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The Establishment and Growth of Loblolly Pine Seedlings on Compacted Soils[1]

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ABSTRACT

Loblolly pine (*Pinus taeda* L.) seedlings were grown from seed on core samples collected from surface soils of Lakeland loamy sand, Coxville loam, and Bayboro clay that had been compacted, puddled, or loosened. Seed germination was not affected by soil type or treatment, but seedlings became established with difficulty on clay cores and on heavily compacted cores of lighter texture. Top height and root length were not related to soil type, but seedlings grown on clay were significantly lighter than the other groups. Loosening the soil from its normal structure reduced growth on light-textured soils, but stimulated it on clay soils. Compaction, whether at 3.5 or 10.5 kg cm^{-2} of surface pressure, greatly reduced seedling size and weight. Small growth differences between compaction treatments indicated that even the smallest pressure applied reduced soil aeration and increased mechanical impedance to root growth to infavorable levels. There were negative linear relationships between root weight and penetration and densities ranging from 0.8 to 1.4 g cm^{-3}.

Additional Key Words for Indexing: aeration, root growth.

Agronomists and soil scientists have long been aware of the possible harmful effects of soil compaction on plant growth. Research on this subject has progressed from descriptive studies involving soils compacted during the course of crop production (1, 6, 7, 9) to greenhouse studies using artificially compacted soils (4, 12, 17) and highly controlled experiments aimed at isolating particular physiological processes and conditions responsible for the abnormal growth of plants in compacted soils (2, 8). Results of these research endeavors were summarized by Rosenberg (16), who observed that the adverse effects of soil compaction on plant growth probably were caused by some combination of poor soil aeration, mechanical impedance to root growth, poor moisture relations, and possibly adverse soil temperature conditions. Separating the influence of one of these factors from the others has proved difficult, and sophisticated experimental techniques will be necessary before final evaluation of single factors becomes possible.

Compaction of forest and range soils has not received as much research attention as has been shown croplands. Lull (11) reviewed accomplishments prior to 1959 and concluded that compaction must surely be a problem on many forest sites, but quantitative data on soil characteristics and tree response were almost completely lacking. Steinbrenner and Gessel (18) and Youngberg (20) studied soil properties of cutover Douglas-fir [*Pseudotsuga menziesii* (mirb.) Franco] stands and concluded that seedling establishment and growth were seriously retarded by unfavorable soil physical properties in areas subjected to heavy logging traffic. Pearson and Marsh (13) also reported that soil damage from trampling and wet weather logging resulted in unfavorable conditions for regeneration of ponderosa pine, (*Pinus ponderosa* Laws).

Little is known of the possible consequences of compaction in the forests of the eastern United States. Perry (14) observed drastically reduced growth of loblolly pine (*Pinus taeda L.*) on abandoned farm roads in North Carolina, and estimated that at least 40 years would be required for natural restoration of the damaged areas.

As pressures for increased forest production lead to more intensive management programs, it seems likely that compaction produced by heavy equipment used in harvesting and cultural operations will become even more important. In order to evaluate the significance of soil compaction in pine management an exploratory study was conducted to observe the growth of loblolly pine seedlings on soils of three textural classes that had been subjected to various compaction treatments.

PROCEDURE

Because of their importance in timber production as well as their variability in soil physical characteristics, certain soils in loblolly pine types of the lower Atlantic Coastal Plain were chosen for this experiment A preliminary survey was conducted on the Santee Experimental Forest, Berkeley County, South Carolina, and sampling areas representative of three soil series with major differences in textural and drainage classes were selected. Cylindrical core samples 10.2 cm in diameter and 12.7 cm deep were extracted from the surface horizons of areas classified as Lakeland loamy sand, Coxville loam, and Bayboro clay. Particle size distribution was determined from composite bulk samples by the Bouyoucos (5) hydrometer method. The undisturbed core samples were saturated by wetting from below and allowed to equilibrate at a tension of 60 cm on a Leamer-Shaw tension table (10). Twelve hours after samples were removed from the tension table, five compaction or amelioration treatments selected to produce effects equivalent to actual compaction in the field were applied to triplicate samples of each soil type. These were:

1) Tillage, by loosening with a trowel
2) 3.5 kg cm^{-2}, static pressure
3) 7.0 kg cm^{-2}, static pressure
4) 10.5 kg cm^{-2}, static pressure
5) Kneading at high moisture content, plus 10.5 kg cm^{-2}, static pressure

Surface pressures were applied with a Soiltest CN 672 testing machine designed for conducting bearing ratio tests in soil mechanics work.[3] Pressure was maintained only momentarily on each core. Triplicate samples of each soil type were left undisturbed to serve as checks.

