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Changes in Soil Physical Properties in Response to Metal-Tracked Skidder Traffic

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Abstract Ground skidding on skid trails affects the physical properties of soil. The objective of this study was to evaluate changes in soil physical properties on skid trails formed due to traffic of metal-tracked skidders with regard to soil bulk density, total porosity, water content and penetration resistance. The studies were implemented on two levels of slope – <20% (SC1) and >20% (SC2) – and three levels of traffic (one, five and nine traffic cycles). The treatment plots with three replications, consequently, were 6 m long and 4 m wide. The measurement of soil penetration resistance was carried out using a cone penetrometer. The samples were taken from 10 cm of top soil at six points in each plot. The results indicated that the skidder traffic did not significantly affect the soil physical properties measured in three levels of traffic at SC1, whereas it was significant between one and five traffic cycles in SC2. Most of the changes in the measured properties in the skid trails occurred after the first loaded skidder traffic. Within all traffic of SC2, differences in the mean values of water content and soil porosity were greater compared with the mean values at the same traffic of SC1, although these differences were not significant. The bulk density and penetration resistance at five and nine traffics of SC2 were significantly different from the same traffic of SC1.

Key words: *Bulk density, Skidding operations, Soil penetration resistances, Total porosity, Water content*

1 INTRODUCTION

Many negative impacts due to harvesting operations of forest trees in the forest ecosystem have been investigated and reported by several authors (Makineci *et al.*, 2007; Agherkakli *et al.*, 2010). Recently, the need for the evaluation of soil properties has increased because of growing public interest in determining the consequences of management practices on the quality of soil relative to the sustainability of forest ecosystems.

Traffic associated with log extraction operations in intensive forest practices leads to changes in soil physical characteristics such as structure, porosity, compaction, strength, pore size distribution, aeration, water retention, infiltrability, and hydraulic conductivity (Cullen *et al.*, 1991; Najafi *et al.*, 2009). Changes in soil physical properties have been linked to changes in chemical, biological and hydrological properties and processes that may impede long-term site productivity (Tiarks and Haywood, 1996; Kelting *et al.*, 1999; Makineci *et al.*, 2007).

Soil compaction caused by forest management activities and can result in high moisture contents and low bearing capacity of forest soils (Carter *et al.*, 2007). Soil compaction has been identified as one of the leading problems causing soil degradation that

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threatens soil productivity and increases soil erosion and run-off.

Soil compaction caused by traffic causes reduced tree growth because of greater penetration resistance, reduced porosity, lower infiltration, hydraulic conductivity and restricted root space (Marsili *et al.*, 1998; Grigal, 2000; Radford *et al.*, 2000; Startsev and McNabb, 2001; Lipiec *et al.*, 2007).

Aeration porosity is a reliable indicator of how compacted a soil has become (Pagliai, 1988). A macroporosity of at least 10% is a prerequisite to allow sufficient air diffusion, microbial activity and root proliferation (Koorevaar *et al.*, 1983). Lowered aeration porosity reduces gas exchange, which affects oxygen and carbon dioxide concentrations in the soil. The extent of severe disturbance caused by log skidding operations varies according to many factors such as site characteristics, slope of the skid trail, production methods applied, planning of skid roads and production season. Regardless of these factors, the majority of compaction occurs during the first few traffic cycles in relation to subsequent passes; however, these may lead to further soil disturbance by deepening the ruts (Rollerson, 1990; Shepperd, 1993). This suggests the same track is used for repeat traffic. Sky line (Miller and Sirois, 1986) or helicopter (Blakeney, 1992) yarding have less negative impacts on the soil characteristics, but these alternative harvesting systems need high investment compared with ground-based skidding. Thus, ground extraction systems are likely to remain important in spite of their negative impacts on soils.

The most common logging operation is the use of rubber-tyred or metal-tracked skidders. Logging forests of Iran are located in mountainous sites with steep slopes and clay soil. Soils of such forest ecosystems are susceptible to disturbance from log extraction and machinery traffic. In spite of the important role of slope on the degree of soil disturbance, there is little information on the effect of this factor. It is important to understand the exact effect of skidding traffic on soil physical properties so as to formulate strategies for its management. Thus, a study was conducted to investigate changes in physical properties of forest soils on skid trails formed by metal-tracked skidder traffic under different slope conditions.

2 MATERIALS AND METHODS

The study area is located at Tarbiat Modares University Forestry Experimental Station, in a temperate forest in the north of Iran, between 36° 31′ 56″ N and 36° 32′ 11″ N latitude and 51° 47′ 49″ E and 51° 47′ 56″ E longitude. The site is located 650 m above sea level with a western aspect and average annual rainfall in the region is 1308 mm (Nowshar station).

