Site Preparation and Fertilizer Increase Pine Growth on Soils Compacted in Logging

Glyndon E. Hatchell

ABSTRACT. Tree-length logging with rubber-tired skidders compacted the soil on a poorly drained site in the South Carolina coastal plain. Soil compaction reduced loblolly pine (Pinus taeda *L.*) *seedling growth but not survival. Bedding or a moderate amount of fertilizer improved four-year growth on compacted soil, and these treatments applied in combination produced the best seedling growth. A greater response to fertilizer was obtained on compacted soil than on uncompacted soil.*

Rubber-tired skidders on the Atlantic Coastal Plain often compact the soil or puddle its structure on primary skid trails and log landings. As a result, growth of loblolly pine seedlings planted after logging disturbances is usually less than on uncompacted soil (Foil and Ralston 1967, Hatchell 1970, Hatchell *et al.* 1970). Skidding on medium- to fine-textured soils usually reduces macropore space, and compaction is greatest when soil is moderately moist. When moisture is nearer saturation, skidders cause puddling (deformation of soil structure by plastic flow).

In earlier studies, soils on log landings recovered in approximately 18 years on the Atlantic Coastal Plain (Hatchell and Ralston 1971). Soil in wheel ruts recovered in about 12 years on the Mississippi Coastal Plain, and soil compacted by logs between ruts recovered in about 8 years (Dickerson 1976). Various treatments for restoration of compacted forest soils have been suggested (Moehring 1970).

Since skid trails and log landings often cover a substantial proportion of a logged area, the loss in growth in the new stand can be considerable. Study results reported here indicate that growth losses on these areas can be minimized through cultural practices including mechanical site preparation and fertilizer application.

STUDY AREA

The study was conducted on a 30-acre clearcut on the Santee Experimental Forest, near Charleston, South Carolina. The soil series is Coxville, which is a member of the clayey, kaolinitic, thermic family of Typic Paleaquults. Coxville is classed as poorly drained and occurs on nearly flat land with low topographic position. The topsoil is loam or silt loam about 6 inches deep, and the subsoil is sandy clay. Soil samples collected from the surface 6 inches contained an average of 7 percent organic matter and had a pH of 4.2.

A well-stocked stand dominated by loblolly pine was clearcut for sawtimber during the summer of 1972, and logs were transported to a landing with an articulated rubber-tired skidder. The area was burned during the spring of 1972 to facilitate timber marking and to reduce competition from hardwoods and shrubs. A log landing and a network of primary skid trails converging at the log landing were laid out in advance of logging. Although rainfall was unseasonably low during logging, the soil retained a moderately high moisture content because of its low topographic position and high moisture-holding capacity.

Rubber-tired skidders formed ruts in primary skid trails averaging 5 inches deep and shoulders of ruts 4 inches high (each measured from soil surface). The depth of ruts is typical for logging under moderately moist conditions. Ruts formed on similar soils under wet logging conditions are commonly 1 to 2 feet deep. More than 10 trips with the skidders caused severe soil compaction. Measurements taken with a pocket penetrometer indicated that average soil strength or hardness on primary skid trails often exceeded 64 pounds per square inch and averaged three times greater on the primary skid trails than on uncompacted soil.

TREATMENTS AND EXPERIMENTAL DESIGN

A split-plot experiment was established. Combinations of soil compaction and site preparation treatments were tested on major plots and were replicated twice in randomized complete blocks. Amounts of fertilizer and organic amendment were tested on subplots. In each block, three major plots for testing randomly assigned site preparation treatments on compacted soil were located in portions of primary skid trails and three were located nearby on uncompacted soil. Major plots were 30 by 198 feet and were divided into three subplots, each 30 feet by 66 feet, or approximately 0.05 acre.

The three site-preparation treatments were: (1) herbicide—spraying woody vegetation with herbicide during summer of 1972 but no mechanical site preparation; (2) disked—shearing trees at ground line, rootraking debris into windrows, and flat disking; and (3) bedded—shearing trees at ground line, rootraking debris into windrows, and then preparing beds at 10-foot intervals. All mechanical treatments were completed in late fall 1972, when soil moisture was ideal for tilling. Two trips were made with the bedding machine on both uncompacted soil and compacted soil; the second trip was needed in the center of the skid trails to penetrate the hard, compacted soil. Bed elevation averaged approximately 1 foot above the original elevation, and the depth of tillage averaged 6 inches. Plots scheduled for flat disking were triple disked to a depth of 5 inches.

