Caspian J. Env. Sci. 2013, Vol. 11 No.2, pp. 151~160

CJES
Caspian Journal of Environmental Sciences

[Research]

Evaluation of Factors Affecting Water Erosion along Skid Trails (Case study; Shafarood Forest, Northern Iran)

I. Bagheri[1], R. Naghdi[2*], A. Moradmand Jalali[3]

1-Dept. of Agricultural Mechanization Engineering, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran
2- Dept. of Forestry, Faculty of Natural Resources, University of Guilan, Someh Sara, Iran
3- General Office of Guilan Natural Resources, Rasht, Iran.
** Corresponding author's E-mail: rnaghdi@guilan.ac.ir*

(Received: Apr. 13. 2012, Accepted: Sept.01. 2012)

ABSTRACT

Water erosion causes severe soil damage in northern forests of Iran which is associated with different rut depths in skid trails. The aim of this study was to assess rutting and soil displacement on skid trails to mitigate water erosion. Therefore the research was carried out in eight parcels of district No 3 of Shafarood Forest in the North of Iran. In order to evaluate the amount of erosion in skid trails, 30 lateral profiles in three slope classes (0-15, 15-25 and >25%) were randomly chosen from 10 skid trails. The amount of soil displaced and ruts were measured using lateral profile of skid trail. Then the effective factors on soil disturbances such as longitudinal slope, soil texture, crown canopy and forest floor cover were separately measured in the studied plots. The results of regression analysis showed that there were significant differences between amount of soil erosion and longitudinal slope, soil texture, crown canopy and forest floor cover. The results from Pearson test showed that there was significant correlation between amount of soil erosion and longitudinal slope of skid trails, soil texture and forest floor cover (α= 0.01 and α= 0.05), but there was no significant correlation between amount of soil erosion and crown canopy. The results of this research showed that by increasing longitudinal slope of skid trail, displaced soil volume and rutting depth increased. The sample plots in longitudinal slope class of >25% and average displaced soil volume of 5.3 m^3 had maximum disturbance. Mean comparison test also showed that there were no significant differences in the displaced soil volume in the two longitudinal slope classes (0-15 and 15-25%), but with an increase in longitudinal slope (more than 25%), the average displaced soil volume increased.

Keywords: *Water erosion, Soil displacement, Rutting, Skid trail, Iran.*

INTRODUCTION

It is important that skid trails are appropriate to harvesting methods, therefore it is essential to properly design these skid trails for better forest unit management, since the general characteristics of existing skid trails in northern forest of Iran are not properly designed and hence cause an increase in soil damage in this area. Designing skid trails with respective standards decrease soil and stand damages.

Naghdi et al (2010) in their study demonstrated that slope steepness had a significant effect on soil compaction and moisture content during skidding operation. By evaluating the trend of soil compaction they found that skid trail longitudinal slope had maximum soil compaction at lower skidder traffic. Najafi et al. (2010) reported that soil disturbance increased significantly on slopes with > 20 % inclination with a dry bulk density of 1100 kg m^{-3} after 3 cycles compared to 830 kg m^{-3} on < 10 % slopes. Skidder traffic on the forest soil bed along skid trails leads to rutting and soil displacement because of weak structure in the top layers of skid trails (Mac Donald et al. 2001; Trautner and Arvidsson 2003; Eliasson 2005). Najafi et al. (2009) showed that rut depth were recorded after 14 passes and was significantly affected by the skid trail slope. Since the soil in skid trails is displaced and disturbed due to traffic, soil erosion along skid trails is noticeably higher than in control areas.

Water erosion causes severe soil damage in northern forests of Iran which is associated with different ruts depths in skid trails. The ruts formed displace soil and damage soil structure and with increasing machinery traffic rutting increases (Pinard et al. 2006). After rainfall water runoff in ruts causes soil erosion in skid trails which generate and carry sediments. The phenomenon of rutting and its expansion rate were more severe mainly in fine grained soils, in a way that with continuous rainfall and increasing machinery traffic the rut depth increased and changed into gully (Quesnal and Curran, 2000).

