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Soil Compaction After Yarding of Small-Diameter Douglas-Fir With a Small Tractor in Southwest Oregon

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Abstract

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This study evaluated the effect on soil bulk density of yarding small-diameter Douglas-fir (*Pseudosuga menziesii* var. *glauca* (Beissn.) Franco) with a small tractor. Levels of compaction were measured before yarding and after one trip, three trips, and six trips by the tractor. Bulk densities in the surface (10 cm) and subsurface (20 cm) for three trips and six trips were higher than pretreatment ($p \leq 0.10$); however, increases in soil bulk density were less than 7 percent and well below standards for detrimental soil compaction used by the USDA Forest Service Pacific Northwest Region. Results from this study support observations made in other compaction studies that much of the increase in bulk density from ground-based yarding operations occurs in the first few trips. Other studies, however, show a much higher increase in bulk density over undisturbed values.

Keywords: Applegate Adaptive Management Area, Douglas-fir, forest harvest, solid compaction, bulk density, logging systems, tractor-yarding.

Summary

Use of ground-based logging equipment is widespread across forests of the Pacific Northwest and can influence forest productivity by increasing soil bulk density. Most compaction studies have focused, however, on the harvest of large-diameter conifers using large ground-based logging systems. This study evaluated the effect on soil bulk density of yarding small-diameter Douglas-fir (*Pseudosuga menziesii* var. *glauca* (Beissn.) Franco) with a small tractor. The study site was located on metavolcanic soils in the Applegate Adaptive Management Area in southwest Oregon. These soils are typically low in organic matter and characterized by inherent high bulk densities. Yarding was completed while soils were dry (6 to 8 percent moisture). Levels of compaction were measured before yarding and after one trip, three trips, and six trips by the small tractor. Bulk densities in the surface (10 cm) and subsurface (20 cm) for three trips and six trips were higher than pretreatment ($p \leq 0.10$); however, increases in soil bulk density were less than 7 percent and well below standards for detrimental soil compaction used by the USDA Forest Service Pacific Northwest Region. Bulk density increases were small compared to other compaction studies where large timber was harvested and yarded with large tractors.

Contents

Introduction

Soil porosity is an essential component of site productivity. It is instrumental in water infiltration, water storage, and gas exchange. Soils with good porosity create favorable conditions for root growth, water movement, and nutrient uptake by roots (Childs and others 1989), survival of planted seedlings (Page-Dumroese and others, in press), and mycorrhizal growth (Amaranthus and others 1996). Ground-based yarding systems can reduce macropore space through the compaction of surface and subsurface soil. Generally, the potential for compaction increases with increasing number of trips and size of yarding equipment (Froehlich and others 1980).

In southwest Oregon, as in many other parts of the Northwest, the demand to harvest small-diameter trees (20-50 cm) has increased substantially since the mid-1980s. The ground-based equipment needed for such silvicultural treatments has shifted from larger to smaller types, which include such systems as pickup trucks, horses, all-terrain-vehicles, and small tractors. These logging systems produce less applied force to the soil and, in principle, should result in less soil compaction. Research is limited, however, on the effects of small, ground-based yarding equipment on the physical properties of naturally high-density soils. Factors such as soil moisture content during yarding and number of trips play a significant role in the degree a soil will be compacted during yarding. Although most compaction occurs within 10 trips (Gent and others 1984), the greatest increases in bulk density occur within the first several trips (Froehlich and others 1980, Shetron and others 1988). Increased soil moisture usually results in increased levels of soil compaction (Alexander and Poff 1985).

Soil compaction is of increasing importance to resource managers in view of national needs for forest health and environmental protection. Of particular importance in much of the Western United States is the effect of harvesting dense stands of small-diameter conifers whose distribution has increased since the successful implementation of fire suppression activities (early 20th century). Forest managers have increased their emphasis on removal of this material to improve overstory vigor, prevent insect infestation, and reduce fuel ladders and the potential for stand-replacing crown fires. Managers need information on equipment that applies less force to soil when low-value timber less than 50 cm in diameter at breast height (d.b.h.) is harvested. The objective of this study was to evaluate the effects of multiple trips with a small tractor yarding system (John Deere 450E[1]) on compaction of a dry soil with a surface bulk density of 1.3 g/cm^3.

