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Efficiency of some conservation treatments for soil erosion control on unallowable slopes of skid trails

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Abstract: The aim of this study was to determine the suitable conservation treatments to control water erosion from skid trails in ShastKalate forests. Two longitudinal slopes of 20-40% and > 40% were considered as critical slopes for skid trails. Treatments of water diversion ruts, water diversion ruts filled with slash and stones were implemented on each slope. A rubber bar was installed at the end of the slope to convert runoff into collectors. Sampling was done during rainfall events in autumn and winter seasons. Findings indicated that the treatment of water diversion ruts filled with slash was better than the other treatments in the control of sediment and soil loss, especially in the slope class of 20–40%. In the slope class of > 40%, there was not any significant difference between treatments in sediment and soil loss control, but generally water diversion ruts filled with slash and stones were better in soil erosion control than water diversion ruts. In both slope classes, the rainfall intensity of 0.11 $mm \cdot h^{-1}$ (2.64 mm in 24 h) was the threshold of soil erosion on skid trails. The control of water erosion of soil on skid trails by the operation of water diversions is a suitable treatment for conserving skid trails.

Keywords: water diversion ruts, slash, stones, soil loss, slope of skid trail

Skid trail construction for timber extraction from forest is an effective factor on soil instability, especially when the soil is exposed to rainfall energy. Primary transportation is performed by skidders and crawlers on skid trails in Iran (Akbarimehr, Naghdi 2012). The slope gradient of trails is one of the effective factors in designing skidding components and environmental consequences (Agherkakli et al. 2014). Soil erosion has been considered as an environmental concern that can influence the forest ecosystem and habitat quality (Dvorak, Novak 1994; Ezzati et al. 2012; Imani et al. 2018). It is well known that the relationships between rainfall, runoff and soil erosion at a given location are usually complex (Adekalu et al. 2006; Ahmadi et al. 2019). Rainfall provides the energy that disperses soil particles. Soil properties include particle size distribution or mean weight diameter of aggregates, texture, aggregate stability indices affect the soil potential to be washed by runoff (Baharuddin et al. 1995; Bolat et al. 2015). Soil can be protected by diverting runoff from the skid trail surface. Runoff is diverted using water diversion ruts, water diversion ruts filled with slash and stones, earthen water bar, rubber water bar and others (Jourgholamiet al. 2017; Lotfalian et al. 2019).

Reinforcement of skid trails with slash has been shown to reduce soil disturbances. Agherkakli et al. (2014) revealed a high protective role of slash, particularly on steep skid trails. Creation of water diver-

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sion structures to reduce runoff generation and sediment yield such as water bars can be a very effective method for limiting sediment delivery to adjacent areas (Solgi et al. 2019). Solgi et al. (2019) used the treatments of water bar, water bar and hardwood brush, and water bar and softwood brush to control runoff and soil loss from skid trails. Results of this study showed that the amount of runoff and soil loss decreased consistently as the thickness of the brush mat increased. Final selection of erosion control treatments should be based on costs, availability of material, or landowner objectives. In a study in the north of Iran four improvement treatments including orthogonal ditch, diagonal ditch and logging residues (slash) were investigated on one-year-old skid trails with two slope classes of low slope (0–20) and high slope (over 20). Among the studied treatments, the combined treatment had the best performance in restoring soil physical properties in both low and high slope classes (Imani et al. 2018). Sidle et al. (2004) found that surface erosion from skid trails in Peninsular Malaysia was 275 ± 20 $t \cdot ha^{-1} \cdot year^{-1}$. However, owing to the lack of connectivity of skid trails to the stream, much of the sediment mobilized on skid trails was stored either on adjacent hillslopes or the trails themselves, rather than being transported to the stream system.

Nowadays, study about the reclamation of skid trails is necessary due to the frequency of disused skid trails in forestry units of northern Iran (Sadeghi et al. 2008; Prats et al. 2012). These skid trails are bare after the primary transportation (especially in the first years) and this causes erosion and damage to soil and forest (Meyer et al. 2014; Mostafa et al. 2016). The aim of this study was to determine suitable conservation treatments to control water erosion from skid trails.

