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# Comparison of different erosion control techniques in the Hyrcanian forest in northern Iran

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**Abstract**

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The aim of this study was to evaluate the effects of closure best management practices (BMPs) on runoff volume and soil loss on skid trails that received two densities of soil cover mats and were located on two slope gradients in an Iranian temperate mountainous forest. The treatments included combinations of three closure BMPs (water bar only, water bar + sawdust, and water bar + hardwood slash), two amounts (densities) of mats (7.5 and 15 kg·m$^{-2}$), and two levels of slope gradients (≤ 20% and > 20%). Results showed that the water bar treatment was the least effective erosion control treatment, followed by the hardwood slash and sawdust treatments. Averaged over mat densities and both slope gradients, the average runoff rates and amounts of soil loss from the skid trails with the water bar treatment were 46.7 l per plot and 6.1 g·m$^{-2}$, respectively, 16.8 l per plot, 2.8 g·m$^{-2}$, respectively, with the hardwood slash treatment and 11.7 l per plot, 1.9 g·m$^{-2}$, respectively, with the sawdust treatment. The results indicated that surface cover is a necessary element for controlling erosion losses following a skidding disturbance, particularly on steep slopes.

**Keywords**: best management practices; runoff; skid trail; soil loss; water bar

With increasing mechanization of forest harvesting operations and increases in size, power and weight of forest machinery, the impacts on soil have increased quite dramatically (Greacen, Sands 1980; Naghdi et al. 2015). Heavy logging machinery easily compacts undisturbed forest soils that are characterized by high macroporosity and low soil bulk density (Botta et al. 2006). Compaction in machine operating trails is considered the most important factor that affects the intensity and frequency of overland flow and surface wash erosion (García-Ruiz 2010). Generally, both runoff and sediment loss increase exponentially with increasing compaction (Motavalli et al. 2003; Arnáez et al. 2004; Solgi et al. 2014). More specifically, the extent and severity of surface erosion on a machine operating trail is related to the soil type (Morgan 1986), soil texture (Croke et al. 2001; Gokturk et al. 2006), slope steepness (Akbarimehr, Naghdi 2012), traffic volume (Arnáez et al. 2004), vegetation cover (Cerdà 2007; Lee et al. 2013), seasonality and rainfall intensity (Martínez-Zavala et al. 2008), and the time since construction (Fu et al. 2010).

To minimize adverse effects on soils after logging operations, a variety of best management practices

(BMPs) for soil erosion control have been developed in many countries. Specifically, BMPs designed to reduce erosion focus on limiting sediment detachment and transport and increasing soil deposition by protecting the soil against rainfall impact, enhancing soil stabilization, and routing flow off roads into the litter layer (Wallbrink, Croke 2002; Wade et al. 2012). For example soil cover BMP methods such as seeding or mulching reduce the amount of erosion by increasing soil stability through reductions in runoff velocity, which more readily results in the deposition of sediments (Wade et al. 2012). Further, the installation of water bars, which is frequently used to slow down the velocity and divert water away from road surfaces, is an effective method for limiting soil erosion (Akbarimehr, Naghdi 2012). It is unclear, however, to what extent the addition of soil cover BMPs is able to reduce surface runoff volume and soil loss beyond levels achieved by the installation of water bars only.

Oriental beech (*Fagus orientalis* Lipsky) is a very valuable tree species for Iranian forestry because of its potential for wood production. Located on good quality sites, beech forests can develop high wood quality and quantity with proper silvicultural treatments. Because most of the beech forests are located on mountainous sites with steep slopes, the use of highly mechanized systems such as harvesters and feller-bunchers is restricted. Instead, felling of trees is done exclusively with chainsaw and timber is extracted to roadside landings by animals (e.g. mules) or with rubber-tired skidders, crawler tractors and modified agricultural tractors (Naghdi et al. 2016).

