The Effects of Different Logging Techniques on the Physical and Chemical Characteristics of Forest Soil

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Abstract

In this study, we investigated the effects of four timber logging techniques (skyline, skidder, manpower and chute system) on the physical (permeability, field capacity, water holding capacity, bulk density, fine and coarse soil, sand, clay and silt ratios) and chemical properties (electrical conductivity, organic matter, total lime, P_2O_5 K_2O, Ca, Mg, Na, Fe, Zn, Cu and Mn contents) of forest soil at two soil depths (0-15 and 15-30 cm) at loading, unloading, skid road, and undisturbed plots. The logging practices, each consisting of three steps, were executed at 12 testing sites in total, where logging through skylines, ground skidding with manpower, skidding with skidders, and sliding within the chute systems were performed.

Our results demonstrate that logging by skidder and manpower can have an important influence on soil permeability, bulk density and soil water balance, and these techniques can significantly reduce soil organic matter content and nutrient levels. It was also noted that these two logging techniques constantly removed the litter and humus from the forest floor, reducing the amount of soil organic matter content and nutrients. The removal of organic matter content and nutrients from the soil will also affect soil organisms, which play an important role in regulating organic matter content decomposition rates.

Key words: logging, forest soil, chemical properties, soil damage, Artvin region.

Introduction

The most difficult and costly stage of wood procurement is logging, when the trees are cut down and hauled to the nearest forest road. Logging is performed using a variety of techniques, and it is important to utilize eco-conscious, efficient, and the least harmful techniques to transport harvested trees to reduce the negative impact on forests.

A great deal of man and animal power is used in logging practices in Turkish forestry. The rate of mechanized production is fairly high in developed countries compared to Turkey. The most widely used logging method in forests on steep terrain is skidding logs downhill by manpower using various manual tools and taking advantage of gravity (Erdaş 1993). As such, there is substantial loss in the quality and quantity of the transported products and heavy damage is inflicted on saplings and planted trees in the logging areas (Acar and Eroğlu 2003, Eroğlu et al. 2009).

It is often impossible to use animal power and manpower under tough and steep highland conditions, and thus skylines are used for logging in these areas. Forest skylines require less power compared to ground skidding and cause less damage to forest soil, the stand, and the quality and quantity of logs (Erdaş 1993).

When harvesting is not performed using proper planning and techniques, it causes severe negative effects on forest soil (Bettinger and Kellogg 1993, Smidt and Blinn 1995, Marshall 2000, Pinard et al. 2000, Quesnel and Curan 2000, Croke et al. 1999, Demir et al. 2007, Akay et al. 2007, Makineci et al. 2007, Horn et al. 2007), the planted trees remaining in the stand (Elias 1995, Johns et al. 1996, Jackson et al. 2002, Krzic et al. 2003), seedlings (Steege et al. 2002, Eroğlu et al. 2007, McDonald et al. 2008), wildlife (LeDoux 1997, Scrimgeour et al. 2000) and logging products (Holmes et al. 2002). As a result, environmental devastation such as degradation of forest land, negative effects on forest soil, erosion and deterioration in water sources occur (FAO 1997). The most appropriate logging technique, particularly in mountainous areas, must be applied for sustainable forestry (Dykstra and Heinrich 1992).

A number of studies on the negative effects of logging practices have been conducted in several countries

(Elias 1995, Elias 1998, FAO 1997, Pinard et al. 2000, Steege et al. 2002, Gerwing 2006, Putz et al. 2008); logging techniques that cause severe environmental damage were compared to those that are less harmful, and the most convenient technique according to terrain conditions was determined. Few such studies have been performed in Turkey and particularly in the Artvin region (North-Eastern Turkey), the forested lands of which are present on steep terrain. For logging operations in Artvin, manpower, skidders and skylines are used widely (Eroğlu and Acar 2007). This study investigated the effects of four logging practices on the physical and chemical properties of soil in this region.

Materials and Methods

Study area: Our study area, the Artvin region, has challenging land conditions for forestry as a result of steep, rugged slopes and the resulting negative environmental effects during timber harvesting. Artvin is also a good region in which to compare the negative effects of logging methods because machine-intensive techniques are used widely and recently developed plastic chute systems have been implemented.

This study was conducted in natural oriental spruce stands of the Taşlıca Forest District (FD) in Artvin Forestry Enterprise (FE), Turkey. The practices, three steps for each, were executed at 12 testing sites in total, where logging through skylines (S1, S2, S3), ground skidding with manpower (M1, M2, M3), skidding with skidders (T1, T2, T3), and sliding within the chute systems (O1, O2, O3) were conducted (Figure 1).

