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Assessing Physical Conditions of Some Pacific Northwest Volcanic Ash Soils After Forest Harvest

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ABSTRACT

A study of impacts of forest harvest on volcanic ash soils was conducted on three National Forests in the Blue Mountains of Eastern Oregon and Washington. Surface soil conditions were assessed in 11 forest harvest units; sampling employed a randomly positioned grid of randomly oriented line transects. In addition, air permeameter readings were tested in seven units for correlation with bulk density values obtained from core samples. Most of the detrimental soil conditions detected were attributable to compaction. Displacement, although readily apparent during harvest or slash piling with ground-based equipment, was nearly undetected by the methods used on these units, which ranged from 14 to 23 yr old. Detrimental compaction averaged 28 or 19% of the harvest unit area when defined as either a 15 or 20% increase in bulk density, respectively. Area percentages included skid trails and landings but not the transportation system. Statistical tests showed that either 5 or 3 of the 11 units exceeded 20% area in detrimental condition, depending on degree of bulk density increase used to define detrimental compaction. Several other units were borderline in exceeding 20% of the area. Given slow recovery from compaction, there is potential for additional area to be adversely impacted by future entries. Air permeameter readings were poorly correlated with bulk density assessments, even though six of seven correlations were statistically significant. Less than 12% of the total variability was accounted for by regression analyses. The air permeameter does not appear to be accurate enough to measure compaction in volcanic ash soils.

INTEREST IN THE ABILITY of forests and rangelands to sustain long-term productivity has risen in recent years. Within the field of forestry, concerns are commonly related to the effects of harvesting activities on the soil resource. Effects including soil compaction, displacement, and erosion are of concern because they can reduce growth of the remaining or ensuing tree crop. Earlier and recent studies of reduced growth have commonly been directed toward the association with compaction, but other impacts are of concern (Lull, 1959; Berg, 1975; Dickerson, 1976; Froehlich, 1979; Wert and Thomas, 1981). On federal lands in the USA, managers are directed to maintain productivity by the National Forest Management Act of 1976, the Forest Land Policy and Management Act of 1976, and the National Environmental Protection Act of 1969.

Aside from research studies, information about changes in forest soil qualities associated with harvest is very limited, so decision making commonly lacks localized data about consequences of management activities, past or present. Sampling to detect soil damage is difficult, and in forestry, little experience exists to help define how, what, where, when, and how often soil sampling is necessary to assess productivity influences. Even so, concerns have led to the adoption of harvest strategies designed to prevent and minimize soil damage.

Extensive logging was conducted in the Blue Mountains before the adoption of preventive strategies, and little knowledge exists about the effects of earlier practices on soil properties. Such information has potential implications on yield forecasts and resource management planning. Our research was aimed at filling some of these knowledge gaps.

We focused our research on volcanic ash soils because of their extensive area of occurrence in the Pacific Northwest and their relatively high inherent productivity. These soils support a large proportion of the commercial forest acreage in the area we studied. Our objectives were: (i) to assess the nature and extent of altered physical conditions resulting from traditional harvest methods using ground-based equipment on volcanic ash soils in the Blue Mountains of eastern Oregon and Washington; (ii) to assess requirements for sampling soil damage using line transects at several specified levels of precision and statistical probability; (iii) to evaluate the potential for using a portable air permeameter as a rapid field indicator of bulk density to diagnose compacted conditions.

METHODS

Eleven forest harvest units in three National Forests (Umatilla NF, five units; Malheur NF, three units; and Wallowa Whitman NF, three units) were sampled to assess postharvest soil conditions. Age of the units ranged from 14 to 23 yr. Logging and slash piling were done by crawler tractor on 10 units; one was logged by feller buncher, and a rubber-tired skidder was employed on two units. Ten were clearcuts and one was a seed tree cut where overwood was not removed. The 11 units provided a good cross-section of the variability of Blue Mountain ash soils and the effects of traditional harvest practices. Units of this age were used because we wanted to know whether harvest effects existed in soils of these older units, and if found, we wanted to use the soil data base to test relationships with tree growth. Older

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units were also needed to provide trees of sufficient growth history for the follow-up measurements.

