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Evaluating the effectiveness of sawdust mulch stripes or reducing soil erosion in skid trail

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Abstract

Skid trails are the most important source of sediment due to the damage they create in the soils. The aim of this study was to evaluate the effectiveness of sawdust in reducing runoff and soil loss for a clay loam soil affected by skid trails. The treatments with three replications each included combinations of two levels of slope gradient (≤ 20% and > 20%), two classes of mulch cover (bare soil, and sawdust cover), and three levels of mulching application schemes (1/3, 2/3, and 3/3 of plot length). Average runoff volume and soil loss under natural rainfall increased consistently with increasing slope gradient. Mulch cover treatments had a significant ameliorating effect on the surface runoff volume and sediment yield throughout the skid trail. The average runoff rates and soil loss from the trails treated with sawdust cover (SC) (0.31 mm and 0.75 g m^{-2}) were lower than on untreated bare soil (BS) trail segments (0.57 mm and 1.74 g m^{-2}). Overall, mulching was more effective when applied over the entire plot length than over the 1/3 and 2/3 plot's length strips, both in terms of runoff and of soil loss. Surface cover is a successful measure to control soil losses following skidding disturbances, particularly in the trails on steep slopes.

Keywords: Forest operation; Mulch cover; Soil disturbance; Soil loss

Introduction

Compaction in skid trails is considered the most important factor that affects the intensity and frequency of overland flow and surface wash erosion (Garcia-Ruiz 2010). Generally, both runoff and sediment loss increase exponentially with increasing compaction (Solgi et al. 2014). More specifically, the extent and severity of surface erosion on a skid trail is related to the gradient of the terrain (Akbarimehr and Naghdi 2012), the volume of traffic of forest machines (Solgi et al. 2014), the cover of ground vegetation (Solgi et al. 2019), the applied loads (Battiato et al. 2013), the seasonality and rainfall intensity (Martínez-Zavala et al. 2008), the soil texture (Masumian et al. 2017), and the time since construction of the skid trail (Fu et al. 2010). While thus affected by a number of factors, the erosional behavior of soils is particularly strongly influenced by the gradient of the terrain and the cover of the ground vegetation (Morgan 1986). Using mulching cover on the soil surface to protect soil and water losses has been widely applied and recognized as a successful technology in many countries (Bhatt and Khera 2006; Keesstra et al. 2019). The major effects of mulching in protecting soil erosion are: i) interception of rainfall and reduction of the raindrops energy, thus reducing the number of the detached and ejected particles, their trajectory, velocity and overall displacement; ii) reduction of the surface sealing effect of raindrops; iii) reduction of sheet flow velocity and rill formation, thus reducing their capacity in soil particles transportation and iv) increased physical restraint of soil movement (Jepsen et al. 1997). However, the effectiveness of a mulching barrier depends on its characteristics and quantities (Solgi et al. 2019).

The objectives of this research were: (i) to evaluate the effects of traffic intensity and skid trail slope on surface runoff and soil loss, (ii) to test for differences in runoff and sediment concentration among three mulch stripes treatments compared to bare soil. The study was conducted following traffic of a rubber-tired skidder operated on two skid trail gradient (steepness) classes.

Material and Methods

Site description

The research was conducted between January and March 2019 in the Shenrood forest, Guilan province, northern Iran between 36°13' N and 36°15' N and 53°10' E and 53°15' E. The forest is composed of deciduous trees dominated by oriental beech (*Fagus orientalis* Lipsky) and common hornbeam (*Carpinus betulus* (L.)) along with caucasian alder (*Alnus subcordata* (C.A.M)) and chestnut-leaved oak (*Quercus castaneifolia* (C.A. Mey)) as companion species. The soil class is a Cambisol (World Reference Base (WRB), FAO 2015). Soil grain size was determined by the Bouyoucos hydrometer method (Kalra and Maynard 1991) and classified as a clay loam soil texture. The average annual rainfall recorded at the closest national weather station, located 20 km from the research area, is 1130 mm with a maximum monthly mean rainfall of 140 mm in October and a minimum rainfall of 25 mm in August.

Experimental design and data collection

With regard to the longitudinal profile and maximum gradient of the skid trail, two slope classes were considered (≤ 20% and > 20%). Traffic frequencies of the loaded cable skidder were held constant to 7 passes. As skid trail surface cover, two types of material were investigated: sawdust mulch cover (SC), and bare soil (BS). Sawdust used to create the soil protective layer was produced from oriental beech and common hornbeam trees and obtained from a sawmill near the study site. Besides the control treatment of bare soil, six mulching treatments were tested. These six treatments combined two slope gradient (G), one mulch types (M), and three mulch application schemes (S), as illustrated in Figure 1.

