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Susceptibility of Volcanic Ash-Influenced Soil in Northern Idaho to Mechanical Compaction

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Abstract—Timber harvesting and mechanical site preparation can reduce site productivity if they excessively disturb or compact the soil. Volcanic ash-influenced soils with low undisturbed bulk densities and rock content are particularly susceptible. This study evaluates the effects of harvesting and site preparation on changes in the bulk density of ash-influenced forest soils in northern Idaho. Three different levels of surface organic matter were studied. Soil samples were taken before and after harvesting to determine the extent and depth of compaction. Soil bulk densities increased significantly after extensive compaction from site preparation, especially when little logging slash and surface organic matter were left on the soil surface. As site preparation intensity increased, bulk density increased significantly at greater depths in the soil profile. Although ash-influenced soils have naturally low bulk densities, they can easily be compacted to levels that limit growth. This experimental site has been designated as part of the Forest Service's national long-term site productivity study into the impacts of organic matter depletion and soil compaction on stand development.

Keywords: bulk density, forest productivity, ash-cap soils, logging, logging effects, soil density, site preparation

Land managers have long been concerned that timber harvesting and mechanical site preparation might harm forest productivity. The Intermountain West has extensive areas of forested land on volcanic ash soils (Geist and others 1989). These areas are highly productive, but prone to compaction because they have a low volume weight (weight-to-volume ratio) and relatively few coarse fragments in the soil profile (Geist and Cochran 1991). Their undisturbed bulk density is about 0.70 g/cm^3, porosity 77 percent, coarse fragments 20 percent, and available water 25 percent (see Geist and Cochran 1991).

Froehlich and others (1985) note a predictable decline in seedling height growth as soil bulk density increases. They also conclude that the effects of compaction can last up to 45 years. Soil compaction in a central Oregon clearcut caused a significant decline ($p \leq 0.05$) in seedling growth after 5 years (Cochran and Brock 1985). Soil compaction also lowers soil porosity (Dickerson 1976; Moehring and Rawls 1970) and hydraulic conductivity (Gent and others 1984).

These studies indicate timber harvesting increases compaction. Relatively little information, however, relates the quantity of residual organic matter and the intensity of site preparation to compaction levels in the soil profile before and after harvest. This study compares soil bulk densities before and after timber harvest for three intensities of site preparation and three levels of organic matter conservation on a volcanic ash soil in northern Idaho.

METHODS

This study was conducted on a bench adjoining the Priest River at the Priest River Experimental Forest, Priest River, ID. The study area receives about 83.8 cm of precipitation annually, with a mean annual temperature of 6.6 °C (Wellner 1976). The habitat type is classified as *Tsuga heterophylla/Clintonia uniflora* (Cooper and others 1991). The soil has a silt loam surface layer 28 to 38 cm thick derived from Mount Mazama volcanic ash. The subsoil is 50 to 75 cm thick. It is a silty clay loam derived from glacial lacustrine (lake) sediments. These are underlain at depths of 60 to 100 cm by gravelly to very gravelly sands and sandy loams deposited by alluvial processes. The soil is a medial, frigid Ochreptic Fragixeralf (Mission series). Before harvest, the site consisted of a well-stocked

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stand of about 90-year-old western white pine (*Pinus monticola* Dougl. ex D. Don), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), and western larch (*Larix occidentalis* Nutt.). In the past, the site was part of the Priest River Arboretum. Approximately 40 years ago some western white pine was selectively harvested, creating one skid trail. This skid trail became part of the buffer around the treatment plots.

This site was divided into nine 0.8-ha plots surrounded by a 200-m buffer. Trees were directionally felled and skidded along a central skid trail or from the plot boundaries to prevent compaction during harvesting. The treatments followed a three-by-three factorial design of three levels of residual organic matter and three levels of site preparation, yielding nine types of treatments. Organic matter treatments were: (1) bole only removal in which the limbs were lopped on the plot before skidding, (2) bole and crown removal in which the entire tree was removed from the plot, and (3) bole and crown removal and surface organic matter displacement in which entire trees were removed and slash and surface organic matter were displaced from the plot. Compaction levels consisted of (1) none, (2) moderate, and (3) extensive. Compaction-free plots did not have any equipment on them during harvesting or site preparation. Moderate compaction was achieved by driving a Grappler log carrier over the plots twice. Extensive compaction was obtained with four passes with a D-6 Caterpillar tractor. On compacted plots with surface organic matter debris was removed with the first tractor pass to prevent organic and mineral components from being mixed. The organic matter was then evenly redistributed on the plots.