Taşlıca Forest District is located between 40°06’ - 41°12’ north and 41°37’ - 41°46’ east. The research area comprises the conditions of the Eastern Black Sea Region with its land structure, climatic conditions, and mountainous and forested aspects.

The altitudes of the testing sites range from 1520 to 2175 m above sea level, land slopes vary between 40 and 100 %, canopy closures vary between 70 and 100 %, and hauling distances range from 100 to 450 m. The aspects of the testing sites are western, north-western, and south-western. The hauling direction of logging using manpower was downhill, whereas logging using skidders and skylines was conducted in an uphill direction (Table 1).

Method: In the testing sites and practice areas, in which logging activities were conducted, soil samples were taken from four soil impact areas, in which: (1) the logs to be hauled were loaded (Load), (2) the logs were unloaded (Unload), (3) transportation or ground skidding had an impact (Transport), and (4) control areas (Control). In these areas the forest soil is mainly affected by the transportation of timber. In each testing site, three points for soil profile measurements were selected, and soil was sampled at two depths for each profile (0-15 and 15-30 cm). Accordingly, a total of 288 soil samples were collected.

The physical characteristics (permeability, field capacity, water holding capacity, bulk density, percentage of particles d < 2 mm, sand, clay and silt percentages, hygroscopic moisture content), physicochemical properties (pH, organic matter content, electrical conductivity, total lime content, and the P_2O_5, K_2O, Ca, Mg, Na, Fe, Zn, Cu and Mn levels of the soil samples were identified. The pH

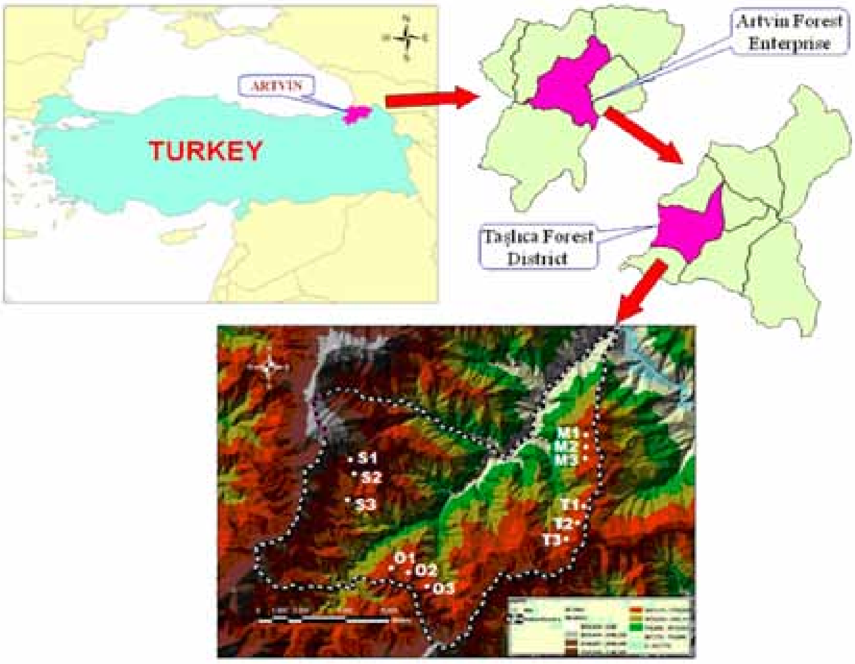

Figure 1. Location of the testing sites

Table 1. Properties of the testing sites

Testing Site No	Logging Technique	Comp. No	Altitude, m	Ground Slope, %	Aspect	Tree Species	Transport Direction	Transport Distance, m
M1	Manpower	99	1520	40	West	SP+S+F	Downhill	200
M2		99	1507	40	West	SP+S+F	Downhill	200
M3		99	1490	40	West	SP+S+F	Downhill	200
T1	Skidder (MB Trac 900)	206	1620	60	South-West	S	Uphill	100
T2		206	1612	80	North-West	S	Uphill	100
T3		249	1600	100	West	S+F	Uphill	100
S1	Forest Skyline (URUS M III)	104	2175	60	South-West	S	Uphill	400
S2		104	2100	50	South-West	S	Uphill	450
S3		103	2122	60	South-West	S	Uphill	450
O1	Chute System (AcarOLUKPeF50/600)	88	1750	30	North-East	S	Uphill	250
O2		88	1800	40	East	S	Uphill	150
O3		84	1774	35	North-East	S	Uphill	175

SP: Scots Pine (*Pinus sylvestris* L.), S: Spruce [*Picea orientalis* L. (Link.)], F: Fir (*Fagus orientalis* Lipsky.)

of the soil was determined in a 1/2.5 soil-water mixture (Gülçür 1974).

