Changes in Soil Bulk Density Resulting from Construction and Conventional Cable Skidding Using Preplanned Skid Trails

Jingxin Wang, Chris B. LeDoux, and Pam Edwards

ABSTRACT

A harvesting system consisting of chainsaw felling and cable skidder extraction was studied to determine soil bulk density changes in a central Appalachian hardwood forest site. Soil bulk density was measured using a nuclear gauge preharvest and postharvest systematically across the harvest site, on transects across skid trails, and for a subset of skid trail transects closest to log landing after each of the first ten loaded machine passes. Bulk density was also measured in skid trails after their construction but prior to skidding. Bulk density did not change significantly across the harvest site, because the extraction equipment stayed on the preplanned skid trails. Bulk density increased on the skid trails as a result of construction by crawler bulldozer and during skidding. Bulk density in the skid trail increased by 30% because of construction by a crawler bulldozer. Fifty-five percent of the increase in bulk density attributable to skidding occurred after one loaded pass, and 80% of the bulk density increase was experienced after two loaded passes. Bulk density increased by only 5% between passes five and ten.

Keywords: soil bulk density, skid trails, skid trail construction, cable skidding, forest operations, Appalachian hardwood forest

Whenever soil is disturbed or compacted, erosion and sedimentation of streams may occur (Martin and Hornbeck 1994). Compaction can also affect the long-term productivity of a stand's soil and alter hydrology. For example, heavy logging equipment may compress and rut the soil during harvesting, which can lead to increased bulk density, loss of soil macroporosity, increased erosion, decreased availability of water, and potential loss of site productivity (Rachael and Karr 1989). Thus, preplanned skid trail networks should be designed to limit the area and degree of soil disturbance and compaction to limit environmental changes.

Many factors influence the degree of soil disturbance/compaction, including site conditions, machine characteristics, and general operations. Equipment use typically is not recommended on wet soils, because moist soils compact more than drier soils (Moehring and Rawls 1970, Greacen and Sands 1980); however, in excessively wet conditions, soil compaction from heavy equipment actually is less than under drier conditions because the water molecules do not allow soil particles to be compressed together. Although soil compaction is less of a concern under these water-saturated conditions, soil disturbance by heavy equipment is much more likely to lead to erosion and sedimentation under wet or dry conditions and should be avoided when possible.

Traffic intensity or the number of machine passes is another significant factor that has the potential to compact and/or puddle forest soils (Aust et al. 1993, McDonald et al. 1995). The use of lighter machines, larger tires, or lower tire pressure can reduce soil compaction (Greene and Stuart 1985, McDonald et al. 1995), but research has shown that the greatest increase in bulk density occurs during the first pass or first few passes (Froehlich et al. 1981, Greene and Stuart 1985, Shetron et al. 1988, McDonald et al. 1995).

In the United States, the effects of forest operations on soil compaction and bulk density have been studied most intensively in the Southeast, where relatively flat terrain and plantation forestry have made intensive silvicultural practices common. Aust et al. (1993) studied soil physical and hydrologic changes caused by wide-tired skidders in the coastal plain of South Carolina. They found that the use of wide tires does not necessarily reduce site disturbance, although wide-tired skidders are the most commonly used machine for logging on wet sites. Visual estimates of soil and site disturbance were conducted to relate quantitative soil and site properties (Aust et al. 1998) or to predict the operability of timber sales in South Carolina (Carruth and Brown 1996). Pote et al. (2000) examined the effects of climate and soil type interactions on probable work days with harvesting machines in Mississippi and Alabama forests. They indicate that sandy soils allow more workdays than clay soils.

In the steeper terrain of the central Appalachian Mountains, forest operations typically are not as intensive with respect to the types of equipment used and the area of a harvest site that actually experiences machine travel. Skidding operations are generally confined to construction skid trails. Although mechanized harvesting with feller-bunchers and grapple skidders has evolved during last the 10–15 years in less steep terrain in the central Appalachians, harvesting with chainsaw and cable skidding is still the dominant system in the region. According to a survey in West Virginia, every logging firm had the capability of felling with chainsaws and skidding with cable skidders, farm tractors, or other similar machines, but only 17% had equipment to perform mechanized harvesting