In this study, we evaluated the efficacy of three erosion control methods on bladed skid trails that used different amounts of soil cover material on two gradient classes (slope steepness) of skid trails in the Hyrcanian forest of northern Iran. Specifically, our goal was to compare whether the application of light (7.5 $kg\cdot m^{-2}$) and heavy (15 $kg\cdot m^{-2}$) amounts of two types of soil cover material (sawdust or hardwood slash) would reduce surface runoff volume and soil loss beyond levels achieved by water bars. The treatments tested in this study were: (*i*) water bar only (control), (*ii*) water bar and sawdust (sawdust), (*iii*) water bar and piled hardwood slash (hardwood slash).

## MATERIAL AND METHODS

**Study area**. This research was conducted in Shenrood forest, Guilan province in northern Iran (36°13'N to 36°15'N; 53°10'E to 53°15'E). The area is predominantly covered by oriental beech (*F. orientalis* Lipsky) and common hornbeam (*Carpinus betulus* Linnaeus) stands. Canopy cover, mean diameter, mean height and stand density were 0.8, 29.72 cm, 22.94 m and 170 trees per hectare, respectively. Brown forest soils were formed on unconsolidated limestone with a moderately deep profile. The soil was classified as Eutric Cambisols (FAO 1990), and Typic Eutrudepts (Soil Survey Staff 1999). Soil texture in the studied skid trails was determined based on particle size analysis using the Bouyoucos hydrometer method (Kalra, Maynard 1991) and classified as a clay loam soil with 24 g of sand (0.05–2 mm) per 100 g of soil, 35 g of silt (0.002–0.05 mm), and 41 g of clay (< 0.002 mm). The average depth of soil to the bedrock was 60 cm. The elevation of the study sites ranged between approximately 900 and 1,100 m a.s.l. with a northerly aspect. The average annual rainfall recorded at the closest national weather station (Shenrood station), located 20 km from the research area, is 1,130 mm, with a maximum mean monthly rainfall of 140 mm in October and a minimum rainfall of 25 mm in August. The mean annual temperature is 16°C, with lowest temperatures in February based on historic weather data of the previous 50 years. At the time of skidding, weather conditions were dry and warm with an average gravimetric soil moisture content of 23%. The soil had not been driven on before the experiment.

In Hyrcanian forest, harvesting and silvicultural operations are the most common in autumn and winter, while extraction of logs is usually completed in spring and summer. Harvesting operations were performed by hand-felling and processing, followed by transportation of logs from forest stand to roadside by a rubber-tired "Timberjack 450C" cable skidder (Timberjack, Canada) (no chains or tracks were installed on the skidder during skidding). Hand-felling, with chainsaw and axes (especially in thinning operations), is the most common harvesting technique in Iran. Highly mechanized systems, such as harvesters and feller-bunchers, are not used because most of the forests are located on mountainous sites with steep slopes or in lowlands on clay soils sensitive to machine disturbance. Furthermore, the stands are dominated by mature hardwood trees, which further limit the potential use of mechanized systems (Jamshidi et al. 2008). The rubber-tired cable skidder was used to extract 3 to 4 m long logs on drivable terrain of up to 35% gradient – use of ground skidding equipment should generally be limited to a maximum of 30–40% slopes (Conway 1976). In the experiments the skidder was driven loaded with the maximum capacity (approximately 3.0–3.5 $m^3$ of logs per load). Neither forest floor nor litter material remained on the skid trails following skidding and skid trails were not covered with slash or received any other treatments.

**Experimental design**. Because the longitudinal slope gradient can strongly affect water movement on skid trails, a trail that covered a range of slope gradients, but without any lateral gradient, was laid out across the harvesting site. Two trail gradient classes were considered: ≤ 20% (actual range 7–15%) and > 20% (range 24–30%). Traffic frequencies of a loaded skidder were held constant at 24 passes. The BMP treatments investigated were water bar only (water bar), water bar and sawdust (sawdust), and water bar and piled hardwood slash (hardwood slash), with two amounts of cover material (i.e., mat density): 7.5 $kg\cdot m^{-2}$ (light) and 15 $kg\cdot m^{-2}$ (heavy). A total of 36 runoff plots were installed that included 12 combinations of the two levels of trail gradient (G), the two levels of mat density (M), and three levels of closure treatment (C), each replicated three times (2G × 2M × 3C × 3 replicates).

