Original scientific paper

Soil Compaction and Porosity Changes Caused During the Operation of Timberjack 450C Skidder in Northern Iran

Ahmad Solgi, Ramin Naghdi, Petros A. Tsioras, Mehrdad Nikooy

Abstract

Skidding by means of heavy forestry machinery can affect soil physical properties. We assessed the effects of ground based skidding on soil bulk density and total porosity under the Iranian mountainous forest conditions. Treatments included a combination of four levels of traffic intensity (1, 3, 6, and 15 passes) of a Timberjack 450C rubber skidder and two levels of slope (<20% and >20%). The bulk density was highest in samples taken in the wheel tracks and between them, and decreased towards both ends of the track (0.5 to 4 m). The results showed that bulk density increased with traffic frequency, while total porosity decreased. Average soil bulk density ranged from 0.96 g cm^{-3} (after one machine pass and slope <20%) up to 1.41 g cm^{-3} (after 15 machine passes and slope >20%) on the skid trail, while the respective value was 0.7 g cm^{-3} for the undisturbed area. On compacted soil, total porosity at the 0–10 cm depth decreased by 37% compared with non-compacted soil. The results showed that slope steepness had a strong effect on the soil disturbance, with the critical value for bulk density occurring after 15 machine passes at slope <20% and six machines passes at slope >20%. The impacts of soil compaction could be evidenced in a distance of up to 2 m from the end of the skidding trail. The latter finding suggests that special interest in the form of managerial measures should be taken during the skidding operations in an effort to minimize the adverse effects of ground based skidding on the physical properties of the soil.

Keywords: bulk density, slope, soil compaction, total porosity

1. Introduction

Wood extraction by means of forest machinery has replaced animal skidding in many parts of the world. This change has resulted in higher productivity rates and efficiency of the forest operations, but at the same time, has brought up the problem of soil disturbance. One of the most commonly witnessed forms of soil disturbance is soil compaction. Soil compaction is a typical process that may appear as a result of inappropriate use of heavy forest machinery (Ampoorter et al. 2010, Greacen and Sands 1980).

Soil compaction refers to the compression of pores, which leads to decreased porosity (Gayoso and Iroume 1991) and pore continuity (Berli et al. 2004), increased bulk density (Eliasson 2005, Greacen and Sands 1980, Solgi et al. 2013), increased soil strength (Horn et al. 2004), decreased gas exchange rates between soil and atmosphere (Shestak and Busse 2005) and lower water infiltration (Dickerson 1976), which in turn leads to increased runoff. Furthermore, when air filled porosity falls below 10% of the total soil volume, microbial activity can be severely limited in most soils (Brady and Weil 2003). Soil compaction, with its multiple adverse impacts to the management and long term productivity of forested areas, is a major problem that should be properly addressed (Matangaran and Kobayashi 1999).

A large number of factors influence the extent and severity of soil compaction. These factors include site and soil properties, such as soil texture, the magnitude and nature of compressive forces, skid trail conditions, forest stand characteristics, harvesting system, and training, experience and expertise of equipment operators (Demir et al. 2007). Traffic intensity (number of machine passes) plays an important role in soil compaction because deformations can increase with the number of passes and may lead to excessive soil disturbance. Also, slope steepness has been associated with a strong effect on soil disturbance during timber harvesting (Krag et al. 1986). Najafi et al. (2009) showed that disturbance increased in both magnitude (extent) and depth with an increasing slope.

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 analysis 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 (Nugent et al. 2003).

The objective of this study was to determine the impacts of ground skidding on soil disturbance at different levels of trail slope and traffic intensity, with regard to a) soil bulk density and b) soil porosity in the wheel tracks, between them and in an area 4 m wide on each side of the skid trail. The results are discussed and threshold levels for machine traffic intensity and skid trail slope are proposed.

2. Materials and methods

2.1 Site description

The study was conducted during the period August – September 2013 in compartment 41 of the third district of Nav-Asalem forest, Guilan Province, northern Iran (Fig. 1), with an area of 62 ha and a slope of 0–50%. The general location of the study site is between 37°37'and 37°61'N latitude and 48°39' and 48°44'E longitude. The area is covered by *Fagus orientalis* and *Carpinus betulus* stands. Canopy cover has been estimated to be 85%, average tree diameter was 32.53 cm, average tree height was 21.76 m and stand density has been measured to be 180 trees/ha. Elevation is approximately 1400 m above sea level with a northern aspect. The average annual rainfall in the area amounts to 1200 mm, with the lowest monthly average precipitation value of 25 mm in August and the highest of 120 mm in October. Mean annual temperature is 15 °C, with the lowest values in February. At the time of skidding, weather conditions were wet with the soil having an average gravimetric moisture content of 28%. Soil texture along the trail was determined to be clay loam after analysis with the Bouyoucos hydrometer method (Kalra and Maynard, 1991). The soil had not been driven on before the experiment.

