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Impact of Skidding Operations on Soil Physical Properties in Southern Italy

A. R. Proto

Department of Agriculture
Mediterranean University
Reggio Calabria, Italy

G. Macrì

Department of Agriculture
Mediterranean University
Reggio Calabria, Italy

A. Sorgonà

Department of Agriculture
Mediterranean University
Reggio Calabria, Italy

G. Zimbalatti

Department of Agriculture
Mediterranean University
Reggio Calabria, Italy

Abstract

Skidding by heavy forestry machinery can affect soil physical properties. We assessed the effects of ground-based skidding on soil bulk density and total porosity in a southern Italian forest. Treatments included a combination of four levels of traffic intensity (1, 5, 10, and 15 passes) of a John Deere 548H rubber skidder and two levels of slope (< 20% and > 20%). Further, soil bulk density and total porosity were evaluated at different distances from the track (BT). The results indicated soil bulk density increased with traffic frequency, while soil total porosity decreased. Further, slope steepness did not affect soil physical properties but interacted with the number of passes to affect soil total porosity. The critical value for this parameter occurred after 15 passes on a < 20% slope and six machine passes on a > 20% slope. The statistically significant impacts of the skidder on soil physical properties were evident at distances of up to 2 m from each side of the skidding trail. The latter finding suggests special attention should be taken during the skidding operations to minimize the adverse effects of ground-based skidding on soil physical properties.

Keywords: Soil, Compaction, Skidding, Slope

1. Introduction

In southern Italy, forests are mainly found in mountainous areas where ground-based wood extraction is still the most common harvesting technique. Even though the highest concentration of woodlands in Italy are in the northern regions, forests in southern Italy are important in terms of forest production, ranking among the regions of the country with the largest forest cover. In these regions, farm tractors and skidders are typically used for skidding operations and most of the machines utilized are of considerable weight. The passage of these heavy machines can cause unfavorable structural changes in forest soils [2, 15]; thus, forest operations have high potential for soil compaction [4].

Skidder machines are widely used in mechanized forest harvesting operations and their impact on soil physical proprieties has been evaluated [14, 19]. However, each skidder model has different mechanical features, such as overall height and width, different configurations of the front axle to the front of the machine and of the front axle to the blade cutting-edge arc, all of which can impact soil physical proprieties in different ways [13].
In this study, we aimed to evaluate the impact of the 548H John Deere skidder on soil disturbance at different levels of trail slope and traffic intensity with regard to: a) soil bulk density, and b) soil porosity in the wheel track. The final objective was to provide useful scientific and technical information, such as threshold levels of machine traffic intensity and skid trail slope, for the development of best management practices for forestry in southern Italy in terms of soil preservation and, consequently, forest productivity and ecosystem functionality.

The experimental study was performed in Calabria, southern Italy. Forests in Calabria have expanded 40.6% (nationwide, forests have expanded 34.7%), and the average annual increase in wood volume in this region (equal to 6–8 m^3 ha^{-1}) exceeds and sometimes doubles the estimated increases in other Italian forests 17, 21].

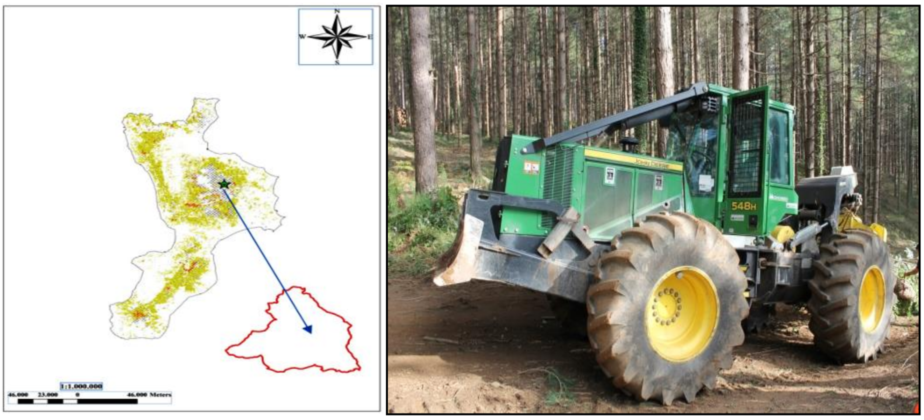
2. Materials and Methods

2.1 Site description

The study was conducted during September–October 2015 in the Sila Massif area (Fig. 1). Elevation is approximately 1150 m above sea level with a northern aspect. Average annual rainfall in the area amounts to 2070 mm, with the lowest monthly average precipitation occurring in August (15.4 mm) and the highest in February (401 mm). Mean annual temperature is 11.4 °C with the lowest values in January. The site is dominated by *Abies alba* and *Fagus sylvatica*, with an area of 24 ha and slope of 0%–40%. Canopy cover was estimated to be 90%, average tree diameter was 32 cm, average tree height was 25.4 m, and stand density was 640 trees/ha. Soil texture along the trail was determined to be clay loam after analysis using the Bouyoucos hydrometer method [10].

