EFFECTS OF SKIDDER COMPACTION AND RUTTING ON SOIL PHYSICAL PROPERTIES AND WATER TABLES IN A SOUTH CAROLINA WETLAND [1]

W. M. Aust, M. D. Tippett, J. A. Burger, W. H. McKee, Jr. [2]

Abstract. Six wet pine flats were salvage-logged following Hurricane Hugo in the fall of 1989. High soil moisture conditions during the salvage operations resulted in soil compaction and deep rutting (puddling) within primary skid trails. Two studies were established to assess the effects of rubber-tired skidder trafficking on soil physical properties and water tables. One study addressed sites that had been compacted, the other study addressed sites that had been rutted (puddled). Each study consisted of three sites (blocks) from which plots were sampled in trafficked and nontrafficked areas. Effects of trafficking on soil properties and water tables were tested by comparing trafficked and nontrafficked plots. Soil compaction resulted in an increase in soil bulk density and a decrease in soil porosity (macro-, micro-, and total), depth to the water table, and saturated hydraulic conductivity. Rutting resulted in an increase in bulk density and a decrease in the depth to the water table, depth of reducing conditions, soil porosity, and saturated hydraulic conductivity. Both compaction and rutting decreased the amount and time of soil aeration by reducing internal water movement. Reduced water and air flow could reduce site productivity.

Introduction

Forest harvesting operations on wet sites have the potential to compact and puddle a site, and these disturbances may result in reduced site productivity (Hatchell et al. 1970, Lockaby and Vidrine 1984, Wert and Thomas 1981, Murphy 1983). Compaction and rutting (puddling) occur at different levels of soil moisture (Greacen and Sands 1980) and the two disturbances may have different effects on soil physical properties. An understanding of the conditions necessary for rutting and compaction and the consequences of each can help the forest land manager avoid, minimize, or mitigate potential problems associated with each.

Numerous investigations have revealed that forest machine trafficking may have little effect on drier soils, yet, moist soils are readily compacted (Greene et al. 1983; Koger et al. 1984; King 1979; Campbell et al. 1973; Hatchell et al. 1970; Lockaby and Vidrine 1984; Wert and Thomas 1981; Murphy 1993). Compaction usually occurs when a soil is at or near field capacity. When a soil is near field capacity cohesive forces of the soil are reduced and the soil's ability to support heavy loads is reduced (Akram and Kemper 1979).

Deep rutting (puddling) generally accompanies forest harvesting operations on very wet to saturated sites. A soil near saturation has very low shear strength and shear failure may occur when a load is applied. Under these conditions soil moisture has reached the liquid limit and flows when trafficked. The liquid nature of the saturated soil results in soil churning and physical displacement, as opposed to compaction (Burger 1989), and results in the destruction of soil aggregates (Sharma and DeDatta 1986). The changes in soil physical properties resulting from compaction versus rutting could cause different hydrologic responses on wetland sites. Therefore, the objective of this research was to determine and contrast the effects of soil compaction and deep soil rutting (puddling) on soil physical properties and hydrologic characteristics.

Methods and Procedures

The study sites were located in the Coastal Plain region of South Carolina on the Wambaw District of the Francis Marion National Forest. The original forest stand was longleaf (Pinus palustris) and loblolly pine (Pinus taeda) and site indices were approximately 90 feet (base age 50 years). All study sites had been salvaged logged under wet soil conditions in response to Hurricane Hugo and had obvious primary skid trails. Overall, the salvage logging operations were similar to commercial

---

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Assistant Professor, Graduate Research Assistant, and Professor, Virginia Polytech. Instit. and State Univ., Blacksburg, and Soil Scientist, U.S. Forest Service, Wetland Research Center, Charleston, SC.

clearcutting operations. Dominant soil series included Bethera (clayey, mixed, thermic Typic Paleaquults), Rains (fine-loamy, siliceous, thermic Typic Paleaquults), Lynchburg (fine-loamy, siliceous, thermic Arenic Paleaquults), and Goldsboro (fine-loamy, siliceous, thermic, Aquic Paleudults). Topography was nearly level (1-2 % slope).

Three sites with compacted primary skid trails and three sites with rutted skid trails were located. The three compacted sites were moderately well to poorly drained. Soils consisted of loamy sands to loam surface horizons overlying sandy clay loam subsoils. Compacted study sites were identified as having no evidence of churning and soil displacement. A typical skid trail on this type of site consisted of a depressed area, without deep ruts or displaced soil.

