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[Research]

Effects of Skid Trail Slope and Ground Skidding on Soil Disturbance

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ABSTRACT

The effects of traffic frequency and skid trail slope on dry bulk density, litter mass and rutting are examined. Treatments included a combination of four different traffic frequencies (3, 7, 14, and 20 passes of a rubber skidder) and three levels of slope (<10%, 10%-20% and > 20%.) The results showed that dry bulk density, rut depth and soil displacement increased with the increase of traffic frequency and slope, but floor coverage decreased. Within each traffic treatment soil compaction raised with the increase of skid trail slope, so that significant differences in dry bulk density were observed between slope of < 20% and those one >20% . Bulk density has become quite close to the critical value after 14 cycles. With increase of the skidder cycles from 14 to 20, bulk density remained approximately constant. We observed soil displacement on the treatments with 7 cycles: rutting on the treatments started with 7 cycles and slope of >20%. Soil disturbance increased significantly on slopes with > 20 % inclination with a dry bulk density of 1100 kg m^{-3} after 3 cycles compared to 830 kg m-3 on slopes < 10 %. In addition the forest floor mass on the treatments with 7 cycles and slopes of >20% (437.6 kg/ha) was significantly *($p<0.05$)* lower than treatments with 14 cycles and slopes of <10% (841.4 kg/ha.) Data suggest that disturbance increased earlier in the steep treatments than in less sloping conditions. The dramatic increase of soil disturbance on treatments with slopes of >20% may be associated with increasing load on the rear axle combined with slipping on steep slope trail.

Keywords: Soil Compaction, Rutting, Forest Floor, Soil Displacement, Skidding, Iranian forest.

INTRODUCTION

With increasing mechanization of forest harvesting operation, the impacts on soil have increased dramatically (Greacen and Sands 1980). Soil compaction, rutting and forest floor removal are an unavoidable consequence of ground skidding operations, and can vary in intensity and distribution. Compaction involves a rearrangement and packing of the solid particles of the soil closer together, resulting in an increase in the bulk density. When dry bulk density increased, the reduction in total porosity (Rab 1994, Woodward 1996, Alakukku 1996, McNabb et al. 2001, Makineci et al. 2007), tree height, diameter and volume growth (Heninger et al. 2002, Gomez et al. 2002, Williamson and Neilsen 2003, Pennington et al. 2004, Murphy et al. 2004, Merinoa et al. 2004,Tan et al. 2006) will be often observed.

The effects of soil compaction can persist in a forest soil for several decades depending on soil texture, machine activity, soil water content, and other soil conditions at the time of harvesting (Corns 1988Kozlowski 1999, Rab 2004, Demir et al. 2007, makinece et al. 2007). Soil compaction affects forest productivity in the long term. Soil displacement occurs by moving equipment and logs on the skid trails. Displacement affects the soil productivity and site hydrology, such as exposure of unfavorable subsoil (dense, gravelly, or calcareous with high pH), redistribution and loss of nutrients, and alteration of slope hydrology (Demir et al.2007, Makineci et al. 2007). Displacement of the weak organic materials by rutting commonly intercepts the water table so that standing water is found in the ruts for prolonged periods. Apart from some specially adapted species, roots are unable to grow through permanently saturated soil or open water because of the lack of available oxygen for root respiration. Furthermore exposure of mineral soil can lead to erosion on steep slopes with certain soil textures.

Mixing and/or removal of litter and soil may change the physical, chemical, biological properties or thermal behavior of the soil (Rab 1994, Woodward 1996). Stone et al. (1999) reported that increasing intensity of organic matter removal decreased both diameter and height growth of aspen on sandy soils in the Lake States region of the U.S.A. Organic matter retains soil water, thus helping soil to rebound against compaction (Hamza and Anderson 2004). Maintaining an adequate amount of organic matter in the soil stabilizes soil structure and makes it more resistant to degradation (Thomas et al. 1996). Most of the physical soil disturbance caused during forest management activities is directly attributable to trafficking by heavy equipment. Traffic intensity (number of passes) of each specific machine plays an important role in soil compaction because deformations can increase with the number of passes, which may lead to excessive soil disturbance (compaction, rutting and litter removal.)

