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Variation in Some Soil Properties, Organic Matter and Soil Compaction after Logging Activities

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Abstract

In Turkey, three types of logging methods are widely used in forest operations; manpower, animal power and mechanical power. In recent years, the most common method involves skidding with farm tractors. In addition, the use of skidding through wire drawing is often applied in the most regions. The objective of this study was to determine the effects of logging activities on soil properties, organic horizon, and soil compaction. Study area was selected from Sarıçam Sub-District Directorate in Kastamonu, Turkey. In the study area, logging activities were carried out by farm tractors and the skidding through wire drawing at two slope classes (30-60% and 60-100%). Mineral soil samples (0-5, 5-10, 10-15, and 15-20 cm soil depths) were taken from four micro-ecological sites; skid road, logging residuals subbase, mineral soil without topsoil, and control (no activity). The soil samples were analyzed for soil pH, soil texture, permeability, bulk density (BD), water holding capacity (WHC), organic matter (OM), skeleton volume (SW) and soil compaction. Results showed that there were significant differences in soil compaction, soil texture, SW and OM between the four micro-ecological sites. However, the variation differed according to the soil depths and soil texture. The mineral soil without topsoil showed the lowest SW, sand and OM, whereas, it had the highest soil compaction and clay. The deepest soil part had the highest soil compaction. The results also showed higher dispersion ratios (higher than 15) which indicated higher erosion risk due to high land slope and low permeability values.

Keywords: Logging methods, Soil disturbance, Soil compaction, Scots pine, Kastamonu

1. Introduction

When forest management practices (i.e. logging, harvesting and mechanical site preparations) are not properly planned and implemented, they can be the most significant soil and site disturbance activities, particularly affecting soil compaction, soil porosity, and organic matter removal from forest surface and mineral soil (Jurgensen et al., 1997; Kozlowski, 1999; Tan et al., 2005; Powers et al., 2005). Expressed as decrease or completely loss of pores in the soil, soil compaction prevents plant roots from reaching lower parts of the soil and benefiting from water and nutrients (Günal and Özgöz, 2015). Soil compaction is a factor that affects and changes many characteristics of the soil, and causes deterioration of structure of soil particles under a significant load or pressure, decrease in soil porosity, infiltration and void ratio and increase in soil volume weight. Many factors play a significant role in soil compaction while the most influential factor is human factor (Savacı and Sariyildiz, 2015). Among all forest management practices, logging activities, mechanical site preparations (Tan et al., 2005; Akay et al., 2007), and use of recreational areas potentially cause serious soil compactions (Turgut, 2012).

Proportional distribution of soil's sand, clay and silt content affects its volume weight as well. Values of 1.40gr/cm^3 and higher indicate compaction in a clay textured soil, while this value is considered as 1.70 gr/cm^3 and higher in silt textured soils (Foth, 1990) Penetration resistance measurement, which is the representative of penetration of roots into soil, is a method that is commonly used in determination of soil compaction. Penetrometer values higher than 2 MPa indicate that the soil has compaction (Günal and Özgöz, 2015).

Impact of soil compaction and organic matter removal on soil physical and chemical properties and tree growth have been widely studied by many researchers (Conlin and van den Driessche, 1996; Huang et al., 1996; Gomez et al., 2002). In general, they have shown that soil compaction reduces soil porosity and can affect soil physical and chemical properties such as aeration, water storage, temperature,

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infiltration and flow, susceptibility to erosion, and heat transfer (Childs et al., 1989; Tan et al., 2005; Gomez et al., 2002). It has been also shown that the soil physical environment, soil nutrient availability, and biological properties such as mycorrhizal inoculum can be affected by removal of forest biomass or forest floors (Henderson, 1995; Jurgensen et al., 1997). However, effects of soil compaction and organic matter removal on biological processes in forest soils have been received less attention (Piatek and Allen, 1999; Li et al., 2003; Li et al., 2004; Li et al., 2007). Although a number of researchers have studied the influence of forest stands and site organic matter on litter decomposition for alternative harvesting regimes (Yin and Perry, 1989; Prescott, 1997), for whole-tree logging (Bird and Chatarpaul, 1988) and for broadcast burning (Bisset and Parkinson, 1980), only a number of field studies have yet examined the combined effects of site disturbance from forest harvesting (i.e. losses in soil porosity and site organic matter) on litter decomposition (Kranabetter and Chapman, 1999).

