Soil Disturbances In Logging

Effects on Soil Characteristics and Growth Of Loblolly Pine in the Atlantic Coastal Plain

Fig. 1.—Deep rutting, puddling, and compaction on log deck after harvesting loblolly pine stands on medium-textured soil at high soil moisture.

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LOGGING CAN CAUSE compaction, puddling, and displacement of soil (Fig. 1). All types of soil disturbance occur in the Atlantic Coastal Plain, where year-round logging is carried out under a wide range of soil conditions. Compaction and disturbance of forest soils have received little attention in research. Lull (*5*) reviewed research accomplishments prior to 1959 and concluded that compaction was likely to be a problem on many forest sites but that quantitative data on soil characteristics and tree response were almost completely lacking. Most of the literature on this problem has dealt with logging disturbance in the Pacific Northwest, where detrimental effects on the physical properties of soil and poor growth of coniferous seedlings were observed in skid trails and logging roads (*1, 9, 10, 11, 12*). Moehring and Rawls (*6*) reported that wet weather logging in a 40-year-old loblolly pine (*Pinus taeda* L.) stand in Arkansas compacted the silt loam soils and significantly reduced diameter growth of trees which had traffic on three sides or on all four sides. Neither diameter growth nor the measured physical properties of soils were significantly affected by traffic under dry conditions.

Greater use of heavy logging equipment and the development of special skidding equipment permit year-round operations on most sites supporting loblolly pine in the Atlantic Coastal Plain. This growing potential for site damage prompted a series of investigations[1] on the nature and extent of the problem of soil disturbance in logging, its severity, the rate of natural recovery of disturbed soils, and the effects of soil compaction and puddling on the establishment and early growth of loblolly pine.

Methods

Investigation of areal extent of logging disturbance.—In the lower coastal plain of South Carolina and Virginia, nine logging areas were surveyed soon after wheel or crawler tractors had been used in tree-length skidding. The proportion of each area in primary and secondary skid trails was estimated by means of line transects. Skid trails were classified as secondary if they led to other trails and as primary if they led to log decks or loading sites adjacent to a permanent road. The perimeters of log decks were measured and their areas computed.

Determination of effects of logging on physical properties of soils.—On each of the nine areas, soil data were collected from plots in log decks, primary skid trails, secondary skid trails, and adjacent undisturbed portions. Bulk densities of surface soils were estimated with nuclear moisture and density probes. Infiltration rate was measured with 4-inch ring infiltrometers, into which water was added in 100-milliliter increments during a 30-minute period. Strength of the surface of mineral soil was measured with a pocket penetrometer.

Vehicular compaction experiment.—The effects of repeated vehicle trips on certain physical properties of soil were assessed at 47 locations on the Santee Experimental Forest, Berkeley County, S. C. Soils with a wide range of surface textures were sampled; soil moisture content ranged from wet to moist. Selected strips at each location were traversed by a crawler tractor pulling a two-wheeled trailer loaded with water. The tractor weighed approximately 12,500 pounds and exerted a ground pressure less than 10 pounds per square inch, whereas the trailer weighed 3,500 pounds and exerted a ground pressure of 46 pounds per square inch, approximately the pressure exerted by a normal load of pulpwood. Density readings and measurement of other soil characteristics were taken exclusively in the trailer tracks (Fig. 2). Nuclear moisture and density probes were used to estimate moisture and bulk density of surface soils initially and after the first, second, fourth, and ninth vehicular trips. Porosity at the 0- to 2-inch depth was determined from soil cores collected from random locations within the compacted strips and also from normal soil adjacent to each plot.

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[1] Cooperative research by the School of Forestry, Duke University, and the Southeastern Forest Exp. Sta. Two dissertations submitted in partial fulfillment of the requirements for the D. F. degree, School of Forestry, Duke University, contain details of the investigations: "The Effects of Compaction on Soil Characteristics and Seedling Growth," by R. R. Foil (1965); and "The Effects of Soil Disturbance in Logging on Soil Characteristics and Growth of Loblolly Pine," by G. E. Hatchell (1968).