The three rutted and puddled sites were somewhat poorly to poorly drained. Soil surface horizons ranged from sandy loam to loam; subsurface horizons ranged from sandy clay loam to clay. Soil displacement, in the form of berms, was evident along all primary skid trails on these sites. Skid trails on these areas were deeply rutted and soil was deposited on either side of the rut.

Soil compaction and rutting were assessed by two parallel studies, each consisting of a completely randomized block design with three blocks. Treatments consisted of nontrafficked and trafficked (primary skid trails) areas. Four measurement plots were established on each block (Figure 1). Each measurement plot measured 80 feet (along the skid trail) by 20 feet and four 20 foot transect lines were randomly established across each plot to measure the disturbance profile (Figure 2).

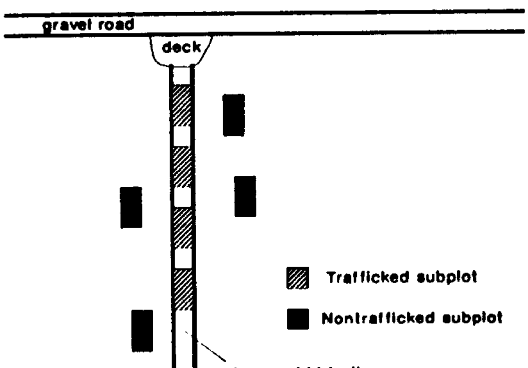

Figure 1. *Example of the layout of 1 site (block).*

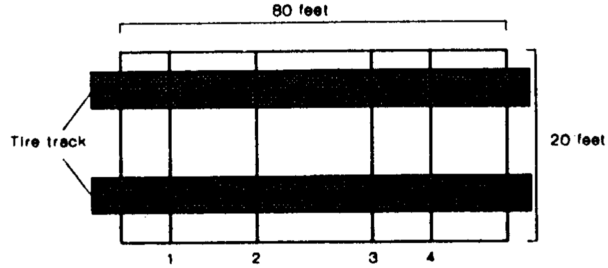

Figure 2. *Example of the layout of 1 trafficked subplot.*

The following measurements were taken along each transect line. Soil surface profiles were taken from a leveled line at 6-inch intervals. Each point was classified as tire track, berm, or between tracks within the trafficked subplots. The control plots were all classified as nontrafficked. Soil core samples (4-inch depth) were taken from areas of each disturbance class, and these samples were subsequently analyzed for saturated hydraulic conductivity (constant head method, Klute and Dirksen 1986), soil pore space (total, macro, micro-) (Danielson and Sutherland 1986) , and bulk density (Blake and Hartge 1986). Augered water table wells and steel rods were installed in the tire track, between the tire tracks, and in the nontrafficked control areas. The auger hole wells were used to monitor water tables (biweekly) (Faulkner et al. 1989) and the steel rods were used to obtain a measure of the average depth of reduced conditions (biweekly) (McKee et al. 1978, Hook et al. 1987).

Results and Discussion

An examination of the rutted (puddled) skid trails revealed that on an average 80- by 20-ft. plot 53% was berm, 43% was within the rutted tire track and 4% was in the unbermed trail center where logs were dragged. The rutted tire track exposed the denser and less fertile subsurface soil and the berm areas were a mixture of mixed a composite of surface and subsurface soil material. The central area of the disturbance where logs had been dragged was not compacted; however, surface soil had been removed.

The shallowest ruts were over 10 inches deep, and average rut depth approached 16 inches. Ruts of this depth may not be filled in by common site preparation disks and may require bedding or dozing in extreme cases.

Rut profiles of compacted sites soils revealed a more uniform and less severe disturbance than the rutted sites. Compacted skid trails had no distinct berms and soil removal by dragged logs was not as evident. The compacted trails consisted of depressions ranging from 2 to 8 inches deep. In these areas, soil was actually compressed instead of being displaced. Approximately 85 % of the compacted trails was in the tire track and 15% was located in the log-drag zone.

Soil bulk densities of the trafficked and nontrafficked areas were compared for both the rutting and compaction studies. Rutting significantly (alpha = 0.05) increased the soil bulk density within the actual tire track, but did not increase the bulk density between the tracks (Figure 3). Mean bulk density of the nontrafficked control area, between the tire track, and in the tire track were 1.04, 1.03, and 1.39 Mg/m3, respectively. Within the compacted sites, trafficking significantly (alpha = 0.05) increased bulk density within both the tire track and in between the tire tracks compared to the non-trafficked control area. However, within the compacted sites, bulk density values at less than 1.2 Mg/m3 were still below the critical values at which root growth becomes limiting. The tire track bulk density within the rutted tire track was approaching 1.4 Mg/m3, a value which may be limiting to root growth, but this higher value is probably a reflection of the inherent density of the subsoil that made up the bottom of the track rather than being a function of rutting disturbance.

