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Impact of forestry operations on forest soil respiration depending on stands features in Kastamonu, Turkiye

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SILVICULTURE

ABSTRACT

Background: Harvesting, especially skidding operations have a significant impact on the forest soil properties. This study aimed to advance understanding of how timber harvesting may influence soil respiration in forested ecosystems. We investigated the impact of soil respiration for some of the skidding techniques after skidding operations depending on slope and stand types.
Results: We measured soil CO_2 efflux to evaluate the skidding techniques on soil, depending on the slope and stand type. Thus, three skidding techniques with tractor for harvesting (1-suspended skidding, 2-using a skidding cone, 3-cable-pulling) were used in 6 different study site and the variations in soil respiration and soil properties were examined at 3 different slopes (0-20%, 20-33%, >33%), 2 different stand types (b-bc, c-cd) at topsoil (0-5 cm). Also soil respiration was measured at intervals of 5 days (on days 1, 5, and 10) after skidding operation. In addition, pH, EC (electrical conductivity), and soil moisture were evaluated depending on slope and stand type in the study.
Conclusion: It was determined that respiration increased on the first day but decreased on day 5 and 10. It was found that the slope and stand type have no effect on soil respiration. It was determined that the skidding technique that reduces the soil respiration the most is suspended skidding with a rate of 90%. However, the skidding technique that reduced respiration the least was skidding by using a skidding cone suspended skidding with a rate of 64% when evaluated on day 10.

Keywords: Skidding operations, Skidding techniques, Forest soil respiration, *Pinus nigra*.

HIGHLIGHTS

Skidding techniques influenced soil respiration depending on slope and stand type.
The most affected negatively soil respiration was the suspended skidding technique (90%).
The technique affected soil respiration less is using a skidding cone technique (64%).
A skidding cone minimizes soil respiration changes, making it a recommended technique.

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INTRODUCTION

Forest resources must be managed according to sensitive forestry principles to meet the needs of present and future generations. The precision forestry approach aims to provide optimum efficiency from forest resources and to minimize environmental damage by using modern techniques and technological tools to make economic, environmental, and sustainable decisions in forestry studies (Gülci et al., 2020).

Forest ecosystems are of great importance for the global carbon cycle. Forests constitute 40% of underground carbon and 80% of above-ground carbon stocks worldwide (Dixon et al., 1994). Approximately 10% of the CO_2 concentration in the atmosphere passes into the atmosphere through the soil every year (Raich and Schlesinger, 1992). This amount is almost 10 times higher than the CO_2 released by burning fossil fuels and deforestation. Soil respiration is, therefore, one of the key components of the global carbon budget (Davidson et al., 2006; Richardson et al., 2012).