Porosity determinations (60 cm) were repeated after disturbance treatments were completed, and 25 stratified loblolly pine seeds were sown on each core soon after removal from the tension table. Cores were arranged randomly in three blocks in a shadehouse. Natural rainfall was supplemented by hand watering as needed. Daily records of germination were maintained for one month, after which the seedlings were thinned to leave 5 plants per pot.

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At the conclusion of one growing season, the soil was washed from the seedling roots, and size and weight of roots and shoots were determined.

RESULTS AND DISCUSSION

The compaction and loosening treatments exerted a strong influence on the physical characteristics of the core samples in which seedlings were grown. As shown in Table 1, bulk density tended to increase with increases in applied compactive effort with highest densities attained on the clay and loamy sand cores. Clay densities were somewhat higher than normally expected, no doubt due to the initially dense condition of the soil, which was quite dry when collected. Puddling with compaction resulted in higher density than that attained by pressure alone in the case of the loamy sand, but reduced the level of density found for similar compactive effort in the finer textured soils. This response is attributed to capillary retention of water by the fine textured soils, leaving water-filled pores to resist compression. In the loamy sand however, water drained rapidly from noncapillary pores, resulting in very favorable conditions for compaction. Observed levels of bulk density are not inordinately high if judged by values previously reported, but increases in density above that of normal undisturbed forest conditions were substantial. By the same standard, loosening by tillage produced growth media of very low density.

It is evident from porosity values given in Table 1 that the volume of pores drained at 60 cm of tension was strongly influenced by treatments. The very low noncapillary pore volumes of clay samples in their natural state was reduced uniformly to about 3% by all compaction treatments. It is apparent also that the tillage treatment lowered normal density in all soils by producing large pores between aggregates and clods, since the percentage of capillary pore space per unit volume was reduced from its *in situ* level by this treatment.

Table 1—Physical characteristics of soil cores as affected by disturbance treatments. (All values are the average of three replications)

Soil	Treatment	Bulk density	Porosity: Total	Capillary	Non-capillary
		g cm^{-3}	% by volume		
Loamy	Loosened	0.955	77.2	32.2	45.0
Sand	Undisturbed	1.072	57.3	31.7	25.6
	3.5 kg cm^{-2}	1.269	47.5	35.9	11.6
	7.0 kg cm^{-2}	1.335	47.4	37.9	9.5
	10.5 kg cm^{-2}	1.325	48.4	39.2	9.2
	10.5 kg cm^{-2}, puddled	1.423	49.1	43.7	5.4
	Average	1.230	54.5	36.7	17.7
Loam	Loosened	0.866	81.7	37.7	44.0
	Undisturbed	1.063	52.8	40.0	12.9
	3.5 kg cm^{-2}	1.195	56.1	49.5	6.7
	7.0 kg cm^{-2}	1.188	54.6	49.3	5.3
	10.5 kg cm^{-2}	1.383	50.5	46.4	4.1
	10.5 kg cm^{2-}, puddled	1.299	57.7	51.2	6.5
	Average	1.166	58.9	45.7	13.2
Clay	Loosened	0.880	79.5	34.1	45.4
	Undisturbed	1.306	49.2	41.1	8.1
	3.5 kg cm^{-2}	1.427	48.7	45.4	3.3
	7.0 kg cm^{-2}	1.483	45.2	42.8	2.4
	10.5 kg cm^{-2}	1.488	51.2	48.7	2.5
	10.5 kg cm^{-2}, puddled	1.210	57.5	54.0	3.5
	Average	1.299	55.2	44.3	10.9

Compaction treatments had little effect on seed germination, but significant differences in seedling establishment became evident early in the study. On heavily compacted soils, many seeds germinated normally, but failed to survive because the emerging radicle did not penetrate the dense soil. Table 2 shows that seedlings surviving 30 days after seed were sown varied from 92% on loosened cores to a minimum value of 46% on cores that had been puddled. General patterns of survival on individual soils were similar, but percentages were significantly lower on clay samples than those of either loamy sand or loam soils.

