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Soil Density and Moisture Content on Two Unused Forest Roads During First 30 Months After Construction

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Abstract

Many foresters and loggers believe that trafficability, or resistance to rutting, improves with time after logging roads are built. However, no one has attempted to quantify the changes or identify the processes involved. In this study, dry density and moisture content of the surface foot of soil were measured at 315 locations on two roads in the central Appalachians over a 30-month period. Density increased slightly during the measurement period at most locations. Almost all of the density changes occurred during the first few months after construction. Moisture content decreased during the first few months after construction, then fluctuated with precipitation amounts.

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Forest access roads are required for most forest management programs because forest products cannot be removed economically without roads. If all-season access is needed, gravel is used to increase traction and stabilize road surfaces. Since road surfacing with gravel is a major cost item ($10,000 per mile in the central Appalachians), a practice that reduces gravel requirements will provide considerable savings. The most obvious way to reduce gravel requirements is to allow traffic only when the road is dry. Also, we have observed that roads constructed and not used for several weeks are more resistant to rutting by logging trucks than newly constructed roads. This increased trafficability was confirmed by loggers and other users of low-standard forest access roads.

Trafficability is the capacity of a soil to withstand traffic of wheeled and tracked vehicles. Silversides and Koroleff (1949) point out that trafficability depends on soil with sufficient bearing capacity to support vehicles and enough traction capacity to provide the necessary forward thrust. The bearing capacity of the soil is a function of the shearing strength and is attributed to friction and cohesion between soil particles. Shear strength is increased when soil density is increased because of increased friction between soil particles. Cohesion of soil is a function of moisture content and it also may increase as fine soil particles fill voids between larger particles.

We hypothesized that the soil in a road unused for a few eeeks after construction is drier, or denser, or both, than when it was first built. To test this hypothesis, we built two roads in 1982 near the Fernow Experimental Forest and allowed no vehicular traffic for the next 2½ years. Soil density and soil moisture measurements were made periodically during this period. The purpose of this paper is to report the results of those measurements.

Study Area

The study was located in the central Appalachians where annual precipitation averages 58 inches, evenly distributed throughout the year. The two roads—Canoe and Haddix—were built in contrasting geologic formations and soil types. The Canoe road is in the Calvin channery silt loam type of the Hampshire formation, whereas the Haddix road is in the Berks channery silt loam type of the Chemung formation. Soil depth on both areas is 5 feet or less. The percentage of coarse fragments[1] is highly variable; cove areas have deeper soils and lower coarse fragment content. Under similar moisture regimes, the potential for rutting is inversely correlated with the coarse fragment content of the soil.

[1]Coarse fragments are mineral or rock particles ranging from 2 mm to 25 cm in cross section.

Study Methods

The minimum standard roads used in this study were described in detail by Kochenderfer and others (1984). The roads were constructed from a flagged centerline. There was no formal road design or construction staking. All right-of-way clearing was done with a bulldozer in conjunction with road building. Standing trees were pushed or pulled over and pushed away from the roadbed with the bulldozer. Cut banks were left vertical if bank height was less than 5 feet, otherwise they were rough sloped with a bulldozer. Water from all streams and live seeps is conveyed under the road through culverts. Finally, broad-based dips spaced at intervals of about 150 feet were used to control surface runoff from precipitation. Figure 1 shows a section of a road immediately after construction.

Figure 1.—A minumum-standard road section with a broad-based dip.

Figure 2.—A minimum-standard road section with a high percentage of coarse fragments. Note the density sampling sites in the upper half of the photograph. The numbers refer to the measurement points on a transect.

Each road was divided into segments at least 200 feet long. Within each segment, nine transects were established across the road. Each transect (Fig. 2) contained five measurement points: (1) the inside portion next to the cut bank, (2) the inside track, (3) between the tracks, (4) the outside track, and (5) the fill. Only road sections with low rock content were selected for study because these are the sections most subject to rutting. The Haddix road had four sections and the Canoe road had three.

