Polish J. of Environ. Stud. Vol. 16, No. 3 (2007), 371-376

Original Research

The Impacts of Ground-Based Logging Equipment on Forest Soil

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Received: March 28, 2006
Accepted: December 20, 2006

Abstract

Skidding logs from stump to landing areas is one of the most important procedures in ground-based logging operations. Rubber-tired skidders often increase soil compaction, which leads to an increase in soil strength (penetrometer resistance) and bulk density (dry soil weight per volume). Woody slash materials (tree limbs and tops) are generally distributed over the skid trails to reduce soil compaction due to machine traffic. In this study, soil compaction was estimated by measuring the values of soil strength and bulk density resulting from a rubber-tired skidder. The effects of not only woody slash materials but also various other slash treatments (chip and sawdust) in reducing soil compaction were investigated by considering the various numbers of vehicle trips (1, 5, and 10 trips) and two soil depth classes (10 and 20 cm depths). The results indicated that soil compaction indicators, soil strength and bulk density, markedly increased as the number of machine trips increased. Woody slash materials distributed over the skid trail provided better soil support capacity than that of other slash treatments. It was also found that there was a significant correlation between soil strength and bulk density with respect to the number of machine trips and slash treatments

Keywords: mechanized logging, soil compaction, penetrometer, bulk density, slash treatment.

Introduction

Mechanized ground-based logging systems are widely used since they generally provide a safer work environment, higher quality end products, and greater labor productivity [1]. In these systems, the forest products are generally transported from stump to the landing areas by rubber-tired skidders or crawler tractors. Ground-based logging systems can cause serious disturbance to the physical properties of forest soil due to soil compaction [6]. Compaction is one of the major causes of soil degradation from logging equipment [4].

Soil compaction decreases porosity and infiltration capacity and increases bulk density and soil strength [9]. Disturbing soil structure results in a considerable reduction in the regeneration and growth of trees [3]. Brais [4] has reported that soil compaction reduced the growth of white spruce (*Picea glauca* Moench Voss) by 25 to 28 percent. Soil compaction may limit root growth, which can also dramatically reduce tree growth [7]. Increasing the usage and weight of machinery in logging operations may cause even more detrimental effects on forest ecosystems [15, 12].

Soil Strength and Bulk Density

The degree of soil compaction due to logging equipments is generally estimated based on soil strength and bulk density. A method using a recording cone penetrometer has been widely used to estimate soil strength during logging operations. Bulk density, the weight (mass)

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of soil per unit volume (weight divided by volume), can be estimated by computing dry weight of soil samples collected using soil hammer and cylinder sampler.

There is a positive relationship between soil strength and bulk density [13]. The greatest increase in soil strength and bulk density generally occurs in the first few trips of a vehicle, while the rate of increase diminishes in the following trips [11]. Besides, they both tend to increase with soil depth [14]. Han et al. [9] reported that logging equipment markedly increased soil strength at 10 and 20 cm soil depth, while increases in soil strength were ignorable at 30 cm soil depth. Ares et al. [2] reported that bulk density increased from 0.63 to 0.82 g/cm^3 at the 0 to 30 cm soil depth in a ground-based harvesting operation.

Slash Layer

The impacts of ground-based logging equipments on forest soil can be reduced by using a ground cover (slash) layer [19]. The slash layer generally consists of logging residues such as limbs and tops of the harvested trees. Distributing the slash material on the logging trail provides significant reduction in soil compaction by decreasing ground pressure [16].

The effectiveness of slash layer in reducing soil compaction can vary with the number of trips, soil depth, and slash density [9]. Erdas et al. [5] suggested that soil compaction increases as the number of trips increase till the point of optimal compaction. However, the effectiveness of slash layer may decrease dramatically after a number of machine trips. Hutchings et al. [10] found that the slash layer had no advantages in reducing soil compaction after 12 machine trips. Besides, soil compaction on the surface soil layer can reach the optimal level much faster than that of deeper soil layers. Therefore, density and quality of material used in slash layers should be carefully determined to provide the soil with the highest support capacity during machine traffic.

Logging systems using rubber-tired skidders can generate more soil compaction than any other logging systems [17]. Therefore, skidding operations should be efficiently designed by considering not only the factors that affect logging costs but also the main factors that influence soil compaction. In this study, soil compaction was estimated by measuring the values of soil strength and bulk density resulting from a rubber-tired skidder. The effect of woody slash material and other low-cost slash materials in reducing soil compaction was investigated by considering the various numbers of vehicle trips and two soil depth classes.