A total of 36 runoff plots were installed that included 12 combinations of two levels of mulch type (M), two levels of slope gradients (G), and three levels of mulch application schemes (S) (2 × (M) × 2 × (G) × 3 (S) × 3 replicates). The three application schemes included mulching the entire plot and mulching two stripes corresponding to the lower 1/3 and the lower 2/3 of the plot. In each plot, five sample lines were delineated perpendicular to the trail with a 2-m buffer zone between lines. Three of the five lines were randomly selected and used for the measurement of soil compaction. Soil samples were collected at different locations: left wheel track (LWT) and right wheel track (RWT) of the skidder. Soil samples were collected with a soil hammer and rings (diameter 5 cm, length 10 cm) and immediately put in polyethylene bags and labeled.

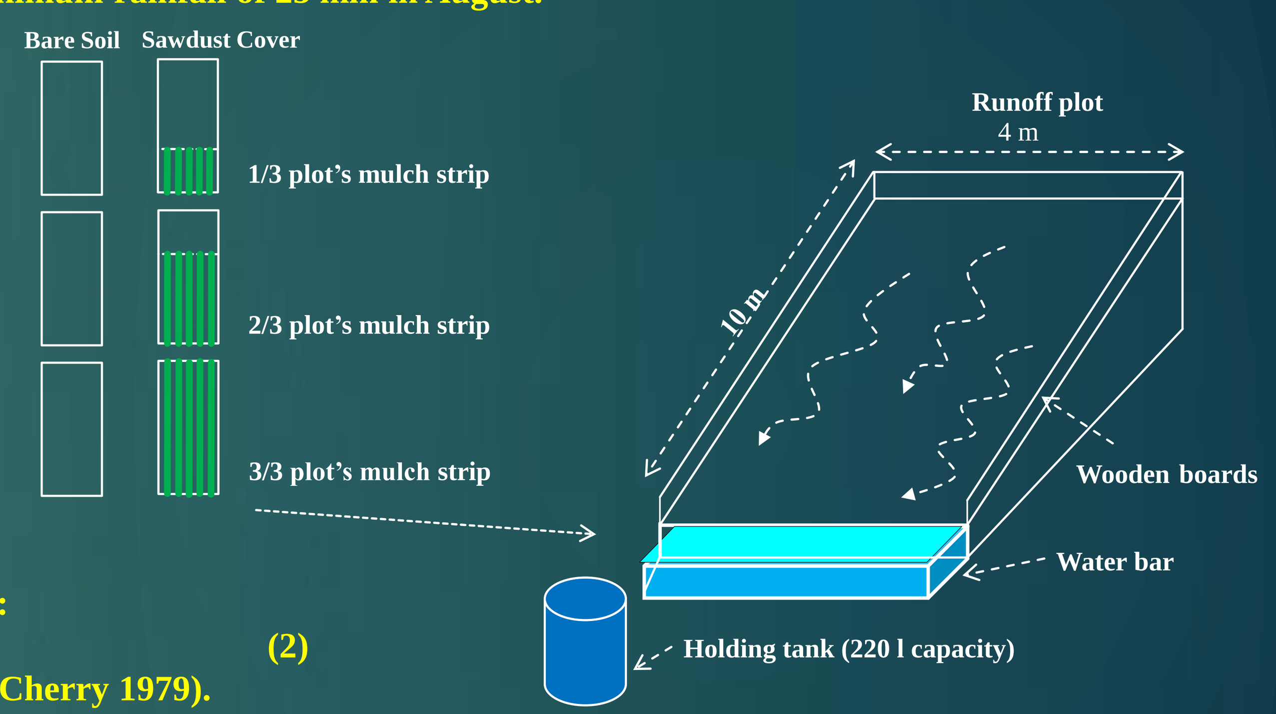

Figure 1. Experimental layout of field trials.

Dry soil bulk density (BD; g cm^{-3}) was calculated as Equation (1):

$$BD = W_d/VC \qquad (1)$$

where W_d is the weight of the dry soil (g), and VC is the volume of the soil cores (196.25 cm^3).

Total soil porosity (TP; %) was calculated as Equation (2):

$$TP = (1 – BD /2.65) \times 100 \qquad (2)$$

where 2.65 (g cm^{-3}) is the soil particle density (Freeze and Cherry 1979).