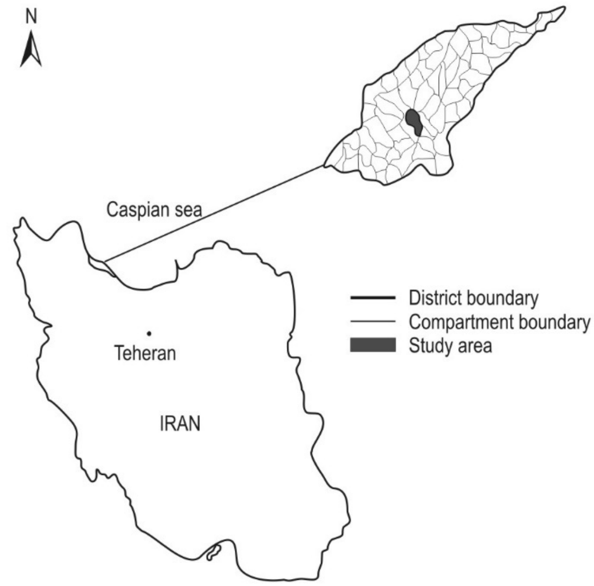

Fig. 1 Compartment 41 of the third district of Nav-Asalem forest in northern Iran (study area)

Single tree selection method was used in the study area. All logs (of various dimensions) were extracted from stump area to road side landing by a ground based skidding system. The machine used was the 4WD Timberjack 450C rubber tired skidder, weighing 10.3 ton without load (axle weight proportion 55% on the front to 45% on the rear axle).The skidder was equipped with the engine model 6BTA5.9 (engine power of 177 PS) and was fitted with tires of 24.5–32 inflated to 220 kPa.

2.2 Experimental design and data collection

A skid trail, 4 m wide and 800 m long with upslope skidding direction, was selected for the experiments. The skid trail passed through the stand in an east west direction and has been used recently. The longitudinal profile showed that the slope of the skid trail ranged from 0 to 36%. In this study, the impacts of skidding on the skid trail surface soil layer (0–10 cm depth) have been examined by a) measuring dry bulk density and total porosity, at different levels of slope and traffic intensity and b) comparing these results with the respective values in samples taken from undisturbed area. Our experimental design included two slope classes (<20%, and >20%) and four levels of traffic intensity (1, 3, 6, and 15 passes). Each treatment was replicated three times.

Twenty four plots, 10 m long and 12 m wide, were delineated randomly prior to skidding. Each plot was divided in three parallel transects with similar dimen-

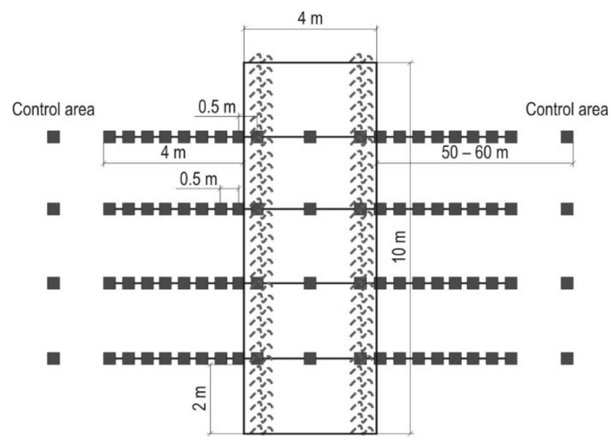

Fig. 2 Study layout

sions (10 m long and 4 m wide), with the central transect characterized as the skid trail area. Buffer zones of at least 5 m length were created between plots in order to avoid interactions. In each plot, samples were taken along four randomized lines perpendicular to the direction of travel, leaving 2 m buffer zone between them to avoid interactions. More specifically, soil samples from the 0–10 cm depth were collected at three different points of each line, one on the left track (*LT*), one between tracks (*BT*) and one on the right track (*RT*). Furthermore, 8 soil sample points were taken on each side of the lines at 0.5 m intervals, extending from the skid trail area to undisturbed soil. For control purposes, soil samples were taken from the undisturbed area, where there was no skidding impact, at least 50–60 m away from the skid trail (at least two – tree lengths away to reduce possible impacts) (Fig. 2).