Methods

The Study Site

This study was conducted in the Little Applegate watershed, Rogue River National Forest, in southern Oregon (lat. 42°07' N.; long. 123°35' W.; elev. 1234 m). The 5-ha site is in the Siskiyou Mountains within the Klamath Geologic Province in the Applegate Adaptive Management Area. Mean annual precipitation is 89 cm, with 80 percent falling as rain and snow between October and March, and mean annual temperature is 8 °C. The plant series is classified as Douglas-fir (*Pseudosuga menziesii* var. *glauca* (Beissn.) Franco). Soils are derived from Applegate Metavolcanics and range from 0.5 to 1 m in depth (fine-loamy, mixed, mesic Mollic Haploxeralf). The surface layer is a silt loam, 10 to 20 cm thick, and the subsoil ranges from a silt loam to a gravelly clay loam. Rock fragments are generally less than 20 percent of soil volume.

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Organic matter content of the surface layer is 3 to 5 percent. Typically, bulk density is about 1.20 to 1.35 g/cm³ in much of the lower elevations of the Applegate Valley (Amaranthus and Steinfeld, unpublished data). These values are relatively high compared with many forest soils in the Pacific Northwest. Duff and litter layer depths range between 2 and 4 cm. Average slope gradient is 20 percent. The site consists of large scattered ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Douglas-fir with an understory of dense, pole-sized Douglas-fir. Aside from several short skidtrails, which were avoided during this study, this area has not been entered by ground-based equipment.

Study Installation and Treatments

The study site was designed to be accessed by a John Deere 450E on predesignated skidtrails. Skidtrails were located in areas without previous ground-based disturbance. Directional felling and yarding of logs were stated in the contract to minimize the percentage of the area in skidtrails. The stand was marked to be thinned; the removal of mistletoe-infected and understory trees around the large (>75 cm d.b.h.), overstory pine was emphasized. About 240 trees per ha were harvested and consisted of 8 thousand board feet (mbf)/ha in the 14- to 25-cm range and 17 mbf/ha from trees in the 25- to 50-cm range. Twelve sampling plots within the stand were randomly selected. At each plot, soil bulk density was measured at the following intervals: (1) zero trip (pretreatment control), (2) one trip, (3) three trips, and (4) six trips with the John Deere 450E. Each trip represented one pass of the unloaded tractor with a return pass of loaded logs.

Bulk Density Measurements

Pretreatment measurements were made on September 3, 1996, and treatment measurements on October 10, 1996. Soil conditions were dry (6 to 8 percent moisture) during sampling for both dates. Three crews collected samples and each crew was assigned four plots for data collection. Because of inherent high bulk density and presence of rock fragments, two different sizes of core samplers were used to measure and compare bulk density. The larger core sampler, 900 cm³, was evaluated to determine if it would more accurately assess soil bulk density in the presence of abundant rock fragments. The smaller core sampler, 280 cm³, is typically used by resource specialists for measuring bulk density in the southwest Oregon area. After each designated trip, crews obtained a bulk density sample about 1 m away from the previous sampling spot to avoid any effects of soil disturbance during the previous sampling. Resampling took place in a few instances when large rocks and large roots either affected adequately obtaining the sample or took up more than a quarter of the volume of the core sample.

At each point, litter was cleared away by hand to expose about 20 cm² of mineral soil. Core samplers were placed to represent the bulk density at two soil depths: 10-cm core-center or 20-cm core-center. Bulk density cores were taken by placing the core ring at the soil surface and using the striking ring until the ring was completely driven into the soil. Intact cores were carefully removed with shovel and trowel, and the soil shaved off the side of the ring so that the soil was flush with the ring. Soil was then placed in airtight plastic bags in the field and taken to the laboratory, weighed, dried for 24 hours at 70 °C, and then reweighed. Ninety-six bulk density samples were taken during the sample period. Bulk densities were determined by dividing the sample oven-dry weight by their respective soil sampler volume. Soil moisture also was calculated for each sample by dividing the sample water weight by oven-dried weight of the soil.