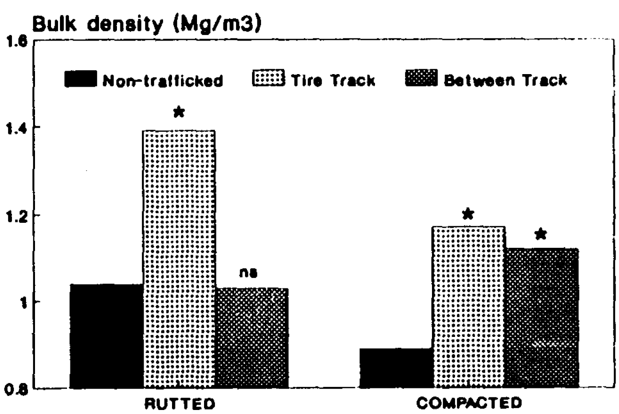

Figure 3. *Average bulk density of rutted and compacted sites.*

Micropore space refers to pores smaller than 0.06 mm in diameter which retain water against the force of gravity. Macropores are larger than 0.06mm and drain under gravitational force and fill with air. Pore space (total, micropore, and macropore) was reduced by both types of disturbance, rutting and compaction (Figure 4). As a soil is trafficked under moist or wet conditions, the macropores collapse. The reduction of macropore space means that these already-wet sites now retain more water than before, reducing aerated pore space well below 10%.

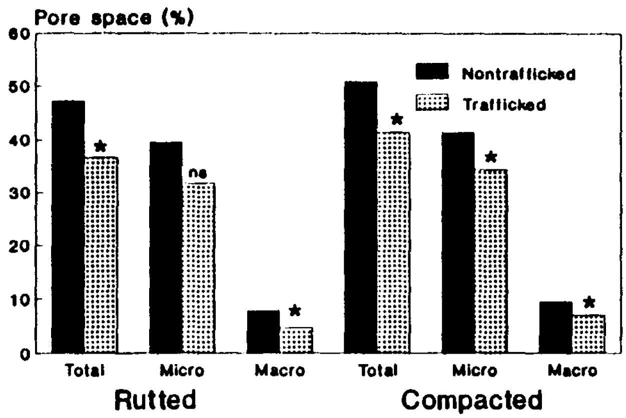

Figure 4. *Average porosity of rutted and compacted sites.*

Saturated hydraulic conductivity (Ks) was initially low on the rutted sites, below 10 cm/hr (Figure 5). This lower average Ks value partially explains why these rutted sites were wetter and also why they were originally more subject to rutting and puddling. Following trafficking, the rutted sites had Ks values below 1 cm/hr, an extremely slow rate. Ks values within the compacted sites responded similarly to trafficking. These sites initially had higher Ks values (2X) than the rutted sites, but trafficking reduced Ks values to below 3 cm/hr (Figure 5).

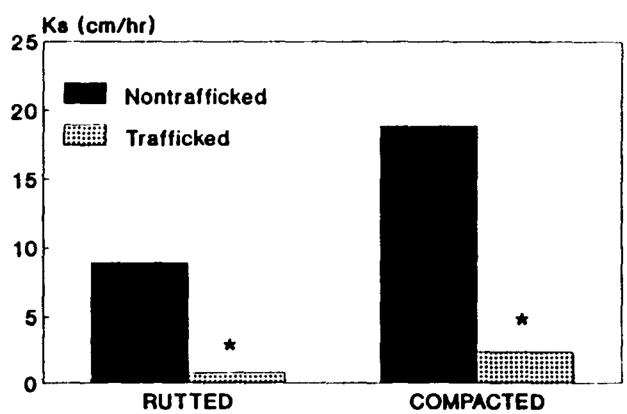

Figure 5. *Average saturated hydraulic conductivity of rutted and compacted sites.*

This dramatic reduction of Ks means that the sites will drain more slowly and less thoroughly. The water tables of the compacted sites reflected the slower drainage (Figure 6). The water table of the nontrafficked plots was used as a normalized control value; all water tables were corrected for elevational differences. Compaction of the moderaly well-drained (MWD) site resulted in a large increase in the relative water table level (Figure 6). Water tables were 35-45 cm higher on the somewhat poorly drained compacted sites, and the poorly drained (PD) site was least affected, having increased by only 5-10 cm.