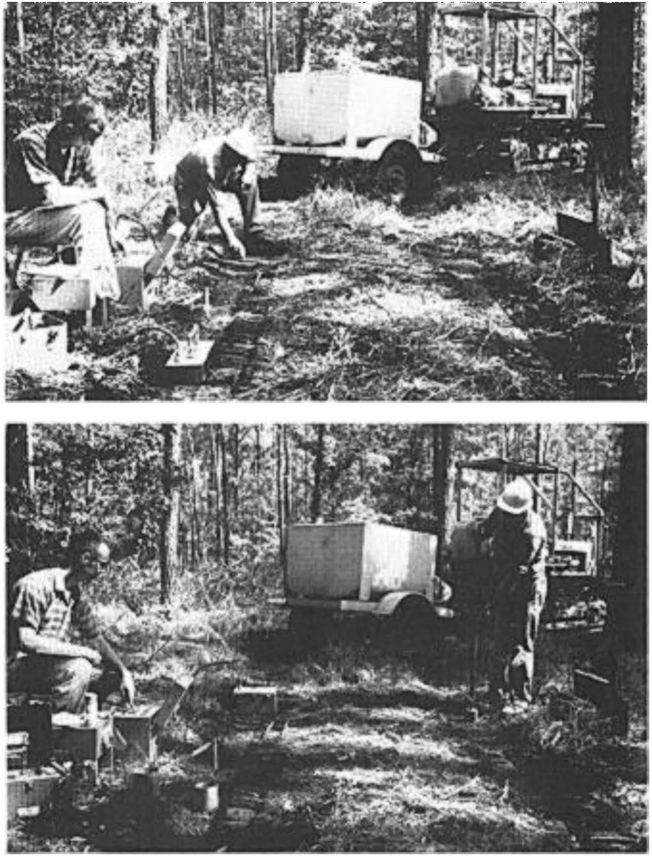

Fig. 2.—Techniques and equipment used in the vehicular compaction experiment. (A) Surface density probe in use. (B) Typical ring infiltrometer, surface moisture determination, and soil core collection.

Estimation of rate of recovery.—Recovery of compacted soils over a relatively short period was evaluated by reexamination of plots installed during the vehicular compaction experiment. After a lapse of one year, properties of normal and compacted soils at 22 locations were determined with the same equipment that had been used initially.

Long-term prospects for recovery were evaluated by examining soil physical properties on disturbed and undisturbed portions of 16 areas logged at various times during a 19-year period.[2] Nuclear equipment was used to determine bulk density of undisturbed soil, primary skid trails, and log decks; all measurements were made on surface soil of the same type.

Measurement of growth response on disturbed soils. The effects of logging disturbance upon loblolly pine establishment and early growth were evaluated on two of the nine areas included in the survey of areal disturbance. The seedlings, which originated from natural seedfall during the same season in which the stands were logged, were measured during the first growing season on 48 paired milacres on both disturbed and undisturbed soils. On one area, topsoil was loamy sand and subsoil, sandy loam; on the other, topsoil was fine sandy loam and subsoil, clay loam. In addition, data were collected on 78 plots early in the third growing season to determine the relationship of pine-shoot growth to certain physical properties of soils. Plots were located in the middle of skid trails, in ruts of skid trails, and in undisturbed soil. A soil core sample of the 0- to 2-inch depth was collected from each plot, and the oven-dry weight of shoots of five seedlings nearest each soil sample was determined.

[2] Work was done on lands owned by the Union-Camp Corp., Franklin, Va. Old log decks and primary skid trails were located from detailed records and maps.