Statistical Analyses

Descriptive statistics were used to summarize the data. Measures of central tendency, variability, and distribution were determined for soil moisture, and density. Data were determined to be normally distributed. A paired T-test was used to compare bulk densities at the two sample depths. An unpaired T-test was used to compare bulk density samples between soil cores of 900 and 280 cm^3. Preharvest and one-, three-, and six-trip bulk density data were subjected to repeated measures of ANOVA (analysis of variance). Means comparisons were calculated by using Fisher's least significant difference (Peterson 1985).

Results

Soil bulk densities in the surface and subsoil following three trips with a tractor were higher as compared to pretreatment bulk densities (fig. 1). Differences were significant at the $p<0.05$ level. Soil bulk densities in the surface and subsoil after six trips also were higher compared to pretreatment (control) bulk densities (fig. 1). Differences were significant at the $p<0.10$ level. Average soil density did not increase significantly after the third trip (fig. 1). About one-half of the increase in bulk density occurred in the first pass. Soil bulk density increased 7 percent for the surface and subsoil by the third pass. This was far less than the USDA Forest Service Pacific Northwest Region soil quality standard of 15 percent for detrimental soil compaction (fig. 2). Bulk densities were nearly identical when the two different core sizes were compared (fig. 3) and were not significant ($p=0.93$).

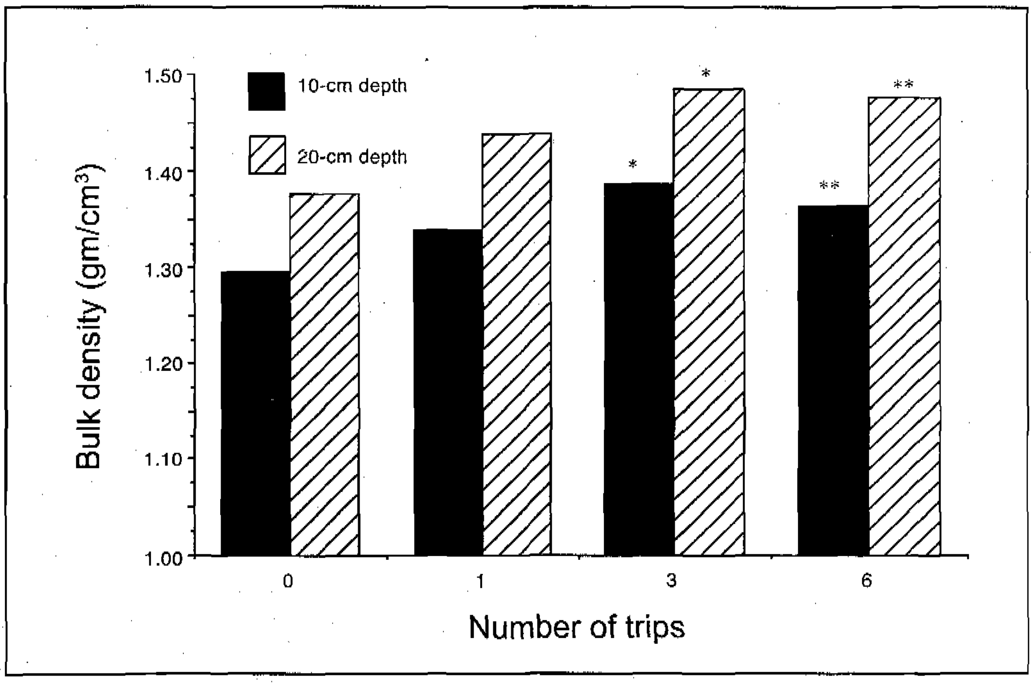

Figure 1—Mean soild bulk densities at 10-cm and 20-cm soil depths following zero, one, three, and six trips with a John Deere 450E in southwestern Oregon.
* = different than zero passes at the same soil depth ($p<0.05$); and
**= different than zero passes at the same soil depth ($p<0.10$).