Slope of any given forest site can be also an important factor influencing the soil properties and soil compaction rates during logging activities. In fact, slope is known as one of the important factors of universal soil loss equation. It is well known that its geometry, such as slope angle, length and curvature influence runoff, drainage, and soil erosion (Aandahl, 1948) causing a significant difference in soil physico-chemical properties (Brubaker et al., 1993). Erosion would normally be expected to increase with increase in slope length and steepness, as a result of respective increase in velocity and volume of surface runoff.

This study aims to establish differences in certain soil characteristics and soil compaction values in microecological sites (i.e. skid roads, logging residuals subbase, mineral soil without topsoil, and control sites) that occurred as a result of wood extraction activities with farm tractor in two slope classes (30-60% and 60-100%) of *Pinus sylvestris* stands subjected to forest harvesting in Kastamonu region. Kastamonu presents 1.7% of Turkey's forest areas and its province is covered by 65% forestland. Besides, 5.4% percent of nation-wide industrial wood production is obtained from Kastamonu's forests. Therefore, the understanding of the effects of forest management practices (i.e. logging, harvesting and mechanical site preparations) on Kastamonu forest ecosystems are getting important for keeping the forest healthy.

2. Materials and Methods

2.1 Study area

This study was conducted in Sarıçam Sub-District Directorate within the borders of Daday district of Kastamonu province. Study area is between 41º33.715' north latitudes, 33º23.107' east longitudes, elevation range of 1458-1467 m, with Southwest exposure, and average ground of slope of 60-100% (Figure 1). Bedrock of the study area consists of schists from the Trias-Sub-Jura geological era. Landuse capability is in class VI. It has a typical continental climate, usually hot and arid in summer and cold and snowy in winter.

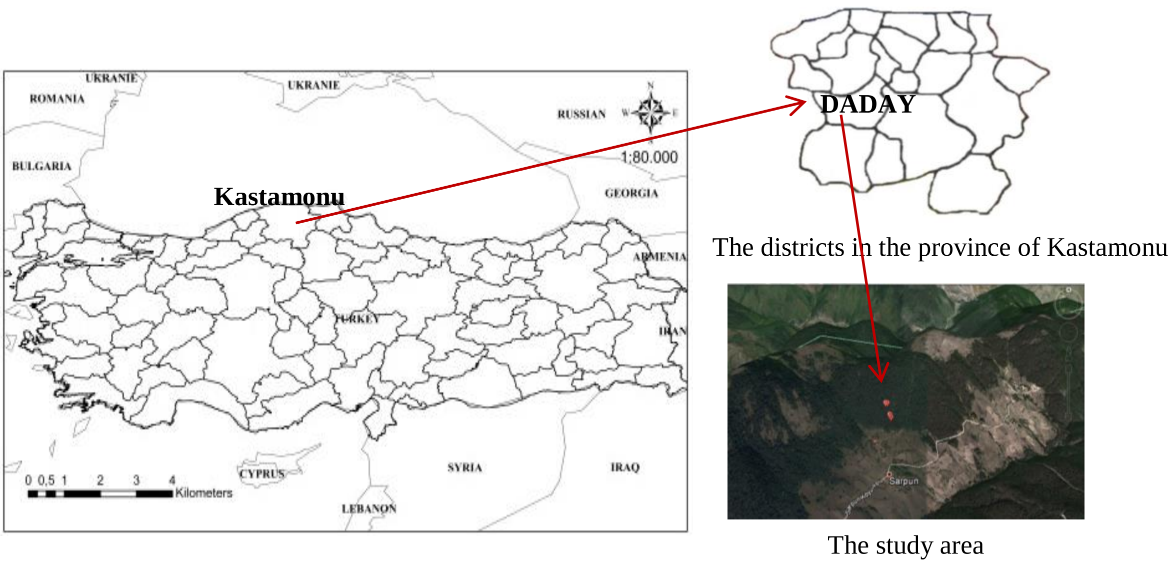

Figure 1. The location of study area

2.2. Soil data collection and analysis

The soil samples were taken randomly from 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm soil depths by digging soil pits at micro-ecologic sites. The samples were air-dried, grounded, and pass through 2 mm mesh-sized sieve. Two core samples from each soil pit were also taken and averaged to obtain representative bulk density. Soil compaction measurements were performed in the field using a 30^0 angled penetrometer [Vicksberg Penetrometer -Proving Ring Penetrometer- (VR-01) ASTM D1558] over a 10 cm profile in 5 cm increments. The soil compaction values (total 16 measurements) were randomly obtained on the route where the product was skidded. The skidding activities were carried out using John Deere (1998), which was owned by the forest villagers. On the route being measured, the products which were removed from the section were transported from a distance of 110 m away from the center, and 69 pieces of 13,23 m^3 products including logs, mine timbers and wood for paper were transported by 23 times on the route.