Each major plot was divided into three subplots and randomly assigned the following amounts of fertilizer and organic amendment: (1) unfertilized check; (2) medium level of fertilizer—200 pounds of nitrogen (N) as ureaformaldehyde, 50 pounds of elemental phosphorus (P) as triple superphosphate, and 100 pounds of elemental potassium (K) as muriate of potash per acre; and (3) high level of fertilizer—400 pounds of N, 175 pounds of P, and 175 pounds of K, in the above forms, plus three-quarter-inch depth of sawdust (15 tons of oven-dry sawdust per acre). Ureaformaldehyde, a relatively expensive, slow-release form of N, was selected primarily to assure an adequate amount of slowly available N for breakdown of sawdust because nitrogen deficiency after sawdust application has been shown to persist for more than a year (Bollen and Lu 1957). Fertilizer and sawdust were broadcast and were mixed with soil during flat disking and bedding.

The treatments described above were also randomly assigned and installed on a single block on a log landing. Since treatments could not be installed on uncompacted soil nearby, data collected on the log landing were not statistically analyzed.

Loblolly pine seedlings were hand planted during March 1973. Three rows of seedlings, with 10-foot spacing between rows and 2-foot spacing along rows, were planted, initially providing 99 seedlings per subplot. On skid-trail plots, the central axis was oriented with the middle of the skid trail, and a row of seedlings was planted between a pair of ruts on soil compacted by skidding logs.

Border effects on adjacent subplots due to application of different amounts of fertilizer and sawdust were not obvious. The three rows of seedlings planted on primary skid trails showed similar survival and growth. Hence, all seedlings on each subplot were included in computations of survival and growth through four growing seasons.

To estimate the aboveground pine biomass after the fourth growing season, 31 trees were selected to represent the sizes encountered on the study area. Each selected tree was cut to ground line, and the total oven-dry weight of stem, branches, and foliage was determined.

SEEDLING SURVIVAL

Site preparation and fertilizer application affected survival of loblolly pine seedlings from the first through the fourth growing season, but soil compaction during logging did not. Mortality was highest during the first growing season and least during the fourth growing season. Grasses and herbs were 3 to 6 feet tall during the first year, and competition from them appeared to cause most of the mortality. Site preparation increased pine survival, apparently by reducing competition during seedling establishment, but fertilizer application at planting time reduced survival, probably by increasing competition from grasses and herbs. Negligible mortality was attributed to insects. Fusiform rust infection on stems averaged 13 percent, but less than 1 percent of all seedlings were killed by this disease. Treatments did not significantly affect the incidence of fusiform rust on stems.

Survival percentages, by treatment, after four growing seasons are presented in Table 1. Mean survival on herbicide plots with no mechanical site preparation (65 percent) was less than on bedded plots (85 percent), but the mean for disking (73 percent) was not significantly different from either of the other two means. The 86 percent mean survival on unfertilized check plots was significantly greater than the 72 percent after medium fertilization and the 66 percent after high fertilization plus sawdust additive. The difference in survival after medium and high fertilization was not statistically significant, and no significant interactions among treatments were detected.

The outstanding response of loblolly pine to fertilizer on compacted soil is attributable in part to elimination of competing vegetation by skidding. Application of fertilizer to uncompacted soil increased competition from other plants, particu-

Table 1. Survival, height, and root collar diameter of loblolly pine after fourth growing season, by treatment.

	Survival			Height			Root collar diameter		
Site preparation and amount of fertilizer	Uncompacted soil		Compacted soil	Uncompacted soil		Compacted soil	Uncompacted soil		Compacted soil
	Percent			Feet			Inches		
Herbicide									
zero[1]	82		76	6.7		5.5	1.3		1.1
medium	56		62	8.1		8.6	1.5		1.7
high	47		64	8.0		10.0	1.5		2.0
means	(62)	65b[2]	(67)[3]	(7.6)	7.8b	(8.0)	(1.4)	1.5ab	(1.6)
Disked									
zero	82		82	5.2		4.3	1.0		0.8
medium	62		78	6.6		8.2	1.3		1.7
high	66		69	7.7		7.9	1.5		1.6
means	(70)	73ab	(76)	(6.5)	6.6b	(6.8)	(1.3)	1.3b	(1.4)
Bedded									
zero	94		97	11.3		9.6	2.2		1.9
medium	86		86	11.6		12.5	2.3		2.4
high	70		78	10.2		11.6	1.9		2.2
means	(83)	85a	(87)	(11.0)	11.1a	(11.2)	(2.1)	2.2a	(2.2)
Means for fertilizer treatments:									
zero	(86)	86c	(85)	(7.7†)	7.1d	(6.5)	(1.5†)	1.4d	(1.3)
medium	(68)	72d	(75)	(8.8)	9.2c	(9.7)	(1.7)	1.8c	(1.9)
high	(61)	66d	(70)	(8.6)	9.2c	(9.8)	(1.6)	1.8c	(1.9)