The soil samples were collected with the help of a soil hammer and cylinders (diameter 5 cm, length 10 cm). All samples were put in polyethylene bags and labelled. Then the samples were brought to the laboratory, where they were promptly weighed. The samples were oven dried at the temperature of 105 °C for 24 h and weighed for a second time. The formulas below were used to determine bulk density and total soil porosity:

Total porosity was calculated as Eq. (1) (Fernández et al. 2002, Ezzati et al. 2012):

$$AP = \frac{1\frac{Db}{2.65}}{VC}\times 100 \qquad (1)$$

Where:

AP total apparent porosity, %;

Db soil bulk density, g cm^{-3};

2.65 particle density, g cm^{-3};

VC volume of the soil cores, 196.25 cm^{3};

Soil bulk density was calculated as Eq. (2) (Tan et al. 2005):

$$Db = \frac{Wd}{VC} \qquad (1)$$

Where:

Wd weight of the dry soil, g.

2.3 Statistical analysis

The data were analyzed using two-way ANOVAs in the SPSS 11.5 software. Mean values of physical soil properties at each plot were compared to those in undisturbed (untrafficked) areas using Duncan's multiple range test (Zar 1999). One-way ANOVA (significance test criterion $P \leq 0.05$) was used to compare the physical soil properties in four traffic intensities (main effects) with those in undisturbed areas. Paired *t*-tests were used to analyze soil properties data in two slope gradients at an alpha level of 0.05.

3. Results

3.1 Soil bulk density

Soil bulk density was measured as 0.7 g cm^{-3} in the general harvesting area (undisturbed area). On the skid trail, soil bulk density increased both with traffic frequency ($p<0.05$) and skid trail slope ($p<0.05$), but the interaction effects of traffic frequency × skid trail slope were found not significant (Table 1). Compared to the undisturbed soil condition, average soil bulk density at the 0–10 cm depth increased by 77% in compacted plots.

Table 1 Analysis of variance (*P* values) of the effects of number of passes and slope class on dry bulk density and total porosit

Source of Variance		*d.f.*	*P* value*
Dry Bulk Density	Number of passes	3	≤0.001
	Slope class	1	≤0.029
	Number of passes × slope class	3	0.137
Total Soil Porosity	Number of passes	3	≤0.001
	Slope class	1	≤0.014
	Number of passes × slope class	3	0.382