Greenhouse experiments.—Two greenhouse experiments were conducted to evaluate the effects of compaction and loosening on germination, establishment, and growth of loblolly pine for one growing season. In the first experiment, soil core samples, 4 inches in diameter and 5 inches deep, were collected from the surface of Lakeland loamy sand, Coxville loam, and Bayboro clay. The following treatments were applied: (1) loosening entire soil column; (2) 50 pounds per square inch static pressure; (3) 100 pounds per square inch static pressure; (4) 150 pounds per square inch static pressure; and (5) puddling followed by 150 pounds per square inch static pressure. Undisturbed samples served as a control. The second greenhouse experiment involved testing growth responses of loblolly pine on soils which were compacted the previous year during the vehicular compaction experiment. Ten locations were selected, with a range in texture of surface soils from loamy sand to clay loam. Soil core samples, 4 inches in diameter and 6 inches deep, were collected from the ruts formed by nine vehicular trips and also from adjacent normal soil. Remedial measures were tested by subjecting the soil core samples to the following treatments: loosening the entire 6-inch core; and loosening surface soil to a 3-inch depth. Unloosened samples served as a control.

Results And Discussion

Areal extent of logging disturbance.—On the nine logging areas, primary skid trails occupied 12.4 (3.2 to 22.8) percent of the total forested area; secondary skid trails occupied 19.9 (8.8 to 42.3) percent; and log decks occupied 1.5 (0.3 to 4.6) percent. Above average disturbance was observed on four of the nine areas which had heavy cuts on imperfectly drained sites, resulting in areal disturbances of 17 percent in primary skid trails, 22 percent in secondary skid trails, and 2 percent in log decks. Primary skid trails covered less area than secondary skid trails except on two areas. On these areas, the larger proportion of primary trails is attributed to wet logging conditions which forced the tractor operators to abandon trails having excessively deep ruts.

Effects of logging on physical properties of soils.—If bulk density of undisturbed soils is used as a standard for comparision, bulk density increased only half as much in secondary skid tails as in primary skid trails (Table 1). Logging disturbance caused a substantial

Table 1. Mean Bulk Density, Soil Strength, Infiltration Rate, and Air Space of Surface Soil Classified by Type of Disturbance

Type of disturbance	Bulk density	Soil strength	Infiltration rate	Air space
	g/cm³	*kg/cm²*	*In./hr*	*Percent by volume*
Log deck	1.14	3.4	2.6	26.2
Primary skid trail	1.08	2.8	2.7	23.1
Secondary skid trail	.92	2.1	5.5	27.5
Undisturbed soil	.75	1.1	25.2	38.5

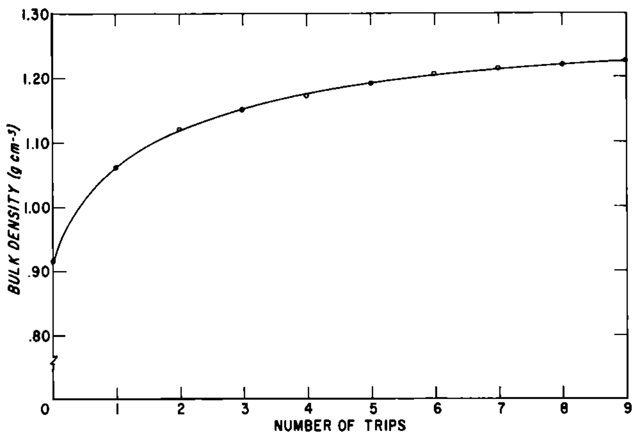

Fig. 3.—Relationship of bulk density of surface soil to number of vehicular trips.

increase in soil strength and a drastic reduction in infiltration capacity. If undisturbed soils are used as the standard, the mean infiltration rate was 22 percent in secondary skid trails, 11 percent in primary skid trails, and 10 percent in surface soils of log decks. Air space of surface soils was found to be consistently higher in undisturbed soils than in soils disturbed by logging, while disturbed soils held more moisture.

Vehicular compaction.—Traffic caused a very sharp increase in bulk density of surface soils after one or two trips and a more gradual increase in density as the number of trips increased (Fig. 3). Two-thirds of the field locations had become compacted by two trips to within 10 percent of the density after nine trips, and an average of 2.5 trips resulted in densities within 10 percent of the maximum attained. Only 7 percent of the locations required more than four trips to reach 90 percent of their final density.