[1] *Zero = unfertilized check; medium = 200 lbs. N, 50 lbs. P, and 100 lbs. K per acre; high = 400 lbs. N, 175 lbs. P, and 175 lbs. K plus 15 tons sawdust per acre.*

[2] *Treatment means without a letter in common are significantly different at the 5-percent level, according to Duncan's New Multiple Range Test.*

[3] *Interactions between treatments on uncompacted soil and compacted soil are within parentheses.*

† *Interaction significant at the 5-percent level, indicating greater response to fertilizer for compacted soil than for uncompacted soil.*

larly blackberry (*Rubus* spp.), yielding higher pine mortality than on compacted areas.

STAND HEIGHT

Without site preparation and fertilization, seedlings on primary skid trails were 1.2 feet shorter than seedlings on uncompacted soil the fourth year after planting (Table 1). This reduction in growth attributable to soil compaction is similar to values reported earlier (Hatchell *et al.* 1970).

An increase in height growth caused by bedding was apparent after the first growing season, and this advantage widened through the fourth growing season. The response to fertilizer also has increased with time.

Site preparation affected stand height at the end of the fourth year to a larger extent than did fertilization (Table 1). Mean heights for bedding, flat disking, and the herbicide treatments were 11.1, 6.6, and 7.8 feet, respectively. Bedding was effective where disking was not because it improved aeration by increasing depth of water table (McKee and Shoulders 1970).

The two rates of fertilizer application were equally effective. They increased tree height by about 2 feet in 4 years. A statistically significant interaction between fertilizer treatments and soil compaction indicates that the response of seedlings to fertilizer was greater on compacted soil than on uncompacted soil.

BASAL DIAMETER

Bedding improved diameter growth, but flat disking by itself was not beneficial on this particular site. The depressed diameter growth on primary skid trails was eliminated by applying fertilizer. The mean diameter produced by fertilization at either the medium level (1.8 inches) or the high level plus sawdust (1.8 inches) is significantly greater than the unfertilized control (1.4 inches). An interaction between compaction and fertilization again indicates that response to fertilizer was greater on soil compacted in logging than on uncompacted soil.

PINE BIOMASS

A regression equation was developed to estimate the oven-dry weight of the aboveground portion of individual pine seedlings: $\text{Log } W = 1.584 + 0.843 (\text{Log } D^2H)$, where W is oven-dry weight in

Table 2. Estimated dry weight of aboveground biomass of loblolly pine after the fourth growing season, by treatment.

Site preparation and amount of fertilizer	Biomass per tree			Biomass per acre		
	Uncompacted soil		Compacted soil	Uncompacted soil		Compacted soil
	Pounds			Pounds		
Herbicide						
zero[1]	1.7		1.1	2900		2000
medium	2.2		2.8	2500		3800
high	2.6		4.1	3000		5600
means	(2.2)	2.4b[2]	(2.7)[3]	(2800)	3300b	(3800)
Disked						
zero	1.0		0.6	2100		1100
medium	1.8		2.7	2700		4700
high	2.4		2.6	4300		3900
means	(1.8)	1.9b	(2.0)	(3000)	3100b	(3200)
Bedded						
zero	4.9		3.2	9900		6800
medium	5.5		6.0	10400		11000
high	4.6		5.1	7700		8800
means	(5.0)	4.9a	(4.7)	(9300)	9100a	(8900)
Means for fertilizer treatments:						
zero	(2.5†)	2.1d	(1.7)	(5000†)	4100c	(3300)
medium	(3.2)	3.5c	(3.8)	(5200)	5800c	(6500)
high	(3.2)	3.6c	(3.9)	(5000)	5600c	(6100)

[1] *Zero = unfertilized check; medium = 200 lbs. N, 50 lbs. P, and 100 lbs. K per acre; high = 400 lbs. N, 175 lbs. P, and 175 lbs. K plus 15 tons of sawdust per acre.*

[2] *Treatment means without a letter in common are significantly different at the 5-percent level, according to Duncan's New Multiple Range Test.*

[3] *Interactions between treatments on uncompacted soil and compacted soil are within parentheses.*

† *Interaction significant at the 10-percent level, indicating greater response to fertilizer for compacted soil than for uncompacted soil.*

grams, D is basal diameter in centimeters, and H is total height in meters (r^2 = 0.984, significant at the 1-percent level).