Moor and Burch (1994) in their study showed that the amount of soil damage in skid trails is related to skid trail design factors such as longitudinal slope, unevenness and soil texture and also factors such as shape and form of loads, load weight and amount of traffic. Rab (1996) studied soil physical and hydrological properties following logging and slash burning in the Eucalyptus regnant forest of southeastern Australia. The results showed that skidding operations cause soil damage and compaction. Also soil damage significantly changes amount of soil organic matter, bulk density, porosity and infiltration rate. The decrease in soil porosity and hydraulic conductivity decreases infiltration rate and increases water runoff. Moor (1992) came to the conclusion that slope is the most important factor in creating rut and destroying road drainage. Naghdi *et al.* (2009) in their study on rutting and soil displacement caused by 450C Timberjack wheel skidder on clay loam and sandy clay loam soils showed that there was a significant difference between the longitudinal slope increase of skid trail and the amount of soil volume displaced. Billby (1998) reported that rainy season and machinery traffic are the most important factors damaging road side channel and over filling culvert with sediment. Hartanto et al. (2003) studied affecting factors on runoff and erosion in Kalimontan, Indonesia. They reported that the amount of erosion and soil bulk density in skid trails with different traffic levels were higher than that in controls. They also showed that there was a correlation between amount of erosion and runoff with soil bulk density. Farabi (2003) showed that skid trails design factors such as longitudinal slope; number and radius of corners present in each skid trail and length of skid trail are effective in damaging skid trails.

In general soil compaction increases dry bulk density and decreases infiltration rate and soil saturated hydraulic conductivity, which cause erosion potential in skid trail to increase. Since the skid trails in the catchment forests under Shafarood Company are generally designed and constructed on steep slopes, therefore longitudinal slopes of skid trails are made based on the maximum acceptable slope guidelines in order to reduce the length of skid trails. This research is essential to know the relationship between the longitudinal slope of skid trails and amount of erosion. The aim of this study was to assess the effective factors in creating and increasing rutting and displaced soil volume in skid trails, in order to prevent water erosion.

MATERIALS AND METHODS

Study area

This study was carried out in eight parcels (306, 307, 314, 317, 328, 329, 336 and 342) of district No 3 of Shafarood forest in northern Iran (Fig.1), with the altitude ranging from 500 to 1600 meters above sea level and an average annual precipitation of 1440 millimeters. The area is located between 47°58' and 48°52' of longitude, and 37°32' and 37°36' of latitude. The forest was uneven-aged and its type was fagetum (*Fagus orientalis Lipsky*) with the average growing stock of 250 cubic meters per hectare. The surface area of the district was 2586 ha and it was divided into 46 parcels, 27 parcels have been harvested in a ten-year period with shelter wood and single selection logging method. The volume of harvested wood in the district was 1450 m^3. Average load in each turn was 2.9 m^3 and the maximum traffic was 27 passes.

