Ground based operation effects on soil disturbance by steel tracked skidder in a steep slope of forest

B. Agherkakli, A.Najafi, S.H.Sadeghi

Tarbiat Modares University, Tehran, Iran

ABSTRACT: In this study, the effects of slope and traffic intensity on soil compaction, rutting and forest floor removal was evaluated on a skid trail in the natural forest of north of Iran. Combination of two levels of slope < 20% (SC1) and > 20% (SC2) and three levels of traffic (one, five and nine traffics) were studied. Treatment plots, with three replications, were established on the skid trail prior to skidding. The results of this study showed that all bulk densities were considerably higher in SC2 than in SC1 and average soil bulk densities were measured from 1.07 ($g\cdot cm^{-3}$) to 1.23 ($g\cdot cm^{-3}$) on skid trail and 0.91 ($g\cdot cm^{-3}$) in undisturbed areas. With the increment of traffic, soil compaction increased but there was no significant difference among the three levels of traffic frequency in SC1 whereas it was significant between one and five cycles in SC2. Greatest rut depth was measured as 12 cm at nine traffics in SC2, although increase of traffic density caused deeper rut depth at all slope treatments, but it was higher at the SC2 in comparison to SC1. Litter mass decreased considerably on the skid trail with the increasing in slope and traffic. No important difference has been detected between SC1 and SC2 in terms of Litter mass removal. These results provide clear evidence that soil disturbance on steep trail is intensified.

Keywords: crawler tractor; forest floor removal; ground based skidding; hardwood forest of Iran; soil compaction

The harvest phase of forest management brings along major disturbances of forest soil. Maintaining the long-term site productivity is an essential requirement for sustainable forest management (Ares et al. 2005). Substantial changes in physical and chemical properties of soil being important for the site productivity can be originated by such intense logging operations.

The common effects on soils from ground based forest operations are increased compaction and removal of litter mass in skid trails (Tan et al. 2008). Soil compaction results in an increase in bulk density (Block et al. 2002; Demir et al. 2007; Makineci et al. 2007), reduction in macroporosity (Rohand et al. 2004; Ampoorter et al. 2007), saturated hydraulic conductivity (Wood et al. 2003; Grace et al. 2006), water content, infiltration (Startsev, McNabb 2000), N mineralization and microbial number biomass and activity (Ares et al. 2005; Tan et al. 2008). Each of these features can potentially reduce the tree growth (Froehlich 1979; Corns 1998). Compaction is not the only type of soil disturbance resulting from harvesting activity, soil mixing, puddling and rutting that can cause a disruption of matter flow are also some other examples of disturbance. Ruts may become channels for surface runoff and thus cause erosion since the infiltration of rainwater is reduced (Jansson, Johansson 1998; Grigal 2000; Bygdén et al. 2004). McDonald et al. (1995) found that the frequency of skidder traffic was the most significant factor influencing the rut formation.

Litter mass is an important source of available nutrients that increases soil nutrient levels and consequently the stand productivity. Zabowski et al. (1994) suggested that the forest floor removal could dramatically intensify nutrient export. The restoration of properties of compacted soil in the lasting process may require between 5 and 40 years to recover (Jakobsen 1983; Croke et al. 2001).

Several studies have examined the relationship between soil disturbance and the associated number of loaded machine passes. The majority of previous studies investigated the effects of wheeled skidders on soil disturbance while a few studies assessed the impacts of steel tracked skidders whereas in many forest areas, particularly in steep terrain with large trees and high precipitation rates, these machines are likely to remain the most common type of skidding machine used.

In mountainous and steep areas, the terrain slope is an important factor that affects operational efficiency, costs and erosion. It may also affect the soil compaction, so in planning forest operations and aligning skid trails the terrain slope may be an important consideration for protecting soil resources (Jamshidi et al. 2008).

The objectives of this investigation were to (1) assess the soil disturbance after ground based logging by a steel tracked skidder and (2) determine the effects of slope on the soil disturbance in a skid trail.

MATERIAL AND METHODS

A field study was conducted at a Forestry Experimental Station of Tarbiat Modares University, located in a temperate forest in the north of Iran, between 36°31'56''N and 36°32'11''N latitudes and 51°47'49''E and 51°47'56''E longitudes, in February 2008. The elevation is approximately 650 m a.s.l. with western aspect, while the average annual rainfall of 1,308 mm has been recorded.

The natural vegetation is a deciduous forest with dominant species of hornbeam (*Carpinus betulus* [L.]) and beech (*Fagus orientalis* Lipsky).