Soil samples collected from the field were sieved (< 2 mm) and the remaining larger structural aggregates (> 2 mm) were calculated. Soil pH was measured in a 1:2.5 mixture of deionized water and soil using a glass calomel electrode (Origon 420 digital pH meter), after equilibration for 1 hr, soil texture analyses were done on soil samples from the 0–20 cm layer. Soil pH was determined for soil samples from the 0–20 cm layer. The moisture content of soils was calculated by weight loss after drying aliquots of ca. 10 g of soil for 24 hr at 105 ^oC.

Soil texture was determined using a Bouyoucos hydrometer in a soil suspension of 100 g of soil in 1 L of H_2O (Bouyoucos, 1962; Gülçur, 1974). Bulk density was determined by weight loss after drying the undisturbed soil core samples for 2 days at 105^{o}C (Blake and Hartge, 1986) Determination of weight percent organic matter in soils have been found with an ash furnace method. Firstly, oven-drying of the sediment to constant weight (usually 24 hr at ca. 105 °C) organic matter is combusted in a first step to ash and carbon dioxide at a temperature between 700 or 800 °C. The loss on ignition is then calculated using the following equation (Gülçur, 1974):

*Loss on ignition (LOI) = ((105°C – 700) / 105)*100* (1)

Petri and Wagner (1978) reference as reported by Trash (1988), amount of inorganic components such as blocks of stone, gravel that has above equivalent diameter of 2 mm in each horizon is estimated as a percentage of a certain soil unit such as volume or weight. Permeability of the soil samples was calculated according to Darcy's law (Darcy, 1856):

$$P= (Q / A) * (H s / Hs + Hw) \quad (2)$$

where, P is permeability (cm/hr), Q is the amount of water flowing at a given time (cm/hr), A is cross-sectional area of soil sample (cm^2), Hs is height of soil sample (cm), and Hw is water column height with hydrostatic pressure (cm).

For soil samples, the Dispersion Ratio, computed as follows (Middleton, 1930):

*DR= (percent silt+clay in water dispersed sample / percent silt+clay in calgon dispersed samples)*100* (3)

was used as an indirect test of water stability (Piccolo and Mbagwu, 1990).

2.3. Statistical analysis

One-way ANOVA (analyses of variance) was applied for analyzing the effects of soil disturbances from logging activities on the forest and soil properties such as soil pH, forest floor water content, and soil water content for Scots pine using the SPSS program (Version 20.0 for Windows). Following the results of ANOVAs, the Tukey’s Honestly Significant Difference (HSD) test ($\alpha = 0.05$) was used for significance.

3. Results and Discussion

As it is known, data must fulfil two assumptions in order to apply the analysis of variance. Firstly, data must have minimum interval scale and secondly, data must show a normal distribution. That the data collected is quantitative data fulfils the first assumption. For the second assumption, fitness of data to normal distribution was checked through the Kolmogorov-Smirnov (K-S) one sample test. It was found that the data collected showed normal distribution (P>0.05) (Table 1).

Table 1. Kolmogorov-Simirnov data normality control test

Soil Properties	N	Arithmatic Mean ± Std. Dev.	P*
Bulk density	16	1.08 ± 0.14	0.987
Water Holding Capacity	16	17.26 ± 5.96	0.418
Skeleton Volume	16	58.74 ± 8.64	0.534
Permeability	16	448.43 ± 212.99	0.892
pH	16	5.12 ± 0.32	0.634
Sand	16	65.32 ± 5.22	0.591
Clay	16	22.08 ± 3.33	0.304
Silt	16	12.60 ± 5.34	0.022
Soil compaction	16	2.48 ± 1.01	0.174
Organic Matter	16	8.06±1.76	0.084

* P<0.05

Constituting the most important part of production activities, the wood extraction is performed with farm tractors in Turkey in line with the current developments. Accordingly, when the analysis of variance was used to see whether there was any difference in certain soil characteristics based on the soil depth in the stand that remain after the wood extraction, it was found that there was no statistical difference in volume weight, water holding capacity, skeleton volume, permeability, pH, sand, clay, silt and compaction values based on different soil depths (P<0.05) (Table 2).

