Geoderma 265 (2016) 12–18

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Soil chemical and physical properties after skidding by rubber-tired skidder in Hyrcanian forest, Iran

Ramin Naghdi [a,*], Ahmad Solgi [a], Ulrik Ilstedt [b]

[a] Department of Forestry, Faculty of Natural Resources, University of Guilan, 1144, Somehsara, Guilan, Iran
[b] Department of Forest Ecology and Management, The Swedish University of Agricultural Sciences (SLU), SE-901 83, Umeå, Sweden

ARTICLE INFO

Article history:
Received 9 August 2015
Received in revised form 15 October 2015
Accepted 8 November 2015
Available online 18 November 2015

Keywords:
Compaction
Ground-based operation
Litter mass
Logging

ABSTRACT

This study evaluates the effects of ground-skidding operations on the physical and chemical properties of soil at different levels of slope gradient and traffic frequency. Three levels of traffic (four, eight and 16 passes of a rubber-tired skidder Timberjack 450 C), and two levels of slope gradients (gentle $<20\%$, and steep $\geq 20\%$) were applied in three replicates consequently, 18 plots with 10 m long by 4 m wide were utilized in the study. In each sampling plot, three lines were set up perpendicular to the skidding direction. At three different points on each line (left track, between track and right track) one sample was taken from forest floor and the 0–10 cm soil layer. Soil bulk density, forest floor biomass, organic carbon (OC), nitrogen (N), phosphorus (P), potassium (K) and soil acidity (pH) were affected by traffic frequency and slope gradient. The soil class of our study area in soil classification according to WRB was Combisols. Soil texture was analyzed using the Bouyoucos hydrometer method and was determined to be clay loam along the trails. Soil bulk density was 60% higher in samples taken from skid trails compared with samples taken from an undisturbed area. The average forest floor biomass ranged from 2185 kg ha^{-1} to 243 kg ha^{-1} on the skid trails, while the respective value was 3335 kg ha^{-1} for the undisturbed area. Skidding caused a decrease in the amount of soil OC (by 38%) and the concentrations of N (57%), P (25%), K (31%) and hydrogen ions (33%) compared with undisturbed areas. Increased soil disturbance occurred more markedly with fewer passes on the steeper trail. The dramatic increase in soil disturbance on the skid trail with a slope $>20\%$ is presumably associated with the difficulties of skidding on steep terrain. To minimize soil disturbance, skidding should be confined to areas with more gentle slopes and alternative harvesting methods should be used where slope gradients exceed 20%. We hypothesized that skidding can jeopardize the sustainability of forest ecosystems by creating unfavorable changes in soil characteristics and nutrient status.

1. Introduction

The extraction of wood using forest machinery yields higher productivity rates and is a more efficient means of carrying out forest operations than manual labor, but often causes soil disturbance (Najafi and Solgi, 2010; Marchi et al., 2014). This disturbance is commonly caused by the removal and shearing of the upper, organically rich, porous soil (Woodward, 1996) down to the denser, organically poor, B horizon (Ilstedt et al., 2004). Soil compaction is one of the criteria used to evaluate the environmental impact of logging machinery traffic on soil (Cambi et al., 2015a). Compaction involves a rearrangement and packing of the solid soil particles, resulting in increased bulk density and reduced total porosity (Makineci et al., 2007a). Smaller pore sizes reduce hydraulic conductivity, leading to a slower water infiltration and increased runoff (Grace et al., 2006). By decreasing the proportion of macropores compared with micropores, soil compaction can cause oxygen deficiency and protect organic material and microbial biomass from degradation by microorganisms and microfauna, therefore inhibiting microbial activities and reducing nitrogen (N) mineralization rates (Frey et al., 2009; Ampoorter et al., 2012). Ilstedt et al. (2006) reported that three months after planting, the soil's organic content was 25% lower on tracks compared to control plots that had not been affected by crawler tractors, while microbial indices of N and P availability were about 50% lower.

