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Considering the relationship of slope and soil loss on skid trails in the north of Iran (a case study)

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ABSTRACT: With increasing mechanization of forest harvesting operations the impacts on soil have increased quite dramatically. The objective of this paper was to examine the relationship of slope and soil loss. This research was carried out in parcels 14 and 26 of the third district of Nav-Asalem forest in the north of Iran. Erosion plots were 75, 150 and 225 m^2 with two slope classes. After each rainfall event the amount of runoff was measured; then, a sample was taken to determine the weight of soil loss. The results of correlation analysis by Pearson's test between soil loss and slope classes, soil loss and slope length showed that there was a significant ($P < 0.05$) and positive correlation between the mentioned factors. Also, linear regression between soil loss, slope length and slope gradient was significant. It could be concluded that studying and underlying factors that increase soil loss such as soil type, rainfall intensity, should also be taken into consideration in future. Skid trail construction and skidding should be limited to the slope of < 20%; machine traffic should be restricted. The above-mentioned conclusions can be applied to proper harvesting and management of forest ecosystems.

Keywords: harvesting; runoff

The use of heavy machinery to perform forest activities such as logging has increased worldwide during the last decades. With increasing mechanization of forest harvesting operations the impacts on soil have increased quite dramatically (Hartano et al. 2003). Forest harvesting practices, such as skid trail construction and logging, can have a significant effect upon surface soil properties and erosion rates. Skid trails are a highly disturbed area both during the construction phase and as a result of subsequent traffic of heavy logging machinery (Rab 1999; Croke et al. 2001; Modrý, Hubený 2003; Najafi et al. 2009). Logging has always led to a wide range of disturbing effects on the forest ecosystem. Soil surface disturbance, changes in chemical and physical properties of soil and damage to natural regeneration and tree stands are the main effects of logging operations (Tan et al. 2005; Agherkakli et al. 2010; Ampoorter et al. 2010). Effective indices in designing skid trails such as longitudinal slope, soil moisture content, depth and texture, as well as effective factors of wood extraction such load volume, weight and shape and number of skidder passes are the most important effective factors of soil disturbance in skid trails (Naghdi et al. 2009). Ground-based skidding may result in compaction and other soil structural changes; compaction associated with harvesting traffic often results in localized surface runoff, which may be channelled by wheel ruts, causing some loss of erodible surface materials (Ballard 2000; Defossez, Richard 2002; Rab 2004; Ampoorter et al. 2007; Najafi et al. 2009; Saffih-Hdadi et al. 2009; Ampoorter et al. 2010; Ampoorter et al. 2011). Also, hydraulic properties of soils change after rainfall, which significantly influences infiltration, runoff and erosion (Erpul, Canga 1999; Horn et al. 2007). The transport network plays an important role in the forest industry production of mountain regions where forest areas are scattered in vast territories (Byblyuk et al. 2010). It seems mandatory that permanent skid trail systems should be developed for forest sites in order to concentrate all forest site operations to such irreversibly compacted area (Horn et al. 2007). The volume of soil erosion inflicted by forest machinery is a function of the gradient and length of slope, degree of soil erosion vulnerability, fraction of area covered by vegetation; intensity, duration, extension and frequency of precipitation (Ziegler, Giambelluca 1997; Grigal 2000; Byblyuk et al. 2010; Fu et al. 2010). Hence, measuring soil loss and sediment delivery are critical for quantifying and predicting the effects of timber harvesting activities in forested watersheds (Litschert, MacDonald 2009).

The primary objective of this paper was to quantify soil loss from skid trails and to examine the relationship of slope and soil loss; and then to determine a multiple linear regression equation that could be used to predict soil loss by slope.

