Effects of ground-based skidding on Forest Soil in Hyrcanian Forest

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Abstract:
The use of rubber-tired skidders is a well accepted practice for the extraction of timber from the forest, but the application causes considerable environmental problems. The aim of the study was to evaluate the effects of slope gradient, number of machine passes on skid trails, soil depth, and soil moisture on soil compaction and rutting in a fined grained soil. The study was designed as a factorial experiment with the factors including slope gradient, soil moisture, and depth in the skid trail and number of machine passes. The effects of four slope classes (flat, 10%, -10%, and -20%), three soil depth classes (5 cm, 15 cm, and 25 cm), and different compaction levels based on various number of machine passes (0, 1, 5, 8, 10, 15, 20, 25, and 30) were evaluated. A Timberjack cable skidder was used and the study location was in the Kheyrud Educational and Research Forest located in Hyrcanian forest in northern Iran. The increased number of machine passes increased soil bulk density, but the highest rate of compaction occurred after the initial few passes. Uphill skidding increases compaction more than downhill skidding. The increases in bulk density were still important at the maximum sampling depth of 20-30 cm. Soil bulk densities at 5, 15, and 25 cm depth averaged 35, 22, and 17% higher than densities in undisturbed soils. Result showed that an increase in the number of machine passes increased rut depth. Rut depths were increased significantly with soil moisture and number of machine passes. Skidding operations should be planned when soil conditions are dry in order to minimize rutting. If skidding must be done under wet conditions, the operations should be stopped when machine traffic could create deep ruts.

Keywords: Hyrcanian forest, soil compaction, wheeled cable skidder, rut formation.

1 Introduction

Soils serve a variety of functions in forest ecosystems. They serve as a medium for tree growth; they anchor the tree physically and supply water and nutrients for uptake by tree roots; and they serve as water-transmitting layers on the earth's surface (Burger 2004). Forest soils, in general, are susceptible to compaction as they are loose with high organic-matter, are generally low in bulk density, high in porosity, and low in strength (Froehlich and McNabb 1984; Froehlich et al. 1985; Kolkaa and Smidt 2004; Horn 2007). The impact of skidding operations on forest soils can be divided into three major categories: soil profile disturbance, soil compaction and soil puddling and rutting (Cullen 1991; Rab et al. 2005). When a mechanical load is applied on the soil, soil particles are rearranged closer together resulting in increased bulk density (mass per unit volume) (Dickerson 1976; Greacen and Sands 1980; Cullen 1991; Eliasson 2005; Grace et al. 2006), reduction of the total porosity associated with a reduction of macropores (Greacen and Sands 1980; Froehlich and McNabb 1984; Gayoso and Iroume 1991; Gomez et al. 2002; Ares et al. 2005), increase in soil strength (Froehlich and McNabb 1984; Horn et al. 1994), decreased infiltration capacity (Horn et al. 1994), decreased gaseous exchange and soil aeration (Horn et al. 1994), an increase in resistance to penetration (Ampoorter et al. 2007), decrease in saturated hydraulic conductivity (Greacen and Sands 1980, Gayoso and Iroume 1991; Horn et al. 1994; Grace et al. 2006), proportion of micropores is increased (Greacen and Sands 1980; Kolkaa and Smidt 2004).

During timber harvesting the degree of soil compaction depends on various factors including: site and soil characteristics (Adams and Froehlich 1984; Froehlich and McNabb 1984; Ampoorter et al. 2007) such as soil texture (Froehlich and McNabb 1984; Adams and Froehlich 1984; Froese 2004; Rohand et al. 2004; Ampoorter et al. 2007; Johnson et al. 2007), Soil moisture (Greacen and Sands 1980; Adams and Froehlich 1984; Froehlich and McNabb 1984; McDonald and Seixas 1997; Johnson et al. 2007), the number of machine passes (Froehlich et al. 1978; Adams and Froehlich 1984; Gayoso and Iroume 1991; Sidle and Drlica 1981; Froehlich and McNabb 1984; Gent and Ballard 1984; Rollerson 1990; Rab 1994; McDonald et al. 1995, McDonald and Seixas 1997; Eliasson 2005; Susnjar et al. 2006; Ampoorter et al. 2007; Eliasson and Wasterlund 2007; Wang et al. 2007), harvesting system (Adams and Froehlich 1984; Miller and Sirois 1986; Han 2006), type of machine (Froehlich et al. 1978; Jansson and Johansson 1998; Susnjar et al. 2006; Wang et al. 2007) and its characteristics includes: mass of vehicles and loads (Rab 1996; Saarilahti 2002; Susnjar et al. 2006; Horn et al. 2007), type, number of wheel and the inflation pressure of the tire (Saarilahti 2002; Eliasson 2005; Ziesak 2006), amount of logging slash (Wronski and Murphy 1994; McDonald and Seixas 1997; Ampoorter et al. 2007; Eliasson and Wasterlund 2007), organic matter (Froehlich et al. 1978; Greacen and Sands 1980; Adams and Froehlich 1984; Froese 2004; Rohand et al. 2004; Johnson et al. 2007).

