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Effect of the skid trail cross section and horizontal alignment on forest soil physical properties

Hossein YAZARLOU[1], *Aidin PARSAKHOO*[1]*, *Hashem HABASHI*[2], *Soltan Ali SOLTAUNINEJAD*[1]

[1]*Department of Forestry, Faculty of Forest Science, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran*

[2]*Department of Forest Ecology and Silviculture, Faculty of Forest Science, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran*

**Corresponding author: Aidinparsakhoo@yahoo.com*

Abstract

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Horizontal alignment and cross section characteristics of a skid trail in a ground-based skidding system including curves, wheel ruts and cross slope can impact on the forest soil. In this study the measurement of cross section and vertical alignment of skid trail in Bahramnia forestry plan was done using a levelling instrument. Horizontal alignment of skid trail including straight routes and curves was taken using polar methods. A 3D map of skid trail was produced in AutoCAD Civil3D software. Soil bulk density was measured after sampling the soil with a core sampler. Results showed that in straight routes, soil bulk density increased by increasing the cross slope of skid trail. Moreover, soil porosity decreased with the increasing cross slope. There was a significant difference between cross slopes in soil moisture. On curves, maximum bulk density occurred when the cross slope was 10%. Findings about soil porosity and moisture on curves of skid trails were similar to those of straight routes. Based on our findings, soil bulk density in wheel ruts was significantly lower than that in the middle part of skid trail. Soil bulk density in the silty soil texture of studied skid trails was a little more than ideal bulk density, so it cannot affect and restrict root growth.

Keywords: soil bulk density; ground-based skidding; cross slope; Civil3D software; Bahramnia forest

Wheel skidders are often used for skidding timbers in mountainous forests of the Hyrcanian zone. Skidders pass on skid trails (Ares et al. 2005). An important consideration in the design of skid trails is the longitudinal and cross slope (Aust et al. 1995). Many studies showed that the steep lateral slope causes an increase in soil bulk density. Moreover, hazard may attend driving on steep cross slopes on straight routes due to the tendency of skidders to veer toward the low edge of the skid trail (Baharuddin et al. 1995; Ballard 2000). Trails should be designed so that none of the design elements causes or promotes soil damage and loss of the skidder control. The dynamic effects of increased cross slope are an increase in driver's discomfort and tire friction demand. Surface characteristics of a skid trail cross section including wheel ruts and cross slope can impact on the soil bulk density and ease traffic of skidder (Horn et al. 2004; Jamshidi et al. 2008).

An example of surface deformation of the skid trail cross section is wheel rutting (Heninger et al. 2002). Rutting occurs when the soil strength is not sufficient to support the applied load from vehicle traffic. Rutting affects aesthetics, biology, hydrology, site productivity and vehicle safety (Williamson, Neilsen 2003). Where a canalized stream flows to an open water body, rutting can result in contributing sediments into the open water body (Baharuddin et al. 1995). While not always a water quality issue, excessive rutting is certainly a sign that ongoing forest operations need to be modified to prevent further damage to soil and forest resources (Aust et al. 1995). In general, increasing levels of skidder traffic lead to an increase in the depth of ruts (Zečić et al. 2005). The extent and degree of soil bulk density are dependent on several factors including soil texture, soil moisture content at the time of trafficking, soil organic matter, slash and twig content, soil structure, parent materials and pore size distribution, vehicle mass, machine size, machine type, number of skidding cycles and duration of loading, grade of skid trail, direction of skidding and extraction pattern, stand structure, density, species composition and life traits, harvesting system training, experience and expertise of equipment operators (Krag et al. 1986; Laffan et al. 2001; Ilstedt et al. 2004).