A one-way ANOVA and Tukey's HSD test ($p = 0.05$) were used to determine the effects of logging operations on forest soil. All statistical tests were performed using SPSS® 15.0 for Windows®.

Results

Variations in the significantly changed physical properties of the topsoil (0-15 cm) and subsoil (15-35 cm) components exposed to the various logging techniques are provided in Table 2. In general, the results demonstrate that using either the skyline or chute system for logging does not significantly change the physical properties of topsoils and subsoils, while using forest skidders and manpower influences the physical properties of soil, especially permeability and bulk density (Figure 2). Regarding the components of topsoil exposed to skidders, soil permeability values were lower at the loading (0.53 cm h^{-1}), unloading (0.47 cm h^{-1}) and ground skidding (0.67 cm h^{-1}) sites compared to the control site (0.93 cm h^{-1}), whereas soil bulk density values were higher at the loading (1.33 g cm^{-3}), unloading (1.27 g cm^{-3}) and ground skidding (1.22 g cm^{-3}) sites compared to the control site (0.91 g cm^{-3}). Similar effects were also noted for permeability and bulk density, when manpower was used for logging (Table 2).

The use of skidders and manpower decreased soil permeability values in the subsoil samples ($p < 0.001$) (Table 2), but had no significant effect on soil bulk density. The percentage of field capacity, water holding capacity and soil clay were significantly influenced by skidder activities ($p < 0.05$), but not manpower (Table 2).

Variations in the chemical properties and nutrient levels of the topsoil (0-15 cm) and subsoil (15-35 cm) components with different logging techniques are shown in Table 3.

In general, logging practices performed by either manpower or skidders significantly affected the organic matter content and soil nutrient levels compared to the

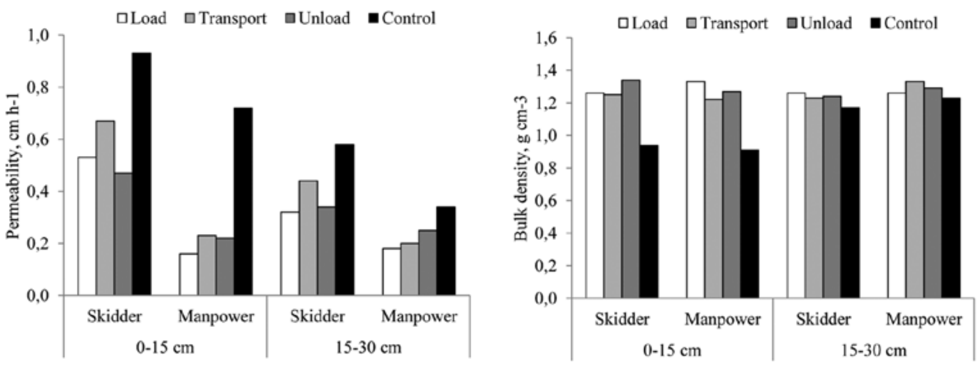

Figure 2. Changes in some physical characteristics of the forest soil according to logging technique and impact area

Table 2. Soil physical characteristics according to logging technique and impact area, and one-way ANOVA-results