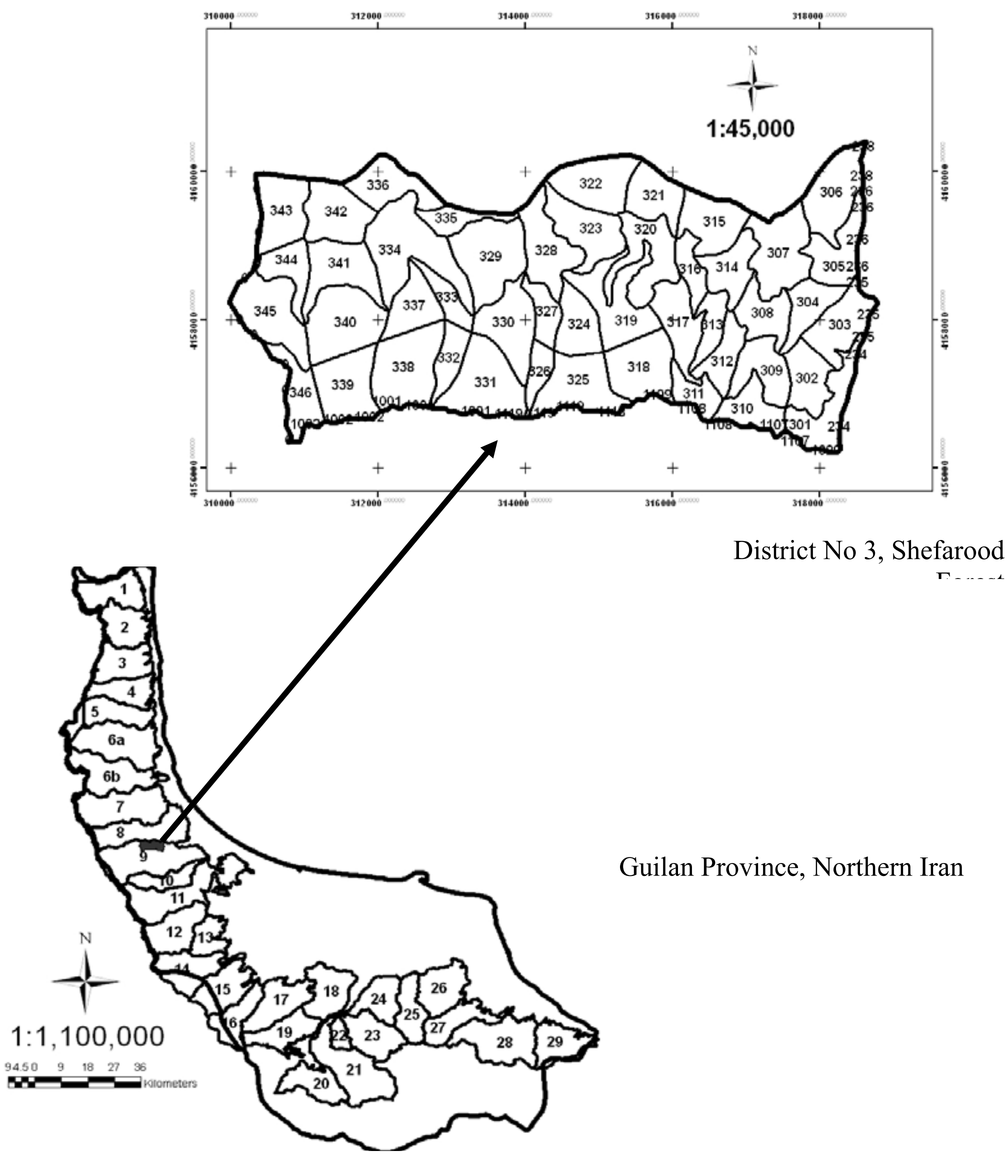

Fig. 1. Parcels 6, 7, 14, 17, 28, 29, 36 and 42 of District No. 3 of Shafarood Forest in northern Iran (study area).

The parent material was calcelous, and the soil texture was clay loam, silty loam and silty clay loam. The road density of the studied district was 14.8m/ha. The extraction of short and long logs from stump area to road side landing, were carried out by ground based skidding system. The skidding direction along the skid trail was downhill. The skidder type used in this study was 450C TimberJack cable skidder, model 6BTA5.9 with 177hp and 10257kg weight.

Experimental design and data collection

In order to select the skid trails, precise field work assessment was carried out in the studied parcels with regards to hypothesis that factors such as tree crown canopy, forest stand density, soil texture, rock bed, topography, slopes and forest floor cover affect soil erosion. The effective factors which were assessed are shown in Table 1.

Table 1. The affecting factors assessed in this study

Studied factors	Slope classes (%)		
Slope	0-15	15-25	>25
Soil texture	Clay loam	Silt clay	Clay
Crown canopy (%)	>70	40-70	40
Forest floor cover	Bush	Grass	Litter

In order to keep the effect of time on erosion constant, attempts were made to select the skid trails, so that harvesting operations in skid trails were not more than one month old. To evaluate the amount and cause of erosion in skid trails, 30 lateral profiles (plots) were randomly chosen in 10 skid trails. Plot selection was based on that medium and maximum traffic levels which occurred at the end of skid trails, therefore chosen plots were in areas which had similar soil compaction.

