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Effects of rubber-tired skidder and farm tractor on physical properties of soil in plantation areas in the north of Iran

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ABSTRACT: Physical properties of soil can be affected by machines that are used for skidding which have the potential to impact soil sustainability and forest productivity. The present study evaluated the effect of timber skidding by a rubber-tired skidder and farm tractor on the soil physical properties. The study site was located in Hafdaghanan plantation region in the north of Iran. Two treatments that consisted of skidding by HSM 904 skidder and ITM285 farm tractor equipped with trailer were applied. The trails were included in three traffic levels: primary, secondary and tertiary. Treatment effects were tested using analysis of variance (ANOVA) with skidding machine types and traffic levels. Results indicated that machine type and traffic intensity are the effective factors on soil physical properties. The results showed that with an increase of traffic frequency, bulk density increased but total porosity and soil water content decreased. The results of the study provide clear evidence that farm tractor is a more environmentally friendly machine than rubber-tired skidder in the plantation area.

Keywords: aspen; skid trail; skidding machine; soil disturbance; timber skidding

In the north of Iran, there are several small patches of plantations which were established by forest wood companies and forestry organizations. Shafaroud, one of the largest forest wood companies in this area, manages both relatively small plantations and large areas of natural forest. Due to the new forest policy in Iran aimed at decreasing the wood removal from natural forests, these plantations are a good resource in order to satisfy the high wood demand in the country (Mousavi et al. 2012).

As timber harvesting operations in the natural forest is being mechanized, rubber-tired and tracked skidders such as Timber Jack 450C, Caterpillar, HSM-904, Ranger 66BDS, Caterpillar Bulldozer D6D7, Zetor and farm tractors are the most commonly used logging machines in the mountainous forests of Iran (Bavaghar et al. 2012). The smallness of plantation areas and limited financial capacity prevent the use of special machines for harvesting; therefore, forest companies use the same ground-based machines and equipment for wood extraction. Mechanization of skidding offers considerable economic advantages over conventional logging (e.g. animal logging) methods used to harvest small diameter timber. Mechanized harvesting has the potential not only to increase production but also to reduce labour costs resulting in lower total logging costs. Timber forest harvesting operations in the terrain require the construction of a relatively dense network of forest roads, including skid roads, haul roads and landings (Ketcheson et al. 1999).

In that regard, machine passes have an important influence on soil structural characteristics, soil aeration, soil water balance, and may, therefore, considerably affect soil organisms and root development (Ampoorter et al. 2007). Concerns about soil degradation after forest operations and its impact on the future stand have increased during recent decades (Jansson, Johansson 1998). Soil disturbance, particularly compaction, is a major modification that can be caused by forest harvesting operations. Compaction involves rearrangement and bringing of solid soil particles closer together and consequently leads