It was found that there were statistically important differences (P<0.05) in skeleton volumes, texture (sand, clay, silt) and soil compaction values among the microecological sites logging residuals subbase, skid roads, mineral soil without topsoil and control sites) that occured as a result of production activities (Table 3). No statistical difference was found among the volume weight, water holding capacity, permeability and pH values (P>0.05). When the microecological sites where different soil characteristics emerged were examined in Table 3, it was observed that skeleton volume in mineral soil without topsoil was different from other microecological sites and others were the same (P<0.05). In addition, amounts of sand, clay and silt in microecological sites were statistically different from each other. When soil compaction values were examined, the level of compaction in soils under production was different from other microecological sites, while others were statistically same with each other. In terms of organic matters, logging residuals and skid roads were statistically different from each other and others and amounts of organic matters in mineral topsoil and control sites showed similarity (P<0.05).

Although the microecological sites emerged after production activities, the data collected showed that two different soil types were observed in these sites: sandy-clay-loam and sandy-clay. Independent t-test was made in order to determine the differences among soil characteristics after wood extraction activities on these different soil types. Accordingly, the difference among skeleton volume, sand, clay, compaction values and organic matter amount was observed as statistically significant (P<0.05) (Table 4).

Table 2. Certain soil properties based on depth levels of forest soil

Soil Properties	Depth level				F	P*
	0-5	5-10	10-15	15-20		
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE		
Bulk density	1.0 ± 0.05	1.13±0.06	1.02±0.06	1.20±0.07	2.345	0.124
Water Holding Capacity	19.14±3.26	18.97±4.17	14.5±2.96	16.44±1.66	0.497	0.691
Skeleton Volume	60.43±1.82	61.24±4.43	54.43±5.34	58.86±5.71	0.440	0.729
Permeability	620.9±127.7	387.15±68.2	443.35±20.3	342.30±142.8	1.429	0.283
pH	5.08±0.17	5.08±0.27	5.08±0.06	5.24±0.13	0.210	0.888
Sand	65.32±2.92	65.32±2.92	65.32±2.92	65.32±2.92	0.000	1.000
Clay	22.08±1.86	22.08±1.86	22.08±1.86	22.08±1.86	0.000	1.000
Silt	12.60±2.99	12.60±2.99	12.60±2.99	12.60±2.99	0.000	1.000
Soil compaction	2.43±0.28	2.45±0.53	2.38±0.63	2.65±0.70	0.047	0.986
Organic Matter	8.89±2.02	8.43±1.01	7.79±2.93	7.13±2.09	0.713	0.563

* P<0.05

Table 3. Certain soil propertiesand differences and F and P values by microecological sites

Soil Properties	Microecological sites				F	P*
	Logging residuals subbase	Skid road	Mineral top soil	Control		
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE		
Bulk density	1.10±0.06	1.08±0.08	1.01±0.07	1.14±0.07	0.592	0.632
Water Holding Capacity	14.24±1.35	19.63±3.94	21.56±2.25	13.62±2.56	2.142	0.148
Skeleton Volume	62.85±2.27[b]	62.19±2.30[b]	46.77±3.77[a]	63.14±2.19[b]	8.655	0.002*
Permeability	556.98±63.3	590.53±116.3	275.45±97.0	370.75±84.4	2.659	0.096
pH	5.16±0.17	4.87±0.23	5.17±0.09	5.28±0.09	1.306	0.318
Sand	67.95±0.0[a]	71.96±0.0[b]	58.67±0.0[c]	62.70±0.0[d]	$2426x10^{28}$	0.000*
Clay	17.76±0.0[a]	24.25±0.0[b]	25.98±0.0[c]	20.34±0.0[d]	$2107x10^{28}$	0.000*
Silt	14.29±0.0[a]	3.79±0.0[b]	15.35±0.0[c]	16.95±0.0[d]	$1238x10^{28}$	0.000*
Soil compaction	0.98±0.32[a]	2.93±0.34[b]	3.15±0.16[b]	2.85±0.06[b]	16.508	0.000*
Organic Matter	6.66±1.04[a]	9.60±2.06[b]	6.97±0.69[c]	9.01±1.09[c]	4.903	0.019*