Biomass in individual trees or in stands was one-third less on compacted, unfertilized subplots with no mechanical site preparation than on uncompacted soil (Table 2). Bedding was the most beneficial treatment affecting pine biomass on both compacted and uncompacted soil. Fertilization produced greater increases in yield on compacted soil than on uncompacted soil. Bedding coupled with fertilization yielded about equal biomass on the compacted soil as on uncompacted soil (Table 2), but the statistical significance of responses to such treatment combinations was not determined because of limitations in the experimental design.

RESPONSES ON THE LOG LANDING

Four-year-old seedlings on the log landing were similar to those on primary skid trails—survival (82 vs. 77 percent), height (9.2 vs. 8.7 feet), and basal diameter (1.8 vs. 1.7 inches). Responses to treatments were also similar on the log landing and primary skid trails. On the log landing, heights were 7.9 feet for herbicide plot without mechanical site preparation, 7.2 feet for disking, and 12.6 feet for bedding; and respective basal diameters were 1.5, 1.4, and 2.4 inches. Mean heights were 7.3 feet for the unfertilized check, 10.7 feet for medium fertilizer, and 9.8 feet for high amount of fertilizer; respective basal diameters were 1.4, 2.0, and 1.9 inches. Bedding coupled with the medium level of fertilizer, the most effective combination of treatments, produced trees 14.6 feet tall and 2.7 inches in diameter.

CONCLUSIONS

The presence of statistically significant interactions makes interpretation of some treatment means difficult, but the overall meaning of the study results is obvious. Soil compaction seriously reduces growth of pines planted on skid trails and landings. This reduction in growth can be eliminated by mechanical site preparation and by applying a moderate amount of fertilizer.

The high rate of fertilizer application plus the organic additive did no more to increase pine yield than the moderate rate without additive. In the study N, P, and K were added together, but only a single fertilizer element may have been required.

An important finding is that biomass production benefited most from bedding on both compacted and uncompacted soil. Also, fertilizer application was particularly beneficial on the compacted soil. Bedding coupled with fertilization produced about equal biomass on compacted and uncompacted soil. Thus, productivity of the compacted soil was restored with these cultural practices.

Fertilization without tillage may lead to poorly developed pine root systems on some compacted soils. In the lower coastal plain of South Carolina, forest industry routinely prepares beds on poorly drained land prior to pine planting. Wherever research or experience indicate that some other method of site preparation such as flat disking or subsoiling, is more practical or beneficial than bedding, that tillage method should be considered.

The four years of data reported here may not fully reflect the detrimental effects of soil compaction on pine growth. Certainly the best approach is to minimize compaction during logging (Hatchell *et al.* 1970). It appears, however, that acceptable pine yields can be obtained on compacted soil through a combination of tillage and fertilizer application.

Literature Cited

BOLLEN, W. B. and K. C. LU. 1957. Effect of Douglas-fir sawdust mulches and incorporations on microbial activities and plant growth. Soil Sci. Soc. Amer. Proc. 21:35–41.

DICKERSON, B. P. 1976. Soil compaction after tree-length skidding in Northern Mississippi. Soil Sci. Soc. Amer. J. 40:965–966.

FOIL, R. R. and C. W. RALSTON. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Sci. Soc. Amer. Proc. 31:565–568.

HATCHELL, G. E. 1970. Soil compaction and loosening treatments affect loblolly pine growth in pots. USDA For. Serv. Res. Pap. SE-72. 9 pp.

HATCHELL, G. E., C. W. RALSTON, and R. R. FOIL. 1970. Soil disturbances in logging: Effects on soil characteristics and growth of loblolly pine in the Atlantic coastal plain. J. For. 68:772–775.

HATCHELL, G. E. and C. W. RALSTON. 1971. Natural recovery of surface soils disturbed in logging. Tree Planters' Notes 22(2):5–9.

MCKEE, W. H., JR. and E. SHOULDERS. 1970. Depth of water table and redox potential of soil affect slash pine growth. For. Sci. 16:399–402.

MOEHRING, D. M. 1970. Forest soil improvement through cultivation. J. For. 68:328–331.

Glyndon E. Hatchell is soil scientist, Institute for Mycorrhizal Research and Development, Southeastern Forest Experiment Station, USDA Forest Service, Forestry Sciences Laboratory, Athens, Georgia. The study was established when the author was stationed at the Forest Service Field Unit in Charleston, South Carolina.