Material and Methods

Study Area

The study area was in Terzi Creek region, which is approximately 40 km west of the city of Kahramanmaras. The forest site was dominated by Brutian pine (*Pinus brutia*) trees with the average ground slope of 25%. The type of soil in the study area was identified as sandy-clay-loam soil.

The impacts of a rubber-tired skidder (MB Trac 900) on forest soil were studied to test the efficiency of alternative slash treatments in reducing soil disturbance (Fig. 1). Engine power, operating speed, and unloaded weight were 63 kW, 30-40 km/hr, and 6360 kg, respectively. The average nominal ground pressure of a single loaded wheel was estimated as 0.36 kg/cm^2. In the experiments skidder was driven unloaded.

Slash Treatments

The research plots were located at the skid trail. Four slash treatments were tested: woody slash, sawdust, chip, and no slash (Fig. 2). The amount of material spread on the research plots were 10kg/m^2 for each slash treatment. The dimension of each plot was 5 meters by 3 meters.

The average diameter of woody slash material was measured as 2.5 cm. The woody slash material was placed perpendicularly to travel direction of the skidder. Chips and sawdust were produced from Scots pine (*Pinus sylvestris*). The average width, length, and thickness of the chips were 1.5 cm, 28 cm, and 0.3 cm,

Fig. 1. A rubber-tired skidder (MB Trac 900) traveling on slash treatments.

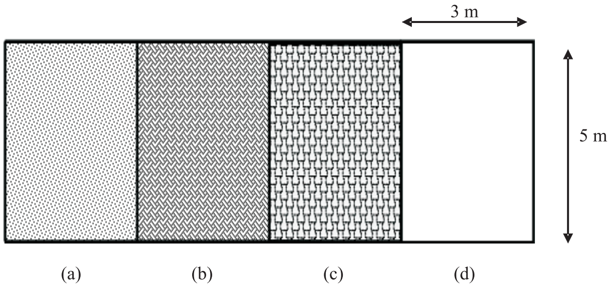

Fig. 2. Research plots containing four slash treatments were tested: a) woody slash, b) sawdust, c) chip, and d) no slash.

respectively. The average air-dried density of the chips was estimated as 0.655 gr/cm^3. Air-conditioned and dried sawdusts were screened for 15 minutes by using a fine wire mesh sieve. The average percentages of the sawdusts based on mesh screen and particle sizes were indicated in Table 1.

Measuring Soil Strength and Bulk Density

Soil strength and bulk density data were collected from the research plots. Ten replicates of soil data were taken from each research plot at two soil depth classes (10 cm and 20 cm) after 1, 5, and 10 skidder trips. In each trip, the skidder moved outhaul and moved back inhaul by following the same wheel track.

FieldScout SC 900 Soil Compaction Meter (cone penetrometer) was used to collect soil strength data. Bulk density data was collected with a bulk density cylinder sampler (7.5 cm length and 5 cm diameter). The volume and weight of the cylinder sampler was 502 cm^3 and 560 g, respectively. The soil samples were wrapped in labeled polythene bags for transport to the laboratory. The moist soil samples were first weighed on an electronic balance with two decimal (nearest 0.01 g). Then, they were dried for 24 hrs at 105°C in oven, and reweighed for determination of moisture content and bulk density.

The soil moisture was calculated as follows:

$$M_s = \frac{(W_w - W_d)}{W_w} 100 \quad (1)$$

M_s = soil moisture content (%)
W_w = moist weight of the sample (g)
W_d = dry weight of the sample (g)

Then, the dry bulk density was calculated from the following formula:

Table 1. The percentages of sawdusts based on their mesh value and particle sizes.

Mesh Screen	Particle Sizes (micron)	Percentage (%)
20	850	12.42
40	425	3.42
60	250	0.84
80	180	0.62
100	150	1.82
480	32	4.78
570	24	32.37
1140	12	44.11

$$\rho_d = \frac{(W_d - W_c)}{V_c} \quad (2)$$

ρ_d = dry bulk density (g/cm^3)
W_c = weight of the cylinder sampler (g)
V_c = volume of the cylinder sampler (cm^3)

Results and Discussion

Soil Strength

The average soil moisture content at the time of the study was estimated at about 7.5%. The value of undisturbed soil strength at soil depth of 10 cm was about 835 kPa. The average percentage of increasing soil strength from undisturbed soil to the first, fifth, and tenth trips was 43, 106, and 139%, respectively. At the 20 cm depth, the value of undisturbed soil strength was about 960 kPa. The average percentage of increasing in soil strength from undisturbed soil to the first, fifth, and tenth trips was 46, 99, and 111%, respectively. After the fifth and the tenth machine trips, increases in soil strength at 10 cm soil depth were higher than the increases at 20 cm soil depth. Han et al. [9] also reported that the largest increases in soil strength with logging machine traffic occurred at 10 cm soil depth and then followed by at 20 cm and 30 cm soil depths. However, increases in soil strength after a single trip of a skidder at 10 cm soil depth were slightly lower than the increases at 20 cm soil depth. The results also indicated that there was a significant increase in soil strength from the first to the fifth trips at 10 cm soil depth.