In order to assess the state of soil damage with regards to sample plots size and width of skid trail (Laflen et al. 1991), sample plots of 4×20 m dimensions were considered. Consecutively sampling was carried out to determine the volume of soil disturbed by skidder traffic in each sample plot on 3 locations (with 5 m interval from each other) and along perpendicular to skid trail (Fig. 2). Then a nylon string was attached to the two sides of skid trail and vertical height (distance) of string to surface of the trail is measured in every 50 cm interval along the string (Fig. 3). In this study soil disturbance (rutting and displaced soil volume) measurement was carried out in different slope classes along the skid trail (0-15, 15-25 and >25%). In each predetermined sample plot, the amount of soil displaced and ruts were measured using lateral profile of skid trail. With regards to this ruts with more than 5 cm depth and minimum of 2 m length are considered as soil damage (Nugent et al. 2003; Quesnal and Curran, 2000; Najafi e al. 2009). Rut depth was measured using a profile meter consisting of a set of vertical metal rods (length 500 mm and diameter 5 mm), spaced at 25 mm horizontal intervals, sliding through holes in a 1 m long iron bar. The bar was placed across the wheel tracks perpendicular to the direction of travel and rods positioned to conform to the shape of the depression (Najafi et al. 2009). Rut depth was calculated as the average depth of 40 reads on the 1 mbar (Fig. 3).

In this study the effective factors on soil disturbances such as longitudinal slope, soil texture, crown canopy and forest floor cover were separately measured in the studied plots.

Data were analyzed using Statistical Package for the Social Sciences (SPSS) of Windows version 11.5. Pearson test was used to attain correlation between soil erosion and factors such as longitudinal slope of skid trails, soil texture, crown canopy and forest floor cover. Treatment effects were considered significant if $p<0.05$. Regressions were used to evaluate the effects of longitudinal slope of skid trails, soil texture, crown canopy and forest floor cover on erosion.

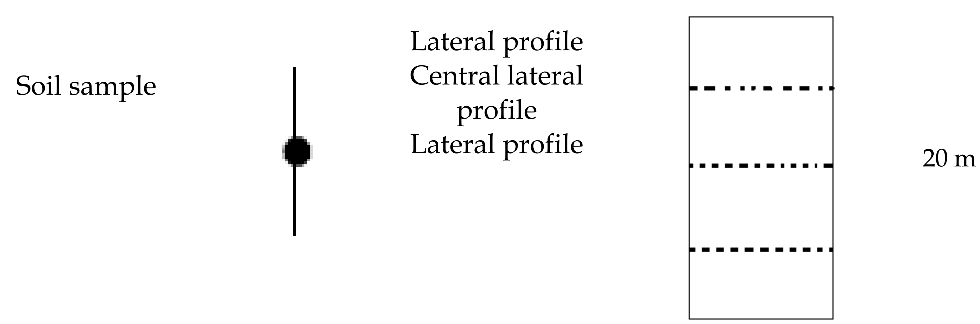

Fig. 2. A sample plot of the study.

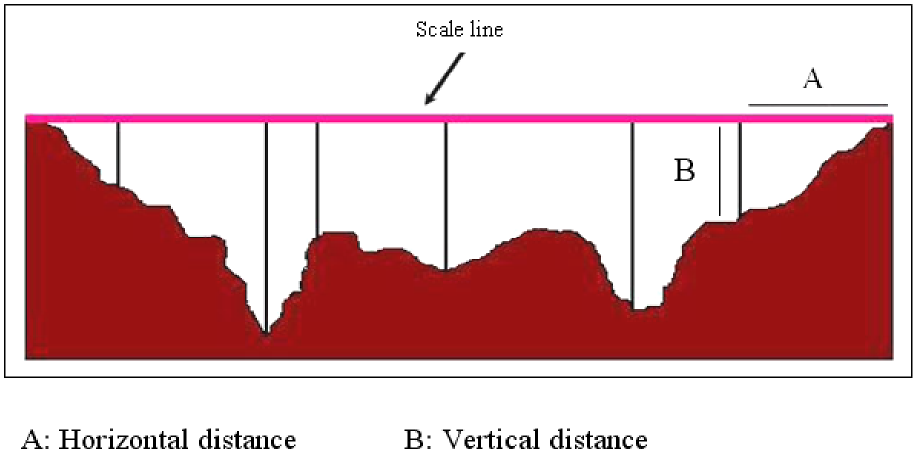

Fig. 3. Lateral profile in each plot

RESULTS

The results of regression analysis between amount of soil erosion and longitudinal slope, soil texture, crown canopy and forest floor cover are shown in Table 2. The results of regression analysis showed that there were significant differences between amount of soil erosion and longitudinal slope, soil texture, crown canopy and forest floor cover.