Each runoff plot was 10 m long by 4 m wide, with a 5-m buffer zone between each plot. Runoff plots were surrounded by wooden boards that were 30 cm tall and inserted 10 cm deep into the soil to control surface water movement from the inside to the outside of the plot area and vice versa (Solgi et al. 2014). A ditch was constructed on the lower side of each plot so that all surface water runoff from inside the area could be collected in a tank that had a capacity of 100 l (Fig. 1). A collection trough made of a metal sheet that was covered with plastic or sheet metal to prevent direct entry of rainfall was positioned at the downslope end of each plot. The volume of the surface runoff was computed after measuring the height of the water in the collecting tanks. The sediment concentration of each plot was determined in the laboratory after thorough mixing that brought all the sediments into suspension and extracting a subsample of 1 l of collected runoff material that was then filtered, oven-dried at 105°C until a constant mass was obtained, and weighed (i.e., the drying and weighing method) (Sadeghi et al. 2007). For each rainfall event, we computed runoff volume and sediment loss from each plot. After each rainfall and sampling event, tanks were emptied and cleaned.

**Statistical analysis**. A three-way ANOVA was used to assess the significance of observed differences in average runoff and soil loss in runoff plots from nine runoff events. We investigated differences

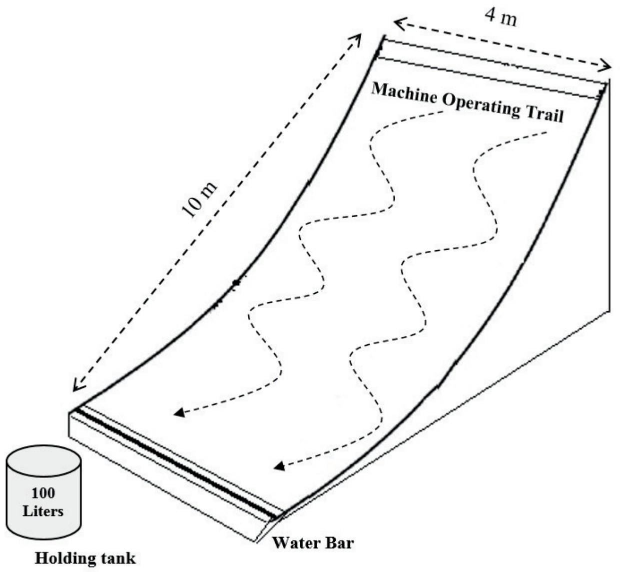


Fig. 1. Experimental design. Plots were surrounded by wooden boards that were 30 cm tall and inserted 10 cm deep into the soil

in average runoff and soil loss as a function of skid trail closure treatment, i.e., water bars plus different mat materials (none, slash or sawdust), and mat density, as well as skid trail gradients (≤ 20% and > 20%) and their interaction effects at a significance level of $\alpha \leq 0.05$. Tukey's honest significant difference test was used to compare the amount of runoff and soil loss among the three trail closure treatments (main effects). All statistical calculations were performed in SPSS (Version 11.5, 2000) (Zar 1999).

## RESULTS

Following ground skidding operations, the average surface runoff volume was significantly affected by the three main factors of closure treatment, mat density, and slope gradient, as well as the two-way interactions of closure treatment × gradient and closure treatment × mat density (Table 1). Similarly, soil loss was significantly affected by the three main factors of closure treatment, mat density, and slope gradient, as well as the two-way interaction of closure treatment × gradient; however the two-way interactions of mat density × gradient and closure treatment × mat density were not statistically significantly different (Table 1). The three-way interaction was not statistically significant for either response.

Average runoff rates and soil loss amounts under natural rainfall are shown in Tables 2 and 3, respectively, for the three closure treatments by mat density and slope gradient.