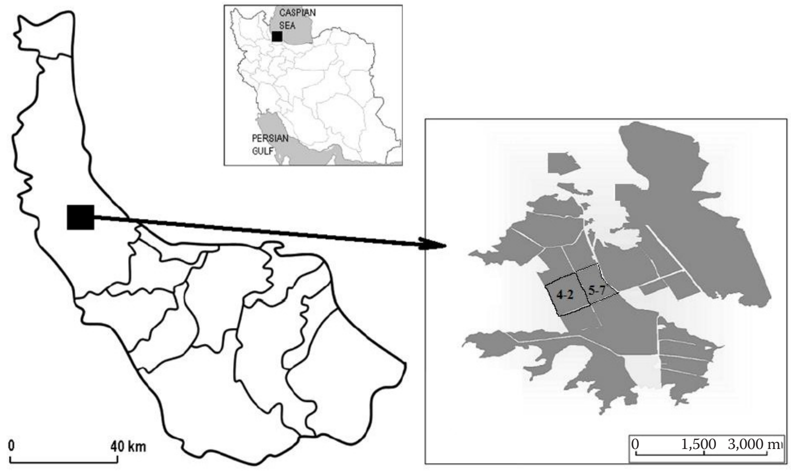

Fig. 1. Location of study area in the north of Iran

to an increase in bulk density. Density is commonly used as a measure of compaction, with the upper limit being determined largely by the shape and size distribution of the ultimate soil particles. Compaction as evidenced by increased soil cone index and bulk density and reductions in soil porosity reduces the penetrability of the soil for roots (Botta et al. 2007). If the internal soil strength is exceeded by the machine load, each machine pass will cause soil deformation, changing soil aggregation as well as its physical, chemical and biological properties (Horn et al. 2004). While research showed that soil compaction reduces future timber yields (Lotfalian, Parsakhoo 2009; Agherkakli et al. 2010; Bagheri, Naghdi 2011; Lotfalian, Bahmani 2011), there is currently little information documented to show the influence of mechanized harvesting on the forest soil in the plantation.

So previous research was focused on soil compaction during skidding operations in mountainous conditions in Iran while there seems to be no study to show its influence in plain areas which is considerably different from mountainous conditions (Mosaddeghi et al. 2000; Naghdi et al. 2007; Najafi et al. 2009; Agherkakli et al. 2010; Bagheri, Naghdi 2011). Moreover, few studies have focused on soil compaction caused by rubber-tired skidders such as Timber Jack 450C or farm tractor and even fewer have followed a mechanized logging operation study in plantation areas like the study by Nikooy et al. (2013). The purpose of this study was to evaluate soil physical properties caused by the skidding of a farm tractor and a rubber-tired skidder in northern Iran.

Table. 1. Technical description of HSM 904 rubber-tired skidder and farm tractor

	Skidder HSM-904	Tractor ITM285
Length (m)	6.4	4.01
Width (m)	2.4	2.06
Horse power (kw)	126.76	55.92
Mass maintenance (kg)	9,000	4,500 (with trailer)
Number of tires	4	6

MATERIALS AND METHODS

Stand description. Two adjacent compartments (number 4–2 and 7–5) with an area of 65.1 and 72.1 ha were selected in Hafdaghanan plantation region (49°10'N, 37°20'E) in the north of Iran (Fig. 1).

The site was planted by aspen (*Populus deltoides* Marsh.) about 25 years ago. The mean annual rainfall for this region is 1,656 mm and the region receives rainfall throughout the year. The soil of the study area was formed on the alluvial fine-textured sediment with silt texture, and with neutral to low acidic reaction. On the basis of available reports (documents) in previous years, machine harvesting or thinning operations, which could affect the soil properties, were avoided on the study site. Two treatments included (a) HSM-904 rubber-tired skidder in compartment 4–2 and (b) ITM285 farm tractor equipped with trailer in compartment 7–5 (Table 1). Two skidding sites had similar characteristics in terms of stand and terrain conditions.

Since the skid trails that are close to a landing have a more intense volume of traffic compared to those far from it (Wang et al. 2003), the measurement locations were identified in relation to the proximity of the landing. The study was carried out on a skid trail of 350 m in length and 2.5–3 m in width in each compartment. Prior to the skidding operations, the treatment plots showed an av-

Table 2. Two-way analysis of variance (ANOVA) for the effects of traffic and skidding machine on different sources

Source	Sum of square	df	Mean square	*F*	*P*
Bulk soil density					
Skidding machine	0.1204	1	0.1204	1.850	0.041
Traffic	2.8319	3	0.9439	14.500	0.001
Total porosity					
Traffic	456.355	2	228.178	5.559	0.010
Skidding machine	9013.576	2	4506.788	109.801	0.000
Soil water content					
Traffic	13.135	2	6.568	4.570	0.121
Skidding machine	43.436	2	21.718	15.111	0.00
Traffic × skidding machine	35.042	4	8.767	6.097	0.001