During the ground skidding on terrain trail, a given load gets uneven weight balance on the axles (usually rear axle is weighted more heavily). Krag et al. (1986) showed that during timber harvesting slope steepness had a stronger effect than season of logging on soil disturbance. Their data suggested that disturbance increased in both extent and depth with increasing slope. They also reported that skid track related disturbance was greater on slopes >20% than on slopes <20%. Effective management of machine mobility, the control of site disturbance, and moderation of potential soil damage due to wood harvesting and extraction machinery traffic requires characterization of the effects of soil–machine interaction. The interaction should take into account the influence of machine variables on a range of forest terrain that may be encountered. In mountainous forest, ground skidding are often employed widely to remove logs from stump to forest road side. Many studies have investigated the effect of ground skidding on soil disturbance, but the effect of skid trail slope on soil degradation has received little attention. The aim of this study was to characterize the effect of skid trail slope on soil disturbance.

This study hypothesized that traffic frequency and skid trail slope affect the dry bulk density, forest floor mass and rutting formation. The objective of this study was to characterize the effects of ground skidding on soil compaction, rutting and litter mass under four levels of traffic intensity and three levels of trail slope in north forest of Iran:

- under 10% (low);
- 10-20% (moderate) ,and
- greater 20% (steep.)

Site study and climate

Research was conducted in September 2006 at Amreh forest, Mazandaran province, North of Iran between 36° 13′ N and 36° 15′ N and 53° 10′ E and 53° 15′ E. Common forest product types include *Fagus orientalis* and *Carpinus betulus*. Elevation is approximately 800 m with a north aspect. Average annual precipitation as rain or snow is about 700mm, generally occurring from mid September through May. It was estimated 620 m3 timbers were skidded recently: all logs were driven down hill, on the skid trail.

Brown Forest soil was formed on unconsolidated limestone with moderately deep profile. The soil was classified as Eutric Cambisols (FAO/UNESCO, 1990), and Typic Eutrudepts (USDA Soil Taxonomy, 1998). Table 1 shows soil physical and chemical properties in the skid trail.

Table 1. Some physical and chemical properties of soil in the skidder trail

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	C:N	pH
A	0-15	32.6	40.3	27.1	CL	11	7.1
B	15-55	29.3	42.4	28.3	CL	12	7.2
C	55-85	26. 5	42.3	31.2	CL	-	7.3

Experimental treatments and layout

A skid trail with the length of 400 m was selected in the Amreh district as the research area. The skid trail passed through the stand in the North-South direction, parallel to slope, and had been recently used.

The skidder was a rubber skidder (HSM 904)- 4 wheeled, tire/chain dimension 600/60-30.5, tire inflation pressure 250 kpa. Its total weight was 8.71 tons (without load) in the proportion of 60% on the front to 40% on the rear axle. This skidder model is usually utilized in the area. In this study the impacts of skidding on the skid trail in the surface soil layer (0 to 10 cm depth) was examined using dry bulk density, soil displacement, rut depth and litter removal at different levels of slope and traffic, in comparison to the undisturbed area. To draw the skid trail profile and identification of the soil type a pre-harvest survey was carried out. Soil texture was analyzed using the Bouyoucos hydrometer method (Kalra and Maynard 1991).

Minimum and maximum slope were 0% and 26% respectively. With regard to the slope, trails were classified in to three categories: 1- low (under 10%) 2- moderate (between 10% and 20%) 3- steep (greater than 20%). Treatments involved twelve combinations of slope class (<10%, 10-20%,>20%) and traffic intensity (3, 7, 14 and 20 passes).

For the treatment plots, three plots were formed in each treatment: 4 m wide by 10 m long delineating prior skidding, with at least 5 m buffer zone between plots to avoid interactions (Fig.1). Plots included four randomized 4 m line samples across the wheel track perpendicular to the direction of travel with 2 m buffer zone between lines to avoid interactions.