MATERIALS AND METHODS

This research was carried out in two adjacent parcels, parcels 14 and 26 of the third district of Nav-Asalem forest in the north of Iran between 48°39'30''–48°44'30''N and 37°37'20''–37° 61'12''E at the altitude ranging from 500 to 2,100 m a.s.l. with monthly mean temperature of 14.8°C. The sites are dominated by *Fagus orientalis* Lipsky, *Carpinus betulus* L. and *Quercus castanifolia* C.A. May. The average annual rainfall recorded at the closest weather station is 1,038.7 mm. The soil texture, precipitation, canopy cover and soil moisture were the same on skid trails. A ground skidding system was the only mechanization method of harvesting used in experimental locations. Wood extraction was carried out from stump to roadside landing in the shape of a long log; the skidding direction along skid trails was downward by a wheeled skidder (Table 1). The soil texture is clay loam and average soil water content after skidding was 18.85%. The experiment was conducted during the autumn season of 2009. Characteristics of rainfall events are shown in Table 2.

Two skid trails of 3 m in width were selected for the experiment. Erosion plots were 75, 150 and 225 m^2 with two slope classes, more than 20% (Parcel 26) and less than 20% (Parcel 14); they were replicated 3 times in a randomized complete block design (Fig. 1). Each plot was bound by earth levees and a tank was installed at its downside. Also, a ditch was installed at the end of each plot to block the runoff and direct it to the bank (Hartano et al. 2003; Abu Hammad et al. 2006). After each rainfall event the amount of runoff was measured; then, the runoff in each tank was mixed thoroughly and a sample was taken to determine the weight of soil loss after oven drying at 105°C and it was used to conduct the statistical analysis. Data were analysed using Statistical Package for the Social Sciences for Windows SPSS 13 (SPSS, Tulsa, USA) and SAS 9.1. (SAS, Cary, USA) Linear regression and Pearson's correlation were used to determine the effects of slope length and slope gradient on soil loss after assumption of normality (by one-sample Kolmogorov-Smirnov test) was tested.

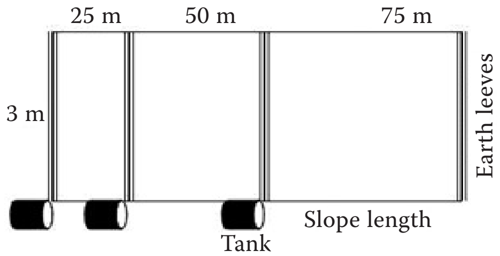

Fig 1. Plan view of experimental plots

RESULTS

The results of soil loss amounts on skid trails are shown in Fig. 2. The highest and the lowest amount of soil loss mean occurred at 225 m^2 on the skid trail of parcel 26 and 75 m^2 on the skid trail of Parcel 14, being 17.2 (± 2.94) g·m^{-2} and 0.19 (± 0.13) g·m^{-2}, respectively.

The results of correlation analysis by Pearson's test between soil loss and two slope classes (> 20% and < 20%) are shown in Table 3. Results showed

Table 1. Timber harvesting characteristics on skid trails

Characteristic	Parcel 14	Parcel 26
Density (trees·ha^{-1})	168	323.9
Volume of harvested timber (m^3)	1,407	1,300
Wood extraction method	ground skidding system	
Skidder type	Timberjack	
Form of timber extraction	long log	
Skid trail use (on skidding duration)	more than 15 passages	

Table 2. Rainfall characteristics

Month, year	Day	Total precipitation (mm)	Mean intensity (mm·h^{-1})
November, 2009	6	7	1.4
	8	0.5	0.25
	17	17.5	1.5
	17	3	0.66
	18	28	1.27
	19	4	0.2
	21	15	0.85
	26	1	0.2
	30	1	0.11
December, 2009	3	8	1.33
	7	34.5	2.6