Before harvest, the study soils generally consisted of about 50 cm (20 in) of silt loam volcanic ash, which overlies a loam to clay loam buried soil of varied depth. These soils, and closely related shallower andic intergrades, included what we believe were members of the Tolo series (medial over loamy, mixed frigid Typic Vitrandepts), Helter series (medial over loamy, mixed Entic Cryandepts), and the Olot series (loamy-skeletal, mixed Mollic Eutroboralfs). The volcanic ash overburden typically has a low content of coarse fragments, whereas significant amounts can occur in buried soil horizons. Bulk densities vary relatively little within the ash overburden, as there is little textural variation within, but abrupt changes occur at the buried soil boundary (Geist and Strickler, 1978).

Associated plant communities were: lodgepole pine–pine grass–grouse huckleberry (*Pinus contorta* Dougl.–*Calamagrostis* Adans.–*Vaccininum scoparium* Leiberg); lodgepole–grouse huckleberry; white fir–twinflower–forb [*Abies grandis* (Dougl.) Forbes–*Linnaea* L.]; and white fir–grouse huckleberry (Hall, 1973). Elevations ranged from 1462 to 1813 m (4800 to 5950 ft), and slopes averaged 3 to 35%.

Our approach to characterization of soil disturbance was to use the line transect method of sampling soil conditions developed by Hazard and Geist (1984) for U.S. Forest Service use in Oregon and Washington. The methodology for field application is described in a user's manual (Howes et al., 1983) prepared for test application of the system. Briefly, the design is a systematic grid of points randomly located over the harvest unit to be sampled. Our sampling covered the operable area, which excluded the primary transportation system but included skid trails and landings. From each grid point, a randomly oriented line transect extended 30 m (100 ft). The number of grid points (and thus transects) was set at 15 for each harvested unit. We sampled surface soil condition in four detrimental (damaged) classes (compacted, displaced, puddled, eroded) or as undisturbed or deposited classes. Classes were recognized visually and their extent measured by determining the length of each transect line contained in each class. Lengths were converted to line percentages that equate directly to area percentages. Three line transects were also established in adjacent unharvested area. Ten soil core samples per transect were obtained to supplement visual compaction assessments. Cores were taken within the 10- to 15-cm (4–6 in.) depth at 3.3-m (10-ft) intervals along each line, bulk density was measured, and the proportion of line in damaged compacted condition class was calculated. Class percentages in damaged soil condition were added to obtain the total percentage area damaged; areas with more than one damage condition were accounted for only once.

There were potentially 150 cores from harvested and 30 cores from unharvested portions of each unit. The criteria for determining compaction damage was based on amount of change in bulk density on an individual core basis. The reference bulk density value, against which change was compared for an individual harvested area, was the average bulk density of the 30 core samples obtained from the three transects on unharvested area.

In 7 of the 11 harvest units, both an air permeameter and core sampler were used to test relations between bulk density and air permeameter readings. The same sampling depth and point was used for both sampling tools to pair the data collected. The permeameter was patterned after one described by Steinbrenner (1959). The maximum reading was set at 103.5 kPa (15 psi). Core samplers contained retaining rings, about 50 cm^3 in volume (ca. 25 mm high and 50-mm diam.). Core samples were taken only in the ash overburden, and we accepted only those cores unaffected by root or coarse fragment interference during sampling. In a few instances an acceptable core could not be obtained, and the total number of cores was reduced accordingly. High quality samples were comparatively easy to obtain in ash layers. Core samples were stored in air-tight cans that were later weighed, oven-dried, reweighed, sieved to 2 mm to separate coarse fragments; the resulting fractions were again weighed. Adjustments for the weight and volume of coarse fragments (specific gravity of 2.65 Mg m^{-3}) were made in bulk density computations for the soil fraction. We developed two computer programs to summarize field and laboratory data. One calculated soil bulk density of cores and field soil moisture (Starr and Geist, 1983); the other estimated the percentages of area in various soil condition classes, together with indices of precision for each class (Hazard et al., 1985). Frequency histograms of bulk density were also prepared for each sample area to examine the distributions. Regressions were computed between percentage change in average bulk density resulting from harvesting and the percentage area having compaction damage.