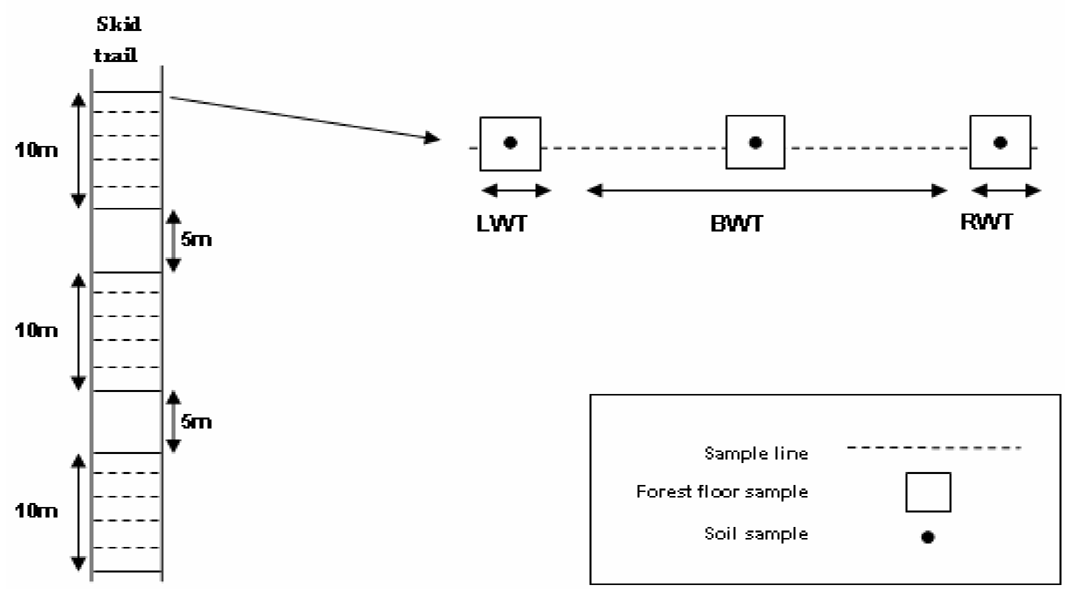


Fig. 1. Sketch of the treatment set-up with the location of the sample lines within the plots and a close-up of the sampling method (for abbreviations).

Three 1 m by 1 m forest floor samples and three soil samples were taken from three different points: left wheel track (LT), between wheel track (BT), and right wheel track (RT), on each line (Fig.1). Moreover for control purposes, soil 0-10 cm and forest floor samples were taken from the undisturbed area, where there was no skidding impact, at least 25-30 m away from the skid road (at least one tree length away to reduce side impacts.)

Experimental variables:

- Soil bulk density was calculated using the rings of thin-walled stainless steel tubing in the sample points, 10 cm in height and 5 cm in diameter. The soil cores were taken down to 10 cm depth and removed from the ring, put into individual plastic bags and labeled.

- Rut depth and soil displacement were measured using a profile meter consisting of a set of vertical metal rods (length 500 mm and diameter 5 mm), spaced at 25 mm horizontal intervals, sliding through holes in a 1 m long iron bar. The bar was placed across the wheel tracks perpendicular to the direction of travel and rods positioned to conform to the shape of the depression. Rut depth was calculated as the average depth of reads across the right wheel track (RWT) and left wheel track (LWT) (2.5 cm interval) and soil displacement was calculated as the average depth of 16 reads (25 cm interval across the trail.) (Botta et al. 2006.)

-The samples of the forest floor were taken from 1m^2 areas by collecting all the forest floor in the litter layer. Each sample was put into a plastic bag and labeled.

Samples brought to the laboratory from the research area, were promptly (within 1 h) weighed. Percentage of moisture was calculated from weight values of wet and oven dried samples after the litter cover samples were dried in an oven at 65 °C, and soil samples dried at 105 °C, both for 24 hour.

Data were analyzed using Statistical Package for the Social Sciences (SPSS) of Windows version 11.5. An analysis of variance (ANOVA) was carried out on the data and means were analyzed by Duncan's multiple range test. Treatment effects were considered significant if $p<0.05$. Regressions were used to evaluate the effects of traffic frequency and skid trail slope on dry bulk density.

RESULTS

Soil texture analysis showed that it was a Clay Loam along the trail. At the time of harvesting weather conditions had been very dry and warm for more than 2 weeks, and these conditions remained more or less constant during harvesting. When taking soil samples for bulk density, average soil moisture content was 16% at 0-10cm.