Soil bulk density from machine traffic is a common consequence of timber extraction from forest (Greacen, Sands 1980). Forest soils easily compact from the use of skidder machines such as TAF E655, HSM and Timberjack machines. The unprotected forest soil acts as a weak receptor against static and dynamic forces created by skidder machines especially on skid trails and landings where a high frequency of machine movement exists (Pinard et al. 2000). The bulk density of soil influences the tree root growth. Cross sections are the natural ground sections perpendicular to the skid trail. They show the cross slope angle and micro topography at any given point on the trail. A better understanding of the effects of the cross section of skid trail on forest soil bulk density during skidder passes will help improve the skid trail design and soil recovery based on management goals. The objectives of this study were to investigate the effects of cross slope and surface deformation of the skid trail cross section on some soil physical parameters including soil bulk density, soil porosity and soil moisture. Moreover the effects of the horizontal alignment of skid trails including straight routes and curves on these soil parameters were assessed.

MATERIAL AND METHODS

District one in Bahramnia forestry plan with an area of 1,713.3 ha is located in the Golestan province and in watershed No. 85 (36°43'27''N to 36°48'6''N and 54°21'26''E to 54°24'57''E). The total length of forest roads in this district is 31,059 m. These roads were constructed in 1989. The bedrock is limestone and sandstone, the altitude ranges from 100 to 1,000 m a.s.l. The forest which has been established on brown forest soil is mixed deciduous. The mean forest growing stock in the study area was 247 $m^3 \cdot ha^{-1}$. The forest is harvested using a single tree selection cutting system according to annual harvesting tables. The climate of the region is Mediterranean warm and moist. The mean annual precipitation is 562 mm with the lowest amount in July and August. In this study a TAF E655 cable rubber-tired skidder (IRUM, Romania) was used for extracting timber from harvesting units. This skidder has a mono-winch system which has been designed for timber skidding operations. The tires of the skidder were normal. The average timber volume per turn of skidding was 1.85 m^3. Articulated skidders have better manoeuvring efficiency and can operate on steeper slopes (Zečić et al. 2005). The other main technical characteristics of the TAF E655 skidder are shown in Table 1.

Table 1. Technical characteristics of the TAF E655 skidder (IRUM, Romania)

Machine	Weight (kg)	Length (m)	Width (m)
TAF E655	6,345–6,800	5.75	2.40

To measure the surface deformation after 15 passes of skidder on a new skid trail, cross sections were taken at every 10 m out of 844 m on straight and curved routes and changes were recorded. A levelling woody ruler perpendicular to the skidding direction was placed on the skid trail and then the vertical distances from the ground surface to every 20 cm of this ruler were measured using a metal meter to the nearest cm. The horizontal alignment of skid trail including straight route and curves was taken using polar methods. Cross sections and horizontal alignment were designed in AutoCAD Civil3D software (Version 20.0, 2014). Cross slopes were classified into 2, 3 and 4% on straight line and 4, 5 and 10% on curves. This classification was done according to the frequency of cross slopes on straight line and curves.

To collect soil samples for each cross slope class (6 slope classes), 10 transects were randomly established perpendicular to the skidding direction and then 3 samples were taken on each transect (one from the middle part of skid trails and the others from wheel tracks). Totally, 210 soil samples including 180 soil samples from the compacted skid trail (6 × 3 × 10) and 30 control samples were taken for this study. A core sampler (196.25 cm^3) was used to evaluate bulk density at each site. Cores were taken at depths of 0–10 cm and then oven dried at 105°C for at least 24 h. Bulk density (BD) was calculated using Eq. 1:

$$\mathrm{BD} = \frac{m_{\mathrm{soil}}}{V_{\mathrm{cylinder}}} \tag{1}$$

where:

m_{soil} – dry weight of soil (g),

V_{cylinder} – cylinder volume (cm^3).

In this study soil porosity (P) was calculated using Eq. 2:

$$\mathrm{P}(\%) = 100 - \left(\frac{\mathrm{BD}}{\mathrm{PD}} \times 100\right) \tag{2}$$

where:

PD – soil particle density which was assumed 2.6 $\mathrm{g \cdot cm^{-3}}$.

Moisture content (W) was calculated using Eq. 3:

$$W(\%) = \frac{W_{\mathrm{w}}}{W_{\mathrm{s}}} \times 100 \tag{3}$$

where:

W_{w} – weight of soil moisture,

W_{s} – weight of dried soil particles.