2.1 Experimental design and data collection

A skid trail was selected with a range of longitudinal slope steepness and without any lateral slope. Regarding the skid trail longitudinal profile and maximum slope (26%), two slope classes were considered (<20% and >20%). A 150-m-long straight skid trail was selected at each slope class (SC). The treatment plots (4 m wide × 10 m long) were delineated prior to skidding and assigned to six combinations of slope classes (SC1 and SC2) and traffic intensities (one, five and nine traffic cycles) with at least a 5-m buffer zone between plots to avoid interactions (Agherkakli *et al.*, 2010).

These plots were randomized with three replications and line samples across the chain rut perpendicular to the direction of travel with a 1-m buffer zone between lines to avoid interactions (Najafi *et al.,* 2009). In this study, a fixed log (diameter 80 cm and length 3.6 m) was hauled by a crawler tractor TLT - 100A (Table 1) for all treatments. Samples were collected in two tracks in every plot after one, five and nine traffic cycles at each SC. The undisturbed soil samples were collected using 10-cm-high steel cylinders with 6-cm diameters from 10 cm depth and were put in double plastic, labeled and then brought to the laboratory. The moisture content in the soil samples was determined thermo-gravimetrically.

Table 1 Technical description of the metal-tracked skidder LTT-100A.

Length(m)	6
Width(m)	2.6
Track(m)	3
Operation power(kWt)	88.2
Ground unit pressure(MPa)	0.049
Track drive sprockets	Cast-steel tooth
Ground unit pressure(MPa)	0.049
Pressure in hydraulic	14
Number of teeth	9
Width of caterpillar(cm)	44
Tractor mass maintenance(kg)	11200

These samples were used for sieving analyses and determination of plastic and liquid limits. The particle density (*Dp*) of the soil samples was determined as the ratio of the mass of oven-dried soil to the volume of soil solids. Total porosity of the soil was calculated as $TP = (1 - Db/Dp) \times 100$ where *TP* is the apparent total porosity (%) and *Db* is the soil dry bulk density (g cm^{-3}) Because of the dependency of penetration resistance to soil water content, measurements have to be taken when the soil is near field capacity, as suggested by Smith *et al.* (1997).

Because penetration resistance is greatly influenced by soil moisture conditions, it was re-measured in each slope class when the soil moisture content was uniform in all three strips. Soil penetration resistance was measured with a cone penetrometer to a depth of 10 cm with vertical separation distance of 5 cm. The penetrometer had a drive mechanism powered by a hand crank, allowing insertion at a constant rate. The cone had a 108° angle with a cone base cross-sectional area of 1 cm^2. For each plot, including the control areas, six penetrometer readings were taken in increments of 5 cm at depth intervals of 10 cm.

Soil texture in the laboratory was determined based on particle size analysis using the Bouyoucos hydrometer method (Kalra and Maynard, 1991).

ANOVA was used to assess the effects of compaction on the measured variables. In the case of a significant *F*-value, multiple comparisons of mean values were performed by the least significant difference method (LSD). SPSS software package version 1.5 was used for all statistical analyses.

3 RESULTS

The treatment plots prior to the skidding operation showed an average soil bulk density of 0.90 g cm^{-3}, total porosity of 66%, water content 36% and soil penetration resistance of 8 kPa.

Soil bulk density, total porosity, water content and soil resistance were affected by a number of skidder traffic cycles and slope; also interaction between the number of skidder traffic cycles and slope on each of the variables was significant. Therefore, skidder traffic significantly increased the bulk density and soil penetration resistance and decreased the total porosity and water content.

3.1 Bulk density

Changes in the bulk density of soil at the two slope classes were significant after one traffic skidder and the greatest change in these values compared with undisturbed areas was observed after one traffic skidder (Fig. 1). The increase in bulk density was significant after one traffic at SC1 but skidding at five and nine traffics did not cause an additional significant increase in bulk density. However, there were significant differences among the three levels of traffic at SC 2 (Fig. 1).

A two-tailed *t*-test analysis with 5% ($P<0.05$) level of statistical significance was performed to compare the mean bulk density of the same number of skidding cycles at two slope classes. The results revealed that the same cycles with the exception of the first skidding cycle were significantly different (Table 2).