Soil samples for detecting the soil texture were collected at ten random points from the top of the 50 cm deep soil profile from an undisturbed area, thus the soil texture was analyzed by the Bouyoucos hydrometer method and the range from loamy to silt loamy soil was determined. Soil water content at the time of skidding on the slope < 20% (SC1) and on the slope > 20% (SC2) was 31% and 28%, respectively. The harvested trees were 80–130 years old and the average diameter at breast height was 80 cm. A 300 m long skid trail was delineated as the research area, passing through the stand in east-west direction. Two slope classes, slope < 20% (SC1) and slope > 20% (SC2), were identified on the skid trail.

A 150 m long straight skid trail was selected in each slope class. Treatment plots 4 m wide by 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 traffics) with at least 5 m buffer zone between plots to avoid interactions. Treatment plots with three replications included three randomized line samples across the chain rut perpendicular to the direction of travel with 1 m buffer zone between lines to avoid interactions. In this study, a fixed log (diameter 80 cm and length 3.6 m) was hauled by a steel tracked skidder TLT-100A (Table 1) in all treatments.

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

Length	6 m
Width	2.6 m
Track	3 m
Operation power	88.2 KWt
Ground unit pressure	0.049 MPa
Track-driving sprockets	cast-steel tooth wheel
Pressure in hydraulic system	14 MPa
Number of teeth	9
Width of caterpillar	44 cm
Tractor mass maintenance	11,200 kg

The effects of skid trail slope and traffic on the surface soil layer (0 to 10 cm deep) were studied using dry bulk density, rut depth and litter mass removal, in comparison with an undisturbed area at different levels of slope and traffic. All samples were collected in two tracks in each plot after one, five and nine traffics in each slope class. The soil samples were gathered using 10 cm high steel cylinders 6 cm in diameter from 10 cm depth and were put in double plastic, and then labelled samples were brought to a laboratory from the research area. The samples of litter mass were taken from 0.5 m^2 area by collecting all the litter mass in that area. Rut depths were measured in the same points of soil samples, a wooden rod was laid across the rut and the distance from the ground surface to the underside of the rod was measured between the holes for the probes. The 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 were dried at 105°C, both for 24 h.

Data analysis was completed by SPSS statistical software (version: 12). Treatment effects were tested using analyses of variance (ANOVA) with slope classes and traffic levels. Independent sample *t*-test slope compared the differences in mean soil bulk density, rut depth and litter mass removal between two slope classes at a 0.05 significance level.

Table 2. Percentage of increasing in soil bulk density (g·cm^{-3}) from post-skidding to pre-skidding for each slope class and effect of slope on soil bulk density

No. of passages	SC1			SC2	
	pre-skidding	post-skidding	changes (%)	post-skidding	changes (%)
1	0.91	1.07*a	17.6	1.1*a	21
5	0.91	1.11*b	22	1.18*a	29.8
9	0.91	1.12*b	24.2	1.23*a	35.2

*Significance level α = 0.05

Mean results are flanked on the same line by letters. Each two means shared a results do not differ significantly

RESULTS AND DISCUSSION

A significant soil compaction occurred on the skid trail in comparison with the undisturbed area, due to high traffic and slope applied. Post-harvesting soil bulk density was measured as minimum 1.07 g·cm^{-3} to maximum 1.23 g·cm^{-3} while the soil bulk density of 0.91 g·cm^{-3} was already recorded prior to skidding (Table 2). Therefore bulk density generally increased with an increase in traffic at all levels of slope.

Although the bulk density increment was measured with an increase in traffic frequency, the increment varied between two slope classes (Fig. 1). According to Fig. 1 the absence of significant differences in bulk density among the traffic treatments in SC1 could be explained by the fact that the highest soil compaction occurs after the first several traffics (McNabb et al. 2000). Although additional passes on the soils are unlikely to increase the bulk density, the continued trafficking of adjacent soil when wet did cause some rutting (McNabb et al. 2000). Once this initial compaction is complete, further compaction is resisted by the increasing soil strength and is therefore considerably slower (Williamson, Neilsen 2000; Nugent et al. 2003; Horn et al. 2004). Therefore these results are in accordance with results of Jansson and Johansson (1988), Grigal (2000), Bygdén et al. (2004) and Ampoorter et al. (2007).