Results

Soil texture did not differ significantly among plots located on different segment of skid trails (Table 1). Average surface runoff (range: 0.058-0.78 mm) and soil loss (range: 0.13–2.45 g m^{-2}) were significantly affected by the trail slope, mulch type and application scheme (Table 2). Regardless of mulch types, and trail gradients, average amount of surface runoff and soil loss decreased with increasing mulch stripe length (Table 2). Whereas the greatest amounts of surface runoff and soil loss were observed on slope gradients >20%, the greatest amount of surface runoff and soil loss occurred when mulch stripe length was 1/3 length of plot length. Average surface runoff volumes and soil loss for both gradients were significantly lower at the 3/3 mulch stripe than at any other mulch stripes. The same was true for 2/3 mulch stripe compared to 1/3 mulch stripe (Table 2). Compared to the BS treatment, 1/3, 2/3, and 3/3 mulch stripes reduced average surface runoff volume over both gradients by 10%, 43% and 80% for SC mulch cover respectively; reductions in soil loss were 28%, 46% and 89% for SC mulch cover respectively.

Table 1. Physical soil characteristics in the experimental plots for different mulch cover types (bare soil [BS], and sawdust mulch [SC]), mulch application scheme, and slope gradient.

Mulch application schemes	Parameter	Slope (< 20%)		Slope (≥ 20%)	
		Mulch Type		Mulch Type	
		BS	SC	BS	SC
3/3	DB (g cm^{-3})	1.19^{a}	1.17^{a}	1.31^{a}	1.30^{a}
	TP (%)	53.6^{a}	54.3^{a}	47.1^{a}	47.8^{a}
	Sand (%)	35.67^{a}	39.28^{a}	37.54^{a}	37.12^{a}
	Silt (%)	26.59^{a}	24.30^{a}	26.29^{a}	27.73^{a}
	Clay (%)	37.74^{a}	36.42^{a}	36.17^{a}	35.15^{a}
2/3	DB (g cm^{-3})	1.20^{a}	1.18^{a}	1.33^{a}	1.32^{a}
	TP (%)	53.3^{a}	53.9^{a}	46.9^{a}	47.2^{a}
	Sand (%)	42.20^{a}	38.73^{a}	36.39^{a}	37.11^{a}
	Silt (%)	25.57^{a}	29.13^{a}	23.84^{a}	24.65^{a}
	Clay (%)	32.23^{a}	32.14^{a}	39.77^{a}	38.24^{a}
1/3	DB (g cm^{-3})	1.21^{a}	1.16^{a}	1.32^{a}	1.29^{a}
	TP (%)	53.0^{a}	54.8^{a}	47.2^{a}	48.4^{a}
	Sand (%)	37.41^{a}	39.38^{a}	40.87^{a}	40.48^{a}
	Silt (%)	31.07^{a}	27.87^{a}	23.65^{a}	23.15^{a}
	Clay (%)	31.52^{a}	$32 .75^{a}$	35.48^{a}	36.37^{a}

Different superscript letters across a row indicate a statistical difference among treatments at alpha = 0.05.

Table 2. Means of runoff (mm) and soil loss (g cm^{-2}) for different mulch cover types (bare soil [BS], and sawdust mulch [SC]) by mulch application schemes (1/3, 2/3 and 3/3), and slope gradient (< 20% and ≥ 20%).

Mulch application schemes	Parameter	Slope (< 20%)		Slope (≥ 20%)	
		Mulch Type		Mulch Type	
		BS	SC	BS	SC
3/3	Runoff (mm)	0.35^{a}	0.058^{b}	0.78^{a}	0.171^{b}
	Soil Loss (g cm^{-2})	1.02^{a}	0.13^{b}	2.45^{a}	0.26^{a}
2/3	Runoff (mm)	0.206^{a}	1.18^{b}	0.78^{a}	0.44^{b}
	Soil Loss (g cm^{-2})	1.02^{a}	0.41^{b}	2.45^{a}	1.21^{b}
1/3	Runoff (mm)	0.35^{a}	0.304^{b}	0.78^{a}	0.72^{b}
	Soil Loss (g cm^{-2})	1.02^{a}	0.65^{b}	2.45^{a}	1.84^{b}

Different superscript letters across a row indicate a statistical difference among treatments at alpha = 0.05.