MATERIAL AND METHODS

Description of the study area. District one in ShastKalate forests with an area of 1 713 hectares is located in Golestan province and in watershed No. 85 (36°43'27" to 36°48'6"N and 54°21'26" to 54°24'57"E) (Figure 1). The bedrock of this forest is composed of limestone and sandstone, the altitude ranges from 100 to 1 000 m above sea level. The forest is mixed deciduous which was established on brown forest soil with mostly clay-loam-silty texture and worn stones. The mean forest growing stock in the study area was 247 $m^3 \cdot ha^{-1}$. The region has the Mediterranean warm and moist climate with mean annual precipitation of 562 mm which is lowest in July and August. In ShastKalate forests, 30.3 km of forest roads were constructed in 1989. Some skid trails in these forests are very steep (unallowable gradient > 20%, Lotfalian et al. 2019) and susceptible to erosion when water erosion often occurs in rainy seasons.

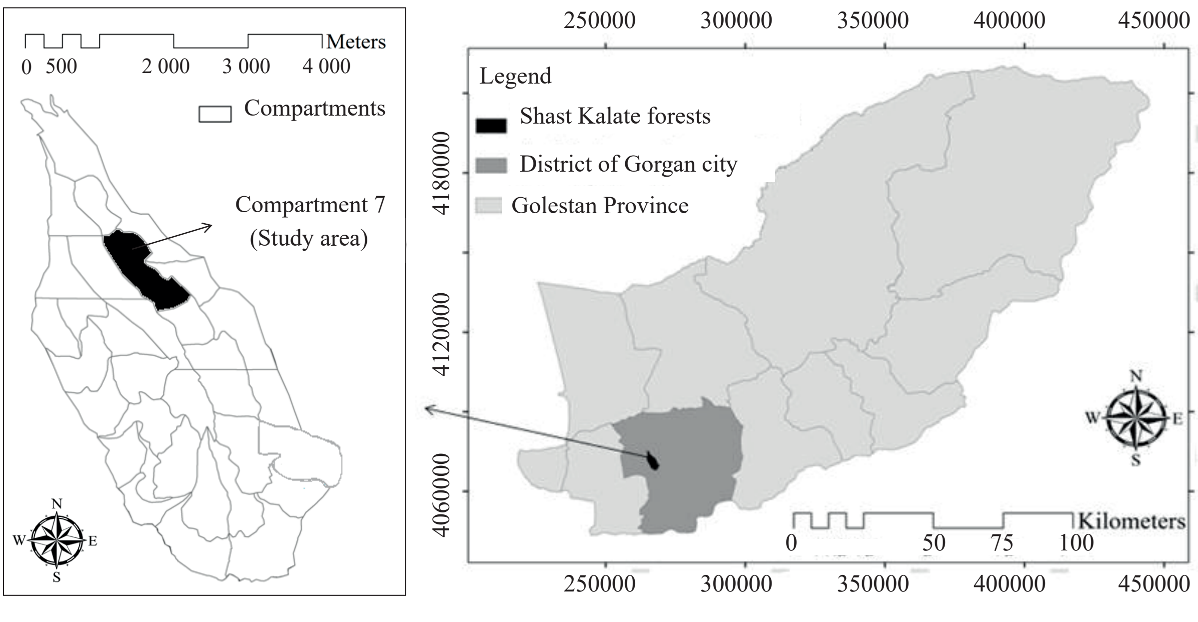

Figure 1. Study area

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Table 1. Laboratory analysis of some soil properties in the studied skid trail

Compaction ($g \cdot cm^{-3}$)	Moisture (%)	Clay (%)	Silt (%)	Gravel (%)	Texture	Traffic
1.35	25	5.2	60	34.8	Silty-loam	16

