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# Mulching and water diversion structures on skid trails: Response of soil physical properties six years after harvesting

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ABSTRACT

In recent years, the application of mulch on machine operating trails has gained popularity as a method of reducing post-harvest soil erosion and water runoff following ground-based harvesting operations. Three treatments immediately applied after ground-based skidding operations were sawdust mulch (SM), water diversion structure or contour-felled log erosion barrier (WDS), and untreated/bare trail (U) in May 2011. At the time of skidding, weather conditions had been very dry and warm. The SM treatment was manually spread on the entire trail surface at a rate of 3.65 kg $m^{-2}$. WDS was created by placing felled logs with diameters ranging from 25 to 30 cm and 4 m in length in a perpendicular direction to the skid trails with the distance between adjacent WDS set at 10 m. This study aimed to determine and compare the effectiveness of three treatments on the recovery of soil physical properties from compacted soil caused during logging operations over a six-year period (from May 2011 to July 2017) in the Hyrcanian forest, north of Iran. Soil bulk density, total porosity, penetration resistance, and rut depth (wheel rut) were measured to assess the recovery process on three abandoned skid trails with varying longitudinal gradients (10%, 20%, and 30%) exposed to different levels of machine traffic (low, medium, and high). On trails with a 10% gradient, the highest recovery values of bulk density (7.8%) and total porosity (8.5%) were observed in the SM treatment, while on the steepest gradients (20 and 30%), the highest recovery values of bulk density (10.9%) and total porosity (12.9%) were found in the WDS treatment. The average recovery of penetration resistance for soil located in the SM and WDS treatments was 19.1% and 10.5%, respectively. Average rut depth recovery, expressed in percent of post-harvest values, was higher on all trail gradients subjected to the WDS treatment (30.6%) as compared to the SM treatment (13.1%). In general, values of soil bulk density, total porosity, penetration resistance and rut depth continued to show signs of machine-induced disturbance over the 6-year monitoring period, compared to the undisturbed area as a benchmark.

## 1. Introduction

One of the important consequences of ground-based mechanized operations is soil compaction, which leads to a reduction in pore volume (Greacen and Sands, 1980; Frey et al., 2009; Labelle and Jaeger, 2011; Bottinelli et al., 2014), lowered soil aeration (Goutal et al., 2013; Epron et al., 2016), and reduced water infiltration and water storage capacity (Sidle and Drlica, 1981). Such alterations to the soil physical parameters result in surface water runoff and soil loss (Croke et al., 2001; Etehadi Abari et al., 2017; Jourgholami et al., 2017), which have downstream consequences related to water quality and sedimentation. Many studies have shown that forest harvesting has a significant impact on sediment and runoff (Sawyers et al., 2012; Jourgholami et al., 2017). Likewise, machine operating trails (skid trails in the case of skidder operations), and forest roads, are the main source of increased runoff and sediment production within a forest stand (Wade et al., 2012; Jourgholami and Etehadi Abari, 2017).

To mitigate the negative subsequent effects of compacted bare soil, certain treatments such as ripping, mulching, seeding, water diversion structures, silt fences, erosion control mats, and combinations of the above-mentioned treatments can be applied to increase ground cover (Luce, 1997; Smith et al., 2011; Wagenbrenner et al., 2015; Fernández and Vega, 2016; Ramos-Scharrón and Figueroa-Sánchez, 2017; Jourgholami et al., 2018). Application of these treatments as a soil covering layer has led to enhanced protection as compared to bare soil since they absorb raindrop kinetic energy, increase infiltration rates,

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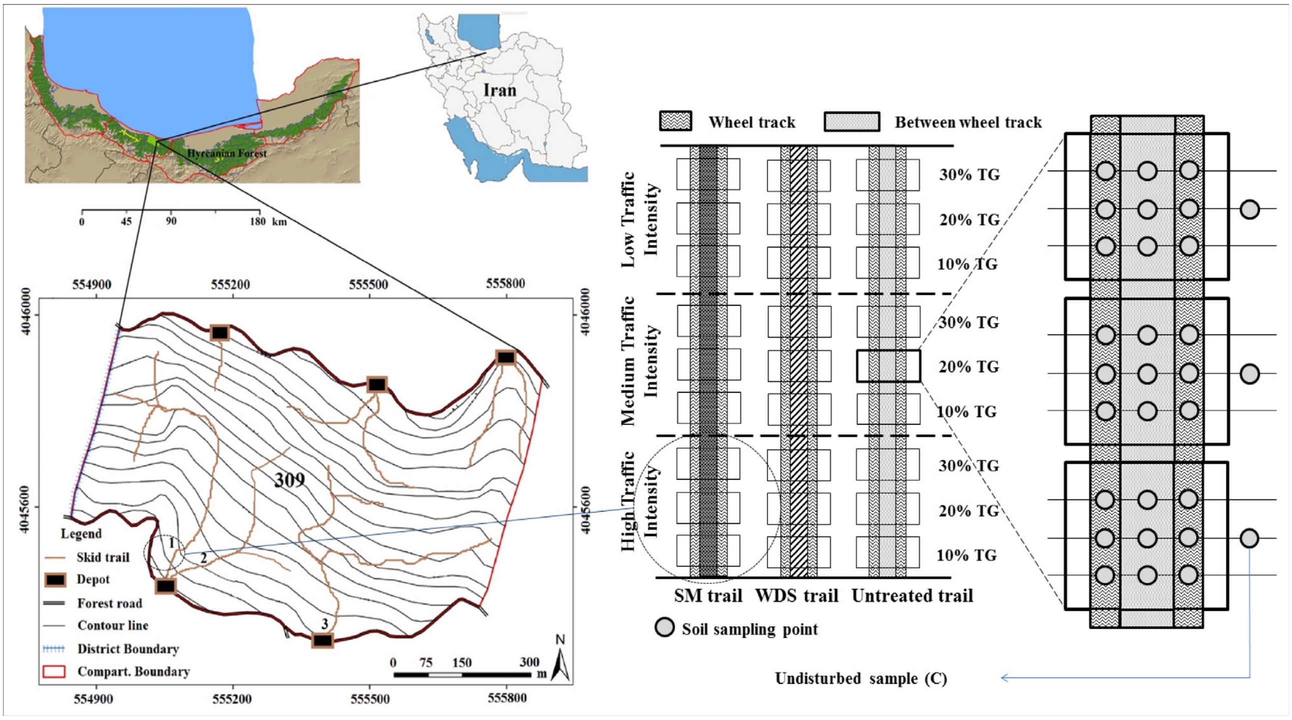