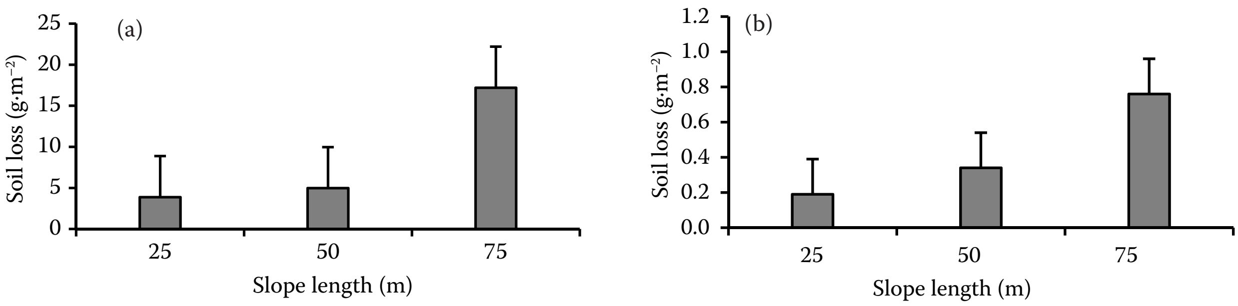

Fig 2. Soil loss on skid trail: (a) Parcel 26 and (b) Parcel 14

that there was a significant and positive correlation between soil loss and slope gradient (n = 18).

The correlation between soil loss and slope length was also analysed by Pearson's test (Table 4). The results showed that there was a significant and positive correlation between soil loss and slope length (n = 9).

The relationship of slope length and soil loss in two slope classes is presented in Fig. 3. The results of linear regression analysis are shown in Table 5 (P < 0.0001). The equation No. 3, 7 and 9 seems be the most appropriate linear regression for this study area where: y – soil loss (g·m^{-2}), x_1– slope length (m), x_2– slope gradient (%). The scatter plot of residual versus predicted value of soil loss is shown in Fig. 4.

DISCUSSION

Skid trail and road building, and the movement of heavy machinery and timber through the forest stand cause disturbances of the soil surface, which can lead to increased vulnerability of soil to erosion, although changes in soil properties were subjects of numerous studies worldwide (Rab 1999; Modrý, Hubený 2003; Horn et al. 2007; Najafi et al. 2009; Byblyuk et al. 2010; Ampoorter et al. 2011). The results showed that slope length and slope gradient can lead to increased soil loss. Impacts of slope on the soil loss characteristics showed similar results in many researches (Fox, Bryan 1999; Gabriels 1999; Luce, Black 1999; Arnaez et al. 2004; Jordan-López et

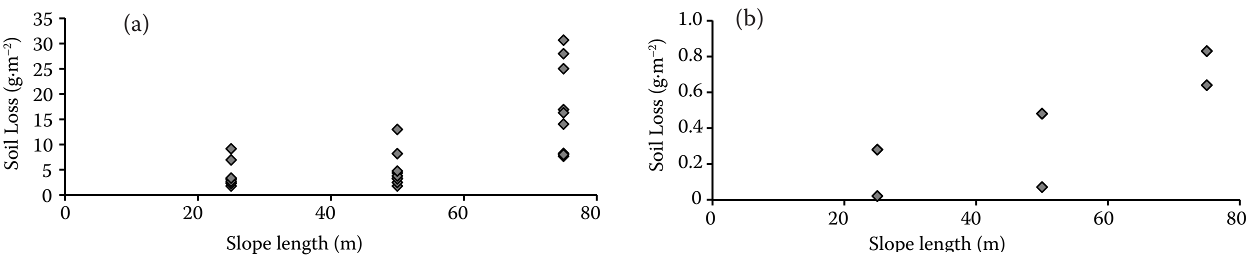

Fig 4. Soil loss as a function of the slope length: (a) Parcel 26 and (b) Parcel 14

Table 3. Pearson R and P-value between soil loss and slope gradient

	Rainfall 1	Rainfall 2	Rainfall 3
R	0.734**	0.634**	0.698**
P	0.001	0.005	0.001

**significant at α = 0.01 (two-tailed), rainfall 1, 2 and 3 – duration when the first, second and third rainfall event occurred