In each 0.8-ha plot, 16 locations were established on a 20-m grid. At each grid point bulk density samples were taken with a core sampler. Samples were taken at 0 to 4-cm, 8 to 16-cm, and 16 to 20-cm depths. Soil moisture during site preparation averaged 25 percent.

The differences in the means of soil bulk densities before and after harvest were compared at the 95 percent confidence interval. A paired *t* test was used to compare means.

RESULTS AND DISCUSSION

Figure 1 shows the effects of harvest method and site preparation on soil bulk densities. When harvest activities were restricted to the designated skid trail, the soil densities were no greater after harvest than before. However, as site preparation encompassed more of the site, the number of passes by heavy equipment increased, or smaller amounts of organic residue were left on the site, bulk density began to increase significantly. The average soil bulk density increased from 0.65 to 0.81 g/cm^3 with extreme compaction when just the boles were removed. But even after harvest, the average bulk density was still much lower than that of many coarse-textured soils in this region, which can average greater than 1.0 g/cm^3. However, bulk density increased more than 20 percent with four vehicle

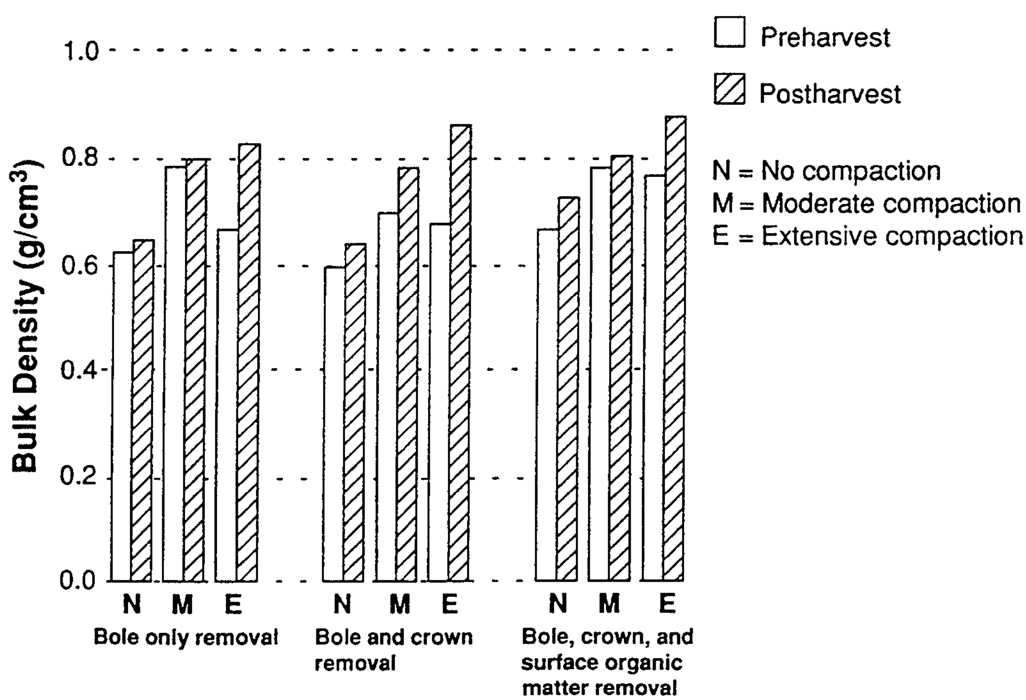

Figure 1—The effects of timber harvesting and site preparation soil bulk density, averaged for three soil depths.

Table 1—The effects of harvesting and site preparation on average bulk density at three soil depths

Treatment	Preharvest			Postharvest		
	0-4 cm	8-12 cm	16-20 cm	0-4 cm	8-12 cm	16-20 cm
	g/cm³					
No site preparation						
Bole only removal	0.43a[1]	0.67a	0.75a	0.48a	0.71a	0.73a
Bole and crown removal	.46a	.61a	.69a	.50a	.68a	.70a
Bole and crown removal and surface organic matter displacement	.53a	.68a	.77a	.63a	.76a	.76a
Moderate site preparation						
Bole only removal	.71a	.78a	.81a	.71a	.82a	.84a
Bole and crown removal	.60a	.67a	.78a	.70a	.78b	.83a
Bole and crown removal and surface organic matter displacement	.66a	.78a	.80a	.78a	.81a	.82a
Extensive site preparation						
Bole only removal	.54a	.69a	.75a	.71b	.71a	.84a
Bole and crown removal	.55a	.74a	.72a	.74b	.85a	.86b
Bole and crown removal and surface organic matter displacement	.65a	.75a	.84a	.84b	.85a	.91b

[1]Different letters indicate significant differences between pre- and postharvest samples for each depth ($p \leq 0.05$).

passes. Large increases in bulk density have been reported to a depth of about 5 cm with the first vehicle pass over the soil (Kroger and others 1984; Miles and others 1981).