The relations between bulk density and the air permeameter were tested by regression analysis, and for one harvest unit, by multiple regression with soil moisture as a second independent variable. Although the permeameter tested was fashioned after that of Steinbrenner (1959), our objective in testing was not the same as his. We used the same upper pressure limit, but we made no attempt to relate readings to macroporosity as he did. We tested the hypothesis that no correlation existed between air permeameter readings and bulk density. In a multiple regression analysis of data where correlation was lowest, we tested the hypothesis that no significant improvement occurred in the regression by including soil moisture. The probability level used for tests of significance was $P \leq 0.05$.

Compaction and displacement were the only damage classes detected, hence our results are limited to those classes. The definitions and testing limits used are commonly applied in the Pacific Northwest. They were:

1. Soil damage level of compaction was designated as $\geq$15 or $\geq$20% higher bulk density than the mean bulk density of the three transects in the unharvested portion associated with a harvest unit; both percentages are commonly applied.
2. Displacement was horizontal removal of more than half of the A horizon from 9.3 m^2 (100 ft^2) or greater area, at least 1.5 m (5 ft) in width.
3. Units were tested to determine whether total damage was $\leq$20% of the area at $P \leq 0.05$.

RESULTS

Sizeable percentages of harvested areas were found to be in damaged condition, but the percentages differed in relation to definitions of compaction damage used. Soil displacement made up a very small amount of the damage detected by methods and definitions used. Other soil damage classes were undetected. Soil coring and processing were the most time consuming parts of the field and laboratory operations. Data summarization posed no difficulties. The average proportion of total area damaged among the 11 harvest units, using the 15% compaction standard, ranged from 19 to 44% (Table 1). Ten values were >20%; however, only 5 of these were significantly >20% standard for total damage in statistical tests. The remaining units were apparently borderline, because of inherent variability of the data. When the 20% compaction standard was used, the percentage area sustaining compaction damage declined overall from 28 to 19%. Total damage values among the study units then ranged from

Table 1. Average bulk densities, percentage change in bulk density, and area percentages of soil damage under the two compaction standards.

Harvest unit	Bulk density			Percentage soil damage			
	Unharvested area†	Harvested area†	Percent change	Compacted	Total damage	Compacted	Total damage
	Mg m^{-3}		%	15% standard		20% standard	
Boundary	~~0.668~~ ± 0.058	0.711 ± 0.083	6	23	25	14	16
Anthony	0.637 ± 0.053	0.669 ± 0.082	5	20	21	10	12
Cow Meadow	0.664 ± 0.061	0.795 ± 0.159	20	44	44*	36	36*
John Day	0.714 ± 0.043	0.800 ± 0.123	12	36	37*	27	30*
Frosty 1	0.707 ± 0.043	0.762 ± 0.093	8	27	27*	18	18
Frosty 2	0.676 ± 0.039	0.726 ± 0.086	7	23	23	15	15
English Springs	0.668 ± 0.059	0.694 ± 0.100	4	21	21	13	14
Jungle Springs 5	0.652 ± 0.066	0.660 ± 0.094	1	18	19	12	13
Jungle Springs 7	0.633 ± 0.065	0.669 ± 0.088	10	34	34*	19	19
Swamp Creek	0.610 ± 0.056	0.685 ± 0.091	12	40	41*	31	31*
Upper Pataha 7	0.735 ± 0.040	0.800 ± 0.102	9	24	24	17	17
Means	0.669	0.725	9	28	29	19	20

* Significantly >20%, at $P \leq 0.05$.

† Means and standard deviation.

12 to 36%, only three tested significantly >20% area, and three units appeared to be borderline.