Table 1. *P*-values based on ANOVA of the effects of skid trail closure treatment (water bar, water bar + sawdust mat, water bar + hardwood slash mat), mat density (7.5 or 15 kg·m$^{-2}$), and skid trail gradient on runoff volume and soil loss

| Source of variable | *df* | *P*-values | |
|---|---|---|---|
| | | runoff | soil loss |
| Closure treatment | 3 | ≤ 0.001 | ≤ 0.001 |
| Mat density | 2 | **≤ 0.001** | **≤ 0.001** |
| Gradient | 1 | **≤ 0.001** | **≤ 0.001** |
| Closure treatment × gradient | 3 | **0.012** | **0.033** |
| Closure treatment × mat density | 6 | **0.035** | ≤ 0.137 |
| Mat density × gradient | 2 | 0.082 | 0.117 |
| Closure treatment × mat density × gradient | 6 | 0.283 | 0.156 |

*df* – degree of freedom, *P*-values lower than 0.05 are given in bold

## DISCUSSION

The closure treatments for bladed skid trails had significantly different erosion rates, with the water bar treatment that had average runoff rates of 46.7 l per plot and soil loss amounts of 6.1 g·m$^{-2}$ being the least effective erosion control treatment (Tables 2 and 3). The addition of hardwood slash and sawdust to the water bar treatment reduced average runoff rates and soil loss amounts from the skid trails to 16.8 per plot and 2.8 g·m$^{-2}$, respectively, in the hardwood slash treatment and to 11.7 l per plot and 1.9 g·m$^{-2}$, respectively, in the sawdust treatment. Similar findings have been reported in other studies. For example, among five closure treatments of bladed skid trails, the highest erosion rate was found when only water bars were used; the lowest erosion rate was observed with mulch treatment (Wade et al. 2012). Contrasting erosion rates on forest roads that received no closure treatments with those that received treatments, Megahan et al. (2001) reported the highest erosion rates when no BMPs were applied, intermediate rates with the seeding treatments, and the lowest erosion rates with a hydroseed + mulch treatment. Closure treatments such as mulching reduce erosion by increasing the surface roughness of the soil, which enhances interception and infiltration of raindrops and delays the onset and flow of runoff (Puustinen et al. 2005; Jordán et al. 2010). Further, mulch application may significantly increase saturated soil conductivity (Lal et al. 1980), perhaps due to higher activity of soil fauna (Prasad, Power 1991).

Table 2. Means of runoff volume (l) on different trail gradients, mat densities and trail closure treatments

| Mat density (kg·m$^{-2}$) | Gradient (%) | | | | | |
|---|---|---|---|---|---|---|
| | ≤ 20 | | | > 20 | | |
| | water bar | hardwood slash | sawdust | water bar | hardwood slash | sawdust |
| 7.5 | 37.18 ± 4$^{Aa}$ | 16.64 ± 3$^{Ba}$ | 11.57 ± 2$^{Ca}$ | 56.26 ± 8$^{Aa}$ | 28.61 ± 5$^{Ba}$ | 21.45 ± 3$^{Ca}$ |
| 15 | 37.18 ± 4$^{Aa}$ | 8.43 ± 1$^{Bb}$ | 4.74 ± 1$^{Cb}$ | 56.26 ± 8$^{Aa}$ | 13.68 ± 2$^{Bb}$ | 8.93 ± 1$^{Cb}$ |

Different letters within each treatment show significant differences ($P < 0.05$). Capital case letters refer to the comparisons among the three closure treatments at different mat density for each trail gradient (row). Lower case letters refer to the comparison among the two mat density levels in each closure treatment and trail gradient class separately (column)

Table 3. Means of soil loss (g·m$^{-2}$) on different trail gradients, mat densities and trail closure treatments

| Mat density (kg·m$^{-2}$) | Gradient (%) | | | | | |
|---|---|---|---|---|---|---|
| | ≤ 20 | | | > 20 | | |
| | water bar | hardwood slash | sawdust | water bar | hardwood slash | sawdust |
| 7.5 | 4.36 ± 0.4$^{Aa}$ | 2.73 ± 0.3$^{Ba}$ | 1.89 ± 0.2$^{Ca}$ | 7.75 ± 0.6$^{Aa}$ | 4.56 ± 0.8$^{Ba}$ | 3.12 ± 0.2$^{Ca}$ |
| 15 | 4.36 ± 0.4$^{Aa}$ | 1.41 ± 0.1$^{Bb}$ | 0.76 ± 0.1$^{Cb}$ | 7.75 ± 0.6$^{Aa}$ | 2.67 ± 0.4$^{Bb}$ | 1.79 ± 0.3$^{Cb}$ |