The results showed that slash layer provided a decrease in soil strength magnitudes which varied with slash treatments, number of machine trips, and soil depth classes. Soil strength values as a function of slash treatments and number of trips for 10 and 20 cm soil depths were indicated in Figs. 3 and 4, respectively. At both soil depth classes, the woody slash layer provided soil with the lowest soil strength magnitudes after machine traffic. At the first and the fifth trips, the ability of chip layer to decrease the soil strength magnitude was higher than that of sawdust layer; however, the sawdust layer provided soil with lower soil strength magnitude than chip layer after the tenth trip. It was observed that chip layer was broken down into small pieces and sunk into the soil after the seventh trip.

At 10 cm soil depth, the average percentage of increases in soil strength for slash, chip, and sawdust layers from the first trip to tenth trip was 36, 79, and 57%, respectively. Increasing the number of machine trips decreased the physical strength of the slash materials which led to considerable increase in their soil strength magnitudes. Han et al. [9] indicated that the effectiveness of slash layer decreased with increase of the number of machine trips. The largest increase in soil strength for the woody slash and chip layers occurred after the fifth machine trip. The soil strength magnitude of the sawdust layer dramatically increased just after the first machine trip, while its effectiveness was almost the same after the fifth and the tenth machine trips.

At 20 cm soil depth, the average increase in soil strength magnitude from the first trip to tenth trip reached up to 65, 93, and 63% for slash, chip, and sawdust layers, respectively. The soil strength magnitude for the woody slash decreased after the fifth machine trip, while effectiveness of chip and sawdust layer decreased after the first machine trip. This indicates an important note that the presence of slash layer cannot generate a significant effect on soil strength at 20 cm soil depth. Similar results were found in Han et al. [9], where the slash layer increased soil strength at 10 cm soil depth, while its effect was not significant from 10 to 30 cm soil depth classes (P>0.05).

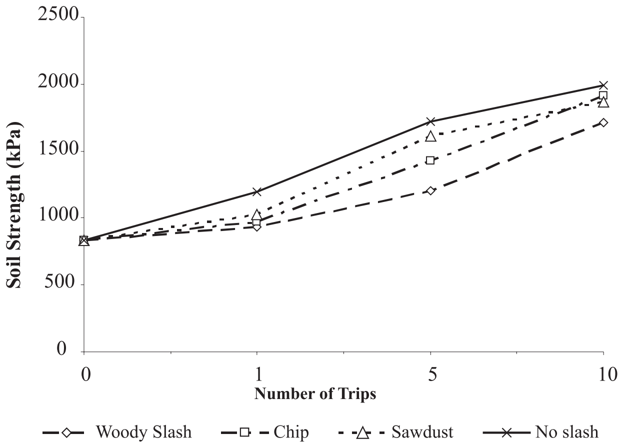

Fig. 3. Effect of slash treatments and machine trips on soil strength at 10 cm soil depth.

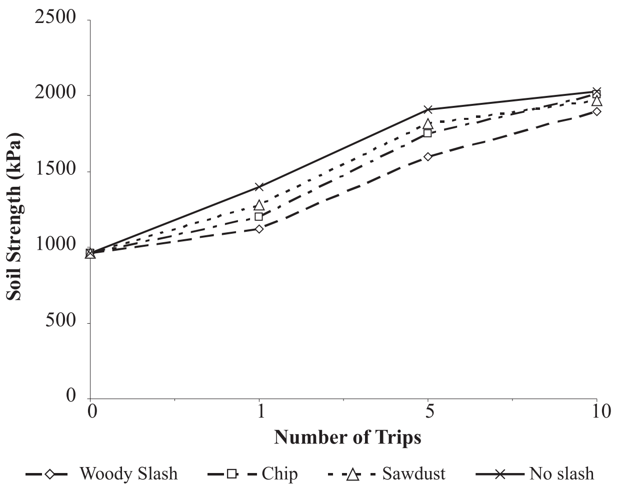

Fig. 4. Effect of slash treatments and machine trips on soil strength at 20 cm soil depth.