2.2. Machine description

The machine used in the study was the 548H John Deere skidder, which is powered by a 6.8-litre John Deere PowerTechPlusTM engine. This machine has a slightly longer wheelbase, meaning more stability (Table 1 and Fig. 2). All logs (of various dimensions) were extracted from the stump area to the roadside landing using a ground-based skidding system.



Figures 1 and 2. Geographic location of the areas (1) and machine used in the experiments (2)

Table 1. Measurements of the Skidder 548 H

Features	Measurement Unit	Value
Power	kW	110
Transmission	-	8 forward 7 reverse
Grapple area	m^2	0.74
Winch	kN	193
Overall Height	mm	3002
Overall Width	mm	2640
Maximum Blade Lift Above Ground	mm	1204

Table 1. (Continued): Measurements of the Skidder 548 H

Maximum Blade Dig Below Ground	mm	295
Front Axle to Front of Machine	mm	1507
Front Axle to Blade Cutting-Edge Arc	mm	2112
Overall Length	mm	6662
Wheelbase		2920
Weight	Tons	12.16

2.3 Experimental design and data collection

Soil disturbance data were collected using line transects spaced 4.5 m wide and 100 m long. In all experimental plots, we measured the following features:

a) Dry bulk density and total porosity at different levels of slope (< 20% and > 20%) and traffic intensity (1, 5, 10, and 15 passes). We compared that with an undisturbed area where there was no skidding impact, at least 50–60 m away from the skid trail, as in similar studies [19].

b) Soil samples from the 0–10 cm depth level were collected at three different points along each transect, one on the left track (LT), one between the tracks (BT), and one on the right track (RT). Furthermore, 10 soil sample points were taken on each side of the tracks at 0.5 m intervals, extending from the skid trail area to undisturbed soil.

Soil samples were collected from 20 and 40 cm depth adjacent to the northern sample point in each plot. The soil samples were gathered using 50 mm high Eijkelkamp steel cylinders (72 mm diameter), thus the soil samples did not contain any stones or rocks. The bulk density core samples were analyzed to determine total porosity, macro porosity, micro porosity, saturated hydraulic conductivity, and bulk density. Comparisons between pre- and post-harvest soil data were made using a paired t-test. The soil cores of known volume were placed in a 105 ^{o}C oven and dried for a minimum of 48 hours. Bulk density was calculated by dividing dry weight by the sample volume [8, 9, 20]. Each treatment was replicated five times.

2.4 Statistical analysis

A two-way ANOVA (calculated using SPSS version 20.1) was used to assess the effects of traffic level, trail slope, and their interaction on soil bulk density and total porosity. Tukey’s test ($p<0.05$) was used to determine significant differences in soil bulk density and total porosity among the different treatments. Further, two-way ANOVA was also used to assess the effects of traffic levels, distance from BT, and their interaction on soil physical parameters.

3. Results and discussion

Soil bulk density measured in the undisturbed area was 0.75 and 0.70 g cm^3 at slopes of < 20% and > 20%, respectively. On the skid trail, soil bulk density significantly increased with traffic frequency ($p<0.05$), in accordance with previous studies [3, 7, 12, 14]. Most of the potential impact occurred after the initial passes, also confirming the results of [1] and [14].

In contrast, slope did not impact soil bulk density (Table 1). This result was different to that found in previous studies [14, 19], but can likely be explained by the larger tire size of the 548H John Deere skidder, which can reduce the impact on soil bulk density on different slopes. The effect of the interaction of the number of passes and slope was not found to be significant (Table 2).

More pressure, slipping, and lower speed dramatically increase soil disturbance on steep slope trails [15]. Previous studies [5, 18] have identified wheel slip on agricultural tractors as causing significant compaction, and wheel slip from forest vehicles can therefore also contribute to compaction. Most of the compaction, expressed as bulk density increase, thus takes place during the initial passes.

The increase of bulk density and decrease of total porosity on steep slope trails and at various distances from the trail may be associated with the lower speed of the skidder on steep slopes.

Previous studies have only evaluated the effects of skidder operations on soil proprieties within the skid trail [14, 19]. We measured skidder impacts on soil properties beyond the left and right tracks. We found the degree of soil bulk density under the main track (right and left track) or log track (between tracks) differed from that found at various distances from the track.

Indeed, the highest soil bulk density was observed in the sample points along the main track; as we moved away from the main track, bulk density decreased.