Strong increase in bulk density for wheel track already appears after one pass of the machine (Ampoorter et al. 2007). Eliasson (2005), Eliasson and Wasterlund (2007) found that Soil density increased significantly with increasing number of forwarder passages. Compacted layer are often found at different soil depths. However, the deeper layers of many soils compacted further after a few passes. Eliasson and Wasterlund (2007) reported that an increased number of machine passages increased soil dry density in the upper 20 cm. Jamshidi et al., (2008) measured the changes in bulk density in the top 10 cm of soil following machine and animal skidding in Hyrcanian forest. They found that average soil bulk density in the tracks of machine skid trails was significantly greater than the soil density outside the tracks, but the increase in bulk density was not significant on the animal trails. The overall goal of this study was performed to broaden existing knowledge on the degree and extent of impacts on soils from cable skidder on fine-textured soils in Hyrcanian forest. The specific objectives were to: Quantify the extent of trail area and winching line (disturbance area) throughout the harvest unit, Assess the extent of the rut formation and its relation with soil moisture, To measure and establish the threshold levels for the machine traffic with respect to bulk density, surface rutting, and slope gradient or direction of skidding for 3 soil depths.

2 Material and Methods

2.1 Study Sites

The research was carried out in mountainous conditions of compartment no. 220 which was located in Namkhaneh District within Kheyrud Educational and Research Forest. The altitude ranging was 1000-1135 meters above sea level and the forest lies on a southwestern aspect. Average rainfall ranges from 1420 to 1530 mm/year, with the heaviest precipitation in the summer and fall. The average daily temperatures are moderate, ranging from a few degrees below 0°C in December, January, and February to +25°C during the summer. This area was dominated by natural forests containing native mixed deciduous tree species such as *Fagus orientalis* Lipsky, *Carpinus betulus* L., *Acer velutinum* Boiss. and *Alnus subcordata*. The management method is mixed un-even aged high forest with single and group selective cutting regime.

2.2 Experimental design and data collection

Twelve sampling transect were selected at different slope gradients along the designated skid trail for bulk density measurements. Organic horizons were removed from the soil surface prior to density measurements, so that depth readings were referenced to the mineral soil surface. Before skidding operation, four slope gradients in the skid trail with 3 replications were established in disturbed areas at 1-10 cm soil profile depth, and the different levels of compaction were applied by varying the levels of machine traffic: 0 (undisturbed), 1, 5, 8, 10, 15, 20, 25, and 30 machine passes. A pass implies a drive back and forth the selected trail. Four slope gradients of skid trail were 0 (flat trail), -10% (uphill skidding direction), 10 and 20% (downhill skidding direction). Also, prior to any skidding operations and after 20 machine passes, bulk density was measured at this four slope gradient of trail (0, -10, 10, and 20%) at the 5 (0-10), 15 (10-20), and 25 cm (20-30 cm) soil profile depths in wheel rut (B) and uncompacted sample point adjacent skid trail (C). The soil sample cores were obtained from the layers of the mineral soil using a thin walled steel cylinder, 40 mm long and 56 mm in diameter, driven into the soil by a hammer-driven device. After extracting the steel cylinder from the soil with minimal disturbance to the contents, the soil cores were trimmed flush with the cylinder end and extruded into a plastic bag for transporting to the laboratory. Samples were weighed on the day they were collected and again after oven drying at 105 °C for 24 h to determine water content and bulk density.