*P<0.05

Table 4. Independent t-test was made since two types of soil were observed

Soil Characteristics	Soil Type		F	T	P*
	Sandy-Clay-Loam	Sandy-Clay			
	Mean ± SE	Mean ± SE			
Bulk density	1.11±0.04	1.01±0.07	0.026	1.247	0.233
Water Holding Capacity	15.83±1.68	21.56±2.25	0.057	-1.782	0.096
Skeleton Volume	62.73±1.18	46.77±3.78	3.550	5.482	0.000*
Permeability	506.08±55.56	275.45±97.001	0.014	2.071	0.57
pH	5.10±0.10	5.17±0.09	2.628	-0.364	0.721
Sand	67.54±1.14	58.67±0.0	9.144	7.756	0.000*
Clay	20.78±0.80	25.98±0.0	10.520	-6.460	0.000*
Silt	11.68±1.71	15.35±0.0	20.876	-2.144	0.055
Soil compaction	2.25±0.31	3.15±0.16	5.904	-2.616	0.020*
Organic Matter	8.42±1.88	6.97±0.69	5.617	2.253	0.041*

*P<0,05

The findings that were obtained as a result of this study show that differences in soil characteristics at different soil depths are not statistically significant but soil compaction has a decrease first depending on soil depth and then shows an increase (Table 2). The highest soil compaction was found at the lowest part of soil, similar to the findingfrom previous studies (Akay et al., 2007; Makineci et al., 2007; Demir, 2007; Menemencioğlu et al., 2013; Savacı and Sarıyıldız, 2015). According to the findings, organic matter accumulation on soil surface decreases with depth, while volume weight increases with depth.

It can be suggested that that the dispersion result is <15 (65.3%), increase in erosion risk due to high land slope and low permeability values play a role in occurrence of soil compaction. Besides, macropores and infiltration of soil decreases because of situations such as use of very heavily loaded equipments, frequency of vehicle passing times and condition of soil surface (wet or dry) during the production activities that are performed using tractor. Consequently, it is possible to observe surface runoff and associated erosion in the site (Balcı, 1996).

It was found that there are differences in soil characteristics of the microecological sites that emerged as a result of production activities and soil characteristics of different soil types (Table 3 and Table 4), while it was revealed that such activities caused soil compaction. In a previous study, Young and Ritz (2000) stated that such difference in soil characteristics affects increase of volume weight when tractors pass during skidding, characteristics, which affected microbial community structure, such as water permeability and aeration.

Among the microecological sites, compaction values are high in samples collected from skid road in high slope group (30-60%) and mineral topsoil (2.93±0.34 and 3.15±0.16, respectively); the highest sand rate was found in skid roads (71.96%); and the lowest sand rate was found in mineral topsoils (25.98%). It is believed that this is because high compaction values in association with increase in amount of clay soils with poor drainage in the site. In addition, it was found in this study that permeability value (mineral topsoils) decreases with the increase in clay and silt rates.

Studies show that compaction occurs with the first impact of machines on the land. For this reason, the road used on a land must always be the same. Compaction will be deeper in areas that are frequently passed, but a deep compaction on a single line should be preferred rather than a compaction on the entire land (Günal and Özgöz, 2015). This situation requires determination and inspection of production activities in forestry, in other words forestry operations, operation plans and particularly skidding routes.

4. Conclusions

Present study has shown that microecological sites created as a a result of production activities (logging activities) can have significant impacts on soil properties. Among the soil properties studied, soil skeleton, texture, soil compaction, organic matter were mostly varied by logging activities. However, this variation in the soil properties differed according to soil depth and soil texture. It is seen that during and after the logging activity, creating skid road and mineral top soil in the forest sites negatively affect soil chemical (low organic matter) and physical properties (high soil compaction).

The heavy pressure on the surface soil during logging activity can create soil compaction and decrease pore sizes, thus negatively affect soil permeability and bulk density. In time, these negative effects can alter the soil structural features, water balance, root progression, organisms, nutrients and water intake, and thus also affect soil fertility and tree development. This present study was not intented to investigate all these factors. So, more studies are in need to understand the effects of logging activities on these factors.

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