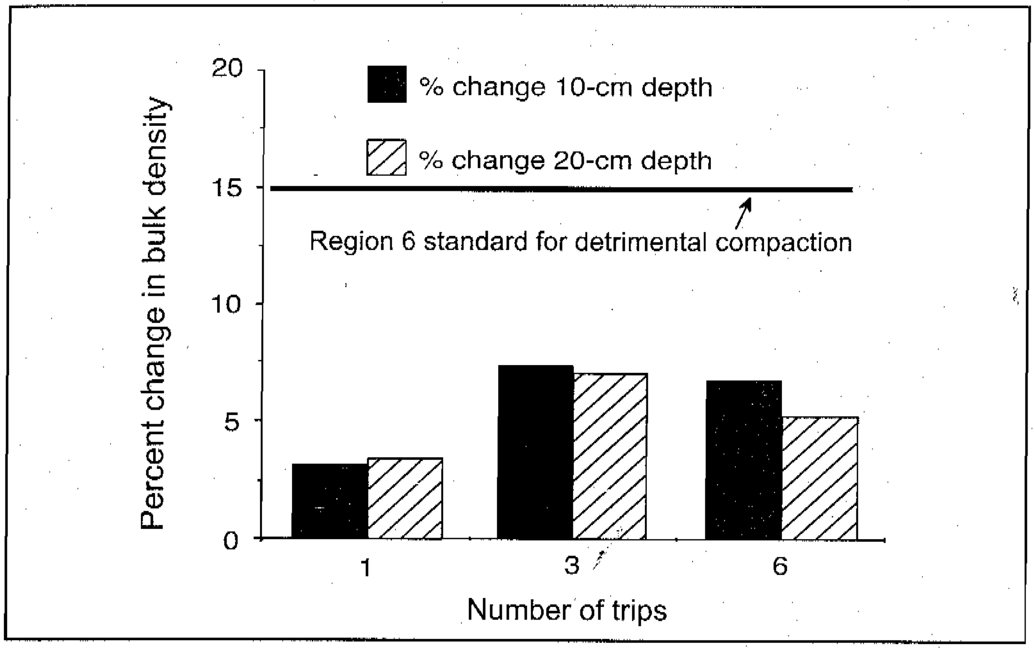

Figure 2—Percentage of increase in soil bulk densities at 10-cm and 20-cm soil depths after zero, one, three, and six trips with a John Deere 450E in southwestern Oregon.

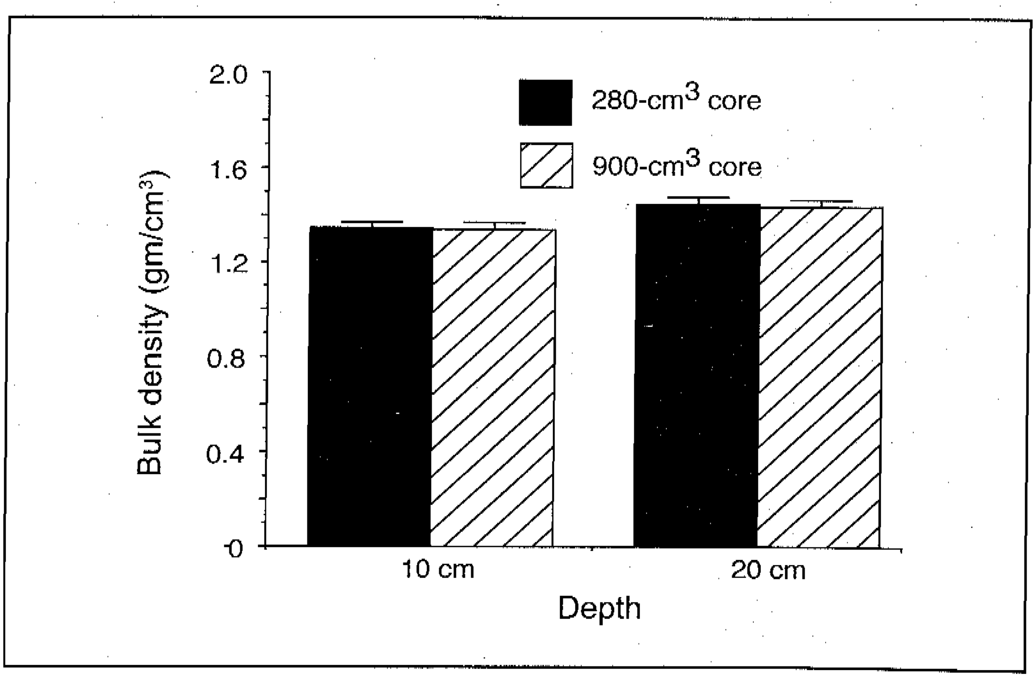

Figure 3—Mean soil bulk densities and standard errors with 280- and 900-cm^3 soil cores at 10-cm and 20-cm soil depths in southwestern Oregon.