The degree of compaction and loss of organic matter from the soil organic layer can have a direct influence on the weathering rates of minerals, nutrient mineralization and, ultimately, plant growth (Makineci et al., 2007b). Jaafari et al. (2014) reported that soil compaction and disturbance of surface soils caused immediate localized reductions in organic carbon (OC), N, phosphorus (P) and potassium (K) and an increase in soil pH in newly compressed topsoils (upper 10 cm). Sustained forest productivity is highly dependent on the maintenance of soil nutrients and, therefore, the effects of forest management practices on soil nutrient status are of great importance (Knoepp and Swank, 1997).

Important factors that have an influence on the extent and severity of soil compaction include the intrinsic properties of the soil; the forest stand characteristics; the harvesting system employed; the training; the

* Corresponding author.
E-mail addresses: rnaghdi@guilan.ac.ir, naghdir@yahoo.com (R. Naghdi).

http://dx.doi.org/10.1016/j.geoderma.2015.11.009

expertise and experience of the equipment operators; the skid trail conditions; and the magnitude and nature of the compressive forces to which the soils are subjected (Demir et al., 2007a; Picchio et al., 2012; Solgi and Najafi, 2014). The number of machine traffic passes may influence the degree of soil disturbance (Jun et al., 2004) because deformations can increase with the number of passes. Ampoorter et al. (2007) found that bulk density increases more gradually with 50% of the total impact occurring after the first three skidder passes. Similar to increased traffic frequency, traffic on steeper slopes can increase soil disturbance in both extent and depth (Najafi et al., 2009; Agherkakli et al., 2010). A study by Krag et al. (1986) indicated that during timber harvesting, slope steepness had a stronger effect than season of logging on soil disturbance.

Many studies have investigated the impact of machine traffic on the physical properties of soil (Greacen and Sands, 1980; Ampoorter et al., 2007; Jamshidi et al., 2008); however, relatively few studies have focused on the effects of skidding on the compaction and chemical properties of forest soils (Demir et al., 2010). There are also relatively few studies that have looked at the combined effects of traffic frequency and slope conditions (Jaafari et al., 2014). It is possible that the effect of traffic frequency interacts with the degree of slope such that the negative effects are increased on steeper slopes. An understanding of the interaction of these factors could help inform decisions about the use of skidding with different slope conditions.

We were interested in (1) the impact of the frequency of ground-based skidding and its interaction with steepness on soil chemical properties (OC, N, P, K concentrations and soil pH) in the top 10 cm of a forest soil, and (2) assessing whether steeper slopes may exacerbate the potential deterioration of chemical soil properties after a single tree selection harvesting operation in the Hyrcanian forest in northern Iran.

We hypothesized that OC, N, P, K concentrations and soil pH rates would be significantly lower in plots that were compacted and/or had organic matter removed than in plots that were non-compacted or had intact forest floor.

2. Material and methods

2.1. Description of study area

The study was conducted in Lomir forest, Guilan province, northern Iran, located between 37° 33′ N and 37° 35′ N and 48° 54′ E and 49° 21′ E. The site is dominated by Oriental beech (*Fagus orientalis* Lipsky) and hornbeam (*Carpinus betulus*) stands. Canopy cover, mean tree diameter, mean tree height and stand density were 75%, 34 cm, 23.7 m and 170 trees ha^{-1}, respectively. The elevation of the site is approximately 650 m above sea level, and the aspect is north facing. The average annual rainfall recorded at the closest national weather station is 1570 mm, with a maximum mean monthly rainfall of 148 mm in December (sometimes in combination with snow) and a minimum rainfall of 25 mm in June, but without a real drought period. The study area enjoys a mild climate with monthly temperatures ranging from 3 °C in February to 25 °C in July; the mean annual temperature is 12 °C.