erage soil bulk density of 1.09 g·cm^{-3}, total porosity of 28%, and water content of 19.67%. The trails were included in three traffic classes; primary (main trail segment originating from the landing, or PST), secondary (branched from the primary trails, or SST) and tertiary (branched from the secondary trails, or TST) skid trails terminating at the stump. Estimated skidding traffic volumes are over 20 passes on primary trails, 10–20 passes on secondary trails and less than 10 passes on tertiary trails. A 100-m long straight skid trail was selected at each traffic class. The treatment plots (4 m wide × 10 m long) were delineated prior to skidding and assigned to six combinations of machine classes (HSM and Tractor) and traffic intensities (PST, SST and TST). Treatment plots with three replications included three randomized line samples across the wheel rut perpendicular to the direction of travel with 1-m buffer zone between lines to avoid interactions (Agherkakli et al. 2010). In order to measure bulk density and soil moisture content, in each plot soil samples were taken along five randomized lines across the wheel track perpendicular to the direction of travel with a 2-m buffer zone between lines to avoid interactions. Then three lines were randomly chosen and one sample was taken at three different points of each line (left wheel track, right wheel track and log track or between tracks) and from the forest floor (control) (Najafi et al. 2009). Soil samples were taken at a depth of 0–10 cm by using a hammer-driven core cylinder that is 10 cm high and 7.1 cm in diameter. Each soil sample was put in double plastics and carried to the laboratory for soil analyses. In the lab, all of the soil samples were air-dried and passed through a 2 mm mesh. Soil bulk density and particle density were obtained by clod method and pycnometer method, respectively, and soil water content was analysed (Kalra, Maynard 1991). SPSS software package version 13 was used for all statistical analyses. The effect of treatments was tested using analysis of variance (ANOVA) considering skidding machine classes and traffic levels. Data distribution was tested for normality using the Kolmogorov-Smirnov test. In the case of a significant *F*-value, tests were performed using Duncan's multiple-range test at the 0.05 level.

Table 3. Measurements in different traffic classes

Soil bulk densities	PST	SST	TST
Farm tractor	2 ± 0.20^{a}	1.76 ± 0.13^{a}	1.62 ± 0.05^{b}
Rubber-tired skidder	2.22 ± 0.30^{a}	1.97 ± 0.18^{a}	1.86 ± 0.04^{a}
Control area	1.13 ± 0.07^{c}	1.15 ± 0.13^{c}	1.04 ± 0.05^{c}
Total porosity percentage			
Farm tractor	15.14 ± 1.76^{b}	17.16 ± 3.8^{b}	25.6 ± 1.17^{a}
Rubber-tired skidder	13.67 ± 4.07^{b}	19.93 ± 3.43^{b}	18.45 ± 5.79^{b}
Control area	24.36 ± 4.73^{a}	26.38 ± 4.73^{a}	30.98 ± 4.34^{a}
Soil water content percentage			
Farm Tractor	17.12^{b}	17.51d^{b}	17.91^{b}
Rubber-tired skidder	15.75^{c}	15.96^{c}	16.32^{c}
Control area	21.94^{a}	19.71^{a}	18.41^{a}

PST – primary segment of trail, SST – secondary segment of trail, TST – tertiary segment of trail; values followed by the same lowercase letter are not statistically significant at the P = 0.05 level

RESULTS

Bulk Density

Due to high traffic and weight of skidding machine, significant soil compaction occurred on the skid trail in comparison with the control area. The analysis of soil bulk density values on skid trail and control area using analysis of variance is shown in Table 2.

Results of soil bulk density on the skid trails and control area showed that there is a significant difference between skidding machines. A maximum value of bulk density belongs to PST of skidder trail (Table 3).

The investigation of soil bulk density variation of tractor skidding path indicated that there is not a significant difference between PST and SST traffic classes ($P \geq 0.05$) while there was a significant difference between these classes and TST ($P \geq 0.05$). The difference between the results of soil bulk density in each traffic class on the skidder trail was not significant ($P \geq 0.05$). The study of soil bulk density in different traffic classes showed that the soil bulk density increases with increasing traffic intensity. In PST area of skidder and tractor path and control area, the highest bulk density value was related to the skidder path. In PST area, there was a significant difference between bulk density of machines and control area. The same results were observed in SST and TST areas.