The regression equation is shown in equation 1.

$$Y=7.932\ x1 - 2.824\ x2 - 1.009\ x3 + 1.851\ x4 + 7.304 \qquad R2= 0/819 \qquad (1)$$

Y= Depth of water erosion (cm)
X1= Longitudinal slope of skid trails (%)
X2= Soil texture
X3= Crown canopy
X4= Forest floor cover

Table 2. Regression analysis of soil erosion and independent variables

	Degree of freedom	Sum of squares	Mean Squares	R^2	F	Sig.
Regression	5	1442.485	21.706	0.819	288.497	0.000
Residuals	24	318.981			13.291	
Total	29	1761.467				

Since there were significant differences between soil erosion and longitudinal slope, soil texture, crown canopy and forest floor cover, Pearson test was used in order to determine the extent of correlation between dependent variables (erosion) and each independent variable (longitudinal slope, soil texture, crown canopy and forest floor cover). The results from Pearson test showed that there were significant correlation between amount of soil erosion and longitudinal slope of skid trails, soil texture and forest floor cover (α= 0.01) and (α= 0.05), but there was no significant correlation between amount of soil erosion and crown canopy (Table 3). The results of regression analysis of dependent and independent variables are shown in Table 4.

Table 3. Pearson test among nonparametric parameters

Parameters	Amount of soil erosion
Amount of soil erosion	1
Longitudinal slope of skid trails	0.846^{**}
Soil texture	-0.396^{*}
Crown canopy	-0.096^{ns}
Forest floor cover	0.181^{*}

Table 4. Regression coefficient of independent and dependent variables

Model	Unstandardized coefficients		Standardized coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	7.304	4.866		1.501	0.146
Longitudinal slope of skid trails	7.932	0.926	0.806	8.570	0.000
Soil texture	-2.824	1.482	-0.181	-1.906	0.050
Crown canopy	-1.009	1.030	-0.090	-0.979	0.337
Forest floor cover	1.851	0.911	0.186	2.033	0.053

The results of this research showed that by increasing longitudinal slope of skid trail, displaced soil volume and rutting depth increases. The sample plots with more than 25% longitudinal slope and average volume of 5.3 cubic meter displaced soil have maximum disturbance (Table 5, Fig.4 and Fig.5).

Table 5. Regression analysis of different longitudinal slope classes

	Source	Sum of Squares	Df	Mean Square	F	Sig.
Displaced soil volume	Between groups	46.844	2	23.422	110.868	0.000
	Within Groups	5.704	27	0.211		
	Total	52.548	29			
Rut depth	Between groups	310.467	2	155.233	107.469	0.000
	Within groups	39.000	27	1.444		
	Total	349.467	29			

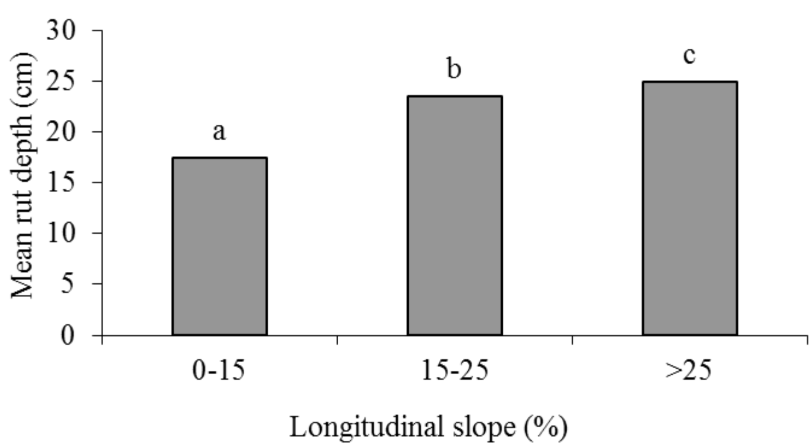

Fig. 4. Mean rut depth in different longitudinal slopes of skid trail.