Average bulk densities for unharvested and harvested conditions varied among units. The unharvested averages of bulk density ranged from 0.610 to 0.735 Mg m^{-3}. The standard deviations ranged from 5 to 10% of the averages. The unharvested average for some units exceeded what would be a damage level of compaction in other units. Average bulk densities for harvested conditions appear to be higher, as do the standard deviations (12–20% of the averages).

There is a high and statistically significant correlation between the percentage change in average bulk density of the units and the percentage area having compaction damage, regardless of standard (r = 0.93 and 0.92 for the 15 and 20% standards, respectively). Equations for the two relationships are: Y(% area compaction damage) = $14 + 1.6X$ (average % change in bulk density) and $Y = 6 + 1.5X$, for the 15 and 20% standards. These equations provide an average relationship for the array of units. If we considered the same variables on a single unit basis, the ratio of % area compacted to % change in average bulk density could be misleading, because the ratios ranged from 2 to 18. Assuming there is potential application for such relationships, it is necessary to use the regressions to avoid being misled.

Frequency distributions help clarify how bulk density changed in response to harvest activities when harvested and unharvested conditions are compared (Fig. 1 and 2). Harvesting may not cause a large change in the average bulk density, but disturbance does tend to increase the variance associated with the mean. Figures 1 and 2 reflect broader ranges in bulk density after harvest than before and frequency distributions of harvested areas appear skewed toward higher bulk densities. The most change occurred in the Cow Meadow unit (Fig. 1), whereas the distribution for the Boundary unit (Fig. 2) better typified the other units. Sampling intensity may have affected the resolution of the distributions for the unharvested condition, but a sample of 30 cores should provide a reasonable representation of bulk density.

Displaced and Other Condition Classes

Displacement damaged area ranged from 0 to 3%, the difference between total and compaction damage (Table 1). Other damage condition classes were not found. We expected the results to reflect more displaced and deposited conditions, especially where high percentages of compacted soil were found. Changes in surface relief, litter addition, and new plant cover likely obscured their visual evidence. During harvest of this kind it is common to observe displacement occurring with compaction, especially along skid trails.

Assessment of Sampling Requirements

If we view the total damage data as presample information, we can use the variances to find the number of transects required to estimate total damage at a given level of error and probability. We computed

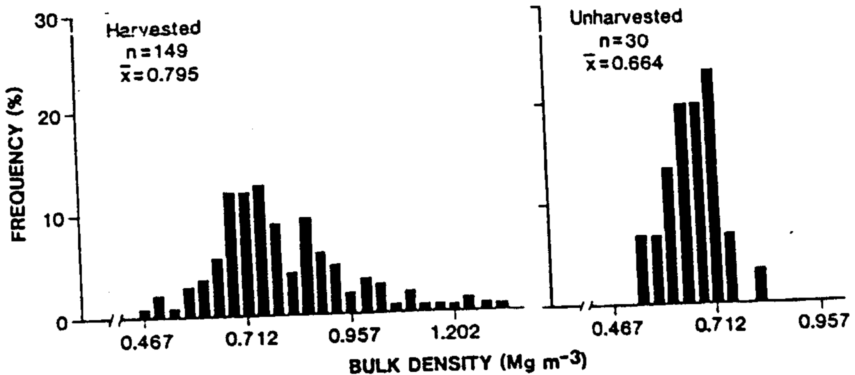

Fig. 1. Frequency distributions of soil bulk density on harvested and unharvested portions of the Cow Meadow unit.

Table 2. Calculated sampling requirements for estimating total damage with 10 and 20% margins of error at three probability levels.