Soils that were normally dense attained a higher density than those that were of low density; however, the porous soils were more subject to changes in density as a result of compaction and thus sustained a relatively greater amount of damage. Final density was positively correlated with percentage of silt in surface soil, negatively correlated with percentage of clay in surface soil, and negatively related to moisture content. Moisture increases that result from filling more pores encourage lateral displacement and deep ruts and also prevent maximum increase in density. The increase in density after compaction was greater in loamy sand or sandy loam than in clay loam or clay. This finding may have resulted from fine-textured soils having nearly saturated pores when wet and an extremely hard and cohesive condition when dry, thus resisting density changes in either extreme.

Compaction resulting from nine trips decreased total porosity and slightly increased capillary porosity, but reduced the volume of non-capillary pores by 50 percent. Capillary porosity was increased from 37.8 percent to 40.0 percent, and non-capillary porosity lowered from 25.6 percent on undisturbed soils to 13.4 percent on compacted soils. Many locations were compacted to a non-capillary porosity below 10 percent, a level often cited as critical for aeration needs of many agricultural crops. Compaction caused a greater reduction in non-capillary porosity in wet soils than in drier soils. Because puddling destroys structural non-capillary pore space with little effect on density, trips on wet soil did not materially increase final densities but did cause greater reduction in aeration porosity and infiltration rates. Steinbrenner (*9*) showed that four trips with a tractor on dry soil reduced the volume in large pores by half and that one trip when the moisture was at field capacity was equivalent to four trips when the soil was dry.

Rate of recovery.—No trends toward partial recovery of compacted soils were detectable during a one-year period. Bulk density and porosity values observed initially and a year later were not significantly different for soils compacted by nine trips with tractor and trailer.

Severely disturbed soils logged at various times over a 19-year period did recover slowly. The average time required for bulk density on log decks to return to density of undisturbed soils was estimated by regression analysis to be 18 years. Data collected on primary skid trails indicated a similar recovery rate, although a greater amount of variation was encountered (*4*). Perry (*7*) estimated that approximately 40 years would be required for recovery of infiltration capacity in an old woods road.

Growth responses on disturbed soils.—On the two areas naturally regenerated with loblolly pine, only secondary skid trails had an initial establishment of seedlings equal to, or greater than, that on undisturbed soils, and shoot growth was retarded on all degrees of disturbed soil during the first two years. Pine stocking during the first year was greater on secondary skid trails than on adjacent undisturbed soils, probably because skidding exposed the mineral soil. However, on area 2, height growth on secondary trails was significantly less than that on undisturbed soils (Table 2). Reduced stocking and retarded height growth were observed on primary skid trails, and detrimental effects were particularly severe on the finer textured soil of area 2. There, seedlings in primary skid trails were less than half as tall as seedlings in undisturbed soil. Establishment and growth of pine were hampered to an even greater extent on log decks, which were severely compacted and puddled, than on primary skid trails. Pomeroy (*8*) found that light scarification in logging resulted in increased germination of loblolly pine but that puddling of a fine-textured soil reduced germination and increased the mortality of the seedlings.

Table 2.—Stocking and Height of Loblolly Pine Seedlings in August of First Growing Season

Logging area	Type of disturbance	Stocking[1]	Height[1]
		Number/acre	*Inches*
1	Secondary skid trail	27,000	5.5 ⌉
	Undisturbed soil	18,000	6.3 ⌋
2	Secondary skid trail	32,000 ⌉	3.8
	Undisturbed soil	26,000 ⌋	4.8
1	Primary skid trail	13,000 ⌉	2.9
	Undisturbed soil	15,000 ⌋	5.1
2	Primary skid trail	12,000	2.7
	Undisturbed soil	36,000	5.8

[1] Paired observations on disturbed and undisturbed soils are significantly different if not connected by a bracket.