*P values less than 0.05 are given in bold

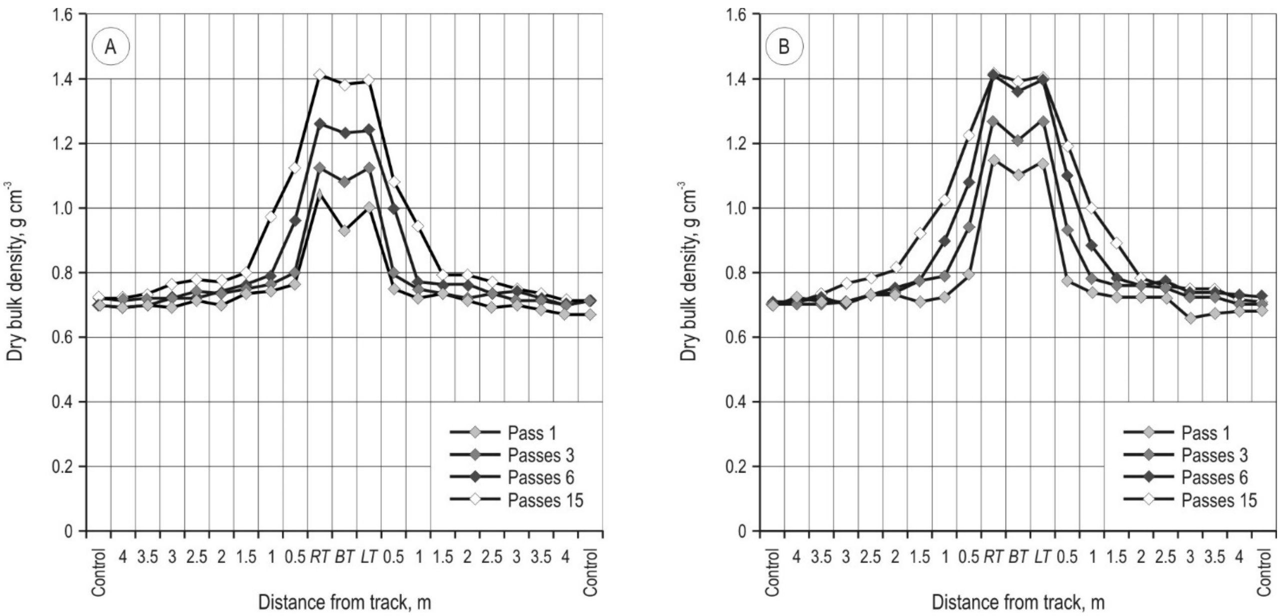

Fig. 3 Soil bulk density under the main track (*LT* and *RT*), log track (*BT*) and at various distances from the track (a: slope <20%; b: slope >20%)

Table 2 Effect of slope and traffic intensity on bulk density (g cm^{-3})

Slope	Cycles				
	0*	1	3	6	15
<20%	0.69^a	0.96^a	1.09^a	1.23^a	1.39^a
>20%	0.71^a	1.13^b	1.25^b	1.40^b	1.41^a

*0 passes denotes undisturbed soil

Table 3 Dry bulk density increase (%) per slope class compared to the previous traffic intensity level

Slope class	Traffic intensity			
	1	3	6	15
<20%	37.14	13.54	12.84	13.00
>20%	61.42	10.62	11.68	0.71

Average soil bulk density values ranged from 0.96 g cm^{-3} (one pass and slope of <20%) to 1.41g cm^{-3} (15 passes and slope of >20%) on the skid trail compared to 0.7 g cm^{-3} in the undisturbed area. The results showed that the dry bulk density was affected by skid trail slope (Table 2).

Average dry bulk density of the samples with one pass and slope of >20% (1.13 g cm^{-3}) was higher than of those after 3 passes and slope of <20% (1.09 g cm^{-3}). Within all traffic frequencies, dry bulk density increased considerably faster with an increase in slope from <20% to >20% (Table 2).

The results showed that most of the potential impact occurred after the initial passes. As it can be noticed in Table 3, substantial increases in bulk density (61.42%) for skid trails at steep terrain appear right after the first skidder pass.

The degree of bulk density of the soil just under the main track (right and left track) or log track (between tracks) differed from those at various distances from the track. In each plot, the highest bulk density was observed in the sample points along the main track. As we move away from the main track, bulk density decreased (Fig. 3).

Bulk density increased at different rates at the sampling points »outside« the skid trail area; however, the amount of increase varied between the two slope classes and the distance from the skid trail (Fig. 4). Also, as traffic intensity increased, the difference between bulk density values on the skid trail, as well as between the skid trail and the adjacent sampling points decreased. This finding suggests that the higher the skid trail usage, the more area adjacent to it is compacted.

3.2 Total porosity

Total porosity changes were influenced significantly by the number of skidder passes (p<0.05) and the slope (p<0.05); however, the interaction between numbers of skidder passes and slope was not significant (p>0.05) (Table 1). Total porosity on the skid trail was considerably lower than the total porosity in the undisturbed area (Table 4).