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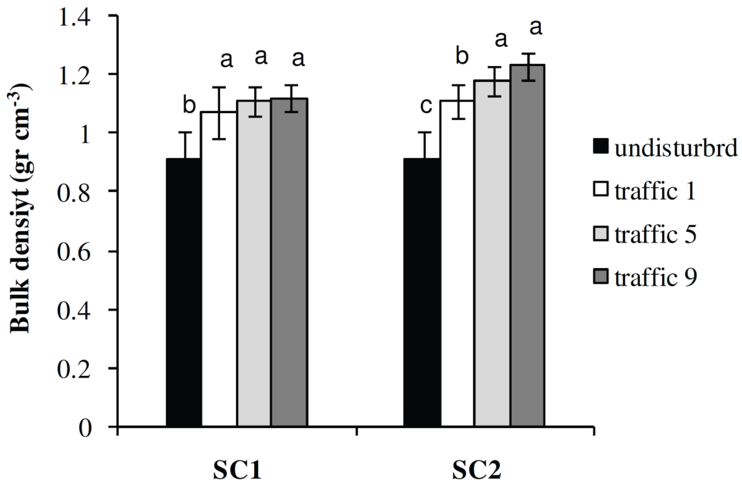

Fig. 1 The effect of traffic level on bulk density. Within each slope class, values followed by same lowercase letter are not significantly different at the $P = 0.05$ level.

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Table 2 Comparison of bulk density, total porosity, water content and penetration resistance in two slope classes at the same traffic level.

	Traffic levels		
	T1	T5	T9
Bulk density			
SC1	1.07a	1.11a	1.12a
SC2	1.11a	1.18b	1.23b
Total porosity			
SC1	59.3a	57.3a	57.7a
Sc2	58a	55.3a	53b
Water content			
SC1	27.2a	25.9a	25.2a
SC2	25.5a	24.3a	23.7a
Soil resistance			
SC1	12a	14a	15a
SC2	15a	23b	25b

3.2 Total porosity

As shown in Fig. 2, the highest values of soil total porosity are found in the undisturbed area. The lowest means of total porosity are determined in areas having nine traffic cycles at each slope class (Fig. 2). At this traffic level, the total porosity at SC1 decreased by 16% compared with undisturbed areas, and by 22% at SC2.

In SC1, the values of porosity obtained were not significantly different, but in SC2 the values of skidding cycle 1 and 9 were significantly different (Fig. 2). These results indicate that the threshold value of soil compaction at SC1 is low and the soil acceded to maximum compaction at low values of bulk density.

A comparison between the same skidding cycles at different slope classes is presented in Table II.

The results indicate that the same skidding cycle with the exception of skidding cycle 9 displayed no significant difference.

3.3 Soil water content

Soil water content in the undisturbed area measured 35%. It decreased with increasing number of skidding cycles. The lowest value of water content was found at SC2 and nine skidding cycles.

The soil moisture values obtained at different skidding cycle levels for two slope classes and compared with the same skidding cycles of slope classes are presented in Table 2.

All of the skidding cycles with the exception of skidding cycle 9 were not significantly different. For the two slope classes, soil water content was decreased significantly and the water content decrease was significant at the first skidding cycle compared with undisturbed areas (Fig. 3). For each SC, the soil water content was not significantly different at the three skidding cycle levels. Therefore, these analyses confirm that the greatest decrease of soil water content occurs after the first skidding cycle. Changes of soil water content were affected by the number of skidding cycles and slope; the interaction between the number of skidding cycles and slope on each of the variables was also significant.

3.4 Soil resistance

Penetration resistance was increased from 7 at the undisturbed area to 25 at the treatment area with a slope >20% and nine skidding cycles. For the two slope classes, the increase of penetration resistance was significant after the first skidding cycle and the greatest increase of soil resistance, compared with the undisturbed area, occurred at this skidding cycle (Fig. 4).

The percentage increases for SC ≤20% and >20% were 57% and 128%, respectively. Separate statistical analysis of the obtained values of penetration resistance from skidding cycle treatment for the two slope classes, showed that at SC1 there were no significant differences among skidding cycles and at SC2, the first skidding cycle was significantly different from the following skidding cycles; subsequent skidding cycles did not cause a significant increase of penetration resistance (Fig. 4).

A two-tailed *t*-test analysis was performed to compare the mean penetration resistance of the same number of skidding cycles at two slope classes. The results indicated that the same cycles were significantly different (Table 2).