A Troxler Model 3411-B Nuclear Surface Moisture Density Gauge[2] was used to measure dry density and moisture content at the 4-, 8-, and 12-inch depths. The procedure at each measurement point was as follows: (1) a metal rod 0.75 inch in diameter was pounded into the roadbed and then extracted, (2) the soil surface was leveled to avoid air spaces at the soil instrument interface, (3) a 1-minute reading was made at each depth as defined earlier, and dry density and moisture content were recorded, and (4) after the measurements were made, a numbered 4-inch square piece of plywood was placed over the hole. Repeat measurements at each subsequent date were made at the same locations. The plywood cover prevented water and transported soil from getting into the hole.

A complete set of measurements on the two roads (945 readings) required about 5 days to complete. We used weather forecasts to avoid periods of unsettled weather so that measurements were not interrupted by rain storms. The first set of measurements was started on August 26, 1982.

[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Subsequent sets began on November 8, 1982, May 9, 1983, August 1, 1983, October 31, 1983, May 16, 1984, July 30, 1984, and March 6, 1985. To test for compaction by loaded log trucks, additional measurements were made at one road section on April 14, 1989. In addition to a few weekly trips by pickup trucks between 1985 and April 1989, about 500,000 feet of logs were trucked over the roads between 1986 and 1987.

Data Analysis

Dry bulk density and moisture content were each averaged by road, by sampling positions across the roads, and by sampling depth. Average values at each depth and measurement position were tabulated and tested by regression for time trends. A regression model of the form

$$\hat{Y} = a + b\,\mathrm{Ln}(x) \qquad (1)$$

was fitted to the data. In this model, $\hat{Y}$ is predicted dry density or moisture content, a is the intercept, Ln is the natural logarithm, x is the number of days after road construction, and b is the slope. The logarithmic model was chosen because we expected density changes to be most rapid during the first few weeks after road construction and more gradual later.

The 1989 measurements were averaged by road position. The effects of traffic on dry density were estimated by comparing density at each sampling depth between the tracks with density of the same depths in the track positions. Presumably, density between the tracks would not be affected by truck traffic.

Results and Discussion

Average dry density and moisture content to a 12-inch depth for the two roads were:

Road	**Dry density** *(Pounds/ft^3)*	**Moisture content** *(Percent by volume)*
Haddix	102.56	19.16
Canoe	112.90	13.26

The roadbed of Canoe road averaged about 10 percent denser and 30 percent drier than the roadbed of Haddix road. Average density and moisture content across the road were as expected (Table 1). Lowest density was on the fill slopes, and density increased uniformly toward the cut bank. Although the values for the two roads were different from each other, relative values across the road were the same. Thus, for both roads, density at the cut banks averaged about 12 pounds per cubic foot greater than at the fills. Moisture content increased slightly from the cut bank to the fill. Table 2 shows that dry density increased slightly and moisture content decreased slightly with depth in both roads.

Table 1.—Average dry density and moisture content to a 12-inch depth by sampling positions on the two logging roads

Sampling position	Dry density		Moisture content	
	Haddix	Canoe	Haddix	Canoe
	Pounds per ft^3		*Percent by volume*	
Cut bank	107.5	119.2	18.8	12.4
Inside track	104.7	117.6	18.4	11.9
Between tracks	102.8	111.4	19.2	13.4
Outside track	102.0	108.8	19.1	14.6
Fill	95.8	107.6	20.3	13.9

Table 2.—Average dry density and moisture content by sampling depths on the two logging roads

Sampling depths (inches)	Dry density		Moisture content	
	Haddix	Canoe	Haddix	Canoe
	Pounds per ft^3		*Percent by volume*	
4	100.7	110.6	19.4	13.4
8	102.9	113.6	19.2	13.2
12	104.0	114.5	18.9	13.1

The regression analysis indicated a slight increase in soil density over time at most sampling locations and depths (Table 3). An exception was the cut bank position of the Canoe road where density decreased over time. This may have been caused by soil swelling after the overburden was removed.