	Total damage†		± 10% error			± 20% error		
			Probability level					
Harvest unit	$\bar{x}$	s	0.80	0.90	0.95	0.80	0.90	0.95
	%		Number of transects					
Boundary	25	20	110	180	261	27	45	65
Anthony	21	25	231	379	538	58	95	135
Cow Meadow	44	25	51	83	118	13	21	30
John Day	37	17	32	53	76	8	13	19
Frosty 1	27	14	49	80	102	12	20	25
Frosty 2	23	18	102	166	235	27	43	59
English Springs	21	15	85	140	199	21	35	50
Jungle Springs 5	19	15	97	160	227	24	40	57
Jungle Springs 7	34	22	68	111	158	17	28	39
Swamp Creek	41	15	21	35	49	5	9	12
Upper Pataha 7	24	16	80	132	187	20	33	47

† Mean and standard deviation (15% compaction standard).

transect requirements for an array of error and probability levels using the data for total damage associated with the 15% compaction standard (Table 2). The results show we could have estimated total damage ±20%, 80% of the time in only 4 of the 11 units, with our chosen number of 15 transects. Had we used 27 transects, we could have achieved these error and probability levels in all but one unit.

Permeameter Analysis

Evaluations of the air permeameter showed little support for its use as a rapid indicator of soil compaction. Correlations between air permeameter readings and bulk density were linear, but were low, and ranged from $r = 0.130$ to 0.342. A much stronger relationship (close to 1.0) would be needed. Our relationships accounted for <12% of the variation (Table 3). Even so, six of the seven relations were statistically significant. Addition of soil moisture to the regression for English Springs resulted in a statistically significant relationship but the multiple $R^2 = 0.25$ reflects little gain in variation accountability.

Table 3. Correlations and coefficients of determination between soil bulk density and air permeability for seven harvest units.

Harvest unit	r value	r^2 value
Cow Meadow	0.323*	0.104
John Day	0.306*	0.094
Swamp Creek	0.318*	0.101
Anthony	0.342*	0.117
English Springs	0.130	0.017
Frosty 1	0.315*	0.099
Frosty 2	0.259*	0.067

* Significant at $P \leq 0.05$.

DISCUSSION AND CONCLUSIONS

Under our first objective, we detected soil damage ranging from 12 to 44% of the operable area in the 11 harvest units, exclusive of the transportation system. Most of the damage was from compaction, and was dependent on the damage definitions applied to the data. If transportation systems averaged only 5%, their addition would mean all or nearly all units would average 20% or more adversely affected area regardless of which damage standard we used. Megahan (1980) reported the area of roads required for tractor logging averaged 13%. Thus, a 5% figure is perhaps conservative, but serves the purpose of illustrating the possible overall adversely impacted area. These findings have bearing on future reentry strategies and on decisions relative to possible rehabilitation of impacted area. Information relative to tree growth reductions and benefits from rehabilitation are also needed in this decision making. A sizable portion of the Blue Mountains may be affected by such decisions, since extensive areas were harvested by the traditional methods used on our study units. Recent harvest strategies have shifted toward designated skid trails, directional felling, line pulling, and other practices aimed at reducing area affected; our findings support use of such strategies.

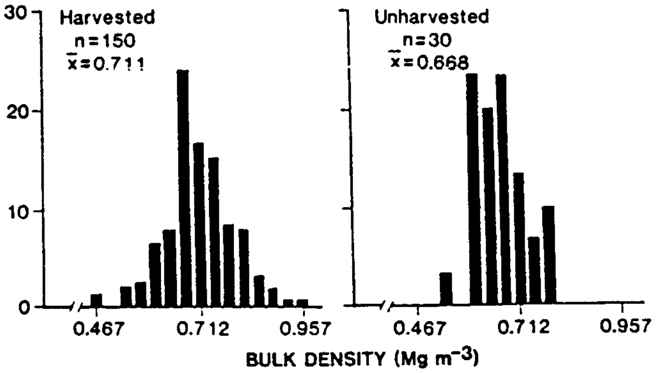

Fig. 2. Frequency distributions of soil bulk density on harvested and unharvested portions of the Boundary unit.

We found some practical drawbacks inherent in the observation techniques utilized (e.g., soil displacement by surface observation, time consumed in core extraction) but not in the sampling system itself. Sampling random or nonrandom soil disturbance with this system offers no problems. Hazard and Pickford (1986) found use of a randomly located grid and random transect orientation provided unbiased estimates regardless of the distribution of the parent population.