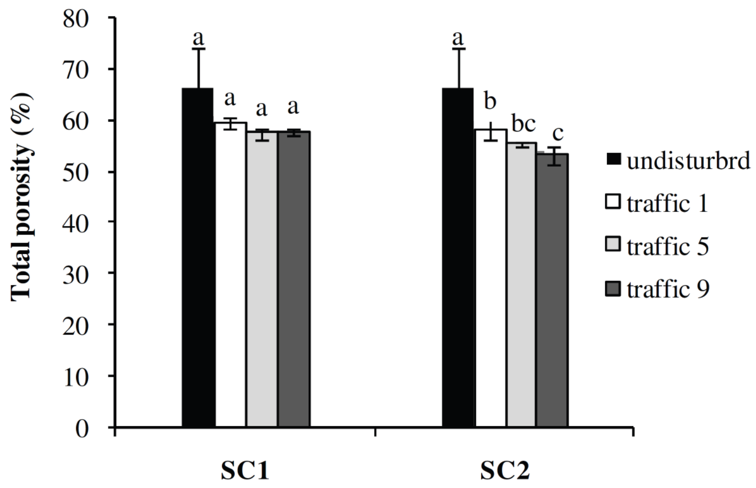

Fig. 2 The effect of traffic level on total porosity. Within each slope class, values followed by same lowercase letter are not significantly different at the $P = 0.05$ level.

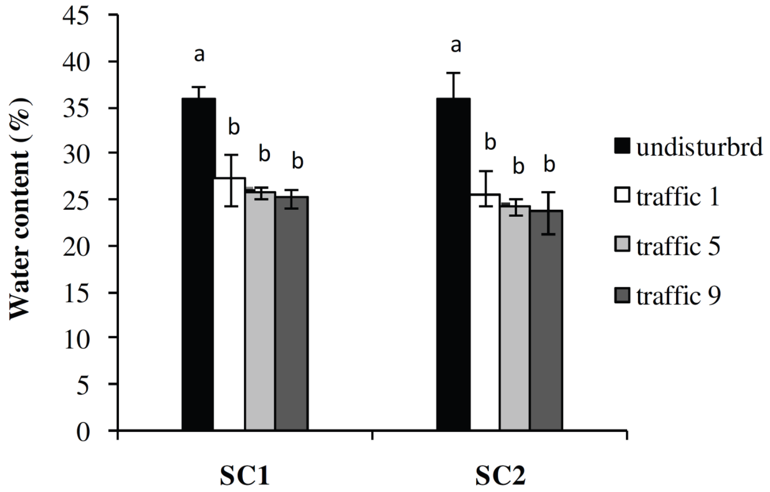

Fig. 3 The effect of traffic level on soil water content. Within each slope class, values followed by same lowercase letter are not significantly different at the $P = 0.05$ level.

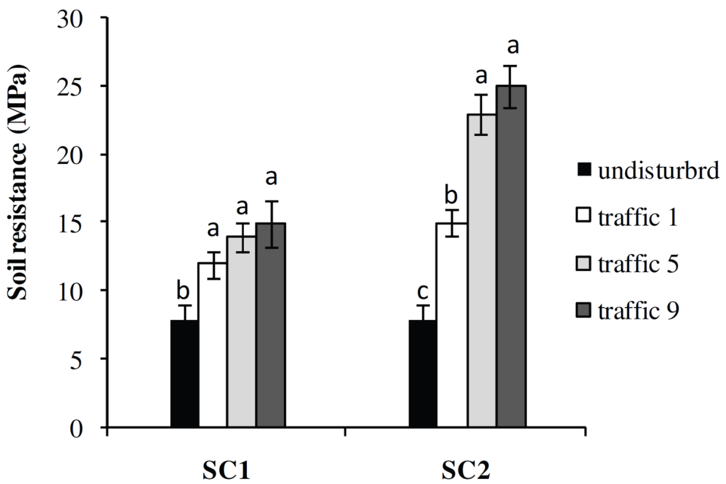

Fig. 4 Effects of traffic on soil resistance. Within each slope class, values followed by the same lowercase letter are not significantly different at the $P = 0.05$ level.

4 DISCUSSION

In this study, soil physical disturbance, characterized as soil bulk density, total porosity, water content and penetration resistance, most probably resulted from traffic at the steep slopes of skid trails.

Our study showed that soil bulk density and soil resistance increased with skidder traffic, and total porosity and water content decreased. These findings are in agreement with the results of Marsili *et al.* (1998), Emily *et al.* (2007) and Nalafi *et al.* (2009). According to the results of this research, soil bulk density increased at skid trails and the effect of machinery traffic was more severe at skid trails with a slope >20%. One outcome of these results was a higher increment of soil bulk density and penetration resistance after the first traffic (which was negligible as the number of traffic cycles increased). However, it is noteworthy that although soil compaction increases after every traffic cycle of the skidder, the increase is at a decreasing rate. The lesser compaction rate at higher number of passes occurs because the soil particles are closer to each other, which produces greater frictional force (Canillas and Salokhe, 2001). This indicates that the traffic effects on bulk density due to the skidding

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operations is greater in the first traffic, as stated by Ampoorter *et al.* (2007) and Agherkakli *et al.* (2010).