Forest soils form the basis of the entire forest ecosystem. Soil plays an important role in the flow of nutrients, water, and energy to maintain forest productivity and biodiversity in forest ecosystems (Dominati et al., 2010). Ensuring the passage and binding of water to plants to ensure the growth and development of plant roots, creating an environment for the healthy growth of plants by providing ventilation through gas exchange between the soil and the atmosphere, increasing soil biodiversity in terms of the diversity and activity of soil flora and fauna in the soil (Latterini et al., 2024). They have important duties. Soil respiration is expressed as various microorganism activities in the soil and the release of CO_2 from plant roots to the atmosphere by changing under temporal and spatial factors (Akburak, 2008; Zhou et al., 2016). In this context, harvesting processes have caused changes not only in forest carbon stocks, but also in soil properties due to soil degradation (Mataix Solera et al., 2011; Yang et al., 2019; Matangaran et al., 2024). The damaged soil system can cause long-term and perhaps irreversible damage to the ecosystem by affecting forest productivity. Especially heavy machinery traffic, cutting, pulling, pushing, and lifting the log during timber harvesting can cause serious losses in forest cover and cause major changes in soil properties (Enez et al., 2016; Ozer Genc and Arıcak, 2020). These operations may affect soil moisture, pH and nutrient availability due to enhanced microbial activity (Yang et al., 2022; Ramesh et al., 2019). Microorganisms that play an active role in the biological structure of the soil are affected by this process and are damaged. Soil compaction, which is usually the most obvious result of skidding, increases soil strength and limits gas diffusion, which inhibits root growth and microbial activity, delaying the physiological and growth characteristics of seedlings trees. Although microorganisms make up a very small part of the soil, it is a living group that performs an important part of the biological activity of the soil with its functions in the cycles of many nutrients such as nitrogen fixation, mineralization and in the decomposition of organic residues (Wang et al., 2023; Cheng et al., 2023). Therefore, microorganisms are the most important components of terrestrial ecosystems with their critical roles in the global carbon and nutrient cycle (Akburak and Makineci, 2015). Microorganisms, which have many types in the soil according to environmental conditions, fulfill many functions necessary for the normal and healthy dynamics of the soil. Therefore, soil respiration can be used as an indicator of soil fertility because through soil respiration, microorganism activity in soil can be measured. Therefore, harvesting works have a significant impact on the sustainability and stability of the forest ecosystem, as they have the potential to affect both root and microbial respiration (Díaz-Maroto and Vila-Lameiro, 2008; Das et al., 2023; Setälä et al., 2023). Soil plays an important role in the flow of nutrients, water, and energy to sustain forest productivity and biodiversity in forest ecosystems and is highly susceptible to inappropriate forestry activities (Chase et al., 2019; Crawford et al., 2021). In this context, although there are studies investigating the effects of dividing works on soil and stand structure in our country, studies on the effects of timber harvesting about soil respiration are very limited. In this study, which was carried out to contribute to the elimination of the existing deficiency, it was aimed to determine the effects of different skidding techniques studies on soil respiration in terms of minimizing the damage to the forest soil by using appropriate techniques and tools specific to the site, as in the precision forestry approach.

The experimental study, the effects of skidding operations on soil respiration on skid roads were determined in *Pinus nigra* stands located in the north of Turkey, and evaluated the temporal change of soil respiration in the first 10 days (1st, 5th and 10th days) following logging operations. The effects of skidding techniques on soil respiration were evaluated by considering different slope classes and stand types. Soil respiration was measured as CO_2 release from the surface soil using the LICOR 8100 (LI-COR, Lincoln, Nebraska, USA) gas analyzer (IRGA) in the field.

MATERIAL AND METHODS

Study site

The research sites were located in the Kastamonu Regional Directorate of Forestry, Aksudere Forest Sub-District Directorate (41° 09′ 20″ – 41° 22′ 25″ northern latitudes, 32° 55′ 10″ – 33° 14′ 30″ eastern longitudes), Kastamonu, Türkiye forests coverage of 60%. These forests were dominated by black pine (*Pinus nigra*). The soil is mainly brown forest soil. The climate is temperate, with a mean annual temperature of 9,8 ^{0}C and an average of 253 frost-free days per year. The mean annual precipitation is 449 mm (GDF, 2014).

Six different harvest units in study sites were selected (Figure 1). The logs used in the harvest units were between 5 and 7 m in length and between 16 and 50 cm in diameter, in compliance with the standard harvesting procedures. The skidding was done when the soil was dry.

Study design

In the study, stand classifications were determined as "b-bc" and "c-cd". In terms of the stand, the stage of "b-bc" indicates a small-size tree (dbh 0 cm-35.9 cm) and the stage of "c-cd" indicates a mid-size tree (dbh 20 cm – > 51.9 cm), while the land slope was classified by the IUFRO slope classification as 0-20%, 20-33%, and >33% slope classification). Accordingly, the study was carried out in six different land types combining "suspended skidding", "cable-pulling" and "using a skidding cone" for topsoil (Table 1).