Logging Technique	Soil Property	Soil Depth, Impact area							
		0-15 cm				15-30 cm			
		Load	Transport	Unload	Control	Load	Transport	Unload	Control
Forest Skyline	Permeability (cm h^{-1})	0.71	0.88	0.77	0.94	0.41	0.52	0.29	0.20
	Field capacity (%)	27.86	31.79	28.69	25.52	27.15	25.97	24.08	22.91
	Water holding capacity (%)	46.43	53.05	56.20	47.30	44.41	40.86	38.30	36.83
	Bulk density (g/cm^{-3})	0.94	1.00	0.83	0.79	1.10	1.19	1.20	1.13
	Particles d<2 mm (%)	55.37	67.08	53.95	56.42	67.43	74.78	55.64	54.89
	Sand (%)	64.19	65.65	69.01	63.53	66.41	58.72	63.8	60.73
	Clay (%)	20.46	19.03	16.29	19.42	23.23	22.49	19.60	24.63
	Silt (%)	15.35	15.32	14.70	17.05	10.36	18.79	16.60	14.64
	Hygroscopic moisture (%)	4.75	4.60	5.05	6.50	4.47	4.59	3.82	4.54
Skidder	**Permeability (cm h^{-1})**	**0.53**^{a*}	**0.67**^{b}	**0.47**^{a}	**0.93**^{c}	**0.32**^{a}	**0.44**^{b}	**0.34**^{ab}	**0.58**^{c}
	Field capacity (%)	**14.31**	**19.59**	**14.61**	**12.18**	**11.53**^{a}	**19.12**^{b}	**18.31**^{b}	**12.59**^{a}
	Water holding capacity (%)	**24.25**	**33.98**	**41.32**	**31.36**	**25.54**^{a}	**35.32**^{b}	**32.30**^{b}	**28.66**^{a}
	Bulk density (g cm^{-3})	**1.26**^{b}	**1.25**^{b}	**1.34**^{b}	**0.94**^{a}	**1.26**	**1.23**	**1.24**	**1.17**
	Particles d<2 mm (%)	29.26	47.70	43.55	49.14	47.82	41.56	44.86	52.85
	Sand (%)	69.39	69.87	73.55	67.52	70.53	69.49	71.62	65.56
	Clay (%)	**12.62**	**13.43**	**11.94**	**15.29**	**12.12**^{a}	**14.63**^{a}	**13.25**^{a}	**18.60**^{b}
	Dust (%)	17.99	16.70	14.51	17.19	17.35	15.87	15.13	15.84
	Hygroscopic moisture (%)	3.68	4.42	3.89	3.38	4.10	3.59	3.39	3.10
Manpower	**Permeability (cm h^{-1})**	**0.16**^{a}	**0.23**^{a}	**0.22**^{a}	**0.72**^{b}	**0.18**^{a}	**0.20**^{a}	**0.25**^{ab}	**0.34**^{b}
	Field capacity (%)	39.05	24.34	35.25	26.79	22.94	25.62	24.91	26.08
	Water holding capacity (%)	71.38	32.94	39.18	45.26	49.37	41.86	36.27	42.74
	Bulk density (g cm^{-3})	**1.33**^{b}	**1.22**^{ab}	**1.27**^{b}	**0.91**^{a}	**1.26**	**1.33**	**1.29**	**1.23**
	Particles d<2 mm (%)	48.44	69.04	53.08	59.35	52.13	60.28	47.72	49.52
	Sand (%)	65.61	63.66	63.80	65.97	67.33	58.78	60.55	56.51
	Clay (%)	16.23	20.53	24.14	20.47	19.07	22.99	17.67	22.25
	Silt (%)	18.16	15.81	12.06	13.56	13.60	18.23	21.78	21.24
	Hygroscopic moisture (%)	10.54	9.81	9.49	9.57	9.89	10.79	10.30	10.78
Chute System	Permeability (cm h^{-1})	0.69	0.59	0.62	0.96	0.64	0.62	0.54	0.46
	Field capacity (%)	28.83	28.47	24.53	27.66	27.08	25.92	25.83	25.92
	Water holding capacity (%)	57.89	55.68	58.92	55.92	41.17	46.40	39.23	41.80
	Bulk density (g/cm^{-3})	0.84	0.85	0.87	0.73	1.21	1.24	1.17	1.20
	Particles d<2 mm (%)	59.70	69.37	57.20	65.57	59.30	67.90	64.60	58.33
	Sand (%)	62.38	63.04	64.28	63.69	65.17	64.38	64.80	62.25
	Clay (%)	21.11	19.99	20.61	20.56	21.03	20.13	19.69	21.50
	Silt (%)	16.50	16.97	15.11	15.75	13.80	15.49	15.51	16.25
	Hygroscopic moisture (%)	6.09	5.16	5.74	6.52	4.00	4.17	4.59	4.27

* Note: Soil properties with significant differences between treatments printed in bold. Different superscript letters indicate statistical differences of total averages for a soil depth class between impact areas at $p < 0.05$ (Tukey's HSD test)

forest skyline and chute systems. The concentrations of nutrients, such as P_2O_5, K_2O, Ca, Mg, Na, Fe and organic matter content in the topsoil and subsoil components were decreased considerably by use of skidder and manpower logging techniques (Figure 3).