Data collection. First, a skid trail with a minimum length of 500 meters was selected in the ShastKalate forestry plan. The unallowable longitudinal slope of this skid trail was divided into segments 20–40% and > 40%. In each class, a segment with a length of 126 meters was determined and treatments of water diversion ruts (ruts with a depth and width of 30 cm and embankments with a height of 30 cm that were installed with an angle of 30–45 degrees along the skid trail), water diversion ruts filled with slash (ruts with a depth and width of 30 cm that were installed with an angle of 30–45 degrees along the skid trail and filled with slash and timber residues) and water diversion ruts filled with stones (ditches with a depth and width of 30 cm that were installed with an angle of 30–45 degrees along the skid trail and filled with stones with a minimum volume of 0.001 m^3) each of 14 m in length with 5 m intervals were implemented (Table 1). A rubber bar was installed at the end of each segment to convert sediment and runoff into a collector. Sampling was done during 19 rainfall events in October, November, December and January (autumn and winter 2019 and 2020). Ten rainfall events produced runoff and sediment. Equation 1 was used to calculate the sediment concentration (Mostafa et al. 2016):

$$SC = SY/RV$$

where:
SC – sediment concentration ($g \cdot l^{-1}$),
SY – sediment mass (g),
RV – runoff volume (l).

Equation 2 was used to calculate the soil loss (Lang 2016):

$$ER = SY/DA$$

where:
ER – soil loss ($g \cdot m^{-2}$),
SY – sediment mass (g),
DA – skid trail area (m^2).

Statistical analysis. Factorial design was used to analyse quantitative factors of sediment concentration, soil loss and runoff volume. *Conservation* treatments and longitudinal slopes had 5 and 2 levels, respectively. Totally 160 samples were collected for sediment and soil loss analysis. Data were statistically analysed using ANOVA procedure and Pearson correlation in SAS program. The LSD test was used to compare means among treatments and the diagram was designed by Excel software (Figure 2).

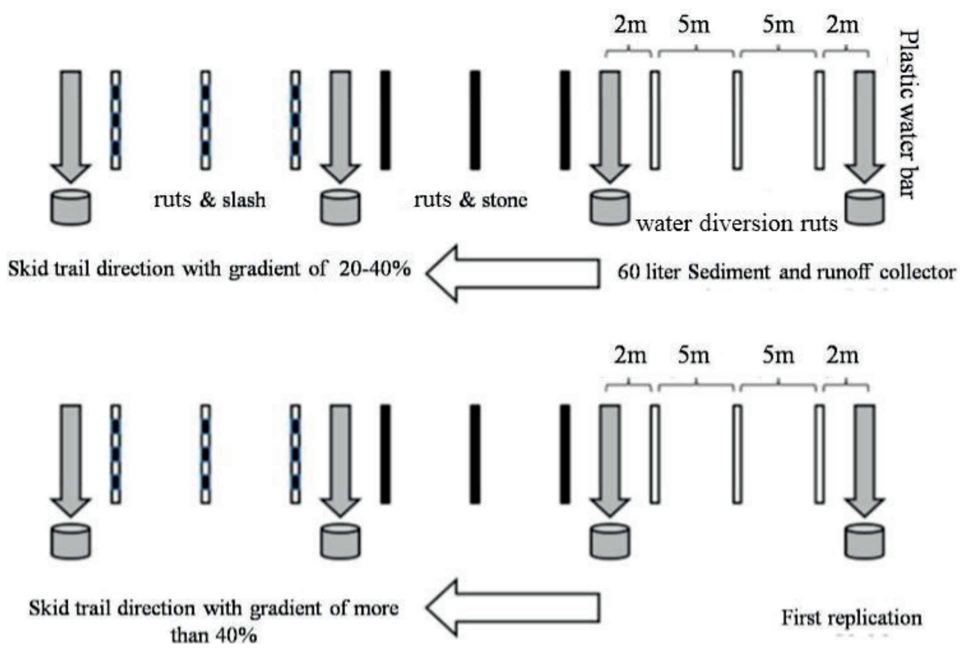

Figure 2. Schematic diagram of the implementation of treatments

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RESULTS

Effect of rainfall on treatment efficiencies in slope class of 20–40%. Findings indicated that in the slope class of 20–40%, amount of runoff, sediment concentration and soil loss significantly increased with increasing intensity and duration of rainfall. In the slope class of 20–40%, the treatment of water diversion ruts filled with slash was better than the other treatments in sediment and soil loss control. Rainfall intensity of 0.11 mm·h^{-1} (2.64 mm in 24 h) was the threshold of soil erosion on skid trails in this slope (Figure 3).