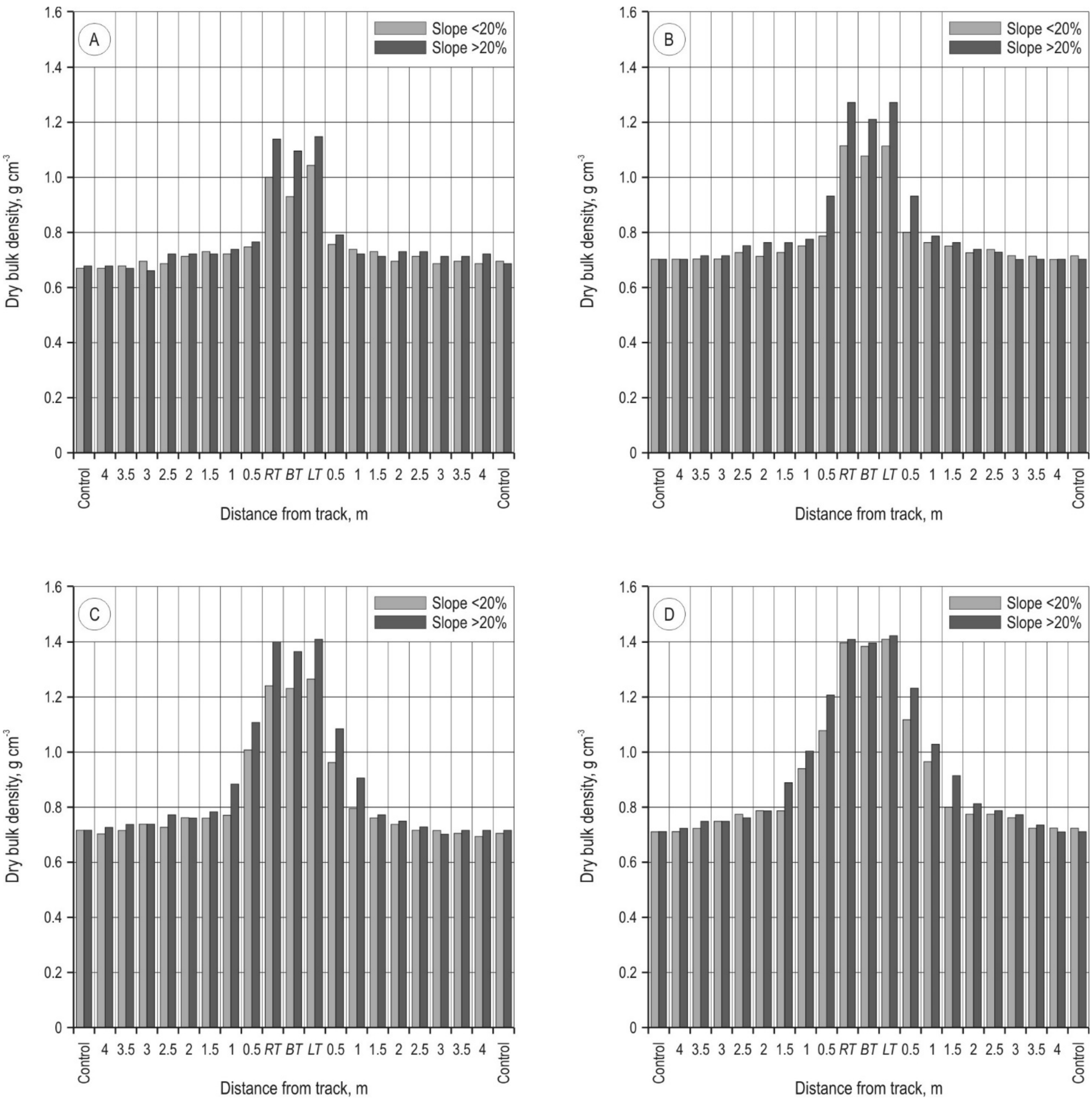

Fig. 4 Effect of different numbers of skidder passes on soil bulk density under the main track (*LT* and *RT*), log track (*BT*) and at various distances from the end of the track (a: one pass; b: three passes; c: six passes; d: fifteen passes)

Table 4 Effect of skidder passes on total porosity (%)

Slope	Number of passes				
	0*	1	3	6	15
<20%	74.62^{a}	62.82^{b}	56.82^{c}	52.67^{d}	49.18^{e}
>20%	74.32^{a}	56.93^{b}	53.12^{c}	49.11^{d}	46.67^{e}

*0 passes denote undisturbed soil

On compacted soil, total porosity at the 0–10 cm depth decreased by 37% compared to non-compacted soil. The average total porosity in the undisturbed area is 74% and on the skid trail 53%. The total porosity was significantly lower on the plots with a slope of >20% than those of <20% in all traffic treatments.