The range in average bulk densities of unharvested areas indicates reference sampling is needed for each unit (assuming no preharvest sample exists). In one unit the unharvested average was higher than even the damage level of bulk density (compaction) calculated for other units. This result occurred even though sampling was restricted to the volcanic ash portion of the soil profile where little textural variation occurs that might affect bulk density. Geist and Strickler (1978) reported little change in average bulk density within the ash layer of 35 Blue Mountain forest soils in preharvest condition. Means and standard deviations for the 0- to 15- and 15- to 30-cm depths were 0.67 ± 0.06 and 0.66 ± 0.07, respectively.

The number of transects/cores we used to obtain a reference bulk density for unharvested conditions, provided what we considered a reasonable estimate of the mean. The low variabilities associated with those means further supports their adequacy.

Our findings agree with those of Froehlich and McNabb (1984), who contend that interpreting the effects of compaction from the average bulk density as an absolute value can be misleading. They preferred to make comparisons based on a percentage change in average bulk density. They also found this expression strongly related to percentage change in juvenile tree growth, using a variety of soils and tree species. Their preferred expression may have even broader application, given there is consistency in our study finding that percentage change in average bulk density may be strongly related to the percentage area damaged by compaction.

Additional perspectives of changes in bulk density are gained from the frequency distributions. We would expect the average bulk density to increase and be correlated with compacted area as more area is affected by ground-based equipment. But more than just increases in bulk density are occurring. There are both higher and lower bulk densities present in the distributions after harvest. Higher values are due to compaction while lower values are due to loosening effects like displacement. By contrasting Fig. 1 and 2, we see the units differ in this regard. Small changes in average bulk density can occur (e.g., 6% on Boundary unit, Fig. 2), where loosening and compacting influences are of about equal area, but significant area of compaction can exist (23 or 14%). With larger increases in the average (20% on Cow Meadow, Fig. 1), the distribution can shift strongly to the right and the area of compaction damage also increases (44 or 36%).

Compaction obviously still exists in what constitute older harvest units of the Blue Mountains. It is evident that compaction may persist 20 or more yr at the 10- to 15-cm depths in the volcanic ash soils we studied. Wert and Thomas (1981) found compacted conditions persisting in skid trails 32 yr after harvest in Oregon's Coast Range. On volcanic sites, Froehlich et al. (1985) found bulk density averaged 26% higher at the 15-cm depth in skid trails 20 to 25 yr old. Recovery rates were slower at lower depths than shallower. Recovery time was projected to be longer on volcanic sites than on granitic sites due to initially higher degrees of compaction on the former; recovery rates were not found to differ between sites.

Displacement was almost undetected by the observational sampling and definitions we used. Since soil displacement is so commonly observed during harvest by ground-based equipment, sampling methods must be changed to improve detection of this potentially significant soil disturbance impact. Augering or digging to assess depth or horizon differences is possibly necessary. An improved definition might also increase sampling sensitivity. Older units are more difficult to assess, but even in younger units deposition and displacement areas can be confused when based on external appearance only. Regardless, the line transect system will accommodate changes in measuring tools and definitions.

Under our second objective we found sampling time and cost will increase dramatically, where requirements call for high precision and low probability of error. If stratification of the harvest units could be achieved, sampling efficiency would likely improve and require fewer transects. We did not test the effect of stratification on sampling efficiency but the transect system will accommodate this approach.

Under Objective 3, we found no potential for using the air permeameter as a rapid field indicator of bulk density in volcanic ash soils. Correlations with bulk density were so poor, it is very unlikely the permeameter could be used in even a double sampling context.

Research of forest soil conditions and development of sampling systems will no doubt evolve in relation to informational needs. Each system will have strengths and weaknesses. We believe our data and methods have strength owing to their statistical foundations. A disadvantage to all quantitative assessments will likely be their time consuming nature. We look forward to progress beyond our efforts.

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