Effect of rainfall on treatment efficiencies in slope class of > 40%. In the slope class of > 40%, there was not any significant difference between treatments in sediment and soil loss control, but generally the treatments of water diversion ruts filled with slash and stones were better than water diversion ruts.

Amount of runoff, sediment concentration and soil loss significantly increased with increasing intensity and duration of rainfall.

Rainfall intensity of 0.11 mm·h^{-1} (2.64 mm in 24 h) was the threshold of water erosion of soil on skid trails (Figure 4).

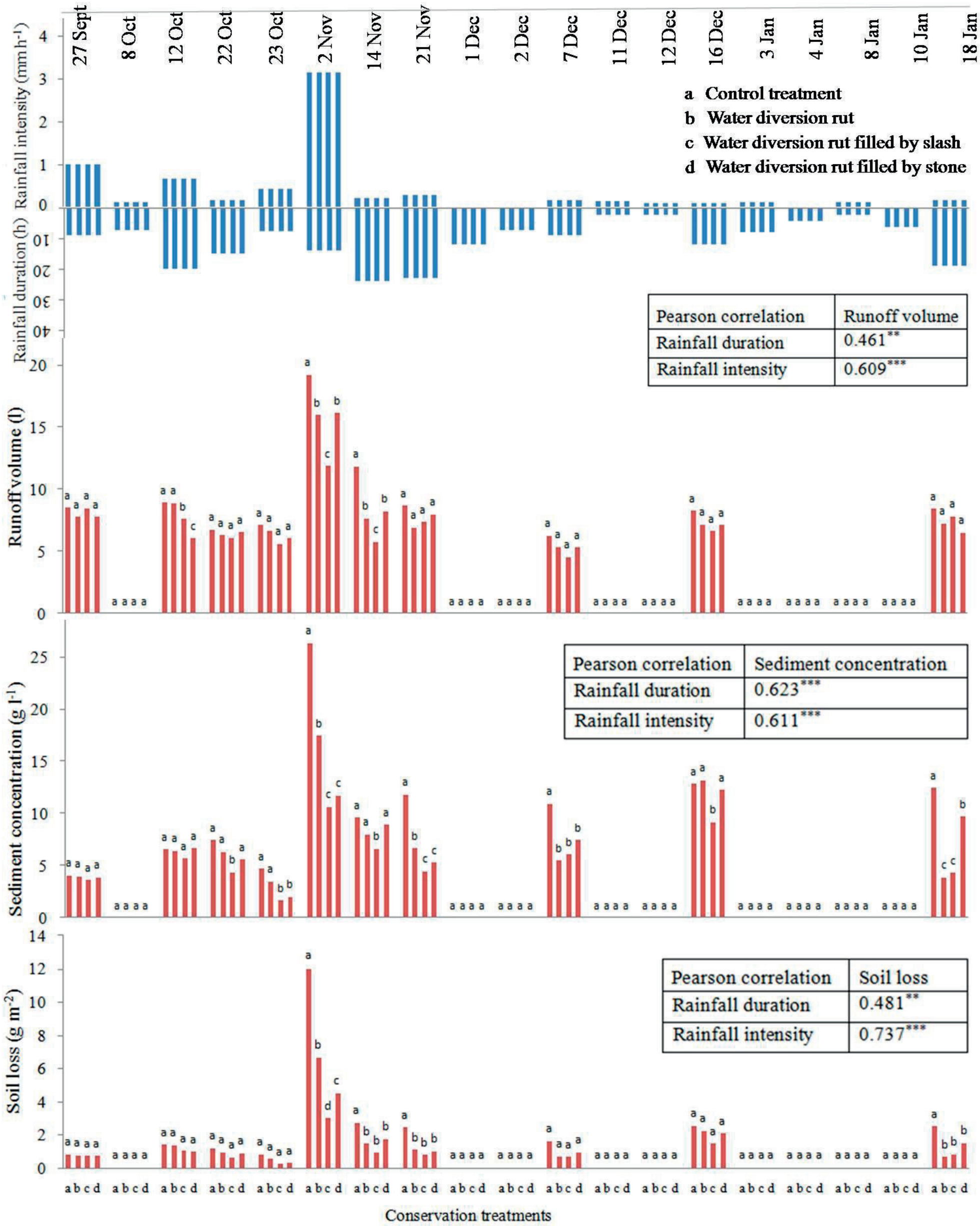

Figure 3. Correlations of rainfall parameters with runoff, sediment and soil loss from the longitudinal slope of 20-40%

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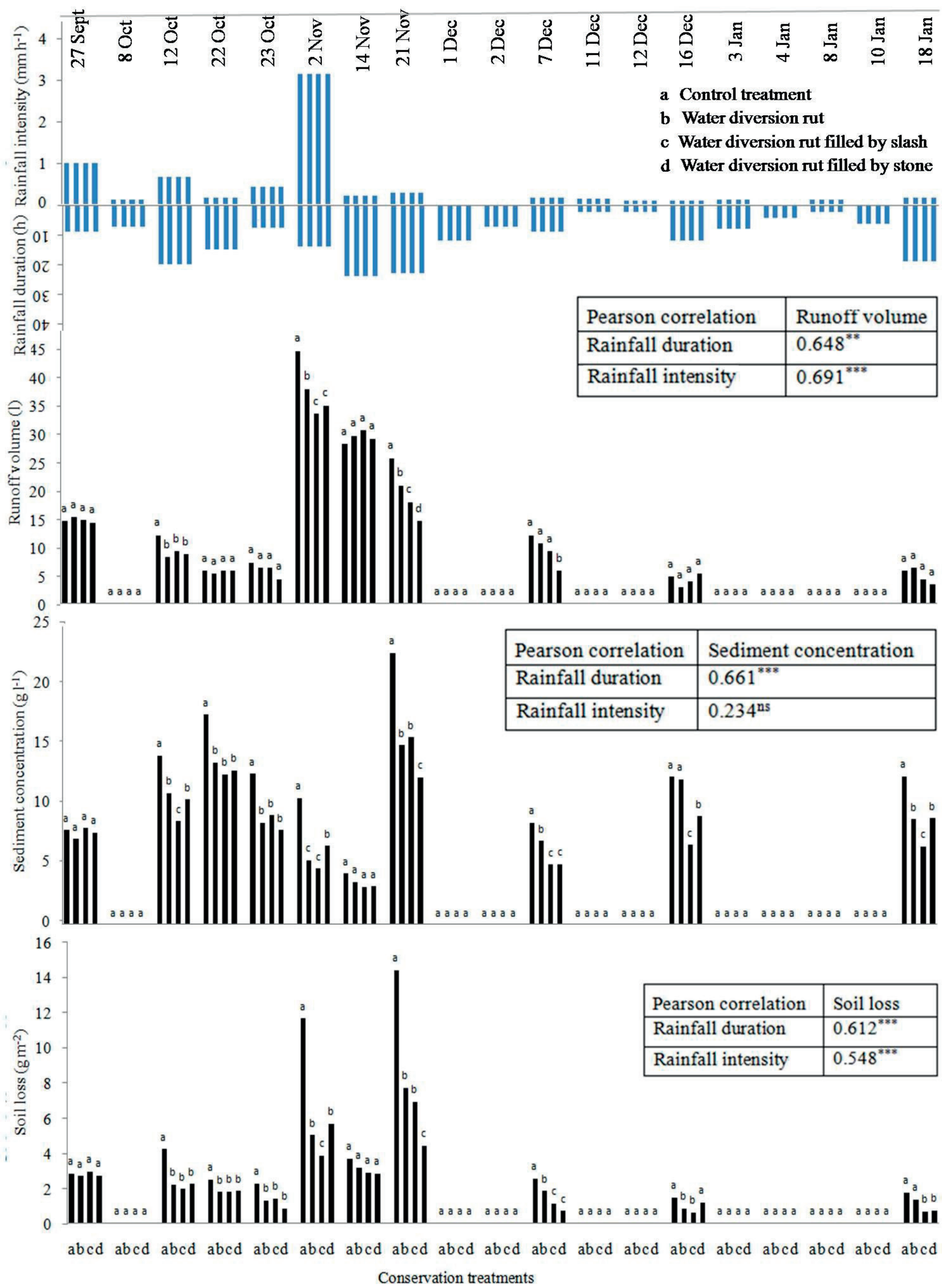