Soil compaction clearly increased with the increasing of slope in a specific traffic (Table 2). There were significant ($p<0.05$) differences between treatments with slope of <20% and those with slope of >20% (Table 2). For instance, difference between average dry bulk density on the treatments with 3 cycles and slopes of >20% (1100 kg m-3) and those of treatment with 3 cycles and slopes of <10% (830 kg m-3) was significant ($p<0.05$).

Table 2. Effect of slope on dry bulk density (kg/m^3)

	cycles			
Slope	3	7	14	20
(0-10)	833 ^{b}	1087 ^{b}	1211 ^{b}	1273 ^{b}
(10-20)	846 ^{b}	1091 ^{b}	1250 ^{b}	1286 ^{b}
(>20)	1097 ^{a}	1202 ^{a}	1342 ^{a}	1291 ^{a}

Different letters within each traffic treatments shows significant differences (P < 0.01 Duncan's multiple range test.)

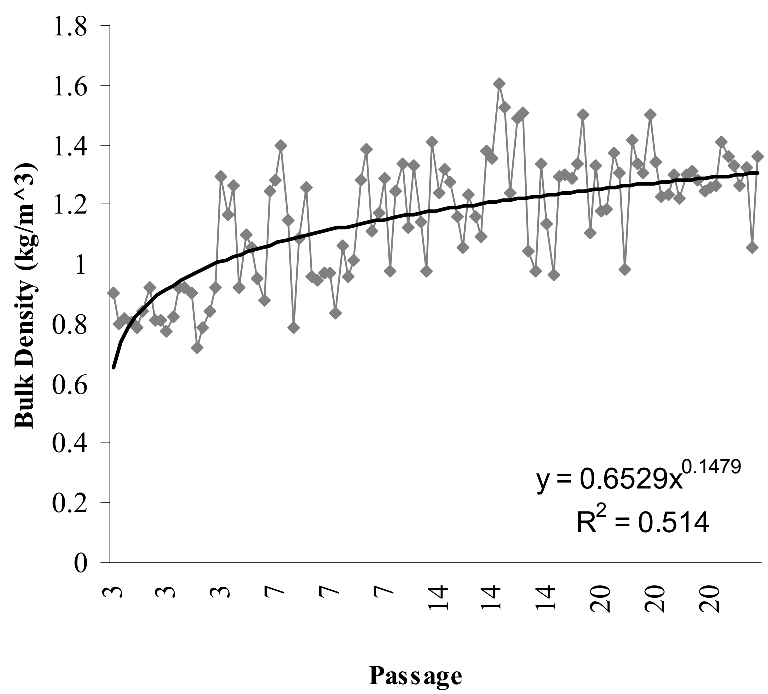
Depending on the traffic, considerable differences were found between treatments with regard to soil bulk density (Table 3). Average soil bulk density on the skid trail has been measured as minimum 830 kg m-3 to maximum 1342 kg m-3 and 760 kg m-3 in the undisturbed area. Dry bulk density reached 62% of the maximum obtained density in surface soils only after three cycles and increased with the increasing of traffic intensity (Table 3), but the differences between average dry bulk density at 14 and 20 cycles were not significant ($p<0.05$.)

Table 3. Effects of traffic intensity on dry bulk density (kg m^{-3})