Pine shoots collected early in the third growing season from the middle of skid trails on logging area 1 had about half the oven-dry weight of seedlings on undisturbed soil, and seedlings from the middle of trails on area 2 had about one-third the weight of seedlings on undisturbed soil. Moreover, seedlings collected from ruts formed by wheels and tracks of tractors were much lighter in weight than seedlings from the middle of trails over which logs had been drawn. Regression analyses were made to test the association of dry-shoot weight and certain properties of the surface soil at the 0- to 2-inch depth. Dry-shoot weight was positively correlated with non-capillary porosity and negatively correlated with bulk density. Non-capillary porosity was found to be more influential on the area having the finer textured soil. On both areas, a greater portion of the variation was associated with bulk density than with non-capillary porosity—an outcome explained by the fact that non-capillary porosity and possibly other factors, such as soil strength, were correlated with bulk density. But the interaction variable (the reciprocal of bulk density *X* non-capillary porosity) accounted for more variation in dry-shoot weight than did either of the soil factors individually; this result suggests that mechanical restraint of root growth and a subsequent reduction in shoot growth could have occurred at high bulk densities. Thus, poor aeration may have been the primary limiting factor, but growth was also affected by mechanical resistance to root extension at high bulk densities and by the interaction of mechanical resistance and aeration.

Greenhouse experiments.—In the first experiment, only small growth differences in loblolly pine were observed between compaction treatments of 50, 100, and 150 pounds per square inch of surface pressure, but even the smallest pressure applied greatly reduced seedling height and weight. These results indicate that surface pressures as low as 50 pounds can reduce soil aeration and increase mechanical resistance to root growth to unfavorable levels. Root weight was negatively correlated with bulk density over a range in density from 0.8 to 1.4 grams per cubic centimeter. Compaction did not affect germination, but seedling survival was poorer on clay soils or on heavily compacted soils of lighter texture (*2*).

In the greenhouse test of growth responses on core samples from the vehicular compaction experiment, mean establishment of loblolly pine was 94 percent on normal soils and 75 percent on compacted soils. The reduction on compacted soils apparently was due to restricted radicle penetration. Loosening compacted soils to either a 3- or 6-inch depth greatly improved establishment. Root and shoot growth on compacted soils was substantially less than on normal soils, but growth responses on compacted samples loosened to either a 3- or 6-inch depth were not significantly better. Shoot-root ratio was positively correlated with non-capillary porosity and oxygen diffusion rate, and dry-root weight and shoot-root ratio were significantly correlated with oxygen diffusion rate per unit bulk density (*3*).

Conclusions

In the Coastal Plain, soil disturbance appears to be most injurious to establishment and growth of loblolly pine when severe compaction is coupled with excessive soil moisture. Greatest damage occurs during wet weather on low-lying flatwoods sites with medium- to fine-textured soils. Such sites drain slowly even when undisturbed, and compaction, puddling, and deep rutting during logging cause critical reductions in non-capillary pore space, surface runoff, and internal drainage. These site alterations, in turn, cause extended periods of poor soil aeration which are detrimental to the establishment and growth of pine seedlings. Compacted forest soils are slow to recover from severe disturbance imposed in logging, and considerable reductions in pine yields may occur over a long period before natural processes fully restore disturbed soils to their original condition.

Obviously, this soil damage is of economic importance, and means should be sought to hold site deterioration to a minimum. On moist, medium-textured soils, damage is likely to be just as serious from one vehicle trip as from several trips. Consequently, logging traffic on these areas should be confined to a few primary trails, which possibly could be restored to a productive state by disking, subsoiling, or some other cultural treatment. Conversely, on dry, initially porous soils, little damage will occur from one or two trips, and logging traffic should be dispersed over many different trails. Such dispersion will reduce the need for restorative practices, expose mineral soil, and improve the seedbed. Damage to low-lying areas of fine-textured soils can be avoided by diverting logging operations to sandy soils during wet periods. Another solution to the general problem of soil compaction is for foresters to specify that harvesting equipment of low-bearing pressure be developed.

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