Significant differences between treatment averages for different parameters were tested at $P < 0.05$ using the least significant difference test. SAS software (Version 9.4, 2015) was used for statistical analyses. Also, a comparison of the soil compaction between the wheel rut and the middle part of skid trail was done using Student's t-test.

RESULTS

The map of the horizontal alignment and the 3D plan of downward skid trails have been extracted for the analysis of a geometric design of routes in Civil3D. The total length of the studied skid trails was 844 m. Maximum and minimum longitudinal slope was 30 and 0%, respectively. Different horizontal curves were determined on the map when their minimum radius was 8 m (Fig. 1).

In this study a maximum cross slope (10%) of skid trails was detected in curves and on steep routes (Fig. 2a). A minimum cross slope (2%) was also observed on straight routes and gentle longitudinal slope (Fig. 2b).

Results showed that on the straight route, soil bulk density increased by increasing the cross slope of skid trail. Moreover, the soil porosity decreased with the increasing cross slope. There was a significant difference between cross slopes in soil moisture. Indeed, the soil moisture decreased with increasing cross slope and soil bulk density. In curves, maximum bulk density occurred when the cross slope was 10%. Findings about soil porosity and moisture in curves of skid trails were similar to those of straight routes (Table 2). Based on our findings, soil bulk density in wheel ruts was significantly lower than that in the middle part of skid trail (Table 3).

The soil texture in the study area was silt loams and silty clay loams. The USDA NRCS Soil Quality

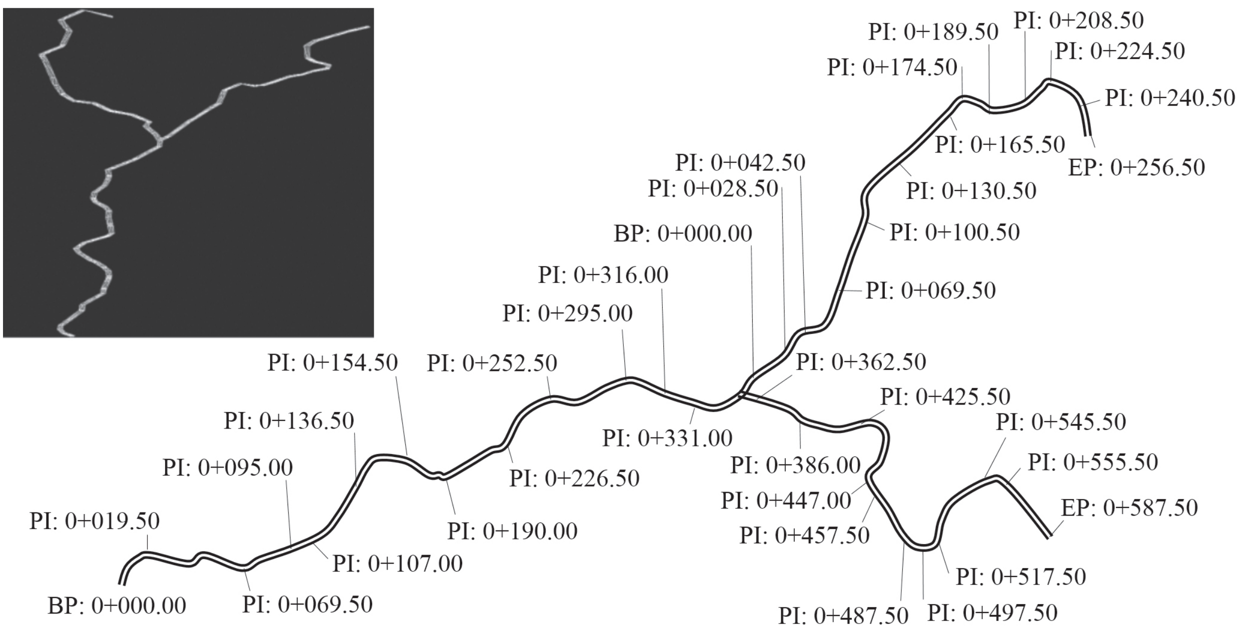

Fig. 1. Horizontal alignment of the studied downward skid trail, numbers show the distances or partial length (PL) from base point (BP) to end point (EP) of skidding