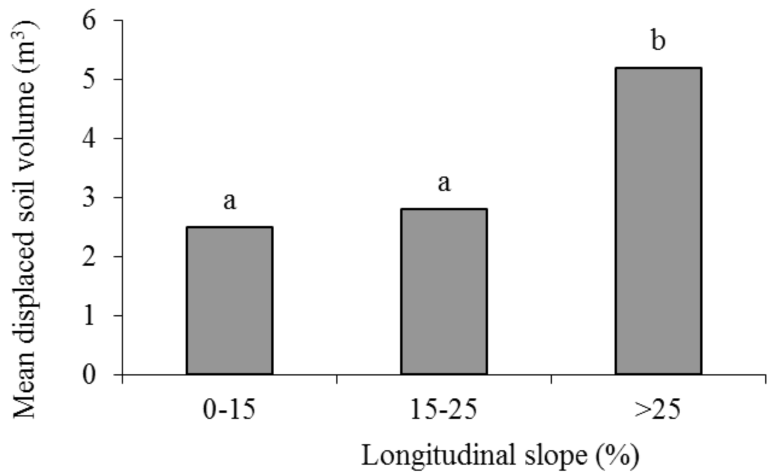

Fig 5. Mean displaced soil volume in different longitudinal slopes of skid trail.

Mean comparison test also showed that there were no significant differences in the soil displacement volume at two longitudinal slope classes (0-15 and 15-25%), but with increase in longitudinal slope (more than 25%) the average soil displacement volume increases. The results also showed that there was no correlation between longitudinal slope and rut depth.

The results from Touché test showed that there were significant correlations between three longitudinal slope classes with displaced soil volume and rutting depth (α= 0.01) (Table 6).

Table 6. Touché test for different longitudinal slope classes

	Slope (I)	Slope (J)	Mean Difference (I-J)	Std. Error	Sig.
Displaced soil volume	0-15	15-25	-0.30000	0.20555	0.326
		25<	-2.78800*	0.20555	0.000
	15-25	0-15	0.30000	0.20555	0.326
		25<	-2.48800*	0.20555	0.000
	25<	0-15	2.78800*	0.20555	0.000
		15-25	2.48800*	0.20555	0.000
Rut depth	0-15	15-25	-5.30000*	0.53748	0.000
		25<	-7.70000*	0.53748	0.000
	15-25	0-15	5.30000*	0.53748	0.000
		25<	-2.40000*	0.53748	0.000
	25<	0-15	7.70000*	0.53748	0.000
		15-25	2.40000*	0.53748	0.000

DISCUSSION

The results of this study showed that there was significant linear correlation between skid trail longitudinal slope and water erosion. These results are in accordance with the results by Rab et al. (2005). Moore and Burch (1994) showed that skid trail design indices (such as longitudinal slope, suitable areas for planning skid trails network, soil depth) were the main factors affecting soil erosion and skid trail damages.

Moore (1992) concluded that topography is the most important factor in creating ruts and destroying drainage in skid trails and also the depth of ruts in skid trails with steep slopes was significantly more than in skid trails with gentle slopes. The results showed that there was significant correlation between skid trail longitudinal slope classes and displaced soil volume.

In the present study the results of mean comparison test showed that there were no significant differences between average displaced soil volume in slope classes of 0-15 and 15-25%, but there were significant differences in average displaced soil volume between slope classes of >25% and 0-15 and 15-25%. The amount of rut depth in skid trails with a steep slope of >25% was significantly higher than skid trail with a lower slope. Therefore increase in speed of surface runoff in the skid trails after rainfall increases water erosion. In accordance with this, Crack et al. (1986) showed that the effect of skid trail slopes on amount of soil disturbances and water erosion was very significant. One of the factors that decreases water erosion is to observe acceptable skid trail longitudinal slope when designing skid trails.

The results of the present study also showed that there was more correlation between soil texture and amount of erosion in clay soils than in silty soils. These results are in accordance with the results of Naghdi et al. (2009) and Eliasson (2005), who showed that the amount of displaced soil volume in sandy clay loam was less than that in the other soil textures.

Larson et al. (1983) suggested that increasing moisture capacity decreases soil strength and the soil become more susceptible to displacement and rutting. Soane (1990) concluded that small grain and moist soils are more prone to rutting. Curren and Quensal (2000) concluded that soil rutting phenomenon and amount of rutting expansion were more intensive in sticky small grain soils, so that with continuous rain fall and increase in traffic, depth of rut increases and the ruts turn into gullies.