**Fig. 1.** The location of the study area in the Gorazbon district in Hyrcanian forest, north of Iran along with a schematic of the experimental design. U = the bare/untreated skid trail, SM = the skid trails treated with sawdust mulch, WDS = water diversion structure; C = untrafficked area (Control sample), L = low traffic intensity (1–5 cycles), M = medium traffic intensity (6–10 cycles), and H = high traffic intensity ( > 10 cycles); three trail gradient classes are included; 10%, 20%, and 30%.

decrease soil detachment rates, and reduce runoff erodibility (Robichaud et al., 2007; Cristan et al., 2016).

The restoration of soil physical properties following soil compaction mostly hinges on natural processes. Presently, restoration treatments have been used to expedite the natural recovery processes of forest soil quality with the application of different mulches (Mulumba and Lal, 2008; Jordán et al., 2010), drainage structures, and the stimulation of biological activity (Ampoorter et al., 2011; Meyer et al., 2014).

Physical properties of a severely compacted soil can take a long time to naturally recover (Kozlowski, 1999; Cambi et al., 2015). In the Hyrcanian forest, rut depth and soil moisture content (moisture weight percentage or gravimetric soil moisture content) recovered on skid trails compared to values of the untrafficked area, but 20 years was not sufficient time for the recovery of bulk density and total porosity, particularly on steep slopes compared to untrafficked area (Ezzati et al., 2012). Therefore, recovery of soil physical properties without restoration and rehabilitation treatments is a slow process (Page-Dumroese et al., 2006).

Mulch is organic or inorganic material that is spread on the bare soil surface to provide ground cover and decrease raindrop energy and splash. Several studies reported that different mulches (litter, leaves, agricultural straw, wood strands, wood fiber, hydromulch, etc.) can be applied as a post-fire rehabilitation treatment (Robichaud et al., 2010, 2013; Wagenbrenner et al., 2010; Prats et al., 2016; Malvar et al., 2017). Recently, mulching treatments have also been used for controlling post-harvest runoff and sediment (Wade et al., 2012; Cristan et al., 2016; Jourgholami et al., 2018). Mulch application on the soil surface increases the amount of soil organic matter content, improves the soil physical quality, and reduces runoff and soil erosion (Foltz, 2012).

Water diversion structures, such as contour-felled log erosion barriers, are logs placed in a shallow trench on the contour by cutting trees so that they fall perpendicular to the main direction of the slope. Contour-felled logs provide mechanical barriers to overland flow, shorten slope length, increase infiltration, provide surface roughness, and trap sediment that may significantly reduce erosion (Yanosek et al., 2006; Robichaud et al., 2008). The water diversion structures are a two-tiered effect; first, they serve as a mechanism to slow down the water flow, and second they offer a settlement zone where fine particles can accumulate, both of which play a role in the recovery of the tested soil physical properties. The effectiveness of a contour-fell log treatment mostly depends on the log distribution, quality of installation, sediment storage capacity, and storm intensity (Wagenbrenner et al., 2006). Furthermore, the use of rice straw (Jourgholami and Etehadi Abari, 2017) and leaf litter mulch (Jourgholami et al., 2018) after ground-based skidding, mulch on decommissioned forest roads (Foltz, 2012) and log erosion barriers after wildfire (Robichaud et al., 2008) have all significantly reduced runoff and soil erosion.

The information about the impact of mulch application on the recovery of soil physical properties after forest harvesting activities is scarce. On cropland, Mulumba and Lal (2008) found that mulch application increased water capacity by 18–35% and total porosity by 35–46% compared to untreated areas, but bulk density was not influenced by applying mulch. Under semi-arid conditions in southern Spain, Jordán et al. (2010) concluded that wheat mulch application improved soil quality over three years.

Most of the Hyrcanian forests are located on steep and compacted (due to previous forest operations) terrain subjected to frequent rainfall events, which tend to increase runoff and sediment to downstream networks resulting in damage to cities and infrastructures. Therefore, efforts must be made to mitigate post-harvest runoff and sediment yield through the application of rehabilitation treatments. However, the effects of sawdust mulch and water diversion structure on the restoration of forest soil physical properties following logging operations have not