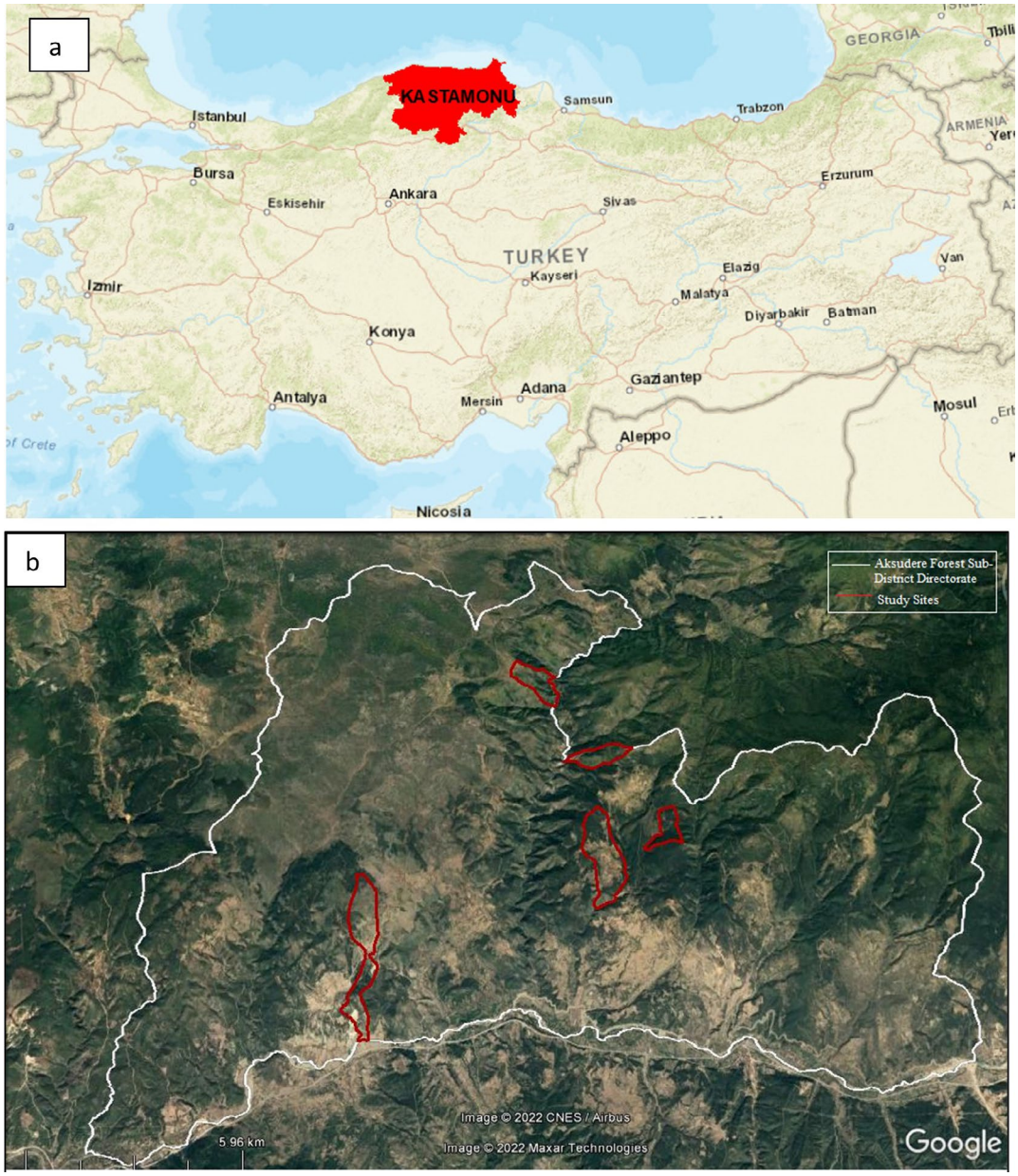

Figure 1: (a) Location of in the state of Kastamonu, Türkiye; (b) study sites in the Aksudere.

Table 1: Planning study areas according to the skidding techniques.

Skidding technique	Control	Suspended skidding	Cable-pulling	Skidding by using a skidding cone
Stand type	b-bc / c-cd	b-bc / c-cd	b-bc / c-cd	b-bc / c-cd
Slope group (%)	0-20 / 20-33 / >33	0-20 / 20-33	20-33 / >33	0-20 / 20-33 / >33

In the suspended skidding technique, the tractor was driven into the stands, and the log was secured to the drum. The logs were skidded with their tips suspended approximately 50 meters up the slope from the starting point of the skid trail. The cable-pulling technique was based on the principle of skidding logs up the slope without using a skidding cone by fixing the tractor at the end of the skidding (the tractor is not moving) and contacting the log's whole with the ground. In the skidding by using a skidding cone technique, the logs were skidded with a cable by attaching the skidding cone to the log. The tractor was fixed at the end of the skidding, and the logs were skidded using the cable from the start of the skidding to the end by contacting the entire log with the ground.