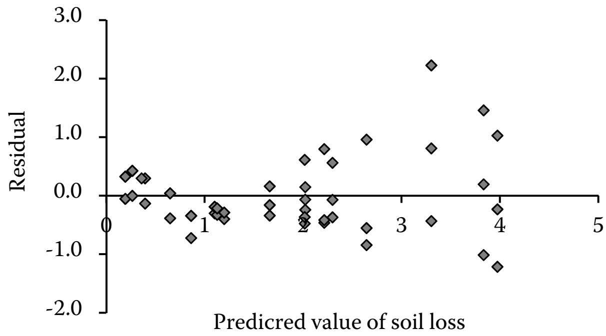

Fig 4. Scatter plot of residual and predicted values of soil loss

al. 2009). Also, linear regression between soil loss, slope length and slope gradient was significant. This indicated that the runoff is capable of eroding further soil particles through its movement action. The high velocity and large amount of runoff in steep slopes enabled it to erode more particles. However, infiltration rate decreased with increasing slope gradient. A positive relationship between soil loss and slope was in accordance with Gabriels (1999), Abu Hammad et al. (2006), Cerdan et al. (2010), Ekwue and Harrilal (2010). Also, in Fox and Bryan (1999) and Ekwue and Harrilal (2010), the relationship between soil loss and slope was linear. In addition to the influence of slope gradient, slope length and runoff characteristics on soil loss, rainfall plays an important role in determining the magnitude of runoff and soil loss (Hartano et al. 2003; Xu et al. 2009). As Fox and Bryan (1999) stated, the principal factor affecting runoff rate within any slope gradient was the variation in rainfall intensity; this factor was the same on two experimental sites of this study.

The vegetation plays a very significant role in controlling runoff and erosion (Calvo-Cases et al. 2003; Hartano et al. 2003; Adekula et al. 2006; Martinez-Zavala et al. 2008). The erosion on skid trails and roads with vegetation is different, the runoff is often discontinuous and in many cases no net increase of total runoff amount with slope length occurs and the average erosion rates may remain constant or even decrease with slope length. But, on skid trails, the absence

Table 4. Pearson R and P-value between runoff volume and slope length

	Rainfall 1		Rainfall 2		Rainfall 3	
	R	P	R	P	R	P
≥ 20%	0.858**	0.003	0.891**	0.001	0.874**	0.002
≤ 20%	0.900**	0.001	0.988**	0.000	0.988**	0.000

**significant at α = 0.01 (two-tailed), rainfall 1, 2 and 3 – duration when the first, second and third rainfall event occurred

Table 5. Summary of equations which relate slope length and slope steepness to soil loss

No.	Equation	Root MSE	R^2	Adj–R^2
1	$y = 0.03x_1$	1.27	0.65	0.64
2	$y = 0.08x_2$	0.86	0.83	0.83
3	$y = -1.31+ 0.02x_1+ 0.09x_2$	0.74	0.71	0.70
4	$y = 0.33 + 0.02x_1$	1.27	0.15	0.13
5	$y = -0.35 + 0.09x_2$	0.85	0.62	0.61
6	$y = -1.64 + 0.01x_1 - 0.61x_2$	0.19	0.86	0.85
7	$y = -4.14 + 0.01x_1$	0.40	0.82	0.81
8	$y = -4.24 + 0.03x_1 - 1.92x_2$	0.64	0.79	0.77
9	$y = -0.08 + 0.05x_2$	0.52	0.81	0.76

y – soil loss (g·m^{-2}), x_1 – slope length (m), x_2 – slope gradient (%)

of the vegetation cover of soil increased runoff generation and soil loss by rainfall and provided unobstructed movement of runoff and soil loss downslope. Hence, the exposure of forest soils, particularly from logging roads and skid trails, is the main source of sediment supply (Lai, Samsuddin 1985). Furthermore, the presence of the canopy also provides the soil with more time to receive the rainfall, thus allowing time for more infiltration before surface runoff starts; it also leads to a higher rate of infiltration and reduces the amount of surface runoff (Sharifah Mastura, Al-Toum 2000).

However, the litter layer is clearly the most important control of soil loss but there was no litter layer on skid trails and the removal of litter layer resulted in an increase in runoff and soil loss (Hartano et al. 2003; Matínez-Zavala et al. 2008). Also, other factors such as soil texture, soil moisture, type of harvesting could affect soil loss (Rab 1999; Matínez-Zavala et al. 2008; Ekwue, Harrilal 2010) but we did not consider these factors in our study and request an urgent need for further research.