Discussion

Results from this study support observations made in other compaction studies that much of the increase in bulk density from ground-based yarding operations occurs in the first few trips. Other studies show, however, a much higher increase in bulk density over undisturbed values (Froehlich 1978, Froehlich and others 1986, Page-Dumrose 1993). The soil quality monitoring standards for the Pacific Northwest Region (Oregon and Washington) considers an increase of 15 percent to be detrimental to site productivity. In this study, bulk densities increased only 5.3 percent in the surface and 6.7 percent in the subsoil after six trips. We believe soil density increases were not greater due to very low soil moistures (6 to 8 percent) at the time of yarding, the small tractor size, and the small diameter of the timber yarded in this study.

Soils in mixed-conifer forests of the Klamath Mountains are highly variable in characteristics of soil texture, soil organic matter, parent material, and previous disturbance history. In the Applegate Adaptive Management Area of southern Oregon, soils on xeric sites and at elevations less than 750 m are very low in soil organic matter. This factor and the weathering of the Applegate Metavolcanics to moderately fine texture contribute to soils having low porosity, high bulk density, and high soil strength when dry. These soils are less likely than others to show an increase in compaction during yarding because there are fewer large soil pores to be compressed.

Using the larger core size (900 cm^3) instead of the smaller (280 cm^3) is generally more labor intensive and requires more laboratory and oven space. Findings from this study showed no differences in bulk density between core sizes. Given the lack of large rocks in these soils, few samples needed to be retaken; our findings thus indicated that soils with small coarse fragments can be adequately measured by using the 280-cm^3 core size.

Recent research in the Applegate Adaptive Management Area indicates that soil bulk densities are lower and soil organic matter higher in late-successional forests adjacent to dense pole stands similar to our study site (Amaranthus, unpublished data). Thinning prescriptions that promote the development of late successional species and structure could help to decrease bulk densities and increase soil organic matter over time (Amaranthus, unpublished data). Site productivity can be enhanced by reducing the potential for hot, uncontrolled wildfires through fuel reduction treatments, encouraging soil organic matter building and hardwoods species, maintaining an adequate duff and litter layer, and encouraging development of large woody debris. Unfortunately these "soil building" processes are slow, and long-term data are necessary to assess silvicultural prescriptions on soil productivity (Amaranthus and others 1995).

Our study examined compaction effects up to six trips. We observed that much of the litter layer on the skidtrails remained intact after the first three trips. By the sixth trip, however, one-third to one-half of the skidtrail area had some mixing of litter with surface exposed mineral soil. This mixing might have caused the observed slight reduction in bulk density at the 10-cm depth on the sixth trip. More than six trips may have other adverse effects in terms of soil puddling, bare soil exposure, and surface erosion.

On Federal lands in western Oregon and Washington, ground-based yarding systems, such as tractors and skidders, are usually restricted to designated skidtrails. Logs are yarded to skidtrails spaced between 30 and 76 m apart (Froehlich and others 1981. This method results in skidtrails occupying less than 10 percent of the harvested unit. However, in thinning operations where the number of small trees removed per hectare can be very high, pulling cables to each log from these distances is very labor intensive, which increases the costs of projects already marginal economically. Pulling logs long distances also increases the risk that the cable and logs will wound residual live trees, thereby causing a loss of tree vigor and providing entry points for insects and diseases. This study indicated that small tractors yarding small-diameter material when soils are dry results in increases in soil bulk density below the Pacific Northwest Region soil quality standards and may reduce the need for pulling logs long distances. These findings do not reduce the need for a well laid out pattern of predesignated skidtrails, which is still essential for minimizing damage to residual trees (Froehlich and others 1981) or the concern for the effects of ground-based systems on displacement and soil erosion.

English Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.39	Inches
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Celsius (°C)	9/5, + 32	Fahrenheit
Grams (g)	0.035	Ounces
Square centimeters (cm^2)	0.16	Square inches
Cubic centimeters (cm^3)	0.061	Cubic inches

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