Leaving woody residue and surface organic matter on the site protects mineral soil from detrimental compaction; it also reduces erosion (Gilmour 1977; Rice and Datzman 1981) and maintains soil nutrition (Page-Dumroese and others 1991) and soil microbe populations (Jurgensen and others 1991). In Vermont, bark mulch applied on a sandy loam soil effectively reduced increases in bulk density from activities that compacted the soil (Donnelly and Shane 1986).

In this study, soils were compacted in the spring when the soil moisture content was about 25 percent. Soil moisture content affects the compactability not only of cohesive soils, but also of noncohesive soils, in which compaction can occur throughout a wide range of soil moisture contents (Davis 1992). Effects similar to those reported in this study could be expected throughout most of the growing season on noncohesive soils.

Site preparation compacted soil deep in the soil profile. Table 1 shows significant increases in bulk density at both the 0 to 4-cm and 16 to 20-cm depths after extensive site preparation. There were no significant differences at the 8 to 12-cm depth. However, at the 16 to 20-cm depth significant increases in bulk density were associated with both the bole and crown removal treatment and the bole, crown, and surface organic matter removal treatment. In the bole only removal treatment, bulk density increased significantly only at the surface. In the moderate site preparation treatments increases in bulk density were rarely significant. However, surface bulk density increased more than 20 percent after two passes of the Grappler when the bole and crown and bole, crown and surface organic matter were removed. On volcanic ash soils in Oregon soil bulk density at the 0 to 20-cm depth increased 35 percent after harvesting and site preparation (Davis 1992). Bulk density increases proportionally with the square root of the number of passes over the same area (Reisinger and others 1988). Most soil damage is seen after one to four passes (Gent and others 1984; Kroger and others 1984).

Compaction on some volcanic ash soils persists for decades (Froehlich and others 1985), depending on the degree of initial change. The degree of initial change depended on soil texture, moisture, structure, number of machine passes, and loading and operator skills (Geist and Cochran 1991). On many sites in the Inland Northwest, deep snow cover early in the winter limits the amount of soil recovery from frost action. The soils in this study have less than 20 percent clay content by weight and very little shrink-swell potential. Therefore, compaction within the soil profile may remain high for many decades until a new stand is ready to be harvested.

Compaction, as measured by changes in bulk density, has been shown to reduce the growth of many commercial timber species. On well-drained soils in Oregon formed from Mount Jefferson ash (Cochran and Brock 1985), compaction reduced the height of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) seedlings for 5 years after planting. Compaction or displacement of organic material significantly reduced one or more growth variables of 15 to 25-year-old lodgepole (*Pinus contorta* Dougl. ex Loud.) and ponderosa pine in north-central Idaho (Clayton and others 1987). Froehlich (1979) has suggested compaction may reduce seedling growth for at least 14 years.

MANAGEMENT IMPLICATIONS

Given the slow rate of natural soil recovery, land managers are concerned about long-term site degradation as soils are compacted or displaced. Direct losses in productivity are often difficult to measure. Reduced seedling growth or long-term losses in soil nutrient content, porosity, and infiltration depend on the percentage of area affected and the rate of the soil's recovery (Clayton and others 1987). Productivity declines associated with compaction are reversible, given enough time for recovery (Froehlich and others 1985). While reduced growth associated with soil displacement is more difficult to quantify, it may result in irreversible long-term impacts (Harvey and others 1989). Geist and others (1989), Froehlich (1979), and Davis (1992) suggest shifting harvest strategies toward the use of designated skid trails, directional felling, and line pulling to reduce the area affected. In some locations, use of a grapple-piler to pile logs can reduce compaction because grapple-pilers apply less pressure on the ground than crawler-tractors used for bulldozer-piling. Leaving the tops of trees and surface organic matter on the site also may reduce the amount of compaction. With the increasing emphasis on uneven-aged management, the effects of multiple-stand entries on compaction of these soils will have to be assessed.