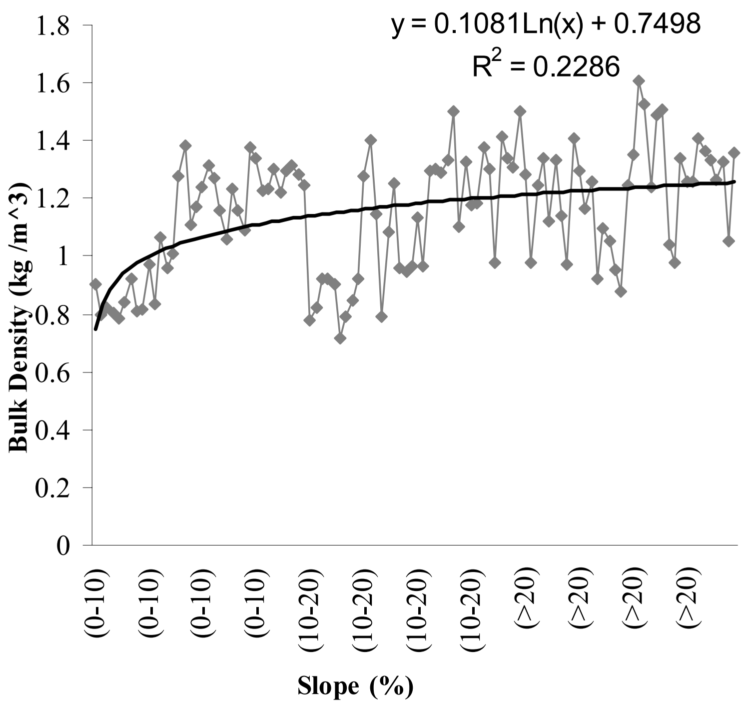
	Slope		
cycles	(0-10)	(10-20)	(>20)
3	830[c]	846[c]	1097[c]
7	1081[b]	1097[b]	1202[b]
14	1211[a]	1250[a]	1342[a]
20	1273[a]	1286[a]	1291[a]

Different letters within each slope treatments shows significant differences (P < 0.01 Duncan's multiple range test.)

Correlation coefficient through in bulk density and traffic and also slope were calculated 0.072 and 0.048 respectively. Although R-squares showed that the estimated value for the trend lines were not very close to actual data, there was a positive relationship between dry bulk density as a function of slope and traffic (Fig.2).



(Fig. 2-a)



(Fig. 2-b)

Fig. 2. Relation between average dry bulk density of treatments and passage (a) and slope (b)

Soil displacement increased with skidder traffic frequency and also skid trail slope. The soil surface was the layer most vulnerable to displacement from the passage of skidder. Displacement was recorded on 7 cycle and slope of <10% treatments, while rutting has been observed on 7 cycle and slope of >20% treatment with slopes of >20% (Table 4.)

Table 4. Effect of skidder traffic frequency and trail slope on soil displacement (cm)

Traffic / Slope	cycle 3	cycle 7	cycle 14
(0-10)	0	0.6^{b}	*5.1^{b}
(10-20)	0	1.85^{ab}	*11.6^{ab}
(>20)	0	*9.8^{a}	*15.8^{a}

Different letters within each traffic treatments shows significant differences (P < 0.01 Duncan's multiple range test.) * Soil displacement classified to rutting

The results showed that the mean depth of rutting at different levels of slope ranged between 5.1 and 15.75 cm. There were significant (*p<0.05*) rut depth differences in treatments with different levels of skid trail slope (Table 3). There is a negative relationship between traffic intensity and forest floor. Total litter mass in a unit area in the undisturbed area was 3764.47 kg/ha and on the disturbed areas from 0 kg/ha (treatment 20 cycles; >20%) to 1798.26 kg/ha (treatment 3 cycles; <10%). The correlation between forest floor coverage and slope under a specific traffic frequency was significant (*p<0.05*) (Fig.3).