Regarding to forest floor cover, there was significant correlation between forest floor cover and water erosion in skid trails (α= 0.05). Therefore with decrease in forest floor cover amount of water erosion increases. Wehner (2003) also showed that one of the effective factors on soil compaction, rutting and soil displacement was the amount and how the surface litter was spread.

However it is not possible to suggest a distinct factor effecting water erosion in the harvested parcel. Instead the conditions for erosion are the interaction effects of collective effective factors causing water erosion. However the results of this study showed that the slope is the most effective factor in creating rutting and destroying drainage of skid trail. So that in skid trails with steep slope the displaced soil volume was more than skid trails with gentle longitudinal slope and hence the amount of water erosion was more severe. Therefore, when designing skid trails, observing technical principles and acceptable slopes are the major factors decreasing rutting and water erosion in skid trails.

ACKNOWLEDGMENTS
This research was sponsored by the office of the Vice Chancellor for Research, University of Guilan, Iran. The authors are grateful to Shafarood Forest Company of Iran for providing the research facilities.

REFERENCES

Billby, O. (1998) The generation and fate of road_ surface sediment in forested watersheds in southwestern Washington. *Forest Science.* 35(2), 453-468.

Eliasson, L. (2005) Effect of forwarder tyre pressure on rut formation and soil compaction. *Silva Fennica.* 39(4), 549-557.

Hartanto, H., Prabhu, R., Widayat, A.S.E. and Asdak, C. (2003) Factors affecting runoff and soil erosion: plot-level soil loss monitoring for assessing sustainability of forest management. *Forest Ecology and Management.* 180(1), 361–374.

Laflen, J.M., Elliot, W.J., Simanton, J.R., Holzhey, C. S. and Kohl, K.D. (1991) WEPP soil erodibility experiments for rangeland and cropland soils. *Journal of Soil and Water Conservation.* 46, 39–44.

Larson, W.E., Pierce, F.J. and Dowdy, R.H. (1983) The threat of soil erosion to long-term crop production. *Science.* 219, 458-465.

MacDonald, L.H., Sampson, R.W. and Anderson, D.M. (2001) Runoff and road erosion at the plot and road segment scales, ST John, Us Virgin Islands. *Earth Surface Process Landforms.* 26, 251-272.

Moore, I.D. and Burch, G.J. (1994) Topographic effects on the distribution of surface soil water and the location of ephemeral gullies. *Journal of American Society of Agricultural Engineers*. 31(4), 1098-1107.

Moor, D. (1992) Length- slope factors for the revised universal soil loss equation: Simplified method of estimation. *Journal of Soil and Water Conservation*. 47(5):423-428.

Naghdi, R., Bagheri, I. and Basiri, R. (2010) Soil disturbances due to machinery traffic on steep skid trail in the north mountainous forest of Iran. *Journal of Forestry Research*. 21(4), 497–502.

Naghdi, R., Bagheri, I., Lotfalian, M. and Setodeh, B. (2009) Rutting and soil displacement caused by 450C Timber Jack wheeled skidder (Asalem forest northern Iran). *Journal of Forest Science.* 55(4), 177–183.

Najafi, A., Solgi, A. and Sadeghi, S.H. (2010) Effects of skid trail slope and ground skidding on soil disturbance. *Caspian Journal of Environmental Sciences.* 8 (1), 13-23.

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

Nugent, C., Kanali, C., Owende, P.M.O., Nieuwenhuis, M. and Ward, S. (2003) Characteristic site disturbance due to harvesting and extraction machinery traffic on sensitive forest sites with peat soils. *Forest Ecology and Management*. 180, 85–98.

Pinard, M., Barkeer, A. and Tay, J. (2006) Soil disturbance and post-logging forest recovery on bulldozer paths in Sabah, Malaysia. *Forest Ecology and Management.* 130,213-225.

Quesnal, H.J. and Curran, M.P. (2000) Shelter wood harvesting in root-disease infected stands-post-harvest soil disturbance and compaction. *Forest Ecology and Management.* 133, 89–113.

Rab, A., Bradshaw, J., Campbell, R. and Murphy, S. (2005) Review of Factors Affecting Disturbance, Compaction and Traffic Ability of Soils with Particular Reference to Timber Harvesting in the Forests of South-West Western Australia. Department of Conservation and Land Management, Technical Report No. 2. pp. 160.