The experimental design was a factorial arrangement of treatments conducted in a completely randomized design. Data were evaluated for normality before running the analyses. We also applied general linear modeling (GLM) to relate bulk density and rut depth to machine passes, slope gradient, depth, and soil moisture in relation to the skid trails. Post-hoc comparison of means was performed using Duncan's multiple design was used to mean-based grouping with a 95% confidence level. Analysis of variance of the test data was conducted in SPSS (release 11.0.0). Treatment effects were considered significant if $p<0.05$. To determine the impact of slope gradient and number of passes with skidder on bulk density, a regression approach was used. Soil bulk density before and after skidder operations was compared using independent samples t-test. One-way ANOVA was performed to identify differences between bulk density values of four slope gradients in skid trails.

3 Results

Table 1 shows the analyses of the soil bulk density data as influenced by machine passes and slope gradient for the cable skidder. Results show that machine passes and slope gradient, and twofold interactions machine passes × slope gradient were all significant variables ($P<0.05$).

Table 1: Analysis of variance (ANOVA) for the effect of number of machine passes (NP) and slope gradient (SG) on bulk density in 0-10 cm soil depth.

Source	SS	df	MS	F	P
NP	1.77	8	0.221	829.34	0.00
S	0.17	3	0.058	216.36	0.00
NP × S	0.06	24	0.003	9.67	0.00

The independent samples t-test indicated that skidding had a statistically significant effect on the bulk density of machine trails before and after machine passes (Figure 1a.). Result shows that bulk density significantly increased as number of machine pass increased (Figure 2); regardless of slope gradient, the degree and level of compaction differ among trail slope with Duncan's. In other hand, generally, trails with four slopes show a similar trend of increasing soil bulk density with increasing amounts of machine passes. In flat trail, the bulk density in the 0-10 cm of soil (1.06 g/cm3) increased by 5% after 1 pass, 19% after 2 passes, 25% after 8 turns, 31% after 15 machine passes. In trail with a 10% slope or uphill skidding, the soil bulk increased by 19% after 1 pass, 43% after 5 passes. Subsequent increase of number pass to 30 turns not increased bulk density significantly. High level of increase in bulk density occurred after 5 machine passes and additional increase of machine pass did not increased bulk density significantly. In area with -10% slope gradient, bulk density increased by 9% after 1 pass, 25% after 5 passes, 34% after 8 turns and in trail with -20% slope, by 9% after 1 pass, 22% after 5 passes, 29% after 8 turns and 34% after 10 passes. In flat trail, the most of the compaction, as bulk density increase, takes place during the 15 first passes by 1.37 g/cm3. In trail with 10% SG, in contrast, high level in bulk density increased (1.44 g/cm^3) occurred in 5 machine passes. Also, in downhill skidding with 10 and 20% GS, soil density increased significantly after 8 and 10 machine passes, respectively. Soil bulk density for 10 and 20% GS at these level were 1.41 and 1.41 g/cm^3, respectively. Bulk density in the 10% GS trail showed the highest value in comparison with other slope gradient of trail (Figure 1b.). Skidding operations along flat trail have the lowest compaction (Duncan's).

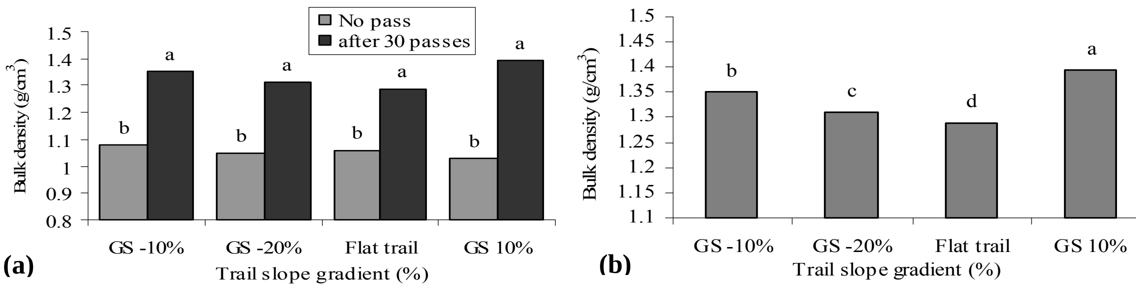

Figure 1: Average of the bulk density (a) in g.cm^{-3} and its relative changes before and after skidding in each of the slope gradient of trail and by independent samples t-test and Duncan's test (b).