In each treatment, as we move away from the main track, the total porosity increased. The lowest total po-

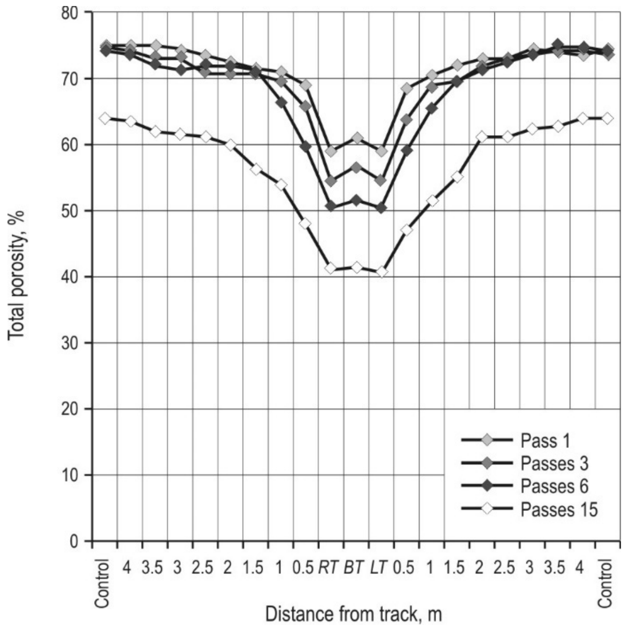

Fig. 5 Soil total porosity under the main track (*LT* and *RT*), log track (*BT*) and at various distances from the track

rosity value was observed in the soil just under the main track, while its highest value was measured in the undisturbed area (Fig. 5).

4. Discussion

Soil compaction was affected by trail slope, with dry bulk density increasing faster at higher slope levels. This may be a consequence of the difficulties that the skidder found when logging in steep terrains. Under these conditions, the machine slipped continuously and remained in a given place for a longer period of time, puddling and dragging the soil (Gayoso and Iroume 1991). When a skidder passes slower on a steep slope, the top soil is obviously vibrated more and consequently gets more disturbances compared to flat terrain. In the case of uphill skidding, higher soil compaction can be explained by the higher load of the skidder rear axle (Najafi et al. 2009). The increase of bulk density and decrease of total porosity in the steep slope trail and at various distances from it may be associated with the lower speed of skidder on steeper slope.

Many previous studies indicated that most of the potential impact occurred after the initial passes (Lacey and Ryan 2000, Startsev and McNabb 2000). As it can be noticed in Table 3, strong increases in bulk density (61.42%) for skid trails already appear right after the first skidder pass at a slope higher than 20%. Such high bulk density changes for this traffic intensity are not uncommon, and they have been reported by Williamson and Neilsen (2000). At lower inclination than 20%, three skidding cycles increased bulk density by 55.7%, which is in line with Ampoorter et al. (2007), who found that bulk density increases more gradually with 50% of the total impact occurring after 3 passes. Our results contradict the findings of other studies, which report that significant changes in soil compaction can occur after six machine passes during skidding operations (Froehlich 1978, Jamshidi et al. 2008). However, such differences may be attributed to a number of reasons, including different soil attributes, different machine types and dimensions, among others (Bustos and Egan 2011, Rab et al. 2005, Williamson and Neilsen 2000).

At lower slope levels, dry bulk density reached the critical value after 15 passes, compared to only 6 passes needed at slope of >20%. There was no significant difference between treatments of 6 passes and slope of >20% and those of 15 passes and slope of <20% from a bulk density point of view. Given that reaching the critical value has an adverse effect on site productivity, a number of managerial measures could allow for increased traffic intensity at reduced soil compaction. In this context, changes in skidding equipment should be considered, when they are not constrained by high purchase costs, increased operational costs, type of silvicultural prescription and potential residual stand damage (Bustos and Egan 2011, Bustos et al. 2010)

There were significant ($p \leq 0.01$) differences in total porosity between treatments with the slope of <20% and those with more than 20%, which is in line with Solgi and Najafi (2014). The major differences in pore volume between the different slope treatments could probably be explained by more soil compaction on the steep trail, indicating the effect of slope on soil porosity during ground skidding. No significant differences were found in porosity between the undisturbed area and various points of the track when skidder passed once, but there was a difference when traffic increased to three passes (at slope of >20%) and more than six passes (at slope of <20%).