By the end of the growing season, treatments had strongly affected seedling size. In loamy sandy (Fig. 1 top), loosening reduced height growth in comparison with undisturbed soil, and compaction treatments resulted in uniformly retarded seedling height growth. Root growth was severely restricted in soil compacted with 7 kg cm^{-2} or more of static pressure resulting in bulk densities of 1.33 or greater. In the loosened treatment, it appears that an aeration porosity of 45% of the soil volume reduced amounts of available water and nutrients to suboptimal levels. Roots penetrated to the bottom of the container, but lateral proliferation of roots was limited. (Fig. 1 center) shows representative seedlings grown in Coxville loam, and a similar pattern may be seen. However, it should be noted that reduced growth was observed at 3.5 kg cm^{--2} of static pressure and densites of 1.2 g cm^{-3} or greater on this finer-textured soil.

Response to compaction and loosening treatments on Bayboro clay was significantly different from that observed for coarse-textured soils (Fig. 1 bottom). Loosening of this soil, which had a normal density of 1.31 g cm^{-3} and non-capillary porosity of 8.0%, resulted in a striking growth increase and differences between compacted and normal soil were not so pronounced. Root penetration in normal or compacted clay samples was limited to cleavage planes between structural units and a few old root channels.

In relating these growth differences to measurable soil characteristics, reduced seedling growth was found to be rather strongly associated with increases in bulk density without regard to soil textural classes. The regression of root length on bulk density was negative and linear within the range of the data (Fig. 2). Root weight (Fig. 3) followed a similar pattern, although the relationship was not as strong due to the tendency for root weight to remain comparatively uniform irrespective of compaction treatment. Observations of root systems developed in heavily compacted soils showed that lateral roots comprised a larger percentage of total root weight than was generally the case in less compact soils. In the loamy sand and loam samples the surface 2.5 cm of the

Table 2—Seedling establishment as affected by soil type and disturbance treatments (All values are averages of three replications)

Treatments	Loamy sand	Loam	Clay	Average
	Extablishment %			
Loosened	92	87	91	90
Undisturbed	92	91	68	84
3.5 kg cm^{-2}	75	89	67	77
7.0 kg cm^{-2}	89	83	35	69
10.5 kg cm^{-2}	85	60	63	70
10.5 kg cm^{-2} puddled	57	46	54	52
Average	82	76	63	74

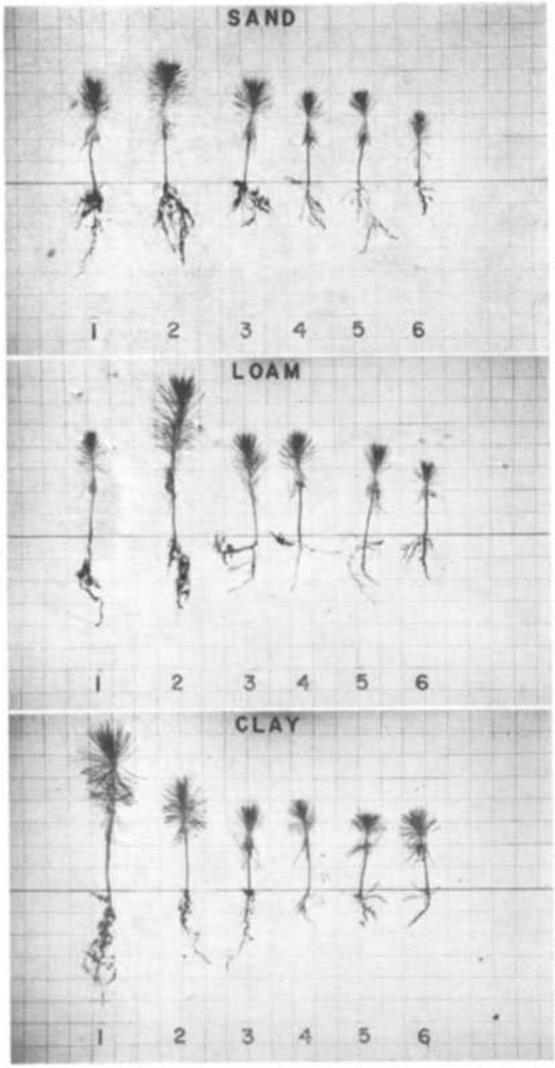

Fig. 1—Loblolly pine seedlings harvested from compacted or normal cores of Lakeland loamy sand (top), Coxville loam (center), and Bayboro clay (bottom). Numbers represent treatments listed below. (Grid lines are 2.54 cm)