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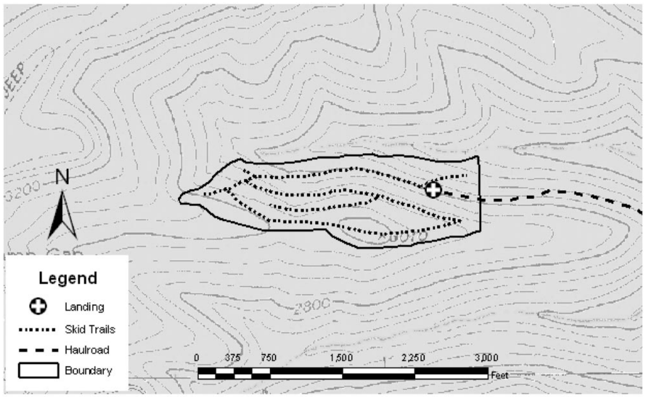

Figure 1. Layout of the harvest tract.

Table 1. Site and harvest information.

Category	Value
Site	
Tract size	31 ac
Volume removed	3,595 bd ft/ac
Species composition	Mixed hardwoods
Slope	35–45%
Aspect	Northeast
Harvest	
Silvicultural method	Selective
Felling machine	Chainsaw
Skidding machine	TJ 460D cable skidder
Skid trail construction machine	Case 650C bulldozer
Skidder tire size	26–28 in.
Weight of skidder	30,245 lb
Skidder payload	641 BF (104 ft^3)

with feller-bunchers and grapple skidders (Milauskas and Wang 2006). Operational production and cost of manual harvesting systems has been studied extensively in central Appalachian hardwood forests (Jones 1983, Brock et al. 1986, Howard 1987, Wang et al. 2004). However, research directly examining soil bulk density changes associated with conventional chainsaw felling and cable skidding systems in the central Appalachians is limited (Egan et al. 2002). Because the rate of forest harvesting is increasing and is expected to continue to increase for some time in states with expansive forestlands in the region, we studied the changes in soil bulk density for a chainsaw/skidder/crawler dozer system using preplanned skid trails.

Methods

The study site was 31 ac in size and was located on MeadWestvaco's forestland in Randolph County, West Virginia (Figure 1 and Table 1). The study area was on a north-facing 30–40 percent slope. Elevation ranged from 2,600 ft at the creek bottom to 3,010 ft at the ridge top. Soils on the site are mapped primarily as the Gilpin series, with some Buchanan series near the valley bottom. Gilpin soils are residual and are found on ridge tops, benches, side slopes. They are well-drained and moderately deep. The Buchanan series is colluvial, consisting of deep, moderately well-drained, acidic soils and commonly found on foot slopes, on drainage ways, on benches, and in coves (US Soil Survey Division 2001). The network of skid trails was preplanned with the intension of requiring the skidder to stay on the skid trail and winch logs to the trail.

The system used for harvesting consisted of two timber fallers using chainsaws, one rubber-tired cable skidder, and one bulldozer (Table 1). A selective cut was used and approximately 3,600 board feet (BF) of wood were harvested per acre.

Soil bulk density, a measurement of soil compaction, was determined on the harvest unit and on transects in the skid trails. Soil bulk density was also measured on the skid trails before and after construction. In our study, dry soil bulk density was calculated as follows.

$$\text{Dry bulk density (lb/ft}^3\text{)} = \frac{\text{Mass of dry soil (lb)}}{\text{Total volume of soil (ft}^3\text{)}} \tag{1}$$

A Troxler Model 3440 density and moisture gauge was used to determine dry bulk density 6 in. below the soil surface. Throughout the harvest unit, 30 sample centers were located systematically in a 3- by 3-chain grid prior to treatment. Four measurements were taken around each sampling center at random directions and distances up to 15 ft from the center point before the site was disturbed, following trail construction, and then after harvesting. Six bulk density measurements were taken across each of 10 randomly located transects across all skid trails in the tract; these measurements were made immediately after the skid trails were constructed but before any loaded passes had been made on them, and then after skid trail use was completed ($n = 60$ total measurements for pre- and postuse). Bulk density for each of the first 10 loaded-skidder/dozer passes also was monitored on the four skid trail transects (described above) that were located closest to a log landing. Skid trail transects closest to the log landing were measured because these portions of the skid trail generally experiences more passes with loaded machines than those farther from the landing. A Trimble GeoXT GPS unit was used to map, record, and relocate bulk density measurement locations throughout the harvest unit and on the skid trails.