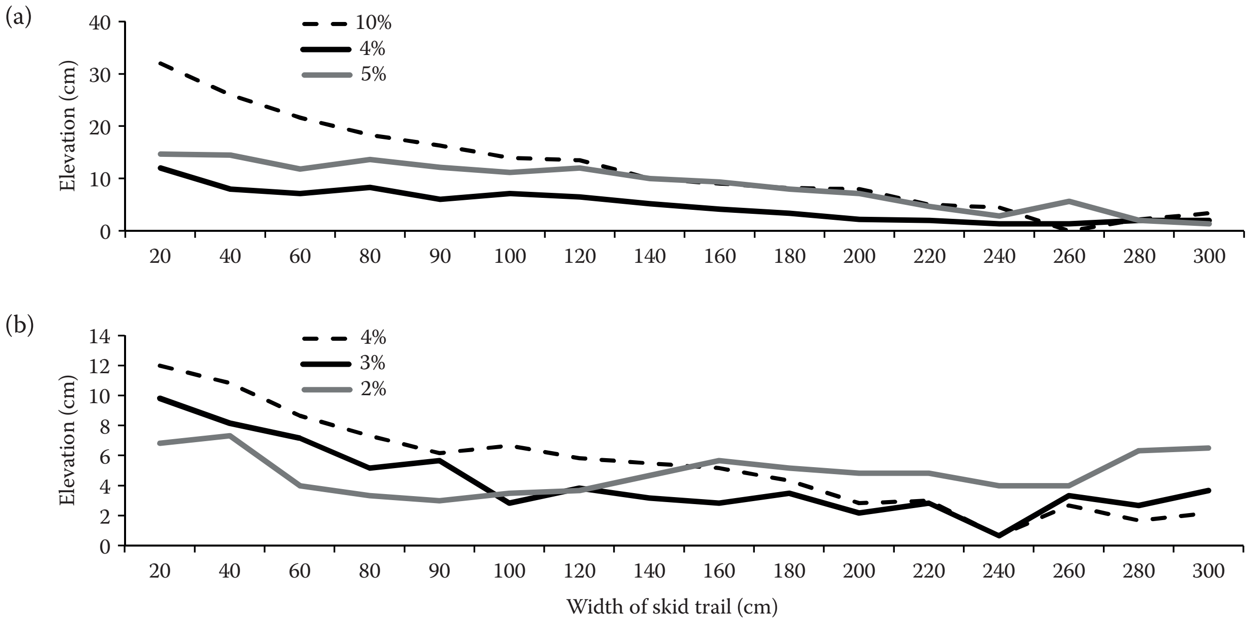

Fig. 2. Map of the cross slope on curves (a) and straight routes (b) of skid trails

Institute has developed Table 4 that shows a relationship between soil bulk density and root growth (Šušnjar et al. 2006). This relationship reveals that the soil bulk density in the present study was a little more than ideal bulk density, so it cannot affect and restrict root growth.

DISCUSSION

Forest soil damage caused by skidding operations can be divided into increasing bulk density, rutting and soil displacement. A unique aspect of forest soils is their low bulk density, high macroporosity, and high rate of infiltration (Rollerson 1990). The increasing soil bulk density due to ground skidding is a common consequence of soil disturbance.

Table 2. Effect of the cross slope of skid trails on soil bulk density, porosity and moisture

Cross slope (%)	Bulk density ($g\cdot cm^{-3}$)	Porosity (%)	Moisture (%)
Straight route			
4.0	1.09^a	60^c	34^b
3.0	1.06^b	63^b	37^a
2.0	1.01^c	66^a	38^a
Curve			
10.0	1.32^a	57^b	32^b
5.0	1.14^b	61^a	34^a
4.0	1.15^b	60^a	33^a

different superscripts show a significant difference at a probability level of 5% based on the least significant difference test