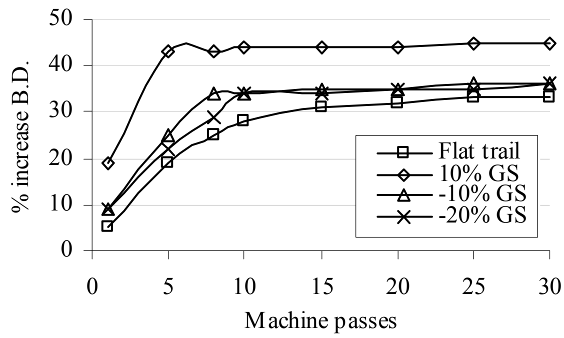

Figure 2: Relationship between % increases in bulk density as influenced by machine pass in four gradient slopes of skid trail

Average pre-harvest bulk densities were 1.06 g/cm^3 for depth 1, 1.27 g/ cm^3 for depth 2 and 1.42 g/ cm^3 for depth 3 for flat trail. After 20 machine passes, bulk density increased in depth under the skid trails in all slope gradient of trails, but the major increases occurred in the top of the soil profile at 1-15 cm. In flat trail, bulk density increased by 30% in 0-10 cm depth, by 20% in 10-20 cm, and by 17.5% in 20- 30 cm, after 20 machines passes. In trails with a 10% slope, the increase in bulk density for all depths was significantly higher as compared with those observed in trails with a -10%, -20% slope, and flat tail. Figure 3 shows how the relative change in bulk density varied with slope trail in soil depth. In trail with 10% slope, bulk density increased by 42% in 0-10 cm depth, by 28% in 10-20 cm, and by 20% in 20-30 cm, after 20 machines passes. The independent samples t-test indicated that skidding had a statistically significant effect on the bulk density of machine trails before and after machine passes in soil depth ($p<0.05$). Deeper in the soil profile, differences between control and the treatments in four slope gradient became smaller. The highest level of increased in bulk density was found in the trail with 10% slope gradient (uphill) between control and the treatments.

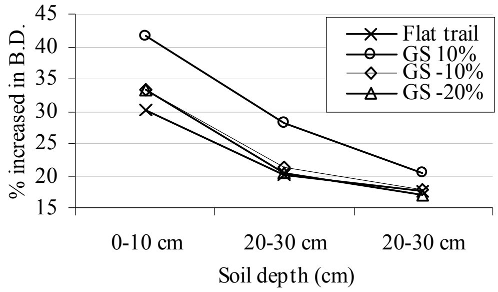

Figure 3: Average increase in bulk density with depth on skid rails on four slope gradient

Rut depth (Table 2) was increased significantly by the soil moisture (p=0.00) and number of machine passages (p=0.00), but not affected significantly with interactions machine passes × soil moisture (p = 0.45).

Table 2: Analysis of variance (ANOVA) for the effect of soil moisture (SM) and number of machine passages (NP) on rut depth in skid trials

Source	SS	df	MS	F	P
NP	148732	2	74336	354.22	0.00
SM	15645.5	5	3129.1	14.9	0.00
NP × SM	2136	10	213.6	1.02	0.45

For comparing the rut depth in tree soil moisture group a machine passes, we used one-way analysis of variance (ANOVA) and Duncan's test to see if there were significant differences ($P \leq 0.05$) between the rut depths. In general, rut depth increased significantly with soil moisture. Average rut depths were 172, 101, and 43 mm for 20-30, 30-40, and 40-50 % soil moisture content, respectively, and rut depth was significantly separated from each others. After 30 machine passes rut depth for the 40-50% soil moisture have the highest value.