According to our findings, soil compaction decreased as the distance from skid trail increased. These results agree with those quoted by Matangaran and Kobayashi (1999). The extent of change in mean bulk density was affected by traffic intensity and slope and was found to be statistically significant for samples taken from points up to 2 m from the end of the trail. Under realistic conditions, where skidder operators do not necessarily drive on the skid track and the number of passes can exceed 15, it is easy to conclude that soil compaction extends to the adjacent area of the skid trail. For this reason, it is necessary to design skidding roads in a way that minimizes logging impact (Matangaran and Kobayashi 1999), which can be accompanied by reduced skidding cost and better spatial allocation of the respective equipment (Najafi et al. 2008). Special attention should be given to the weather conditions suggesting that machine traffic should be reduced to dry and favourable weather conditions (Hittenbeck 2013). In the case of existing skid trails, restricting skidding traffic to a smaller portion of the harvest site (Zenner et al. 2007) designated as permanent skidding tracks, might be an alternative, when applicable. Special interest should be given to the human factor. Tiltable seats and cabins can reduce the operator stress at higher inclinations (Hittenbeck 2013), with a possible positive effect on work safety, as well as on a more considerate driving style of the machine operator under adverse conditions. Finally, the forest crews should be aware of the adverse impacts of soil compaction in forest stands and participate in training seminars, in an effort to minimize the environmental impacts (Tsioras 2010).

5. Conclusion

This study was conducted with the overall objective to assess the impacts of ground skidding on soil disturbance at different levels of trail slope and traffic intensity. Dry bulk density increase by 61.42% was measured after the first skidder pass at slope >20%, while it took more than three passes at slope <20% to reach this value. The critical value for bulk density was also achieved after 6 machine passes for slope >20% compared to 15 needed at slope <20%. Bulk density increase extended for the respective slope and traffic intensity up to an area of 2 m from the end of each wheel track. Total porosity decrease ranged from 15.5% for the low traffic (1 pass and slope of <20%) up to 37.27% for the severe (15 passes and slope of >20%) treatments.

The impacts of skidding operations on soil disturbance can be ameliorated with a number of managerial and technical measures. Changes in equipment and better forest road design, which takes into consideration the, above mentioned, soil responses to compaction and restriction of traffic in heavily trafficked parts of the forest compartments, can mitigate the effects of ground based skidding operations. However, all these changes will have suboptimal results, unless special interest is given to the forest operation crews. For this reason, training seminars on the proper use of forest machinery should be introduced, which will benefit the forest enterprises not only in reducing logging impact but also in various other levels, such as improved operational efficiency, reduced operational costs and higher safety during forest work.

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6. References

Ampoorter, E., Goris, R., Cornelis, W.M., Verheyen, K., 2007: Impact of mechanized logging on compaction status of sandy forest soils. Forest Ecology and Management 241(1–3): 162–174.

Ampoorter, E., Van Nevel, L., De Vos, B., Hermy, M., Verheyen, K., 2010: Assessing the effects of initial soil characteristics, machine mass and traffic intensity on forest soil compaction. Forest Ecology and Management 260(10): 1664–1676.

Berli, M., Kulli, B., Attinger, W., Keller, M., Leuenberger, J., Flühler, H., Springman, S.M., Schulin, R., 2004: Compaction of agricultural and forest subsoils by tracked heavy construction machinery. Soil and Tillage Research 75(1): 37–52.

Brady, N.C., Weil, R.R., 2003: Elements of Nature and Properites of Soils, 2nd ed. Prentice Hall, 1031 p.

Bustos, O., Egan, A., 2011: A comparison of soil compaction associated with four ground-based harvesting systems. Northern Journal of Applied Forestry 28(4): 194–198.

Bustos, O., Egan, A., Hedstrom, W., 2010: A comparison of residual stand damage along yarding trails in a group selection harvest using four different yarding methods. Northern Journal of Applied Forestry 27(2): 56–61.

Demir, M., Makineci, E., Yilmaz, E., 2007: Investigation of timber harvesting impacts on herbaceous cover, forest floor and surface soil properties on skid road in an oak (*Quercus petrea* L.) stand. Building and Environment 42(3): 1194–1199.

Dickerson, B.P., 1976: Soil compaction after tree-length skidding in northern Mississippi. Soil Science Society of American Journal 40(6): 965–966.

Eliasson, L., 2005: Effects of forwarder tyre pressure on rut formation and soil compaction. Silva Fennica 39(4): 549–557.

Ezzati, S., Najafi, A., Rab, M.A., Zenner, E.K., 2012: Recovery of soil bulk density, porosity and rutting from ground skidding over a 20-year period after timber harvesting in Iran. Silva Fennica 46(4): 521–538.

Fernández, R.A., Mac Donagh, P.M., Lupi, A.M., Rodolfo, M., Pablo, C., 2002: Relations between soil compaction and plantation growth of a 8 years old Lobolly pine second rotation, in Misiones, Argentine. Written for presentation at the 2002 ASAE annual international meeting/CIGR XVth world congress sponsored by ASAE and CIGR Hyatt Regency Chicago Chicago, Illinois, USA. Paper Number: 025012.