REFERENCES

Clayton, J. L.; Kellogg, G.; Forrester, N. 1987. Soil disturbance-tree growth relations in central Idaho clearcuts. Res. Note INT-372. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 6 p.

Cochran, P. H.; Brock, T. 1985. Soil compaction and initial height growth of planted ponderosa pine. Res. Note PNW-434. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 4 p.

Cooper, S. V.; Neiman, K. E.; Roberts, D. W. 1991. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 143 p.

Davis, S. 1992. Bulk density changes in two central Oregon soils following tractor logging and slash piling. Western Journal of Applied Forestry. 7: 86-88.

Dickerson, B. P. 1976. Soil compaction after tree-length skidding in northern Mississippi. Soil Science Society of America Journal. 40: 965-966.

Donnelly, J. R.; Shane, J. B. 1986. Forest ecosystem responses to artificially induced soil compaction. I. Soil physical properties and tree diameter growth. Canadian Journal of Forest Research. 16: 750-754.

Froehlich, H. A. 1979. Soil compaction from logging equipment: effects on growth of young ponderosa pine. Journal of Soil and Water Conservation. 34: 276-278.

Froehlich, H. A.; Miles, D. W. R.; Robbins, R. W. 1985. Soil bulk density recovery on compacted skid trails in central Idaho. Soil Science Society of America Journal. 49: 1015-1017.

Geist, J. M.; Cochran, P. H. 1991. Influences of volcanic ash and pumice deposition on productivity of western interior forest soils. In: Harvey, A. E.; Neuenschwander, L. F., comps. Proceedings—management and productivity of western-montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 82-89.

Geist, J. M.; Hazard, J. W.; Seidel, K. W. 1989. Assessing physical conditions of some Pacific Northwest volcanic ash soils after forest harvest. Soil Science Society of America Journal. 53: 946-950.

Gent, J. A., Jr.; Ballard, R.; Hassan, A. E.; Cassel, D. K. 1984. Impact of harvesting and site preparation on physical properties of Piedmont forest soils. Soil Science Society of America Journal. 48: 173-177.

Gilmour, D. A. 1977. Logging and the environment, with particular reference to soil and stream protection in tropical rainforest situation. In: Conservation guide 1: guidelines for watershed management. Rome: Food and Agriculture Organization: 223-225.

Harvey, A. E.; Meurisse, R. T.; Geist, J. M.; [and others]. 1989. Managing productivity processes in the Inland Northwest—mixed conifers and pines. In: Perry, D. A.; [and others], eds. Maintaining the long-term productivity of Pacific Northwest forest ecosystems. Portland, OR: Timber Press: 164-184.

Jurgensen, M. F.; Tonn, J. R.; Graham, R. T.; Harvey, A. E.; Geier-Hayes, K. 1991. Nitrogen fixation in forest soils of the Inland Northwest. In: Harvey, A. E.; Neuenschwander, L. F., comps. Proceedings—management and productivity of western-montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 101-109.

Kroger, J. L.; Burt, E. C.; Trouse, A. C., Jr. 1984. Skidder tire size vs. soil compaction in soil bins. Transactions of the American Society of Agricultural Engineers. 27: 655-669.

Miles, J. A.; Hartsough, B. R.; Avalani, P.; Chancellor, W. J. 1981. A soil compaction study on the Blodgett Experimental Forest. In: Forest regeneration: Proceedings of the symposium on engineering systems for forest regeneration; 1981 March 2-6; Raleigh, NC. St. Joseph, MI: American Society of Agricultural Engineers: 72-82.

Moehring, D. M.; Rawls, I. W. 1970. Detrimental effects of wet weather logging. Journal of Forestry. 68: 166-167.

Page-Dumroese, D.; Harvey, A.; Jurgensen, M.; Graham, R. 1991. Organic matter function in the western-montane forest soil system. In: Harvey, A. E.; Neuenschwander, L. F., comps. Proceedings—management and productivity of western-montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 95-100.

Reisinger, T. W.; Simmons, G. L.; Pope, P. E. 1988. The impact of timber harvesting on soil properties and seedling growth in the South. Southern Journal of Applied Forestry. 12: 58-67.

Rice, R. M.; Datzman, P. A. 1981. Erosion associated with cable and tractor logging in northwestern California. International Association of Scientific Hydrology. 132: 362-374.

Wellner, C. A. 1976. Frontiers of forestry research - Priest River Experimental Forest, 1911-1976. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 148 p.

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