The increase in soil loss with slope length and slope gradient is consistent with findings in other studies; so skid trail drainage and rehabilitation are an essential process in the management of soil loss. Hence, the creation of water diversions to control runoff, reduce runoff and soil loss is necessary. Sediment delivery from harvested areas can be greatly reduced by constructing more water diversions along skid trails to reduce runoff and soil loss (Croke et al. 2001; Wallbrink, Croke 2002; Litschert, MacDonald 2009).

This study was conducted with the overall objective of characterizing the effects of skid trail slope on soil loss. It could be concluded that studying and underlying factors that increase soil loss such as soil type, rainfall intensity, should also be taken into consideration in future. A multiple regression equation derived to relate soil loss to the experimental factors was significant and confirmed that slope gradient and slope length were important factors that affected soil loss. This study suggests that Best Management Practices are largely effective in reducing soil loss; also, the incorporation of organic materials in steep slopes could greatly reduce surface runoff and soil loss. Furthermore, skid trail construction and skidding should be limited to the slope of < 20%; machine traffic should be restricted. The above-mentioned conclusions can be applied to proper harvesting and management of forest ecosystems.

References

Abu Hammad A.H., Boressen T., Haugen L.E. (2006): Effects of rain characteristics on runoff and erosion under the Mediterranean. Soil and Tillage Research, ***87***: 39–47.

Adekalu K.O., Okunade D.A., Osunbitan J.A. (2006): Compaction and mulching effects on soil loss and runoff from two southwestern Nigeria agricultural soils. Geoderma, ***137***: 226–230.

Agherkakli B., Najafi A., Sadeghi S.H. (2010): Ground based operation effects on soil disturbance by steel tracked skidder in a steep slope of forest. Journal of Forest Science, ***56***: 278–284.

Ampoorter E., Frenne P., Hermy M., Verheyen K. (2011): Effects of soil compaction on growth and survival of tree saplings: A meta analysis. Basic and Applied Ecology, ***12***: 394–402.

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***: 162–174.

Arnaez J., Larrea V., Ortigosa L. (2004): Surface runoff and soil erosion on unpaved forest roads from rainfall simulations tests in northeastern Spain. Catena, ***57***: 1–14.

Ballard T.M. (2000): Impacts of forest management on northern forest soils. Forest Ecology and Management, ***133***: 37–42.

Byblyuk N., Styranivsky O., Korzhov V., Kudra V. (2010): Timber harvesting in the Ukrainian Carpathians: ecological problems and methods to solve them. Journal of Forest Science, ***56***: 333–340.

Calvo-Cases A., Boix-Fayos C., Imeson A.C. (2003): Runoff generation, sediment movement and soil water behavior on calcareous climate stone slopes of some Mediteranean environments. Geomorphology, ***50***: 269–291.

Cerdan O., Govers G., Le Bissonnais Y., Van Oost K., Poesen J., Saby N., Gobin A., Vacca A., Quinton J., Auerswald K., Klik A., Kwaad F.J.P.M., Raclot D., Ionita I., Rejman J., Rousseva S., Muxart T., Roxo M.J., Dostal T. (2010): Rates and spatial variations of soil erosion in Europe: A study based on erosion plot data. Geomorphology, ***122***: 167–177.

Croke J., Hairsine P., Fogarty P. (2001): Soil recovery from track construction and harvesting changes in surface infiltration, erosion and delivery rates with time. Forest Ecology and Management, ***143***: 3–12.

Defossez P., Richard G. (2002): Models of soil compaction due to traffic and their evaluation. Soil and Tillage Research, ***67***: 41–64.

Ekwue E.I., Harrilal A. (2010): Effects of soil type, peat, slope, compaction effort and their interactions on infiltrations, runoff and raindrop erosion of some Trinidadian soils. Biosystems Engineering, ***105***: 112–118.

Erpul G., Canga M.R. (1999): Effect of subsequent simulated rainfalls on runoff and erosion. Tropical Journal of Agriculture and Forestry, ***23***: 659–665.