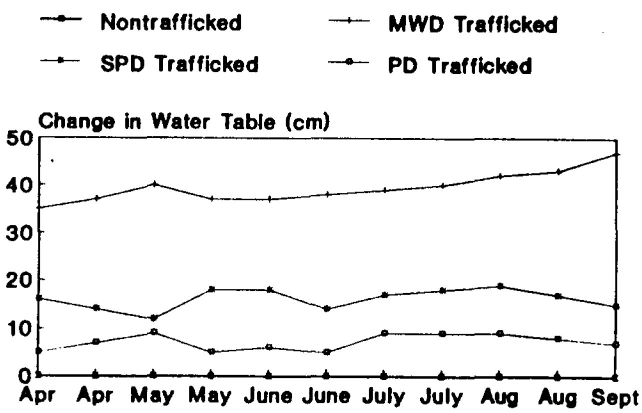

Figure 6. *Relative response of water table to compaction.*

Water table levels of the rutted (puddled) blocks responded similarly to disturbance. The relative water table change was greatest on the somewhat poorly drained site, while only small changes occurred on sites that were poorly drained (Figure 7).

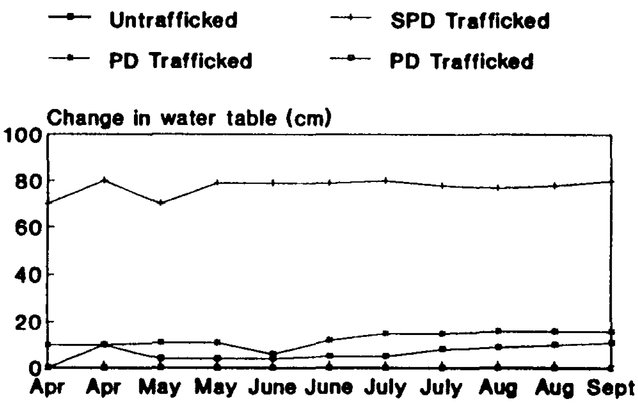

Figure 7. *Relative response of water table to rutting.*

The increases in the relative depth of the water tables within the compacted and rutted areas implies that soil aeration will not be as great within the skid trail as in nontrafficked areas. The depth of rust on steel rods was used as an indication of the relative oxidation-reduction status of the soil. Overall, rust occurred closer to the soil surface in the trafficked areas than in the nontrafficked areas (Figures 8 and 9). This was more pronounced in the rutted (puddled) areas than in the compacted areas, especially during early and late summer.