Total porosity

Control area and PST allocated the highest and lowest values of total porosity, respectively. The analysis of soil total porosity values on skid trail and control area using analysis of variance is shown in Table 2.

Data analysis of soil total porosity percentage on the skid trails for both vehicles showed a significant difference in comparison with the control area. The highest value of total porosity of soil was found in TST area on the tractor path. No significant difference was found between total porosity values of traffic classes on skidder trails whereas these values were significantly different between TST and other traffic areas (Table 3).

Soil water content

Soil water content decreased with the increasing traffic of each machine. The lowest value of water content was found in PST area of the skidder trail. The analysis of soil water content values on skid trail and control area using analysis of variance is shown in Table 2.

The analysis of soil water content on skidding path compared with the control area is given in Table 3. For both vehicles on the skid trails, water content decreased significantly and it was also significant for different classes compared with the control area (Table 3).

DISCUSSION

Forest operations, especially log skidding, cause major changes in soil physical properties such as increasing soil bulk density, decreasing total porosity and water content (McNeel, Ballard 1992; Bengtsson et al. 1998; Laffan et al. 2001; Rab et al. 2004). The size, power and weight of forest machines are the main sources of soil disturbance. Many studies have concluded that log skidding by skidders significantly increased soil bulk density (McDonald, Seixas 1997; Page-Dumroese et al. 2006). Heavier machines cause more pressure on the soil than lighter machines such as farm tractor (McDonald et al. 1996). There was a significant increase in soil bulk density between skidding machines. In a farm tractor with 6 wheels, the weight is distributed on a larger area and the pressure is lower than that of the skidder. Lower weight of farm tractor with more wheels leads to weight distribution and lower soil compaction. In the present study, bulk density of soil increased in all traffic classes. These findings are in agreement with the results of Rab et al. (2004) and Zenner et al. (2007). One of the previous studies (Lacy, Ryan 2000) suggested that there is a high correlation between an increase in bulk density and traffic. The highest values of bulk density were observed on the primary skid trails with an average of 2.22 $g \cdot cm^{-3}$. Except for TST area, there was no significant difference between traffic classes. A great deal of research indicated that a higher increment of soil bulk density arises after the third pass and the subsequent passes have a lower effect (Horn et al. 2004; Ampoorter et al. 2007). The lower bulk density value for TST traffic class of farm tractor in comparison with the other classes depended on the lightweight of the tractor and weight distribution through more wheels (6 wheels). A decrease of soil porosity during log skidding is more related to soil bulk density.

The pressure caused by the weight of skidding machines on soil reduced the soil void volume and brought the particles closer (McNeel, Ballard 1992; Harvey, Brais 2002). In this study, with increasing traffic intensity from low to high, the percent of soil porosity decreased on all skidding trails; therefore, the lowest porosity is related to high traffic classes. These findings are in agreement with the results of McNabb et al. (2001), Rab (2004) and Blouin et al. (2005). The change in soil water content is one of the negative impacts of soil compaction because it decreases the soil volume, which eventually leads to a decrease in total soil porosity (Kachamba 2007).

Results of this study indicate that an increase of soil bulk density in each traffic class resulted in a significant increase of soil water content which, in turn, led to a decrease in soil porosity.

The increasing soil bulk density of skid trails in each traffic class decreased soil total porosity and water content simultaneously, which are important for plant growth. The lowest value of water content was observed in TST traffic class of skidder path while the highest values belonged to the control area. The changes in soil physical properties would be expected in response to machine trafficking as a result of reductions in soil volume, closer proximity of soil particles and aggregates and reduction in soil water content (Carter, McDonald 1997). When the soil moisture is close to saturation and soil empty cavities are filled with water, skidding operations result in soil loss, rutting, breaking the natural drainage structure, digging the surface layer of soil and reducing the soil stability.

CONCLUSIONS

This investigation examined the impacts of farm tractor and rubber-tired skidder on soil physical properties in plantation areas. Results indicated that machine type and traffic intensity are effective factors on soil physical properties. Practically, log skidding with skidder is preferred to farm tractor while farm tractor is a more environmentally friendly machine.

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