The skid trails where the skidding techniques were applied in the six different study sites were determined for three slope classes, two stand types, and control sites (approximately 50 m). The study sites were designed parallel to each other with at least one tree-length spacing (10 log passes on the skid trails) (Figure 2).

Soil analysis

Before the skidding, soil samples were obtained at topsoil (0-5 cm) from the undisturbed areas of six different study sites. Accordingly, a total of 12 soil samples (2 stand types x 3 slopes x 2 duplications) were collected for control purposes for the areas where the three skidding techniques were applied. Following the completion of the skidding operations, a total of 36 soil samples were also obtained from 0-5 cm on the skid trails. Two replicates were taken from each of the six different study areas.

We measured a suite of soil chemical properties to identify other important effects of timber harvesting and potential relationships with soil respiration. We collected soil samples (0–5 cm depth) from July to August using a steel cylinder (5 cm in diameter and 5 cm in height). pH was measured with a pH meter on soil solutions made by adding 2 g of soil to 20 ml nano-pure water (WTW spectrophotometer). pH and electrical conductivity (EC) values were measured with a digital WTW brand spectrophotometer device by preparing a 1:2.5 soil-pure water suspension. EC values are expressed in µs/cm (Özyuvacı, 1971; Gülçur, 1974).

The moisture content of the soil samples was determined gravimetrically by drying at 105 °C for 24 hours (Karaöz, 1992). Formula 1 was used to determine the % moisture content in soil samples (Gülçur, 1974).

$$\%Moisture = \frac{DW - ODW}{ODW} \times 100 \quad (1)$$

DW = Dry Weight (gr)
ODW= Oven Dry Weight (gr)

Soil respiration

Soil respiration was measured with LI-8100 console and soil CO_2 flux chamber of 11 cm in diameter and 5 cm in height placed carefully directly on the soil. The chamber was pressed about 3 cm down into the soil to avoid any air leakage. The changes in CO_2 concentration were detected

Figure 2: Shows soil respiration measurement studies after harvesting operations. (a) Soil respiration measurement method; (b) soil respiration measurement points.

for 2 min. At each station, the measurements were taken between 10 a.m. and 3 p.m. The CO_2 evolution rate was expressed as $\mu molm^{-2}\ s^{-1}$.

Statistical analysis

One-way analysis of variance (ANOVA) was used to compare the soil respiration before and after the skidding operations on days 1, 5, and 10. Also, One-way ANOVA was used to assess the significance of observed differences in pH, EC, and soil moisture under different combinations of skidding techniques, stand type, and slope. Duncan's test was used to determine which combinations showed significant differences at an overall significance level of $p < 0.05$. All statistical calculations were performed using SPSS version 20. The relations between the soil respirations and soil properties were evaluated by Pearson Correlation Test.

RESULTS

Soil respiration

From the six study sites, 40 soil samples were analyzed and evaluated according to the different stand types and slope groups. Table 2 shows the mean, F values, and the differences in soil respiration between the stand types, slopes, and the skidding techniques on days 1, 5, and 10.

The ANOVA results suggested that soil respiration generally increased following skidding operations on day 1. However, soil respiration decreased on days 5 and 10 after skidding operations.

For the b-bc stand type and 0-20%, a technique in which respiration decreased the most was the suspended skidding with a rate of 84.6%. For the b-bc stand type, 20-33% slope group, the technique in which respiration decreased the most was again the suspended skidding with a rate of 90.23%. For the b-bc stand type and 33%< slope group, the technique in which respiration decreased the most was again the cable-pulling with a rate of 78%.

For the c-cd stand type and 0-20% slope group, the technique in which respiration decreased the most was the skidding by using a skidding cone with a rate of 79%. For the c-cd stand type, the 20-33% slope group technique in which respiration decreased the most was the cable-pulling technique with a rate of 72%. For the c-cd stand type and 33%< slope group, the technique in which respiration decreased the most was the cable-pulling technique, with a rate of 81%.