Discussion

This study has demonstrated that among the four logging practices studied, skidders and manpower significantly influence soil physical and chemical properties compared to the skyline and chute system techniques. In

Table 3. Soil chemical properties and content of nutrients according to logging technique and impact area, and one-way ANOVA-results

Logging Technique	Soil Property	Soil Depth, Impact Area							
		0-15 cm				15-30 cm			
		Load	Transport	Unload	Control	Load	Transport	Unload	Control
Forest Skyline	**pH (H_2O)**	**4.15**^{a*}	**4.45**^{b}	**4.54**^{b}	**4.42**^{b}	**4.44**	**4.59**	**4.71**	**4.69**
	Organic matter (%)	5.05	4.85	5.77	5.46	2.90	2.58	3.16	3.61
	Electrical conductivity (μS)	40.1	38.0	37.6	43.3	24.40	28.9	25.1	31.1
	Lime (%)	1.30	1.43	1.12	6.88	8.37	1.07	2.00	1.44
	P_2O_5 (mg kg^{-1})	7.11	6.47	8.59	7.18	7.89	4.66	6.61	6.68
	K_2O (mg kg^{-1})	66.5	205.5	66.8	75.5	40.2	42.2	27.5	56.7
	Ca (mg kg^{-1})	244.3	645.7	492.3	442.7	238.4	839.9	237.2	497.9
	Mg (mg kg^{-1})	56.3	125.0	114.3	108.8	68.0	178.1	132.7	151.7
	Na (mg kg^{-1})	1.73	4.39	0.65	4.55	0.75	7.49	0.66	6.41
	Fe (mg kg^{-1})	231.6	180.0	138.0	213.8	87.8	107.7	85.8	112.7
	Zn (mg kg^{-1})	2.66	4.22	2.02	4.54	1.71	2.48	1.48	2.35
	Cu (mg kg^{-1})	0.57	0.96	0.53	0.79	0.64	0.97	0.61	0.86
	Mn (mg kg^{-1})	9.42	84.1	7.13	30.3	35.6	55.6	16.4	52.3
Skidder	pH (H_2O)	4.43	4.98	4.66	4.40	4.54	5.04	4.77	4.48
	Organic matter content (%)	**5.46**^{b}	**3.94**^{a}	**5.59**^{b}	**6.24**^{c}	**3.29**^{a}	**3.59**^{a}	**3.73**^{a}	**5.03**^{b}
	Electrical conductivity (μS)	40.7	45.8	47.6	52.6	29.0	33.6	31.2	42.6
	Lime (%)	2.47	2.67	1.70	1.87	1.97	8.23	5.40	6.57
	P_2O_5 (mg kg^{-1})	**7.55**^{b}	**5.99**^{a}	**7.25**^{b}	**9.66**^{c}	**6.53**^{b}	**5.70**^{a}	**6.40**^{b}	**8.97**^{c}
	K_2O (mg kg^{-1})	**22.5**^{a}	**42.1**^{b}	**44.5**^{b}	**79.7**^{c}	**46.3**^{a}	**67.4**^{c}	**58.4**^{b}	**85.2**^{d}
	Ca (mg kg^{-1})	**205.8**^{a}	**414.6**^{c}	**332.0**^{b}	**710.5**^{d}	**313.2**	**492.8**	**333.9**	**472.2**
	Mg (mg kg^{-1})	**44.7**^{a}	**79.8**^{b}	**82.4**^{b}	**163.7**^{c}	**81.2**^{a}	**85.3**^{a}	**82.2**^{a}	**148.5**^{b}
	Na (mg kg^{-1})	2.54	5.50	5.06	5.42	3.35	0.42	6.11	1.95
	Fe (mg kg^{-1})	**194.2**	**131.3**	**107.9**	**175.1**	**59.6**^{a}	**94.8**^{b}	**104.4**^{b}	**165.6**^{c}