Different letters within each treatment show significant differences ($P < 0.05$). Capital case letters refer to the comparisons among the three closure treatments at different mat density for each trail gradient (row). Lower case letters refer to the comparison among the two mat density levels in each closure treatment and trail gradient class separately (column)

Our results clearly showed that the sawdust treatment provided a better erosion control than the hardwood slash treatment and are in agreement with other studies that demonstrated the effectiveness of mulch or fibre mats for erosion control (Megahan et al. 2001; Wade et al. 2012). The greater effectiveness of sawdust over the hardwood slash treatment was primary because sawdust provided a better soil coverage. Whereas the mechanism by which sawdust and hardwood slash decreased overland flow and protected against erosion is similar for both treatments, sawdust is less persistent than piled slash, because it can be moved off the site by strong winds and has a faster decomposition rate than slash (Wade et al. 2012).

Regardless of the closure treatment, amounts of runoff and soil loss decreased consistently with increasing mat density on both trail gradients (Tables 2 and 3). In comparison with the low mat density, where average runoff rates and soil loss amounts from the hardwood slash and sawdust treatments were 22.6 and 16.5 l per plot and 3.6 and 2.5 $g{\cdot}m^{-2}$, respectively, runoff rates and soil loss were significantly lower on high mat densities and amounted to 11.1 l per plot and 2.0 $g{\cdot}m^{-2}$, respectively, for hardwood slash and 6.8 l per plot and 1.3 $g{\cdot}m^{-2}$, respectively, for dense sawdust mats. Mats primarily protect soils from rainfall-induced erosion by reducing the physical impacts of rain drops (Jordán et al. 2010). The amount of mat material covering the soil surface is thus a strong determinant of runoff dynamics, affecting amounts of runoff and soil loss (Rees et al. 2002; Findeling et al. 2003). Similarly, leaving plant residues as soil cover can also protect soils against runoff and erosion and significantly reduce soil loss (Blavet et al. 2009).

In all closure treatments and regardless of mat density, the amounts of runoff and soil loss increased consistently with increasing trail gradients (Tables 2 and 3). The greatest amounts of runoff and soil loss were observed on the low mat density on trail gradients > 20%; in contrast, the smallest amounts of runoff and soil loss were observed on the high mat density on trail gradients ≤ 20% regardless of the closure treatment (Tables 2 and 3). These surface runoff and soil loss results confirm findings from previous studies that documented a considerable impact of increasing trail gradients on erosion (Koulouri, Giourga 2007; Solgi et al. 2014). In this study, the increase in slope gradient > 20% resulted in greater absolute amounts of runoff and soil loss and greater relative rates of loss on denser mats. The reason for this drastic increase in runoff and soil loss is likely the much higher velocity of surface water at slope gradients > 20%, which enhances the erosive power of the water (Ekwue, Harrilal 2010) and which, in turn, increases the detachment and transport of soil particles (Chaplot, Le Bissonnais 2000).

## CONCLUSIONS

Sediment yields were significantly reduced by slash and sawdust treatments compared to the bare soil control (water bar only) that had greater runoff and soil loss rates. The greater soil loss observed on bare soil can be attributed to the lack of ground cover that protects soil from physical impacts of raindrops and overland flow. Ground surface cover has been accepted as a minimal requirement in forest management to mitigate the effect of forest harvesting and road construction. This study clearly documents that surface cover is a necessary element for controlling erosion losses following a skidding disturbance, particularly on steep slopes. We conclude that doubling mat densities from 7.5 to 15 $kg{\cdot}m^{-2}$ can reduce runoff and soil loss by about 50%.

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