Discussion

Compaction of the soil increases bulk density, reduces soil porosity, decreases infiltration rates, and lowers soil permeability (Froehlich et al. 1981, Solgi et al. 2020). It has been well established that these changes in soil physical properties increase surface runoff and erosion and create less favorable soil environments for plant growth (Solgi et al. 2014). Many factors can influence the magnitude of these negative effects on soil characteristics. The most important characteristics are those of the soil itself that influences its susceptibility to disturbances and erosion, including soil texture, moisture content, and organic matter content. Regarding forest operations, machine type, traffic intensity, slope of trails, tire pressure, vibrations transmitted by vehicles, and work organization (e.g., the experience and the expertise of operators) are important additional factors that can aggravate or reduce the impacts on soils (Ares et al. 2005, Najafi et al. 2009, Cambi et al. 2015). This study found that ameliorating effects following the application of different mulch covers on runoff and erosion is highly variable along the skid trail. Adverse effects were significantly more severe in steeper slope gradients compared to gentler slope gradients.

The strong effect of increasing slope of the skid trail on rates of BD increases that are faster on steeper slopes for the same number of passes has also been observed in previous studies (Najafi et al. 2009, Naghdi et al. 2016b, Solgi et al. 2018). This may be a consequence of the difficulties of skidding in steep terrain, where machines can slip continuously and remain in a given place for a longer period of time, resulting in more puddling and dragging of the soil (Gayoso and Iroumé 1991). Soil physical conditions can deteriorate twice as fast on steeper slopes (>20 %) than on more gentle slopes (<20 %) (Najafi et al. 2010). The increase of dry bulk density on steeper trails may be associated with changes in the machine weight distribution. Driving uphill on steep trails, the rear axle has a higher load than in flat terrain and the probability that the wheels could slip increases. When this happens, soil particles are pushed together closer than normal, increasing soil compaction in consequence (Frey et al. 2009). Furthermore, when a machine passes more slowly on steeper trails, the top soil is vibrated more and therefore compacted more than on gentle trails that are traversed with higher speeds (Solgi et al. 2017, Sadeghi et al. 2022).

Our findings showed that for all treatments, the amounts of runoff and soil loss increased consistently with increasing slope gradients, with greatest amounts observed on bare soils (control treatment) on gradients > 20%, and smallest amounts observed on treatment covered with SC on 3/3 mulch stripes on gradients of < 20%. These results confirm previous findings about the considerable impact of increasing slope gradients on soil erosion (Solgi et al. 2014; Solgi et al. 2019). As slope gradients increase, the velocity of water that runs over the skid trail surface increases, resulting in a greater erosive power (Ekwue and Harrilal 2010). The greater sheet and rill flow velocities the higher the detachment and transport capacity of soil particles by water (Chaplot and Le Bissonnnais 2000).

Our results showed that the use of mulch, like sawdust, is an effective method to prevent and mitigate runoff and soil loss on the skid trail after logging operation (Wade et al. 2012; Masumian et al. 2017), especially on steep terrain. Moreover, these treatments maintain soil moisture and improves fertility, i.e. soil health (Lotfalian et al. 2019; Solgi et al. 2019). Wade et al. (2012) in a study carried out in the Piedmont of Virginia found that the highest erosion rate was observed when only water bars (made of bare soil) were used for the skid trails closure. The other four treatments applied in the study (i.e.evaluating (i.e. water bar and grass seed; water bar, grass seed, and straw mulch; water bar and piled hardwood brush; water bar and piled softwood brush), the, resulted in a lower erosion rate and the lowest value was recorded under the mulch treatment. Similarly, Lotfalian et al. (2019) showed that cover of jute or mulch was more effective at reducing soil erosion over bare soil (cutslope) under natural rainfall conditions. Application of mulch provide immediate cover and protect bare soil from raindrop impacts, minimizing soil particles detachment an, reduce the velocity of surface runoff and enhance infiltration rate and deposition of sediment (Puustinen et al. 2005). Mulching treatments increase the surface roughness and raindrops interception, thus mitigating runoff and soil erosion (Jordán et al. 2010).

The results of this study showed that strip-wise mulching (i.e., the inverse of the density of water bars) is another important factor that influences unit area runoff and soil loss, with increasing stripe length resulting in decreased runoff and soil loss. These findings confirm other field (Bhatt and Khera 2006; Cawson et al. 2013; Harrison et al. 2016; Martinez-Raya et al. 2006) and laboratory studies (Prats et al. 2015, 2017). In a field study, Harrison et al. (2016) found that 1.25 m stripe of a 5 m long plot mulched with forest residues reduced soil erosion by 97%, a value that was obtained in this study only by mulching the entire plot. Martinez-Raya et al. (2006) found similar reductions with four plant-cover stripes of 3m across their 24 m long plots (97% erosion reduction).