At the time of the skidding experiment, weather conditions had been dry and warm for more than 3 weeks; the average soil water content at the time of logging was 23%. The soil class of our study area in soil classification according to WRB was Combisols. Soil texture was analyzed using the Bouyoucos hydrometer method and was determined to be clay loam along the trails (Table 1). The site was harvested for the first time; the soil had not been driven on before the experiment.

A single tree selection method was used in the study area. Hand-tree felling and tree processing was followed by transportation logs (of various dimensions) to the roadside landing by a ground-based skidding system. The machine used was a 4WD Timberjack 450 C rubber-tired skidder, weighing 10.3 tons without a load (axle weight proportion was 55% on the front and 45% on the rear). The skidder was equipped with a 6BTA5.9 engine (engine power 177 PS) and was fitted with 24.5–32 tires inflated to 220 kPa.

Table 1
Soil texture classes at different depths for skid. The range of particle size was <0.002, 0.002–0.05 and 0.05–2 mm for clay, silt, and sand, respectively.

Horizon	Depth (cm)	Soil particle size distributions ($g\ 100\ g^{-1}$)			Soil texture
		Sand (%)	Silt (%)	Clay (%)	
A	0–15	33	41	26	Clay loam
B	15–55	29	43	28	Clay loam
C	55–85	26	42	32	Clay loam

2.2. Experimental design and data collection

A Skid trail 4 m wide and 900 m in length, running parallel to the slope, was selected for the experiments. In choosing the skid trail, an attempt was made to select a trail that had different longitudinal slopes and no lateral slope. The longitudinal slope of the skid trail ranged from 0 to 36%.

In this study, the impacts of skidding on the surface soil layer (0 to 10 cm depth) of skid trail were quantified using dry bulk density, forest floor biomass, OC, N, P, K concentrations and soil pH and compared to the undisturbed area at different levels of slope and traffic intensity.

For this reason a trail was selected with a range of longitudinal slope steepness and without any lateral slope. With regard to the longitudinal profile and maximum slope of the skid trail, two slope classes were considered (<20% and ≥20%). The slope class <20% included trail sections that ranged from 3 to 15% in slope, whereas slope class ≥20% contained sections within the range of 22–31%. Estimated traffic volumes were 16 passes for heavy traffic, 8 passes for moderate traffic, and 4 passes for light traffic sections.

Treatment plots included the combination of two levels of slope and three levels of traffic intensity. There were six combinations of traffic intensity and slope classes and each treatment was replicated three times, so a total of 18 plots were obtained. Moreover for control purposes, soil samples were taken from the undisturbed area at least 50–60 m away from the skid trail (at least two tree lengths away), where there was no direct skidding impact.

On skid trails, each sample plot was 10 m long by 4 m wide with a 5 m buffer zone between each to avoid interactions. In each sampling plot, five lines, of which three lines were chosen at random for sampling, were set up perpendicular to the skidding direction with a 2 m distance between each of them. Soil samples were then taken from a depth interval of 0–10 cm at three different points on each line: the left wheel track (LWT), between tracks (BWT), and the right wheel track (RWT). Eighteen soil samples were also taken from control plots (Fig. 1).

Forest floor biomass samples were taken by collecting the entire soil surface from 1 m^2 of the forest floor. Two sets of soil samples (cleaned of forest floor material) were collected at a depth of 0–10 cm with a soil hammer and rings (5 cm in diameter, 10 cm in length). The samples were put in polyethylene bags, labeled, and transported to the laboratory on the same day and weighed immediately.

2.3. Laboratory analysis

2.3.1. Soil physical properties

The soil and forest floor samples were dried in an oven at 105 °C (24 h) and 65 °C (48 h), respectively.

Soil bulk density was calculated using Eq. (1):

$$Db = \frac{Wd}{VC} \quad (1)$$

where: Db = soil bulk density, Wd = weight of the dry soil (g), VC = volume of the soil cores (196.25 cm^3).