Figure 4. Correlations of rainfall parameters with runoff, sediment and soil loss from the slope of > 40%

Effect of treatment types and slope on treatment efficiencies. Results of the analysis of variance showed that the independent effect of slope and treatment types on runoff volume, sediment concentration and soil loss from the skid trail was significant. The interaction of slope and treatment types on runoff volume, sediment concentration and soil loss from the skid trail was not significant (Table 2).

DISCUSSION

The use of heavy logging machines in a forest ecosystem can disturb the forest environment by influencing the water regime, soil bulk density, soil stability and infiltration. Therefore, soil conservation programs are necessary for integrated management of skid trails in forest watersheds (Lang 2016; Masumian et al. 2017a; Masumian et al. 2017b). Water

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Table 2. Comparison of the efficiency of soil erosion control treatments in each slope class

Treatments	Runoff volume (l)		Sediment concentration (g·l^{-1})		Soil loss (g·m^{-2})	
	20–40%	> 40%	20–40%	> 40%	20–40%	> 40%
Control	4.95a	9.10a	5.62	6.52	1.48	2.50
Water diversion ruts	4.20b	8.14b	3.94	4.65	0.86	1.43
Ruts & Slash	3.77c	7.72b	2.98	4.46	0.54	1.32
Ruts & Stones	4.09b	7.22b	3.86	4.45	0.77	1.22

different letters in each column indicates significant differences at a probability level of 95%

diversion ruts, water diversion ruts filled with slash and stones are used to urgently prepare and protect the soil against erosive agents such as rainfall, facilitate water infiltration, repair the damaged surfaces, reduce the splash, sheet and rill erosion, prevent the soil compaction and increase fertility and improve the soil structure (Jourgholami et al. 2014; Jourgholami et al. 2018). Findings from the present study indicated that the amount of runoff, sediment concentration and soil loss increased with increasing intensity and duration of rainfall. A water diversion rut filled with slash was better in sediment and soil loss control than the other treatments. This finding was in agreement with Agherkakli et al. (2014), who detected a high protective role of slash, particularly on steep skid trails.

Many researchers demonstrated that logging residues or slash can be used to reduce the sheet erosion that occurs on skid trails after log extraction (Wagenbrenner et al. 2016; Turk, Yildiz 2019). Particle detachment is caused by both raindrop impact (splash erosion) and superficially flowing water. The latter rarely occurs in all undisturbed conditions as high infiltration rates cause minimal amounts of overland flow. On the other hand, splash erosion is caused by the kinetic energy of the raindrop impact and could potentially affect any bare surface (Zemke 2016). According to the results of this study, the effect of slope and treatment type on runoff volume, sediment concentration and soil loss from skid trails was significant. Sidle et al. (2004) showed that steeper skid trails (> 20%) had slightly higher erosion rates than trails with gentler gradients.

CONCLUSION

In this study it was concluded that ditch & slash treatment is an appropriate practice for sediment and soil loss control. Runoff diversion ruts filled with slash have the potential to prepare the protective soil cover and layer that can protect soil against erosion. The plot hydrological response threshold of soil erosion on skid trails was about 0.11 mm·h^{-1} of rainfall intensity in slopes more than 20%. The threshold is affected by several parameters such as slope gradient, soil properties and soil coverage factor. In skid trails with water diversion ruts filled with slash, the thresholds become higher, indicating that more rainfall is needed to trigger sediment. The practical result of the present study for users is that the control of water erosion of soil on skid trails by the operation of water diversions is a suitable treatment for conserving skid trails.

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