Soil bulk density changes were computed as the differences between postharvest and preharvest bulk densities, between postconstruction of the skid trails and preharvest bulk densities, and postuse and preuse bulk densities of skid trails used by loaded machines. Statistical tests were used to determine whether significant differences existed in soil bulk density changes for both the harvest and skid road measurements. A correlation matrix was developed to examine whether the bulk density measured after each of the loaded passes was significantly different from the first loaded pass and whether there were differences between each pass and the subsequent pass (i.e., comparing passes i and $i + 1$).

Results

Bulk Density within the Harvest Unit

Bulk density measurements that were made off the road system did not increase significantly from the harvesting ($P = 0.4280$). Prior to harvesting, bulk density averaged 65.8 lb/ft^3 and ranged from 45.0 to 97.6 lb/ft^3 (Table 2). In contrast, after harvesting was completed, the bulk densities at the same measurement points averaged just 1.2 lb/ft^3 greater (mean = 67.0 lb/ft^3); the lowest measured bulk density was the same as that measured during pretreatment, and the highest measured value was approximately 16.4 lb/ft^3 greater than the highest value measured before harvesting.

The logging equipment stayed on the skid trails, and cables were pulled to the trees, which were then winched to the trail. The lack of a significant increase in bulk density at the 120 sampling points

Table 2. Statistics of bulk density changes for measurements points within the harvest unit and in the skid trails.

		Mean	Standard deviation	Minimum	Maximum
		Within harvest unit			
Preharvest	Bulk density (lb/ft^3)	65.8	10.4	45.0	97.6
Postharvest	Bulk density (lb/ft^3)	67.0	13.9	45.0	114.0
	Bulk density change[a] (lb/ft^3)	1.2		0	16.4
		In skid trails			
Preuse	Dry bulk density (lb/ft^3)	85.9	11.5	60.0	103.6
Postuse	Dry bulk density (lb/ft^3)	93.2	9.9	68.6	110.2
Preuse	Bulk density change[b] (lb/ft^3)	20.1		15.0	6.0
Postuse	Bulk density change[c] (lb/ft^3)	7.3		8.6	6.6

[a] Difference between postharvest and preharvest bulk densities.
[b] Difference between preuse and preharvest bulk densities.
[c] Difference between postuse and preuse bulk densities.

Table 3. Probabilities that mean soil bulk density comparisons were significantly different between machine passes. Comparisons are statistically significant if the probability value is <0.05.

	No. of loaded-machine passes										
No. of passes	0	1	2	3	4	5	6	7	8	9	10
0											
1	0.0162										
2	0.0008	0.2550									
3	0.0009		0.9960								
4	0.0024			0.6974							
5	0.0002				0.3526						
6	0.0001					0.8560					
7	0.0002						0.8023				
8	0.0001							0.8214			
9	0.0002								0.8279		
10	0.0004									0.8316	

across the harvested area indicates that skidding and log dragging had a limited effect on bulk density changes.

Bulk Density in the Skid Trails

The preplanned skid trails were constructed using a bulldozer; thus, bulk density on the skid trails was significantly higher than the soil within the general harvest area before harvesting began ($P = 0.0001$). The bulk density in the skid trails increased 30% from 65.8 lb/ft^3 before construction to 85.9 lb/ft^3 after construction (Table 2). The bulk density on the skid trails averaged 85.9 lb/ft^3 following construction (range, 60.0–103.6 lb/ft^3) but before any loaded skidding passes (Table 2). After skid trail use was completed, average bulk density increased significantly ($P = 0.0003$) to 93.2 lb/ft^3 (range, 68.6–110.2 lb/ft^3). However, it should be noted that although the average bulk density increased by 7.3 lb/ft^3, the bulk density at some measurement points did not increase at all.

First 10 Loaded-Machine Passes

Statistical comparisons using a *t*-test showed that the bulk density after the first loaded pass was significantly different from the initial bulk density without any loaded passes ($P = 0.0162$) (Table 3). However, the soil bulk density changes were not significantly different between two consecutive passes after the first pass at $\alpha = 0.05$ level. For example, the bulk density after two passes did not differ significantly from the bulk density after the first pass ($P = 0.2550$), and the density after three passes was not significantly different from the density after two passes ($P = 0.9960$) (Table 3). These results suggest that most of the soil bulk density changes occurred after one loaded machine pass in the skid trails.