	Zn (mg kg^{-1})	**3.86**	**3.18**	**2.42**	**6.11**	**1.35**^{a}	**1.57**^{a}	**1.90**^{b}	**3.40**^{c}
	Cu (mg kg^{-1})	0.80	0.48	0.37	0.37	0.24	0.67	0.45	0.32
	Mn (mg kg^{-1})	**27.2**^{b}	**28.6**^{b}	**10.5**^{a}	**59.6**^{c}	**4.03**^{a}	**20.5**^{c}	**13.3**^{b}	**44.7**^{d}
Manpower	pH (H_2O)	5.69	5.46	5.35	5.25	6.04	5.83	5.45	5.77
	Organic matter content (%)	**5.08**^{b}	**4.37**^{a}	**5.53**^{b}	**7.13**^{c}	**3.61**^{a}	**4.32**^{a}	**3.41**^{a}	**5.12**^{b}
	Electrical conductivity (μS)	161.9	83.6	96.2	82.7	56.3	99.0	96.9	71.8
	Lime (%)	1.50	1.47	3.57	8.07	1.40	1.47	1.40	1.43
	P_2O_5 (mg kg^{-1})	**8.80**^{c}	**8.10**^{c}	**5.98**^{a}	**10.6**^{b}	**5.11**	**5.33**	**4.56**	**7.9**
	K_2O (mg kg^{-1})	**126.4**^{c}	**50.2**^{b}	**28.8**^{a}	**172.8**^{d}	**81.9**^{b}	**80.0**^{b}	**46.7**^{a}	**164.7**^{c}
	Ca (mg kg^{-1})	**727.0**^{b}	**588.2**^{a}	**694.8**^{b}	**1329.7**^{c}	**611.3**^{b}	**471.0**^{a}	**1279.0**^{c}	**1566.0**^{d}
	Mg (mg kg^{-1})	**506.4**^{b}	**357.4**^{a}	**489.9**^{b}	**805.6**^{c}	**491.0**^{b}	**389.5**^{b}	**330.7**^{a}	**663.0**^{c}
	Na (mg kg^{-1})	**5.33**^{a}	**11.0**^{b}	**4.07**^{a}	**6.91**^{a}	**22.1**^{a}	**32.1**^{b}	**21.1**^{a}	**35.0**^{b}
	Fe (mg kg^{-1})	**82.6**^{a}	**150.5**^{b}	**152.7**^{b}	**139.0**^{c}	**43.3**	**41.9**	**50**	**41.7**
	Zn (mg kg^{-1})	1.44	1.12	1.29	1.17	0.43	0.38	0.94	0.34
	Cu (mg kg^{-1})	2.18	2.04	1.70	1.86	1.86	1.50	1.43	1.75
	Mn (mg kg^{-1})	40.2	45.4	48.8	43.9	19.9	23.4	16.8	32.9
Chute System	pH (H_2O)	4.48	4.42	4.41	4.49	4.55	4.59	4.62	4.63
	Organic matter (%)	6.42	4.45	5.57	5.55	3.44	3.71	3.50	3.66
	Electrical conductivity (μS)	42.90	40.43	34.70	40.30	26.53	27.73	27.30	26.17
	Lime (%)	1.27	1.43	1.47	1.27	4.27	1.77	2.80	1.63
	P_2O_5 (mg kg^{-1})	8.70	7.97	8.03	7.27	6.37	5.33	6.57	6.43
	K_2O (mg kg^{-1})	89.30	94.90	72.60	91.00	40.97	52.73	44.00	48.87
	Ca (mg kg^{-1})	459.83	525.97	516.20	593.57	363.93	608.73	307.90	470.53
	Mg (mg kg^{-1})	90.60	107.52	108.27	112.50	151.60	117.67	191.63	193.03
	Na (mg kg^{-1})	2.67	4.10	2.10	3.70	1.80	4.07	4.43	5.23
	Fe (mg kg^{-1})	204.83	189.90	158.53	189.20	149.40	109.80	118.07	107.97
	Zn (mg kg^{-1})	2.30	4.33	4.57	3.97	2.00	2.37	1.73	1.93
	Cu (mg kg^{-1})	0.77	0.97	0.53	0.97	0.77	1.00	0.80	0.80
	Mn (mg kg^{-1})	17.05	33.78	14.99	38.12	51.47	55.00	45.37	58.33