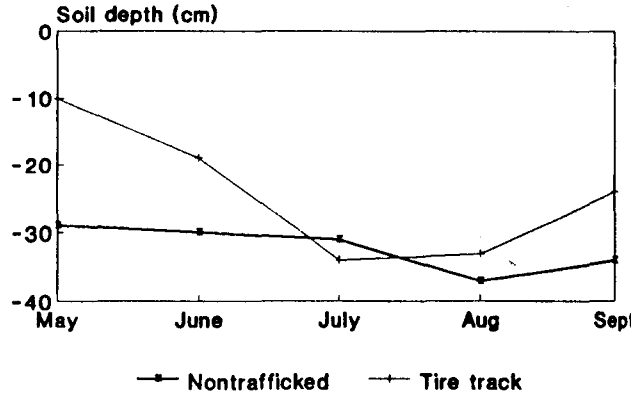

Figure 8. *Effect of rutting on depth of rust on steel rods.*

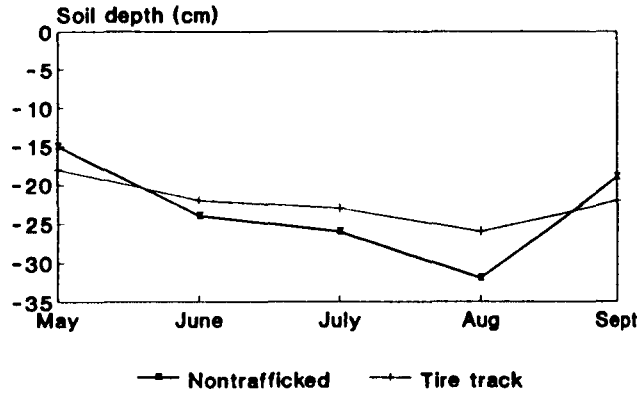

Figure 9. *Effect of compaction on depth of rust on steel rods.*

Conclusions

Visually, the rutted areas appeared to be more highly disturbed than the compacted areas, and measurements of soil physical and hydrologic properties verified this. Neither compaction nor rutting had an important effect on soil bulk density as density affects root exploitation of the soil volume. The compacted area bulk density values were relatively low, even after trafficking, due to the high sand and organic matter content of these surface soils. Macropore space values were initially low on all sites and trafficking further accentuated the problem, resulting in decreased saturated water flow (Ks), increased water table levels, and decreased soil aeration. The decreases were greatest in the areas which initially had the best drainage. This suggests that trafficking on better-drained sites under moist or wet conditions may result in more serious change than sites having poorer natural drainage. Upland studies of the effects of trafficking on tree growth have tended to concentrate on problems associated with soil strength. On these wet sites, the more serious consequences of rutting or compaction are reduced air and water movement. The reduction in aeration can have serious effects on tree growth and the decreased drainage may reduce the opportunity for silvicultural operations. Site preparation and fertilization are possible but uncertain solutions. The effects of these and other ameliorative techniques should be evaluated. In any case, avoidance of the disturbances is the preferred solution.

Acknowledgements

This project was conducted and supported by the U.S. Forest Service and the Department of Forestry, Virginia Tech.

Literature Cited

Akram, M.; W.D. Kemper. 1979. Infiltration of soils as affected by the pressure and water content at the time of compaction. Soil Science Society of America Journal 43: 1080-1086.

Blake, G.R; K.H. Hartge. 1986. Bulk density. p. 363-367. In: Klute, A. (ed.); Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. 2nd ed. American Society of Agronomy - Soil Science Society of America Publishing. Madison, WI. 1188 p.

Burger, J.A.; K.J. Wimme; W.B. Stuart; T.A. Walbridge. 1989. Site disturbance and machine performance from tree-length skidding with a rubber tired machine. p. 521-525. In: Proceedings of Fifth Southern Silvicultural Research Conference, Memphis TN, Nov. 1-3, 1988. USDA Forest Service General Technical Report SO-74. 618 pp.

Campbell, R.G.; J.R. Willis; J.T. May. 1973. Soil disturbance by logging with rubber tired skidders. Journal of Soil and Water Conservation 28: 218-228.

Danielson, R.E.; P.L. Sutherland. 1986. Porosity. p. 443-462. In: Klute, A., (ed.); Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. 2nd ed. American Society of Agronomy - Soil Science Society of America Publishing. Madison, WI. 1188 pp.

Faulkner, S.P.; W.H. Patrick, Jr.; R.P. Gambrell. 1989. Field techniques for measuring wetland soil parameters. Soil Science Society of America Journal 53: 883-890.

Greacen, E.L.; R. Sands. 1980. Compaction of forest soils: a review. Australian Journal of Soil Research 18: 163-189.

Greene, W.D.; W.B. Stuart; J.V. Perumperal. 1983. Skidder and tire size effects on soil compaction. American Society of Agricultural Engineers, ASAE Paper No. 83-1620. 16 pp.

Hatchell, G.E.; C.W. Ralston; R.R. Foil. 1970. Soil disturbances in logging: effects on soil characteristics and growth of loblolly pine in the Atlantic Coastal Plain. Journal of Forestry 68: 772-775.

King, A.L. 1979. Measuring soil compaction in mechanically thinned pine plantations. American Society of Agricultural Engineers, ASAE Paper No. 79-1600. 8 pp.

Klute, A.; C. Dirksen. 1986. Hydraulic conductivity and diffusivity laboratory methods. p. 687-734. In: Klute, A., (ed.); Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. 2nd edition. American Society of Agronomy - Soil Science Society of America Publishing. Madison, WI. 1188 pp.

Koger, J.L.; A.C. Trouse, Jr.; E.C. Burt; R.H. Iff; A.C. Bailey. 1984. Skidder tire size vs. soil compaction in soil bins. Transactiona of the American Society of Agricultural Engineers 27(3): 665-669.

Lockaby, B.G.; C.G. Vidrine. 1984. Effect of logging equipment traffic on soil density and growth and survival of young loblolly pine. Southern Journal of Applied Forestry 8(2): 109-112.

McKee, W.H., Jr. 1978. Rust on iron rods indicates depth of water table. p. 286-291. In: Balmer, W.E. (ed.); Soil Moisture - Site Productivity Symposium., Myrtle Beach, SC, Nov. 1-3, 1977. USDA, Wash., DC.

Murphy, G. 1983. Pinus radiata survival, growth and form four years after planting off and on skid trails. New Zealand Journal of Forestry 28(2): 184-193.

Sharma, P.K.; S.K. DeDatta. 1986. Physical properties and processes of puddled rice soils. Advances in Soil Science 5: 139-168.

Wert, S.; B.R. Thomas. 1981. Effects of skid roads on diameter, height and volume growth in Douglas-fir. Soil Science Society of America Journal 45: 629-632.