Froehlich, H.A., 1978: Soil compaction from low ground-pressure, torsion-suspension logging vehicles on three forest soils. Forest Research Laboratory, Oregon State University, Corvallis, p. 12.

Gayoso, J., Iroume, A., 1991: Compaction and soil disturbances from logging in southern Chile. Annales des Sciences Forestieres 48(1): 63–71.

Greacen, E.L., Sands, R., 1980: Compaction of forest soils. A review. Australian Journal of Soil Research 18(2): 163–189.

Hittenbeck, J., 2013: Estimation of trafficable grades from traction performance of a forwarder. Croatian Journal of Forest Engineering 34(1): 71–81.

Horn, R., Vossbrink, J., Becker, S., 2004. Modern forestry vehicles and their impacts on soil physical properties. Soil and Tillage Research 79(2): 207–219.

Jamshidi, R., Jaeger, D., Raafatnia, N., Tabari, M., 2008: Influence of two ground-based skidding systems on soil compaction under different slope and gradient conditions. International Journal of Forest Engineering 19(1): 9–16.

Krag, R., Higginbotham, K., Rothwell, R., 1986: Logging and soil disturbance in southeast British Columbia. Canadian Journal of Forest Research 16(6): 1345–1354.

Lacey, S.T., Ryan, P.J., 2000: Cumulative management impacts on soil physical properties and early growth of *Pinus radiata*. Forest Ecology and Management 138(1–3): 321–333.

Matangaran, J.R., Kobayashi, H., 1999: The effect of tractor logging on forest soil compaction and growth of Shorea selanica seedlings in Indonesia. Journal of Forest Research 4(1): 13–15.

Najafi, A., Sobhani, H., Saeed, A., Makhdom, M., Mohajer, M.M., 2008: Planning and assessment of alternative forest road and skidding networks. Croatian Journal of Forest Engineering 29(1): 63–73.

Najafi, A., Solgi, A., Sadeghi, S.H., 2009: Soil disturbance following four wheel rubber skidder logging on the steep trail in the north mountainous forest of Iran. Soil and Tillage Research 103(1): 165–169.

Nugent, C., Kanali, C., Owende, P.M.O., Nieuwenhuis, M., Ward, S., 2003: Characteristic site disturbance due to harvesting and extraction machinery traffic on sensitive forest sites with peat soils. Forest Ecology and Management 180(1–3): 85–98.

Rab, A., Bradshaw, J., Campell, R., Murphy, S., 2005: Review of factors affecting disturbance, compaction and trafficability of soils with particular reference to timber harvesting in the forests of south west western Australia. Sustainable Forest Management Series, 145 p.

Shestak, C.J., Busse, M.D., 2005: Compaction alters physical but not biological indices of soil health. Soil Science Society of American Journal 69(1): 236–246.

Solgi, A., Najafi, A., 2014: The impacts of ground based logging equipment on forest soil. Journal of Forest Science 60(1): 28–34.

Solgi, A., Najafi, A., Sam Daliri, H., 2013: Assessment of crawler tractor effects on soil surface properties. Caspian Journal of Environmental Sciences 11(2): 185–193.

Startsev, A.D., McNabb, D.H., 2000: Effects of skidding on forest soil infiltration in west central Alberta. Canadian Journal of Soil Science 80(4): 617–624.

Tan, X., Scott, X.C., Kabzems, R., 2005: Effects of soil compaction and forest floor removal on soil microbial properties and N transformations in a boreal forest long term soil productivity study. Forest Ecology and Management 217(2–3): 158–170.

Tsioras, P.A., 2010: Perspectives of the forest workers in Greece. iForest 3: 118–123.

Williamson, J.R., Neilsen, W.A., 2000: The influence of forest site on rate and extent of soil compaction and profile disturbance of skid trails during ground-based harvesting. Canadian Journal of Forest Research 30(8): 1196–1205.

Zar, J.H., 1999: Biostatistical analysis, 4th edition, Prentice Hall, Upper Saddle River, NJ, USA. 662 p. plus appendices.

Zenner, E.K., Fauskee, J.T., Berger, A.L., Puettmann, K.J., 2007: Impacts of skidding traffic intensity on soil disturbance, soil recovery, and aspen regeneration in North Central Minnesota. Northern Journal of Applied Forestry 24(3): 177–183.

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