For the cable-pulling technique, the highest soil respiration value was at the control points in the 20-33% slope group at b-bc stand type, and no significant differences were found between on the days 5 and 10. In the 33%< slope group, soil respiration was the highest on day 1, while the soil respiration values on days 5 and 10 days decreased, and no significant differences were found between them. In the c-cd stand type 20-33% and 33%< slope group, the soil respiration values were high on the 1 day, but the soil respiration values decreased on days 5, 10 and no significant differences were found between them (Figure 3).

Table 2: Analysis of variance (ANOVA; F test) for the effects of skidding techniques according to days of the stand types, slopes, and their interactions with the soil respiration ($\mu molm^{-2}\ s^{-1}$).

Skidding techniques		Stand type	Slope classes (%)	Control	Day 1 respiration	Day 5 respiration	Day 10 respiration	F value
Suspended skidding	Log track	b-bc	0-20	2.48 c	1.225 b	0.525 a	0.38 a	73.621-000
			20-33	3.79 b	1.98 a	0.5 a	0.48 a	10.016-0.001
		c-cd	0-20	3.79 bc	4.215 c	2.405 ab	0.905 a	8.877-0.002
			20-33	2.295 b	3.775 c	1.975 b	1.0 a	33.205-0.000
	Wheel track	b-bc	0-20	2.48 c	1.99 b	0.665 a	0.515 a	103.222-0.00
			20-33	3.79 b	2.5 b	0.415 a	0.370 a	8.970-0.002
		c-cd	0-20	3.79 b	4.055 b	2.55 b	0.935 a	8.419-0.003
			20-33	2.295 c	4.385 d	1.75 b	0.795 a	106.063-0.000
Cable-pulling		b-bc	20-33	3.79 b	1.52 a	0.65 a	0.655 a	10.853-0.001
			33<	1.07 b	1.47 b	0.36 a	0.225 a	14.922-0.000
		c-cd	20-33	2.295 b	2.28 b	1.17 a	0.63 a	9.394-0.002
			33<	2.715 b	2.805 b	0.63 a	0.49 a	596.479-0.000
Skidding by using a skidding cone		b-bc	0-20	2.48 b	2.5 b	0.88 a	0.695 a	58.839-0.00
			20-33	3.79 b	1.805 a	0.52 a	0.6 a	11.450-0.001
			33<	1.07 c	2.09 d	0.5 b	0.265 a	226.980-0.000
		c-cd	0-20	3.79 b	5.295 b	2.12 a	0.79 a	13.530-0.000
			20-33	2.295 b	3.45 c	2.15 b	0.82 a	16.428-0.000
			33<	2.715 c	1.965 b	0.565 a	0.535 a	4497,806-0,000

* Different letters in soil respiration indicate significant differences among days ($p<0.01$) based on Duncan's test.

For skidding by using a skidding cone technique, the highest soil respiration value in the 0-20% slope group in the b-bc stand type was on day 1 measurement, but the soil respiration values decreased on days 5 and 10. In the 20-33% slope group, the soil respiration value increased in the following days, but no significant differences were found between the days. In the 33%< slope group, the highest value was on day 1, and the lowest soil respiration value was on day 10. The highest soil respiration value in the 0-20% slope group in the c-cd stand type was on day 1, and the soil respiration values decreased on days 5 and 10, but no significant differences were found between them. The highest soil respiration values in the 20-33% slope group were on day 1 measurements and the lowest soil respiration values were on day 10. In the 33%< slope group, the soil respiration values decreased in the following days, but the lowest soil respiration value was in the soil respiration data on days 5, 10, and no significant differences were found between them (Figure 4).

For the log track in the suspended skidding techniques, the highest soil respiration value was measured at the control point, and the lowest respiration was on days 5 and 10 in the 0-20% slope group in the b-bc stand type. In the 20-33% slope group, it was determined that respiration decreased in the following periods, but there was no difference between on days 1, 5, and 10. In the 0-20% slope group in the c-cd stand type, the highest soil respiration values were in the control and day 1, and no significant differences were found between them. Also, soil respiration values decreased on days 5, 10 and no significant differences were found between them. In the 20-33% slope group, the highest soil respiration rate was on day 1, and the lowest soil respiration rate was on day 10 (Figure 5).