Forest soils easily compact from the use of logging machinery, such as skidding machines, which carry heavy loads in off-road conditions. In this study, the TAF E655 skidder traffic significantly increased the soil bulk density. A maximum increase in soil bulk density occurred in higher cross slopes of curves and in the middle part of skid trails. Naghdi et al. (2016) showed that the increase in soil disturbance on the skid trail with a steep slope is presumably associated with the difficulties of skidding in a steep terrain. They recommended that to minimize soil disturbance, skidding should be confined to areas with more gentle slopes and alternative harvesting methods should be used. Jamshidi et al. (2008) found that soil bulk density, total porosity and moisture content were affected considerably on skid trails by traffic frequency and skid trail slope. They showed that bulk density is higher and total porosity is lower on the skid trail compared to the undisturbed area, which is in agreement with our findings in Bahramnia forestry plan.

Based on our findings, the soil bulk density in wheel ruts was significantly lower than that in the

Table 3. Comparison of the soil compaction between the wheel rut and the middle part of skid trail

Cross section	Compaction ($g\cdot cm^{-3}$)	
	wheel rut	middle part
Straight route	1.01^b	1.19^a
Curve	1.06^b	1.28^a

different superscripts show a significant difference at a probability level of 5% based on the least significant difference test

Table 4. General relationship of soil bulk density to root growth based on the soil texture, data provided by USDA NRCS Soil Quality Institute (2000)

Soil Texture	Bulk density ($g \cdot cm^{-3}$)		
	ideal	that may affect root growth	that restricts root growth
Sands, loamy sands	< 1.60	1.69	> 1.80
Sandy loams, loams	< 1.40	1.63	> 1.80
Sandy clay loams	< 1.40	1.60	> 1.75
Loams, clay loams	< 1.40	1.60	> 1.75
Silts, silt loams	< 1.30	1.60	> 1.75
Silt loams, silty clay loams	< 1.10	1.55	> 1.65
Sandy clays, silty clays, clay loams (35–45% clay)	< 1.10	1.49	> 1.58
Clays (> 45% clay)	< 1.10	1.39	> 1.47

middle part of skid trail, which may be caused by dragged logs. Jourgholami and Majnounian (2011) suggested that skidding operations should be planned when soil conditions are dry in order to minimize rutting. Ruts more than 15 cm deep can indicate more serious problems and the skidding should be stopped and the skid trail surface should be reshaped as soon as possible. Smaller ruts are easy to see and are sufficiently deep to carry a potentially damaging amount of water (Eliasson 2005).

When planning skid trail layouts, it is necessary to keep them as straight as possible. Straight skid trails seem to compensate partially for the added cost of pulling a winch line to the logs. In the present study maximum bulk density occurred on curves especially when the cross slope was high (Ezzati et al. 2015; Safari et al. 2016). The effect of increasing soil bulk density on root growth largely depends on the skidder traffic and soil wetness when the machine is used (Wallbrink et al. 2002). In this research the skidder passes did not affect the root growth. A common response of the root system to increasing bulk density is to decrease its length, concentrating roots in the top layer and decreasing the rooting depth (Wang 1997). The forest soil bulk density and rutting problems can be reduced by restricting the amount of the ground area covered by skid trails, use of tire pressure control systems and choice of the best machine with respect to environmental impacts and productivity (Lotfalian, Parsakhoo 2009).

CONCLUSIONS

The purpose of this study was to investigate the effect of skidding geometric design including plan and horizontal alignment on soil bulk density in Bahramnia forestry plan. In straight routes, soil bulk density increased by increasing the cross slope of skid trail. Moreover, soil porosity decreased with the increasing cross slope. There was a significant difference between cross slopes in soil moisture. On curves, maximum bulk density occurred when the cross slope was 10%. Findings about soil porosity and moisture on curves of skid trails were similar to those of straight routes. Based on our findings, soil bulk density in wheel ruts was significantly lower than that in the middle part of skid trail. Soil bulk density in the silty soil texture of studied skid trails was a little more than ideal bulk density according to the reports of USDA NRCS Soil Quality Institute (2000), so it cannot affect and restrict root growth. A skid trail with downward direction was selected. According to research findings, downward skidding routes and lower cross slope should be constructed.

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