Soil total porosity measured in the undisturbed area was 49.18 and 47.18% at < 20% and > 20% slope, respectively. Soil total porosity was influenced significantly by the number of skidder passes ($p<0.05$) but not by slope (Table 3). In particular, soil total porosity on the skid trail was considerably lower than in the undisturbed area. This result was partially confirmed by Naghdi [14]. The interaction between the number of skidder passes and slope was significant ($p>0.05$): the decrease of the soil total porosity was more pronounced at > 20% slope (Table 3). In each treatment, as we moved away from the main track, soil total porosity increased. The lowest total porosity value was observed in the soil just under the main track, while the highest value was measured in the undisturbed area (Fig. 3).

Table 2. Effect of slope and traffic intensity on soil bulk density (g cm^3)

Statistic	Number of Passes (NP)	Slope (S)		Mean Number of Passes
		< 20	>20	
NP 13.62*** S 0.119^{ns} NPxS 0.751^{ns}	0	0.75^c	0.70^c	*0.72^z*
	1	0.91^b	1.04^b	*0.98^y*
	5	0.98^{ab}	1.07^{ab}	*1.02^{xy}*
	10	1.10^{ab}	1.23^{ab}	*1.16^{xy}*
	15	1.18^a	1.25^a	*1.22^x*
	Mean Slope	*0.98^A*	*1.06^A*	-

Significant effects due to the number of passes (NP), slope (S), and their interaction (H x O) are presented as F-values and level of significance (*P<0.05; **P<0.01; ***P<0.001; ns not significant), as estimated by a two-way ANOVA. Capital letters indicate significant differences among row means. Small letters indicate significant differences among column means.

Figure 3 shows the inverse response of soil total porosity and bulk density: a decrease in mean porosity is associated with an increase in mean bulk density after skidding. When a skidder passes slower on a steep slope, the topsoil is obviously vibrated more and consequently gets more disturbance compared to flat terrain. In the case of uphill skidding, higher soil compaction can be explained by the higher load of the skidder rear axle [16]. The increase of bulk density and decrease of total porosity on the steep slope trail and at various distances from it may be associated with the lower speed of the skidder on steeper slopes.

Table 3. Effect of slope and the traffic intensity on soil total porosity (%).

Statistic	Number of Passes (NP)	Slope (S)		Mean Number of Passes
		<20	>20	
NP 83.21*** S 3.08^{ns} NPxS 5.52***	0	47.48^a	49.18^a	*48.33^x*
	1	32.38^b	39.29^b	*35.85^x*
	5	31.40^b	38.50^b	*34.95^x*
	10	28.66^b	23.55^c	*26.10^y*
	15	22.17^c	20.49^c	*21.33^z*
	Mean Slope	*32.42^A*	*34.20^A*	-

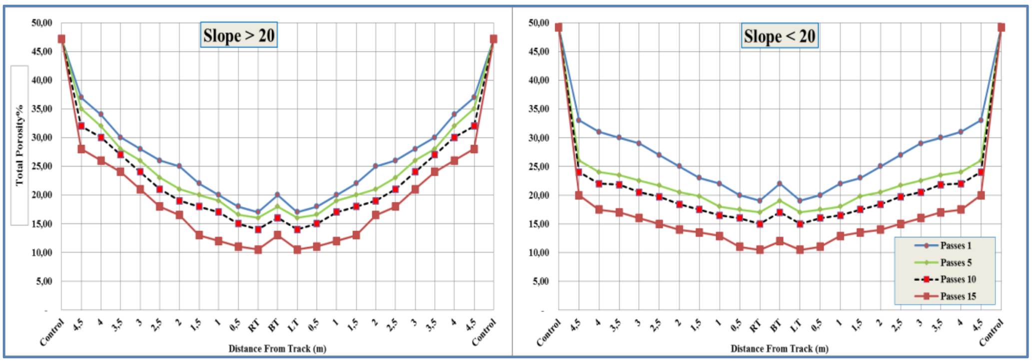


Figure 3. Total porosity on the distance from track

Conclusions

The present work represents a first phase of investigation for defining the impact of skidders on forest soils in southern Italy. In particular, the results pointed out that traffic intensity (number of machine passes) plays an important role in forest soil compaction: soil deformation can increase with the number of passes and may lead to excessive soil disturbance. One pass of the skidder is enough to cause ruts classified as medium–heavy disturbance and to induce a significant increase in soil bulk density. Conversely, the two different classes of slope did not show significant effects on soil bulk density and porosity.

The impact of the skidder on soil physical proprieties was more noticeable under the main track (right and left track) or log track (between tracks) than at various distances from the track. This finding suggests that special attention should be taken during the skidding operations to minimize the adverse effects of ground-based skidding on soil physical properties.

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