Fig. 4 shows that forest floor was also

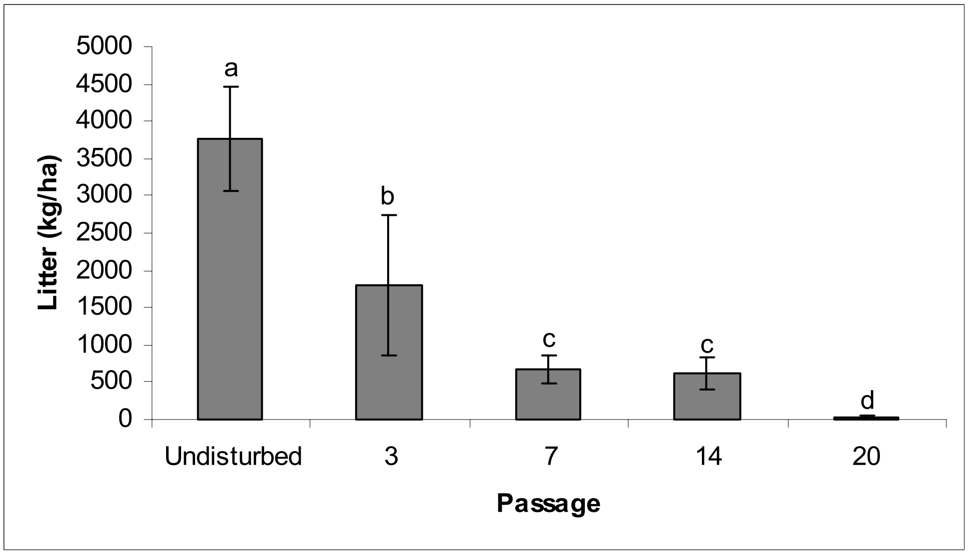


Fig. 3. Litter mass comparison among slopes.

removed more rapidly with increasing trail slope under specific traffic intensity. For example, lost forest floor percentage at the treatment of 3 cycles and slope>20% was almost equal to that of 14 cycles and slope <10%. The undisturbed area has considerably higher amount of forest floor. Less forest floor on the skid trail shows that the forest floor has been moved out by skidding.

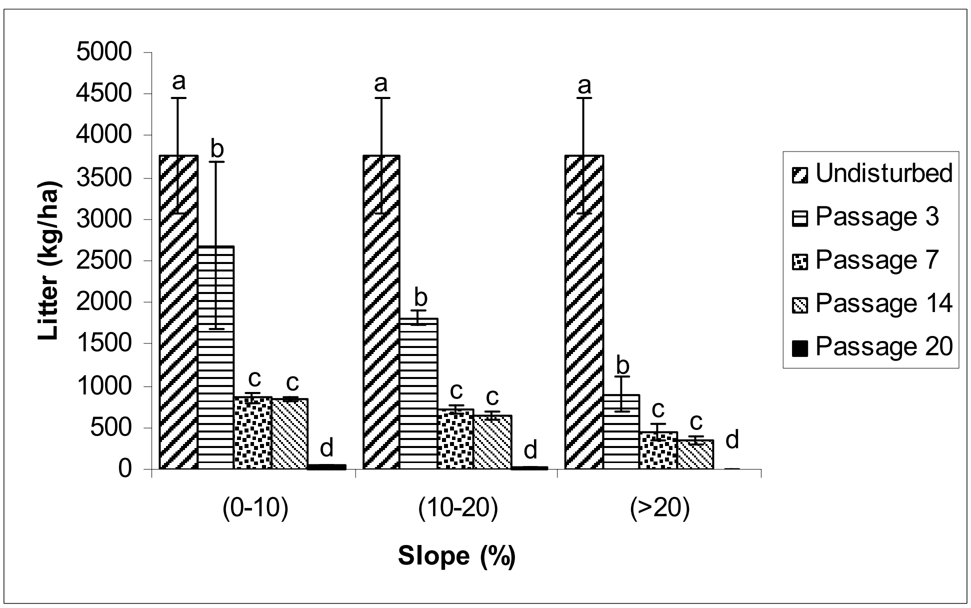


Fig. 4. Effect of traffic intensity on litter mass (Kg/ha).

DISCUSSION

Dry bulk density has been affected by traffic intensity and trail slope. Most of the compaction occurred during the first seven cycle on the treatments of low (under 10%) and moderate (10%-20%), while on treatments of steep (greater 20%), most of the increase in dry bulk density happened in first three cycles. Soil was compacted faster on treatments of >20% than those of <20% (Table1). The increase of bulk density in the steep trail slopes may be associated with the increasing of load on the rear axle and slipping on steep slope trail. When logs were pulled downhill on a steep slope, load increased on rear axle and slipping occurred because the rear compressed tires rolled shorter radius than the front wheels, consequently the loaded skidder had to slip. With increased load on the rear axle and slipping of the machine the compaction increased.

The results of the present study are consistent with those of Ampoorter et al. (2007) and Brais and Camire´ (1998) who found that bulk density increases more gradually with 50% of the total impact occurring in the first three cycles. There was no significant difference in dry bulk density between 14 and 20 cycles. This is in contrast with Ampoorter et al. (2007), who found that when the number of machine cycles increases, the additional bulk density increment is negligible.