Average bulk density increased dramatically, from 85.5 to 92.8 lb/ft^3 after one loaded machine pass and to 96.1 lb/ft^3 after two machine passes in the skid trails; it then leveled out through pass three (Figure 2). There was a slight decrease in bulk density in the skid trails after pass four, followed by gradual increasing trend through pass 10, at which the bulk density neared 98.9 lb/ft^3. If we assume that essentially 100% of the bulk density change that could occur did occur by pass ten, approximately 55% of the change occurred after one loaded machine pass and 80% of the change occurred after two passes (Figure 2). After five passes, the soil bulk density change level reached 95% in the skid trails.

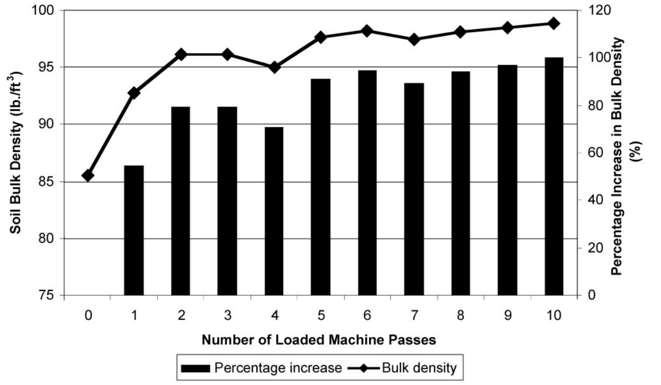

Figure 2. Average soil bulk density and percentage increase for each of the first 10 loaded machine passes on the skid trail transects nearest to the log landing.

Considerations for Managers

In this study, there was no significant change in bulk density after harvest within the harvest unit. However, the preuse soil bulk density in the preplanned skid trails was significantly changed because of construction with a bulldozer. It increased 30% or 20.1 lb/ft^3, from 65.8 to 85.9 lb/ft^3. The bulk density in the skid trails after one loaded machine pass was also significantly different from the bulk density after trail construction but without any loaded machine passes. However, there was no significant bulk density change between two consecutive loaded passes after pass one. The bulk density increased 8% from 85.5 to 92.8 lb/ft^3 after one pass, 12% to 97.7 lb/ft^3 after five passes, and 16% to 98.9 lb/ft^3 after 10 passes.

The cable skidder operator on the site sometimes skidded logs from the same point along the skid trail three or four times before moving to another location. The Timberjack 460D cable skidder used in the study had a ground pressure of 7.2 psi and a tire size of 26–28 in. that could contribute to the relatively higher bulk density changes across the site and in the skid trails.

Whenever mineral soil is exposed, the risk of soil erosion is increased, and nutrients can be exported from a site in solution or by mass transport (Jurgensen et al. 1997, Alcazar et al. 2002). Alcazar et al. (2002) studied soil disturbance and the potential for erosion after mechanical site preparation and suggested that managers must achieve a balance in mechanical site preparation between too much and too little soil disturbance. Timber harvesting is likely to have greater impacts on soil properties, species composition, and future productivity than any other activity during the rotation (Stone 2002). Heavy compaction could reduce stem biomass production by about 12 percent overall (Ponder 2003, Souch et al. 2004). Stone (2002) also indicated that best management practices (BMP) guidelines could be effective in communicating management objectives to foresters and loggers, increasing their sensitivity to soil compaction or disturbance, and thus contribute to sustaining future productivity. In our study, we experienced no significant change in bulk density throughout the site. Thus, we can infer from this that there would be no increase in erosion, sedimentation, or loss of forest productivity due to the harvest. This result is caused by the use of preplanned skid trails and requiring the skidder to stay on the trail during the harvesting process. Our results also suggest that bulk density changed significantly on the skid trail because of construction activities by the bulldozer. This result is as expected and could lead to an increase in erosion and sedimentation and a loss in forest productivity on the skid trail. Careful attention to BMP guidelines for seeding, mulching, and waterbarring the skid trail could serve to control much of the erosion and sedimentation. The loss in forest productivity within the skid trail could be mitigated by mechanical site preparations such as tillage followed by seeding. Alternatively, the area in skid trails could be viewed as part of the permanent transportation network for that site, and as such, that area would be taken out of production.

Our results support the recommendations of state BMP to focus skidding to a few well developed preplanned designated skid trails and minimize trafficking across the general harvest area to protect soil (and water) resources. The findings from this study suggest that (1) most bulk density increase on skid trail is caused by construction and after the first loaded machine pass, (2) preplanned skid trails minimized bulk density increase on overall site, and (3) emphasis should be placed on the amount of permanent trail constructed by careful planning.

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