A considerably higher value of bulk density was recorded in SC2 at all levels of traffic in comparison with SC1 (Table 2). A maximal significant increase in bulk density occurs in SC1 after one pass (17.6%). In SC1 and SC2, the percentage of change in bulk density after the first traffic was 17.6% and 21%, respectively. The USDA forest service has used a threshold value of 15% increase in bulk density for determining detrimental soil compaction in their monitoring programs (Powers et al. 1999). Applying these standards to our data, it can explicitly realize that the threshold of detrimental compaction was exceeded in the first traffic. The increment of bulk density in terms of percentage in SC1 was 3%, 6% and 8% at the one, five and nine traffic frequency, respectively. The significant increase in soil bulk density in SC2 can be interpreted that the movement of a vehicle on the slope causes a high stress, even under the front chain-saw track, which is frequently unloaded as the weight of the vehicle is transferred to the low contact area (Marsili et al. 1998). Another reason could be that the average speed of machines was lower compared to SC1. When the skidder passes more slowly on a steep slope, the top soil is obviously vibrated

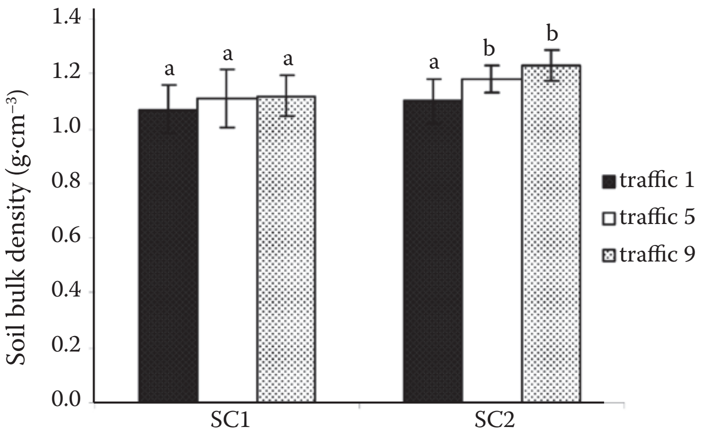

Fig. 1. Effect of traffic on soil bulk density at separated analyses for each slope class

Table 3. Analysis of variance (ANOVA) for the effects of slope and traffic on soil compaction, rutting and litter mass removal

Source	*P*	*F*	MS	df	Type III SS
Compaction					
Traffic	0.001*	8.303	0.052	2	0.150
Slope	0.000*	16.005	0.101	1	0.101
Traffic × slope	0.254	1.396	0.009	2	0.018
Rutting					
Traffic	0.000*	237.893	736.714	2	1,473.428
Slope	0.000*	57.538	178.186	1	178.186
Traffic × slope	0.000*	9.384	29.061	2	58.122
Litter mass removal					
Traffic	0.000*	500.101	9,954,233.33	2	9,344.44
Slope	0.498	0.469	9,344.444	1	199,088,466.6
Traffic × slope	0.001*	8.173	162,677.77	2	325,355.556

* Significance level α = 0.05

Table 4. Effect of slope on rut depth (cm)

P	Slope class		Traffic
	SC2	SC1	
0.964	2.4	2.2	1
0.000*	10.5	6.9	5
0.000*	12.0	9.2	9

*Significance level α = 0.05

more and consequently gets more disturbances compared to a gentle trail (Najafi et al. 2009).

As a whole, the effects of slope and traffic frequency significantly influenced bulk density changes ($P < 0.001$) but the interaction between slope and traffic frequency was not significant ($P = 0.254$) (Table 3).

Analyses of measured rut depths confirm that the rut depth increased with an increase in traffic intensity. Thus our results are in accordance with findings of many researchers (McNabb et al. 2000; Eliasson 2007; Eliasson, Wasterlund 2007). In both slope classes, rut depths increased with the increase in traffic but the extent of rut depths varied between slope classes (Table 4). In all traffics, the rut depth in SC2 was higher than in SC1 and the highest depth value was at nine traffics in SC2 (Fig. 2). The rut depth in SC1 and SC2 was 9 cm and 12 cm, respectively. Results of the rut depth suggest that logging and skidding on steep slopes have a pronounced effect on the rutting. In up-slope moving,

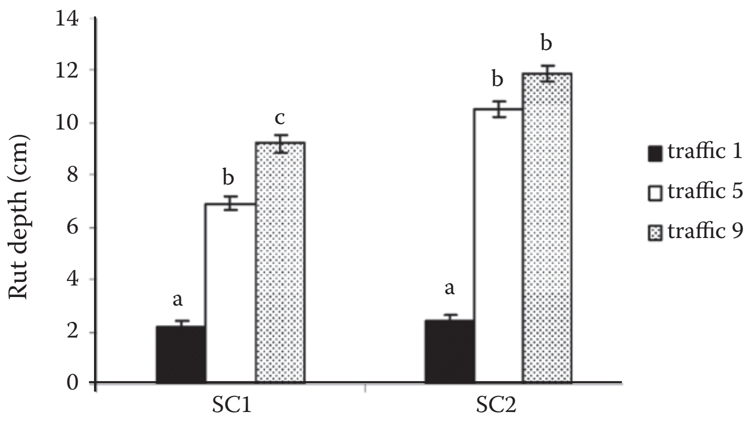

Fig. 2. Effect of traffic on rut depth separated analyses for at each slope class