Fox D.M., Bryan R.B. (1999): The relationship of soil loss by inter rill erosion to slope gradient. Catena, ***38***: 211–222.

Fu B., Newham L.TH., Ramos-Scharron C.E. (2010): A review of surface erosion and sediment delivery models for unsealed road. Environmental Modeling and Software, ***25***: 1–14.

Gabriels D. (1999): The effects of slope length on the amount and size distribution of eroded silt loam soils: short slope laboratory experiments on interrill erosion. Geomorphology, ***28***: 169–172.

Grigal D.F. (2000): Effects of extensive forest management on soil productivity. Forest Ecology and Management, ***138***: 167–185.

Hartano H., Prubhu R., Widayat A.S.E., Asdak Ch. (2003): Factors affecting runoff and soil erosion: plot–level soil loss monitoring for assessing sustainability of forest management. Forest Ecology and Management, ***180***: 361–374.

Horn R., Vossbrink J., Peth S., Becker S. (2007): Impact of modern forest vehicles on soil physical properties. Forest Ecology and Management, ***248***: 56–63.

Jordan-López A., Martínez-Zavala L., Bellinfate N. (2009): Impact of different parts of unpaved forest roads on runoff and sediment yield in a Mediterranean area. Scientific Total Environment, ***407***: 937–944.

Lai F.S., Samsuddin M. (1985): Suspended and dissolved sediment concentrations of two disturbed lowland forested watersheds in Air Hitam forest reserve, Selangor. Pertanika, ***8***: 115–122.

Litschert S.E., MacDonald L.H. (2009): Frequency and characteristics of sediment delivery pathways from forest harvest units to streams. Forest Ecology and Management, ***259***: 143–150.

Luce C.H., Black T.A. (1999): Sediment production from forest roads in western Oregon. Water Resources Research, ***35***: 2561–2570.

Martínez-Zavala L., Jordan-López A., Bellinfate N. (2008): Seasonal variability of runoff and soil loss on forest road back slopes under simulated rainfall. Catena, ***74***: 73–79.

Modrý M., Hubený D. (2003): Impact of skidder and high-lead system logging on forest soils and advanced regeneration. Journal of Forest Science, ***49***: 273–280.

Naghdi R., Bagheri I., Lotfalian M., Setodeh B. (2009): Rutting and soil displacement caused by 450C Timberjack wheeled skidder (Asalem forest northern Iran). Journal of Forest Science, ***55***: 177–183.

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

Rab M.A. (2004): Recovery of soil physical properties from compaction and soil profile disturbance caused by logging of native forest in Victorian Central Highlands, Australia. Forest Ecology and Management, ***191***: 329–340.

Rab M.A. (1999): Measures and operating standards for assessing Montreal process soil sustainability indicators with reference to Victorian Central Highlands forest, southeastern Australia. Forest Ecology and Management, ***117***: 53–73.

Saffih-Hdadi K., Défossez P., Richard G., Cui Y.J., Tang A.M., Chaplain V. (2009): A method for predicting soil susceptibility to the compaction of surface layers as a function of water content and bulk density. Soil and Tillage Research, ***105***: 96–103.

Sharifah Mastura S.A., Al-Toum S. (2000): A study on surface wash and runoff using open system erosion plots. Pertanika Journal of Tropical and Agricultural Science, ***23***: 43–55.

Tan X., Chang S.X., 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***: 158–170.

Wallbrink P.J., Croke G. (2002): A combined rainfall simulator and tracer approach to assess the role of Best Management Practices in minimising sediment redistribution and loss in forests after harvesting. Forest Ecology and Management, ***170***: 217–232.

Xu X., Liu W., Kong Y., Zhang K., Yu B., Chena J. (2009): Runoff and water erosion on road side-slopes: effects of rainfall characteristics and slope length. Transportation research, ***14***: 497–501.

Ziegler A.D., Giambelluca Th.W. (1997): Simulation of runoff and erosion on mountainous roads in northern Thailand: a first look. In: Walling D.E., Probst J.L. (eds): Human Impact on Erosion and Sedimentation. Wallingford, International Association of Hydrological Sciences: 21–29.

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