The effect of slope on soil compaction was observed up to 14 cycles. In lower traffic intensities with an increase in trail slope, the average dry bulk density ascends faster (Table 2), because in the higher traffic intensities (14 and 20 cycles), the soil is already compacted to its maximum level, whereas in the lower intensities it still has capacity for more compaction.

Bulk density between 1.40 and 1.55 Mg m^{-3} is considered as the critical level at which plant roots cannot penetrate into soils with light and medium texture (Kozlowski, 1999). Our results showed that bulk density is drawing quite close to the critical level after 14 cycles (Table 2).

As a given slope, dry bulk density increased significantly up to 14 cycles while below a traffic, with the increasing of slope from low to moderate, dry bulk density increases was not significant. Dry bulk density increment was affected by more traffic than slope. For this reason, correlation between dry bulk density and traffic is considerably more than between dry bulk density and slope. Fig. 2 supported the results in Table 1 and Table 2 that show dry bulk density are classified in 2 and 3 categories regarding to slope and traffic respectively.

The differences of forest floor weight are significant, even at the same traffic frequency under different levels of slope (Fig. 3). This shows that during skidding, slope steepness has a strong effect on the forest floor removal. Weight of forest floor decreased with the increasing of traffic frequency (Fig. 4). Less forest floor on the skid trail shows that the forest floor has been moved out by skidding. The skidder power decreases with the increasing of trail slope, especially slopes of greater than 20% . So when heavy logs are skidded, wheels spin and the skidder travels more slowly. Spinning, digging and slipping may mix mineral soil and litter resulting in increasing of displacement, rutting and decreasing of litter mass.

Impact of skidding operations on the forest floor characteristics have been shown to be similar results by many researchers (Jurgensen et al. 1997, Bengtsson et al. 1998, Ballard 2000, Marshall 2000, Arocena 2000, Johnston and Johnston 2004, Demir et al. 2007).

Soil displacement was recorded at 7 cycles and was increased with an increase in traffic intensity and skid trail slope. Rut depth increased with the number of passes, but its differences were not significant in the control plot and in 3 and 7 cycles. The skidding operation was performed in dry season with low moisture content (16%): consequently ruts were not observed before 7 cycles.

Results showed that soil disturbance increased dramatically on the treatments with the slopes of >20%. In this study, the logs were pulled downhill. Frequently on such trails one axle (usually the rear) supports considerably more load than the other in comparison with flat trails. The uneven axle loads pronounced in skidders are exacerbated by the weight of logs being supported behind the rear axle. With the consequent uneven axle load on the terrain trail, soil disturbance increased. Furthermore, when rear tires get more pressure, their effective radius is shorter than that of the front tires, leading to increased slipping during log extraction.

Our results are similar to the studies of Davies et al. (1973) and Raghaven et al. (1977) who identified wheel slip on agricultural tractors as causing significant compaction. Therefore, it is not surprising that wheel slip from forest vehicles should also contribute to compaction. Pressures generated in the soil can be considerably greater than nominal contact pressures, depending on tire geometry and nature of the operation. Pressures in the soil up to five times the nominal contact pressures have frequently been recorded under the back wheels of agricultural tractors (Greacen and Sands, 1980). Increased soil disturbance with an increase in skid trail slope on all traffic intensities supported the hypothesis that skid trail slope affects dry bulk density, forest floor removal and rutting formation. The effect of slope on disturbance is in agreement with Davies et al. (1973), Raghavan et al. (1977) and Krag et al. (1986).

The damage may be reduced by avoiding steep skid trail >20%, controlling the number of machine passes, and by limiting the contact pressure imposed by wheels or tracks through proper selection of the size and type of traction mechanism (tires or tracks) used.

Rehabilitation works (Pinard et al., 2000; Ilstedt, 2004; Kolka and Smidt, 2004) on the skid roads where soil properties have been drastically degraded would help regeneration of the ecosystem. In order to prevent and lessen negative impacts and to prevent the forest floor and the herbaceous understory losses on the soil caused by compaction, attaching a conical skid cap at the end of the timber that is being skidded, or usage of slides, may decrease the damage.

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