The extent of changes in soil physical properties can be influenced by several factors such as soil type, amount of moisture at the time of skidding, slope gradient of the skid trail, vibration and number of machine skidding cycles (Jun *et al.*, 2004; Botta *et al.*, 2007; Najafi *et al.*, 2009).

Soil compaction caused by traffic was affected by the total porosity and water content and soil resistance (Servadio *et al.*, 2003; Demir *et al.*, 2007). In this study, with increase of bulk density the total porosity and water content decreases. This result can be attributed to the under skidding operation; soil water content is high and may act as a lubricant among mineral particles, allowing them to approach one another, thus reducing pore spaces and water content. In subsequent traffic, due to low water content and pore space, relative displacement among the soil particles was reduced and the increment of soil bulk density was reduced. This was previously observed by Marsili *et al.* (1998), Lacy and Ryan (2000), Mosaddeghi *et al.* (2000), Canillas and Salokhe, (2001), and Ampoorte *et al.* (2007).

Previous studies (Pagliai *et al.*, 1992; Marsili *et al.*, 1998) on the effects of compaction caused by subsequent skidder traffic on total porosity and soil structure appear to have demonstrated a good correlation in the compacted surface layer (0–0.10 m) between macroporosity and soil penetration resistance. They found that with the increase of traffic and decrease of total porosity, soil penetration resistance increased. This result is in good agreement with our results. Ferrero *et al.* (2007) found that correlation coefficients between bulk density and penetration resistance were significant.

In general, at each traffic level, the extent of change in bulk density values, total porosity, water content and soil resistant was high at SC2 compared with SC1. The reason for these differences can probably be explained by more soil disturbance following traffic of skidding machines in steep trails. The traffic of skidding machines on slopes causes high stress, even under the front chain-saw track, which frequently lessened as the weight of the vehicle was transferred to the low contact area (Marsili *et al.*, 1998). Another reason could be attributed to the lower speed of the skidder on steep slope trails compared with SC1 where the topsoil obviously is vibrated more and consequently receives more disturbance compared with gently sloping trails (Najafi *et al.*, 2009).

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تغییرات ویژگی‌های فیزیکی خاک در اثر تردد اسکیدر چرخ زنجیری

بردی‌محمد آق‌ارکاکلی، اکبر نجفی و سیّدحمیدرضا صادقی

چکیده چوبکشی زمینی روی ویژگی‌های فیزیکی خاک موثر می‌باشد. هدف این پژوهش ارزیابی تغییرات ویژگی‌های فیزیکی خاک مسیر چوبکشی ناشی از تردد اسکیدر چرخ زنجیری از طریق اندازه‌گیری پارامترهای وزن مخصوص ظاهری، تخلخل، میزان رطوبت و مقاومت به نفوذ خاک بود. این پژوهش در دو سطح شیب کم‌تر از ۲۰ (SC1) و بیش‌تر از ۲۰ درصد (SC2) و سه سطح تردد (یک، پنج و نه) انجام گرفت. هر یک از تیمارها با سه تکرار دارای ابعاد ۶ متر طول و ۴ متر عرض بودند. اندازه‌گیری‌های مربوط به مقاومت به نفوذ توسط یک دستگاه نفوذ سنج رقومی انجام شد. نمونه‌ها تا عمق ۱۰ سانتی‌متری خاک در ۶ نقطه در هر پلات برداشت شدند. نتایج نشان داد که تردد تأثیر معنی‌داری روی ویژگی‌های فیزیکی خاک در سه سطح تردد در SC1 نداشت در حالی‌که این تفاوت بین تردد یک و پنج در SC2 معنی‌دار بود. بیش‌ترین تغییرات پس از تردد نخست اندازه‌گیری شد. در تمامی ترددها در SC2 تفاوت در میانگین‌های رطوبت و تخلخل در مقایسه با همان ترددها در SC1 بیشتر بود، هرچند این تفاوت‌ها معنی‌دار نبود. وزن مخصوص ظاهری و مقاومت به نفوذ در ترددهای ۵ و ۹ بطور معنی‌داری بیشتر از همان ترددها در SC1 بود.

کلمات کلیدی: وزن مخصوص ظاهری، عملیات چوبکشی، مقاومت به نفوذ خاک، تخلخل کل، رطوبت خاک

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