* Note: Soil properties with significant differences between treatments printed in bold. Different superscript letters indicate statistical differences of total averages for a soil depth class between impact areas at $p < 0.05$ (Tukey's HSD test)

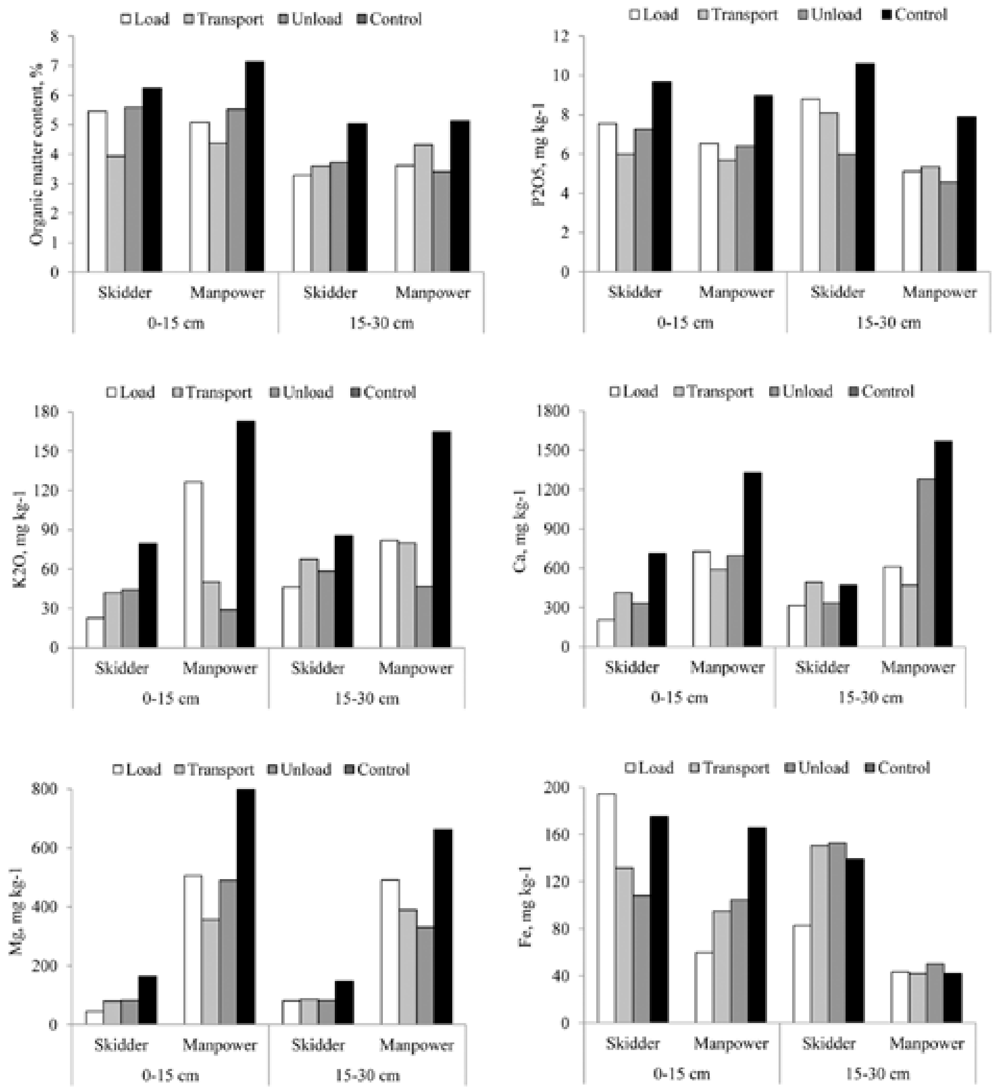

Figure 3. Changes in some chemical characteristics of the forest soil according to logging technique and impact area

general, our results are in agreement with those of similar studies. The properties of both the topsoil and subsoil components, especially permeability, bulk density and nutrient concentrations, were significantly affected by ground skidding both by skidders and manpower techniques. In addition, the soil on areas, where the harvested spruce logs were loaded and unloaded, was also degraded to a considerable extent. We observed that use of a skyline did not lead to a negative change in the physical characteristics of forest soils. Similar studies by Elias (1998) and Bock and Van Ress (2002) showed that hauling logs using skylines did not cause major changes in the physical characteristics of soil due to minor contact of hauled logs with the ground.

Changes in the physical characteristics of soils were detected only along the ground skidding trails, which occurred during logging practices performed using manpower, animals, or skidders; these characteristics have been investigated previously. For example, Makineci et al. (2007) analyzed changes in forest soil properties at different distances on ground skidding trails in *Abies* stands and found that clay content, percentage of field capacity and bulk density decreased significantly at 0-5 and 5-10 cm depths of soils. Demir et al. (2007) studied beech and oak stands in the same region and found that ground skidding operations increased the percentage of field capacity and bulk density of topsoil (0-5 cm), but the same properties of subsoil decreased markedly.