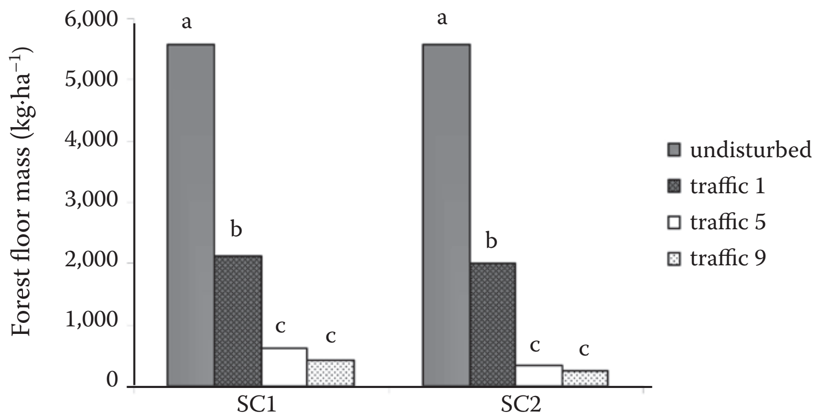

Fig. 3. Effect of traffic on litter mass removal at separated analyses for each slope class

travel speed and the power of the machine are limited and accrued rutting and mixing of mineral soil with litter mass by the track grouser of this machine type. However, the large ground contact area of this machine results in high tractive efficiencies, low ground pressures and good stability on steep slopes. The rut depth is often the only criterion that forest managers have to assess soil damage as harvesting occurs (Lacey, Ryan 2000) and is often used in visual assessments of site productivity changes because they indicate changes in infiltration, erosion, water retention and the water-air balance as an early indicator of altered productivity (Schoenholtz et al. 2000). Common descriptors include undisturbed and three categories of disturbance: light disturbance, with shallow scarification; moderate disturbance, secondary skid trails or compaction and/or rutting up to 5–8 cm deep; heavy disturbance, primary skid trails, landings, or rutting at least 10–15 cm deep (Grigal 2000). According to results of the present study, the categories of soil disturbance were moderate and heavy disturbance for SC1 and SC2, respectively.

A comparison of rut depths at each level of traffic using *t*-test analyses showed that irrespective of the slope class, the rut depth increase at five and nine traffics was significant (Table 4). The results showed that traffic and slope, and also traffic × slope interaction affected the rutting significantly ($P < 0.001$) (Table 3).

Litter mass removal was also quantified by measuring the displacement of litter mass on the skid trail after skidding. Total litter mass weight in unit area was 5,567 kg·ha^{-1} in undisturbed area. Litter mass removal was not affected by the slope significantly ($P = 0.498$) but the effects of traffic, and also of the interaction between traffic and slope on litter mass removal were significant ($P < 0.001$) (Table 3). At all levels of the slope, forest floor was removed significantly after one traffic in comparison with general harvesting area whereas the difference in forest floor removal between five and nine passes was not significant (Fig. 3). Reduction of litter mass following the first traffic on the skid trail area was approximately 60% in both slope classes. In ground-based skidding some of the trees along the skid trail were cut during the construction of skid trail in order to prevent any preclusion on skid trail works (Demir et al. 2007; Makineci et al. 2007) since the mixing of mineral soil with litter mass in this type of machines is high, therefore considerably less litter mass on the skid trail is obvious.

CONCLUSION

This study was conducted with the overall objective of describing the effects of the slope of skid trail and traffic frequency on soil compaction, rutting and litter mass removal. Although the damage resulting from logging traffic for forest harvesting that differs between treatments was significant; soil disturbance (soil compaction and rutting) occurs on slopes > 20% and can be of ecological importance. No significant differences were found in forest floor removal between slope classes in response to traffic frequency. The relative increase in soil bulk density was less for SC1 following traffic, thus the skidding operations on the slope of smaller gradient were found to be more reasonable to alleviate the effects of subsequent machine traffic. Prompt actions should be taken in order to prevent and minimize negative impacts of soil disturbance in logging forest. Especially, the skidding operations should be limited on the slope of < 20 %. A practical recommendation would be to minimize traffic in order to affect the soil as little as possible.

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Received for publication September 23, 2009
Accepted after corrections November 2, 2009

Corresponding author:

Akbar Najafi, Ph.D., Tarbiat Modares University, Jalal Ale Ahmad Highway, P.O.Box: 14115-111, Tehran, Iran
tel.: + 981 226 253 101-3, fax: + 981 226 253 499, e-mail: najafi_akbar@yahoo.com