Number	*Treatment*
1	Soil loosened
2	Undisturbed
3	3.5 kg cm^{-2}, static pressure
4	7.0 kg cm^{-2}, static pressure
5	10.5 kg cm^{-2}, static pressure
6	10.5 kg cm^{-2}, static pressure, plus puddling

soil contained many dead roots of herbs and grasses, and pine seedling roots were able to follow these surface root channels, whereas penetration into deeper layers was precluded by unfavorable soil conditions and the absence of old root channels.

Although the net effects of treatments are conspicuous, the mechanism that led to reduced plant growth in this experiment cannot be determined precisely. Previous investigators have stressed the difficulty of separating the effects of mechanical impedance, poor aeration, and unfavorable moisture relations on plant growth (15, 16), and compaction techniques employed here do not lend themselves to separate factor analysis. However, soil densities attained by compaction were not as high as those often quoted as being restrictive to root penetration (19, 21), but noncapillary porosities were well

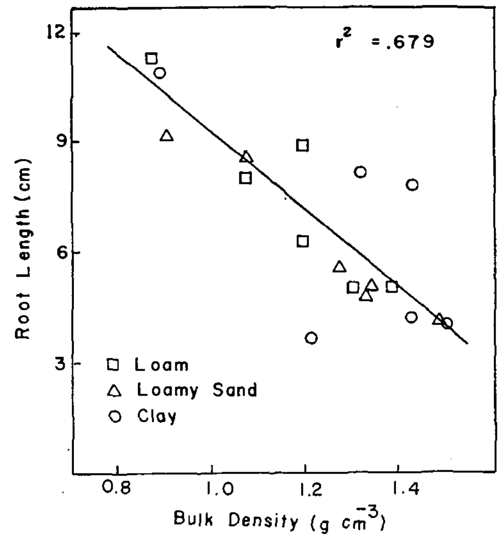

Fig. 2—The relationship between root length and soil density. (Points shown are averages of 3 replications).

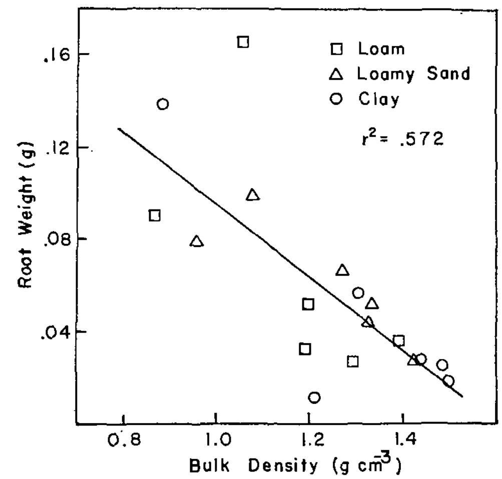

Fig. 3—Root weight as affected by soil density. (Points shown are averages of 3 replications).

below levels generally reported to be limiting to oxygen supply of roots (1, 3, 4, 8). In all likelihood, no single factor was entirely responsible for retarding plant growth, but rather an interaction of several conditions combined to produce this effect. Rosenberg (16) concluded his review article on this problem by observing that an understanding of the effects of compaction on the physiological processes and conditions of plants would be required before this complex interaction could be meaningfully evaluated. In addition, a great deal of refinement in measurement techniques will be necessary before the mechanical impedance and aeration aspects of compaction can be separated effectively.

Even though separate effects of causative factors could not be isolated in this experiment, retardation of seedling growth was quite substantial and this points to the need for further study of forest soil compaction problems. Particular emphasis should be placed on investigations of amelioration treatments, since damage to soil and seedling trees equivalent to that observed in this study can be found on significant percentages of the land area currently being harvested for southern pine products.

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