Rab, M.A. (1996) Soil physical and hydrological properties following logging and slash burning in the Eucalyptus regnans forest of southeastern *Australia. Forest Ecology and Management*. 84(1-3), 159-176.

Soane, B.D. (1990) The role of organic matter in soil compatibility: a review of some practical aspects. *Soil and Tillage Research.* 16, 179-201.

Trautner, A. and Arvidsson, J. (2003) Subsoil compaction caused by machinery traffic on a Swedish Eutric cambisol at different soil water contents. *Soil and Tillage Research.* 73, 107-118.

Wehner, Y. (2003) Environmental impacts of modern harvesting systems on soil new results technological assessment. 2nd Forest Engineering Conference Sweden, 154-160.

Zar, J.H. (1999) Biostatistical Analysis. New Jersey, Prentice Hall, Inc., Englewood Cliffs. pp. 620.

ارزیابی عوامل موثر بر فرسایش خاک در مسیرهای چوبکشی (مطالعه موردی جنگل شفارود در شمال ایران)

ا. باقری[1]، ر. نقدی[2]*، ع. مرادمند جلالی[3]

1- گروه مهندسی مکانیزاسیون کشاورزی، دانشکده علوم کشاورزی، دانشگاه گیلان، رشت، ایران
2- گروه جنگلداری، دانشکده منابع طبیعی، دانشگاه گیلان، صومعه سرا، ایران
3- اداره کل منابع طبیعی استان گیلان، رشت، ایران

(تاریخ دریافت: 91/1/25 - تاریخ پذیرش: 91/6/11)

چکیده

فرسایش عامل شدیدترین آسیبها به خاک در جنگلهای شمال ایران بوده که با شیارهایی با عمقهای مختلف در مسیرهای چوبکشی همراه است. هدف از این مطالعه ارزیابی میزان حجم خاک جابه جا شده و متوسط عمق شیار ایجاد شده در مسیرهای چوبکشی به منظور کمک به کاهش فرسایش آبی در این مناطق می‌باشد. بدین منظور این تحقیق در سطح هشت پارسل از سری 3 شفارود در جنگلهای شمال ایران انجام گردید. برای بررسی میزان فرسایش در 10 مسیر چوبکشی انتخاب شده از این سری، تعداد 30 پروفیل عرضی به صورت تصادفی در 3 کلاسه شیب طولی (15-0، 25-15 و 25< درصد) تعیین و برداشت شد. حجم خاک جا به جا شده و عمق شیارها در پروفیل عرضی مسیر چوبکشی اندازه گیری شد. سپس عوامل موثر بر تخریب خاک مانند شیب طولی، بافت خاک، تاج پوشش و پوشش کف جنگل به صورت جداگانه در پلاتهای مورد مطالعه اندازه گیری شد. نتایج حاصل از تجزیه و تحلیل رگرسیون نشان داد که تفاوت معنی داری بین میزان فرسایش خاک و شیب طولی، بافت خاک، تاج پوشش و پوشش کف جنگل وجود دارد. نتایج حاصل از آزمون پیرسون نشان داد که ارتباط معنی داری بین میزان فرسایش خاک و شیب طولی مسیرهای چوبکشی، بافت خاک و پوشش کف جنگل وجود دارد ($\alpha= 0.01$ و $\alpha= 0.05$)، اما هیچ ارتباط معنی داری بین میزان فرسایش خاک و تاج پوشش وجود ندارد. نتایج حاصل از این تحقیق نشان داد که با افزایش شیب طولی مسیر چوبکشی، حجم خاک جابه جا شده و متوسط عمق شیار ایجاد شده افزایش می‌یابد. به طوری که قطعات نمونه با شیب طولی بیش از 25 درصد، با میزان متوسط حجم خاک جا به جا شده 5/3 متر مکعب بیشترین تخریب را از این نظر متحمل شده‌اند. نتایج حاصل از آزمون مقایسه میانگین‌ها نیز نشان داد که بین حجم خاک جا به جا شده در کلاسه‌های شیب طولی (15-0 و 25-15 درصد) اختلاف معنی‌داری مشاهده نمی‌شود ولی با افزایش شیب طولی مسیر چوبکشی (بیش از 25 درصد)، میانگین حجم خاک جا به جا شده افزایش می‌یابد.

*مولف مسئول