Figure 3 is a plot of Canoe road density over time by road position at the 4-inch and 8-inch depths. The 12-inch depth followed the same trend as the 8-inch depth. As stated earlier, the sampling sites nearest the cut bank became less dense over time, possibly because the removal of the overburden allowed these soils to expand slightly. Density of the other sites increased slightly, but the amounts were small. Most of the change occurred during the first winter after road construction. Subsequent changes were very small and probably related to weather. Density changes on the Haddix road were inconsistent as shown by the R^2 values (Table 3). Only the track sampling positions showed consistent density changes over time. The lack of a significant density change at the fill position was surprising, and we have no reasonable explanation for it.

Moisture content of both roads decreased sharply soon after construction, but it increased at the end of the study in response to rainfall. Since all sampling sites across the roads showed similar trends, only the average values are presented (Fig. 4).

Logging traffic had only minor effects on road density at the section measured in 1989. Density at the 4- and 8-inch depths averaged only 2 percent greater than that between the tracks. The 12-inch depth was unaffected by traffic.

Table 3.—Regression coefficients for predicting dry soil density over time, after road construction

Road position	Depth	Haddix road			Canoe road		
		R^2	a	b	R^2	a	b
	Inches						
Cut bank	4	0.07	103.2	0.15	0.52	116.9	−0.40
	8	0.04	107.7	0.07	0.50	121.8	−0.35
	12	0.02	110.2	0.05	0.60	124.9	−0.41
Inside track	4	0.02	103.1	−0.05	0.66	112.4	0.45
	8	0.32	104.2	0.14	0.69	116.6	0.31
	12	0.70	104.4	0.38	0.25	118.5	0.25
Between track	4	0.39	99.2	0.38	0.29	107.9	0.32
	8	0.67	101.1	0.37	0.33	110.7	0.28
	12	0.71	102.4	0.37	0.01	112.4	0.02
Outside track	4	0.56	99.4	0.34	0.81	103.6	0.89
	8	0.23	101.0	0.20	0.73	106.1	0.72
	12	0.47	101.1	0.35	0.53	105.7	0.51
Fill	4	0.21	93.1	0.29	0.80	101.3	0.82
	8	0.12	95.2	0.28	0.62	104.3	0.72
	12	0.03	95.8	0.06	0.47	106.0	0.60

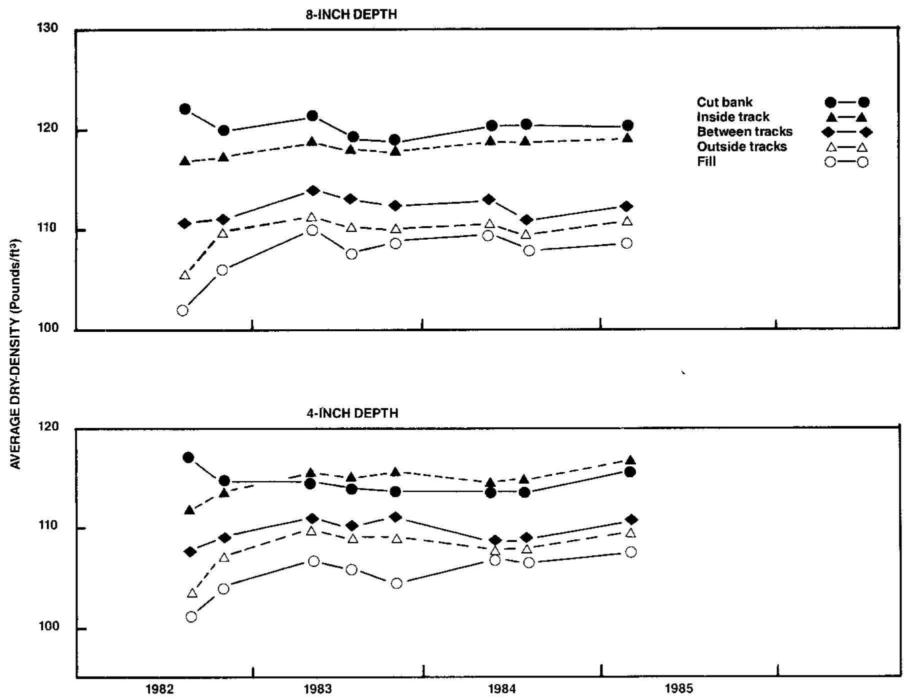

Figure 3.—Average road density of the Canoe road over time at the 4- and 8-inch deposits.