Bulk Density

The average bulk density of the undisturbed soil at soil depths of 10 cm was about 1.50 g/cm^3. The average percentage of increasing in bulk density from undisturbed soil to the first, fifth, and tenth trips was 14, 51, and 61%, respectively. At 20 cm depth, the average bulk density of undisturbed soil was about 2.07 g/cm^3. The average percentage of increasing in bulk density from undisturbed soil to the first, fifth, and tenth trips was 12, 27, and 32%, respectively. After the fifth machine trip, bulk density at the soil depth of 10 cm increased remarkably than that of 20 cm depth, while bulk density only increased slightly after the first and tenth trips for both soil depth classes. Startsev and Mcnabb [17] found similar results where the largest increase in bulk density occurred after three trips of a rubber-tired skidder, while increase in bulk density was relatively lower after 7 to 12 trips.

In all slash treatments, the values of bulk densities increased at 10 and 20 cm soil depth classes as a function of machine traffic (Table 2). McNabb et al. [15] reported that three skidder trips significantly increased the bulk density (P<0.05) until the depth of 22 cm and the maximum bulk density occurred after 12 tips. Increase in bulk density at woody slash treatment was smaller than the increase at chip and sawdust treatments for both soil depth classes. After the tenth trip, increases in bulk density using sawdust layer was less than that of using chip layer; however, increase in bulk density using chip layer was less than that of using sawdust layer at the first and the fifth trips.

After the first trip, the percentage of increases in bulk density at 10 cm soil depth was almost the same as at 20 cm soil depth for all slash treatments. From the first trip to tenth trip, the average percentage of increases in bulk density at 10 cm depth was found to be 39, 42, and 36% for slash, chip, and sawdust layers, respectively. At 20 cm

Table 2. Effect of slash treatments and machine trips on bulk density (g/cm^3) at two soil depth classes.

Slash Treatments	10 cm Soil Depth Class			20 cm Soil Depth Class		
	1 Trip	5 Trips	10 Trips	1 Trip	5 Trips	10 Trips
Woody Slash	1.56	1.95	2.17	2.11	2.41	2.58
Chip	1.61	2.03	2.28	2.19	2.47	2.71
Sawdust	1.65	2.14	2.25	2.24	2.56	2.65
No Slash	1.71	2.27	2.42	2.32	2.62	2.74

soil depth, the average percentage of increase in bulk density from first trip to tenth trip was found to be 22, 24, and 18%, respectively. For both soil depth classes, the largest increase in bulk density occurred after the fifth trip in all slash treatments. The percentage of increases in bulk density at 10 cm depth was almost twice more than that at 20 cm depth. Han [9] also found that the percentage of increase in bulk density at 10 cm soil depth was greater than that at 20 cm depth, due to a logging operation.

Conclusions

The multiple trips of a rubber-tired skidder were examined to investigate the impacts of logging equipment on forest soil as a function of machine trips, soil depths, and slash treatments. The magnitude of soil compaction was highly related to the intensity of machine trips on the soil. For the first, fifth and tenth machine trips, increases in soil compaction at 10 cm soil depth were higher than the increases at 20 cm soil depth. Soil compaction tended to increase markedly after the fifth skidder trip in both soil depth classes.

The efficiency of various slash treatments were investigated to evaluate their benefits in reducing soil compaction by absorbing ground pressure of the logging equipment. The support capacity of the slash layers decreased with the increase in the number of machine trips. The soil support capacity of the slash layers was not significant at a soil depth of 20 cm.

The effectiveness of the woody slash material in reducing soil compaction during ground-based logging operation has been studied previously. In this study, besides woody slash material, the performance of low-cost slash materials was also examined. The woody slash layer provided soil with the highest support capacity, followed by the chip and sawdust slash layers. The effectiveness of the chip slash layer was higher than that of the sawdust slash layer at the first and the fifth trips. After ten trips, the effectiveness of the sawdust layer became higher than that of the chip layer due to rapid reduction in the physical strength of the chip layer.

From the economical point of view, one might think that using low-cost slash material increases the logging cost. However, the woody slash materials can be collected before skidding operation to be used in producing biomass energy. When the cost of using low-cost slash material is less than the net economic value of using woody slash material in providing biomass energy, low-cost slash materials can substitute woody slash material in ground-based logging operations. In this case, using low-cost slash material can even reduce the overall logging costs.

Acknowledgements

This research was supported by the Research Fund of the Kahramanmaras Sutcu Imam University, Kahramanmaras, Turkey. Project Number: 2005-2-7.

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