333	75/302
Mechanical/	0.1586	0.9503	0.1220	0.8388	0.1833	0.7448	*0.0194*	0.0225
Chemical	742/690	7.7ff.5	692/633	5681586	4581346	6.8/6.3	365/267	3481210
Single disk/	0.2648	0.4300	0.1184	0.3047	0.3815	0.3072	0.8093	0.7382
Double Disk	719/766	6.8/8.6	657/727	5161619	416/500	5.917.8	371/359	337/359
Single disk once!	0.174:	0.2869	0.3345	0.0121	0.8214	3.1678	0.1053	0.0289
Twice	677/760	5.0/8.5	6271687	325/707	4011431	3.7/8.0	3171424	230/445
Double disk once/	0.0014	0.0060	0.0377	0.011 1	0.1237	0.0043	0.3528	0.0135
Twice	6571875	3.7/13.5	660/795	4251814	3931607	3.6/11.9	3301389	2351483
Herbicide early/	0.5567	0.5100	0.5705	0.8286	0.3079	0.0737	0.6050	0.7773
Late	7071673	8.6/6.5	6501615	6011570	415/276	8.713.9	2841251	2231197
				Conventional Harvest				
Mechanical/	-	0.3551		0.4034		0.0273		0.0801
Chemical	-	16.3/12.5		7641678	-	19.3/5.5	-	566/236
Windrow/		0.3407		0.0823		0.4490		0.0942
Windrow +Double disk	-	14.0/18.5		6091919		18.0/20.5		392/740

Table O.-Soil bulk density (g/cm') at two depths before and after harvest and after initial site preparation by harvest regime.

Depth	Before harvest	After harvest	After single disk	After double disk	After shearing, rootraking & double disk
			Integrated Harvest[1]		
O-2 in.	1.19a	1.55b	1.24a	1.23a	--
2-4 in.	1.39a	1.60b	1.42a	1.38a	
			Conventional Harvest[2]		
O-2 in.	1.17	1.49			1.27
2-4 in.	1.41	1.50			1.36

[1] Different letters within a row indicate significant differences at the 0.10 level of probability as determined by a paired-t test between before harvest soil bulk density and subsequent samplings.
[2] No statistical tests were calculated.

decrease in survival with Tordon + Garlon applications by age 5 resulted in no differences in fifth-year per-acre volumes.

To calculate per-acre volume indices for windrowed plots on the conventional harvested blocks, it was assumed that windrows occupied 10% of the area (from field estimations) and the proportional growth within the windrows was added to the between windrow growth. When the within-windrow growth was included, the windrow-disk plots after conventional harvest had the greatest fifth-year volumes of all harvest-treatment combinations for loblolly (919 ft^3/ac) and for slash pine (740 ft^3/ac) (Table 8). Mechanical site preparation treatments generally performed better for slash pine when compared to chemical treatments, with a probabiiii of 2% for second-year volumes and 8% for fifth-year volumes.

As far as projecting these relative volume increases, short- and long-term research suggests: (a) the maximum growth gains from site preparation occur within the first 8 years, and (b) these gains are maintained until rotational ages of 20 to 25 years on some sites. In support of these hypotheses, Cathey and others (1989) found that yearly incremental gains from mechanical site preparation for loblolly pine establishment on the Piedmont were greatest in years 1-3 and declined to almost similar growth rates by age 6. Haywood and Tiarks (1990) observed the same pattern with both woody and herbaceous control treatments. On the sites reported by Haywood and Tiarks the response has been sustained through age 11. Glover and Zutter (1992) found that after 27 years, the heights and basal area of loblolly pines have not converged following various site preparation treatments on a Hilly Coastal Plain site in Alabama. Clason (1989) reported actual and projected treatment gains from vegeration control that were maintained to ages 20-30. Schmidtling (1987) also reported sustained height increments from cultivation for slash, lobloliy, and longleaf pines up to age 25. There is evidence that these growth gains are probably maintained if nutritional demands are met (Allen and others 1990), which means that gains on some sites will not be maintained. It could be argued also that on some sites nutritional removals associated with integrated harvesting may result in mid-rotation growth declines (Tew and others 1986. Wells and Jorgensen 1977, Wells and Morris 1983). Long-term measurements of intensively harvested and site prepared plots, necessary to answer this latter question, are not generally available,

Harvesting and Site Preparation Influences on Soil Bulk Density

Soils were significantly compacted to a 4-in. depth with integrated harvesting as indicated by the bulk densities in Table 9. This level of compaction of sandy loam soils have been shown detrimental to loblolly pine seedling growth (Simmons and Ezell 1983, Tuttle and others 1988). Similar trends were evident with conventional harvesting. All three mechanical treatments yielded bulk densities comparable to pre-harvest conditions. No appreciable decrease in bulk density was evident by the additional right-angle pass of the disk (i.e., double disking). It is assumed, though not determined, that bulk densities remained elevated on herbicide treated plots.

Disk harrowing has been shown effective in reducing bulk densities after harvest-caused soil compaction (Campbell 1973, Gent and Ballard 1985). Such reduction in bulk density is an indication of improvements in both nutritional and physical properties that have been shown to increase early loblolly pine growth (Foil and Ralston 1967, Hatchell 1970, Lockaby and Vidrine 1984, Simmons and Ezell 1983, Tuttle and others 1988). Such treatments appear necessary with the extra traffic of intensive integrated harvested areas that results in compaction (Gorden and others 1981, Slay and others 1987).

Windrowing has been shown to increase bulk density of surface soils (Slay and others 1987, Stransky 1981), with the influence of disking to loosen soils still in question. The 80-100% increase in both loblolly and slash volume found in the current study following disking of inter-windrow areas would suggest an improvement in soil conditions and/or reduced competition. However, windrowing treatments can also displace and concentrate a significant amount of the site's nutrient resource into windrows (Morris and others 1983, Swindel and others 1988, Tew and others 1986). This displacement of topsoil into windrows has contributed to the greater than IO-fold difference in growth between the intra-windrow and inter-windrow grown trees in the current study. The future growth on the inter-windrow area may be slowed due to this displacement

CONCLUSIONS

Mechanical and herbicide treatments for site preparation after intensive integrated harvesting can result in an increase fifth-year volume of two to three times greater than none-site prepared growth for loblolly and slash pine. Thus, intensive harvesting practices do not lessen the need for effective site preparation treatments. In general, disking treatments for two consecutive years resulted in the greatest early growth for both loblolly and slash pine. With loblolly pine, the herbicide site preparation treatments that were tested produced comparable fifth-year volumes to the range of mechanical treatments tested. But for slash pine, mechanical treatments yielded more fifth-year volumes than the herbicide treatments.

With conventional whole-tree harvesting, mechanical and chemical site preparation treatments produced comparable volumes for both slash pine and loblolly pine. But again, disking treatments yielded improved growth of slash pine.

As mechanized harvesting intensity increases, site preparation treatments that both ameliorate soil compaction and reduce competition will provide the greatest improvement in volume growth of loblolty and slash pine plantations.

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