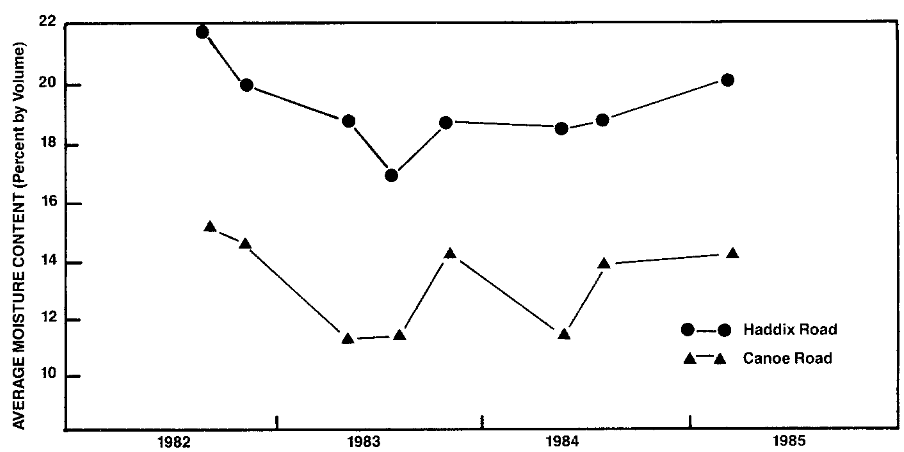

Figure 4.—Average moisture contents of the two roads over time.

Conclusion

The results of this study show a small, but consistent pattern of increasing soil density over time at most sampling locations. Some possible causes for the density changes are as follows. When soil is exposed in a roadbed, it becomes subject to the bombardment of raindrops. Hewlett and Nutter (1969) stated that 1 inch of rain, falling at terminal velocity, generates 50.5 foot-pounds of energy on each square foot of surface area. In the study area, where annual rainfall averages 58 inches, the average annual energy would be more than 2,900 foot-pounds per square foot. This energy compacts the surface layer of soil and overland flow carries the fine soil particles away. The result is a slight increase in soil density over time, as shown by our measurements. Also, average moisture content of the soil decreases slightly over time because infiltration is reduced.

Although the combination of increased density and decreased moisture content of the roadbed would logically improve trafficability, we did not attempt to quantify the degree of improvement. Several tests, including shear strength, resistance to compression and penetration, bearing capacity, and so on, have been developed for rating soils. However, to our knowledge, these tests have not been correlated specifically with trafficability. Such correlations, along with measurements of bulk density and moisture content, would be very useful and should be developed as suggested by Silversides and Koroleff (1949).

Literature Cited

Hewlett, John D.; Nutter, Wade L. 1969. **An outline of forest hydrology.** Athens, GA: University of Georgia Press. 137 p.

Kochenderfer, J. N.; Wendel, G. W.; Smith, H. Clay. 1984. **Cost of and soil loss on "minimum-standard" forest truck roads constructed in the Central Appalachians.** USDA For. Serv. Res. Pap. NE-544. 8 p.

Silversides, C. R.; Koroleff, A. 1949. **Construction and maintenance of forest truck roads.** Woodlands Research Index No. 60 (B-8b), Montreal, Canada: The Pulp and Paper Research Institute of Canada. 137 p.

Helvey, J. D.; Kochenderfer, J. N. 1990. **Soil density and moisture content on two unused forest roads during first 30 months after construction**. Res. Pap. NE-629. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Reports results of soil density and soil moisture measurements on two roads in the central Appalachians over a 30-month period. Density increased slightly during the measurement period at most locations. Almost all of the density changes occurred during the first few months after construction. Moisture content decreased during the first few months after construction, then fluctuated with precipitation amounts.

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