The impact of skidding operations on soil causes soil compaction. According to Herbauts et al. (1996), these impacts led to a 20 % decrease in the total volume of soil pores. As the result, it was noted by Ablan et al. (1994) that bulk density of soil increased by approximately 22 %. Conversely, Miller et al. (1996) reported that bulk density values increased by up to 40 % in similar situations. We detected an increase in bulk density of 42 % using skidders and 46 % using manpower. Decreased soil pore size increases water retention in the soil (Ballard 2000), and soil compaction causes soil permeability to diminish by 30-50 % (Aust et al. 1998). Dickerson (1976) reported that the permeability rates on areas without soil compaction (11.4 cm h^{-1}) decreased in skidder wheel tracks (1.1 cm h^{-1}). Similar results were reported by Cullen et al. (1991) and Ballard (2000). In this study, while permeability values decreased by 50 % in areas logged using skidders, this reduction reached 70 % in areas subjected to manpower logging.

Soil compaction generated by heavy machinery or human activity has a great impact on the structural characteristics, aeration, and water balance of soils, and may affect soil organisms and root development (Makineci et al. 2007). The changes in these factors can reduce the growth of primary roots and their ability to penetrate through soil, as well as weaken their ability to receive nutrients and water (Kozlowski 1999), eventually reducing tree growth (Gebauer and Martinkova 2005). Soil compaction and shifts in soil characteristics cause soil fertility to decline by affecting the activities and varieties of organisms that play significant roles therein by mediating litter decomposition, for example (Gobat et al. 1998).

Although it is generally agreed that logging practices using heavy machinery and humans have significant negative effects on areas with loamy and slimy soils (Fisher and Binkley 2000), some studies have also reported that these activities also affect the permeability and bulk density of soils to a significant degree by causing soil compaction in areas, where the content of sand is high (Ampoorter et al. 2007). Likewise, in this study, logging practices using skidders and manpower affected the permeability and bulk density of soils to a marked extent despite the relatively high content of sand.

Our results are similar to those of previous studies by Makineci et al. (2007) and Demir et al. (2007). Makineci et al. (2007) reported about declined amounts of organic carbon and nutrients at depths of 0-5 and 5-10 cm of forest soils exposed to ground skidding at various distances in *Abies* stands. Logging techniques that apply pressure to the soil surface and cause the litter on the surface to drift away negatively affect both the physical and chemical characteristics of soil (Makineci et al. 2007). Among the three techniques studied here, logging using skylines is the most appropriate in forested areas as it does not affect the chemical properties and nutrient levels in the subsoil and topsoil parts of the soil to any significant degree.

The principal sources of organic matter and hence soil nutrients are leaching into and mixing with the soil as a result of litter decomposition on the surface (Sarıyıldız et al. 2005, Sarıyıldız and Küçük 2008, Sarıyıldız and Küçük 2009). Other important sources of organic matter and nutrients are tree roots; Fogel (1983) demonstrated that the capillary root mass under coniferous forests varies between 1,000-12,600 kg ha^{-1}. Similar results were reported by Hendrick and Pregitzer (1993) in thickets composed of a mixture of oak, beech and maple. Whether on the soil surface or underground, there is a relationship between the soil organic matter content and nutrient levels due to the presence and decomposition of plant residue. Besides providing the nutrients necessary for the development of trees within the forest ecosystem and allowing these nutrients to become a source of sustenance in the cyclic process, litter decomposition is also a source of energy for soil micro- and macro-organisms (Sarıyıldız et al. 2005, Sarıyıldız and Küçük 2008). Removal of these sources from the environment as a result of logging or creation of unsuitable conditions for the macro- and micro-organisms will reduce the levels of organic matter and nutrients in soil.

Conclusions

The results of this study demonstrate that timber haulage by manpower and skidders negatively affect soil chemical properties and nutrient levels. These negative impacts will also affect plant nutrient intake, and hence also plant development. Logging performed using manpower and skidders degrade the permeability of both the topsoil and subsoil to a considerable degree, while also increasing the bulk density.

The pressure applied to the surface of the soil during cable skidding by skidders and ground skidding of logs by humans leads to soil compaction and decreases pore sizes, thus negatively affecting soil permeability and increasing bulk density. Over time, these effects will alter the soil structural features, water balance, root progression, organisms, nutrients and water intake, and thus also affect soil fertility and tree development. These factors were not investigated in this study; therefore, further research on this subject is warranted.

It would be useful to determine the appropriate logging time and technique to reduce soil losses caused by logging. This involves identifying routes suitable for free sliding with manpower and cable skidding by skidder, hauling of logs by skylines, and utilizing chute systems that are least harmful to the environment in thin-scale forests.

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