4 Discussion

Result shows that average bulk density significantly increased after wheeled skidder operations. In flat trail, the bulk density in the 0-10 cm of the soil (1.06 g/cm^3) increased by 33% after skidding operations. This value (% increased bulk density) for tail with 10% SG, -10% SG, and -20% SG were 45, 36 and 36%, respectively. However, in different slope gradient percentage of increased bulk densities were statistically different. Results of majority of studies were consistent with our result (Sidle and Drlica 1981; Froehlich and McNabb 1984; Rollerson 1990; Gayoso and Iroume 1991; Eliasson 2005; Susnjar et al. 2006; Ampoorter et al. 2007; Eliasson and Wasterlund 2007; Horn et al. 2007; Jamshidi et al. 2008). The numerous literatures have studied the impacts of the frequency of vehicle passes on soil compaction. These studies show that most compaction occurs during the first few passes of a machine (Froehlich et al. 1980; Sidle and Drlica 1981; Gayoso and Iroume 1991; Jamshidi et al. 2008), one pass (Ampoorter et al. 2007), first 10 to 20 passes (Rollerson 1990). Subsequent machine passes increased the soil compaction at a lesser extent until there is little or no more compaction associated with a machine pass. In this study, flat trails have the lowest bulk density; the trails with -10 and -20% slope gradient (downhill skidding) have intermediate bulk density and the trails with 10% slope gradient (uphill) have the highest compaction. This result was explained based on the uneven load distribution between the downhill and uphill tires of the skidder on the trail with a transversal slope or between the front and rear axles of the skidder on the trail with a longitudinal gradient which would result in higher dynamic peak loads being exerted on the ground (Jamshidi et al. 2008).

Results show that average pre-harvest bulk densities significantly increased as soil profile depth increased for all slope gradient. In other hand, the values of the native soil bulk density mostly depend on quantity of organic matter, and as with increase of depth, organic matter is rapidly decreased, and the bulk density increased in subsoil. In the upper soil, biological activity (roots and animals) can act to reduce resistance and soil bulk density while at lower depths soil texture, gravel content and structure may increase soil resistance and soil bulk density. For the pre-harvest soil bulk density samples, bulk density increases with depth similar to other studies (Greacen and Sands 1980; Adams and Froehlich 1984; Froese 2004; Johnson et al. 2007). In this study there was not only compaction at all three depths but also with increasing compaction by depth accordance to other studies (Greacen and Sands 1980; Sidle and Drlica 1981; Gent and Morris 1986; Gayoso and Iroume 1991; Ares et al. 2005; Eliasson and Wasterlund 2007; Johnson et al. 2007). In general, rut depth increased significantly with soil moisture. Average rut depths were 172, 101, and 43 mm for 20-30, 30-40, and 40-50 % soil moisture content, respectively, and rut depth was significantly separated from each others. Several authors reported that in wet soils that have very low bearing strength, rutting is produced by the largely lateral soil displacement by wheels or tracks (Greacen and Sands 1980; Rollerson 1990; Turcotte et al. 1991, Reisinger et al. 1994; McNabb 1997; Eliasson and Wasterlund 2007).

Forest soils with high organic-matter, low bulk density, high porosity, low strength and high permeabilities are very susceptible to soil compaction and shear effects. According to our findings, we have to conclude that the most compaction occurred after the initial few passes and reducing the number of trips made over the same trail has not any effect for reducing soil compaction. Hence, even one pass is already sufficient to induce a strong increase in bulk density. Slope gradient and soil moisture have significantly effects on soil compaction. Also, slope gradients on trails should be as low as possible, particularly when vehicles are traveling loaded. Severe compaction of soil adversely affects the growth of plants by a combination of physical soil changes and plant physiological dysfunctions. One strategy to limit soil disturbances is to avoid traffic whenever the water content approaches the limit of liquidity, or even exceeds it. Skidding operations should be planned when soil conditions are dry so as to minimize rutting, but if skidding must be done under wet conditions, the operations should be stopped when machine traffic creates deep ruts. Another approach is to limit traffic on skid trails. Traffic trails should be developed for forest sites in order to concentrate most forest operations to compacted trails. The distance between these trails must depend on the length of the felled tree and may range between 50 and 70 m distance. Preplanning of skid trails and directional felling will improve skidding efficiency, increase safety, and reduce ground disturbance.

5 References

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