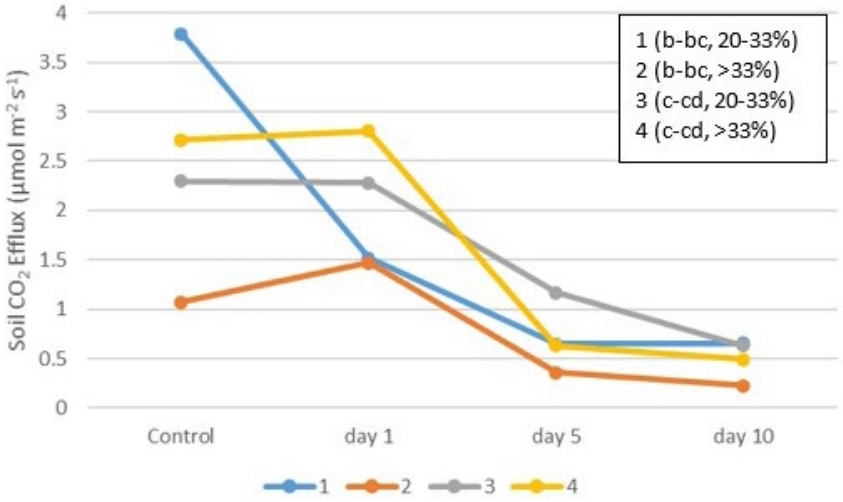

Figure 3: Impact skidding techniques on soil respiration in the skid trails and control area by days for cable-puling.

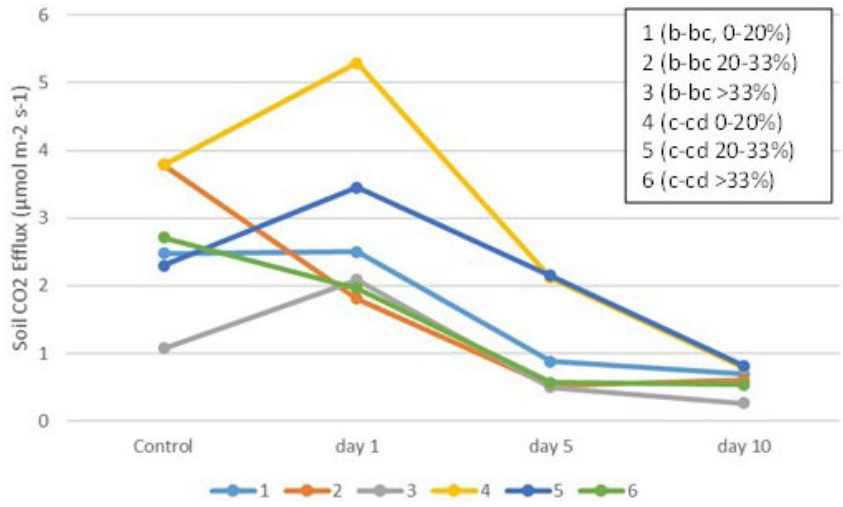

Figure 4: Impact skidding techniques on soil respiration in the skid trails and control area by days for skidding by using a skidding cone.

For the wheel track decreased in the suspended skidding techniques, the soil respiration values of the 0-20% and 20-33% slope groups in the b-bc stand type in the following days, but no significant differences were found between the days 5 and 10 respiration values. The soil respiration values on day 5 were the highest in the c-cd stand type, and no significant differences were found between them, but it had the lowest soil respiration values on day 10. In the 20-33% slope group, the lowest soil respiration values were determined to be on day 1, while the highest soil respiration values were determined to be on day 10 (Figure 6).

EC (Electric Conductivity)

There was no statistically significant difference between the control point and techniques in the 0-20% slope group at the "b-bc" stand type. In the "b-bc" stand type, while in the 20-33% slope group, it was determined that the wheel track did not significantly change the EC value, but the log track significantly reduced the EC value. It was determined that the skidding by using a skidding cone and cable-pulling techniques also increased the EC value significantly, and it was determined that the highest value occurred in the skidding by using a skidding cone technique. There was no statistical difference between the techniques in the "b-bc" stand type in the 33%< slope group. There was no statistically significant difference between the techniques of EC values in all slope groups and soil depths at "c-cd" stand type (Table 3).

pH

There was no statistically significant difference between the techniques in the 0-20% slope group in the "b-bc" stand type. It was determined that the techniques

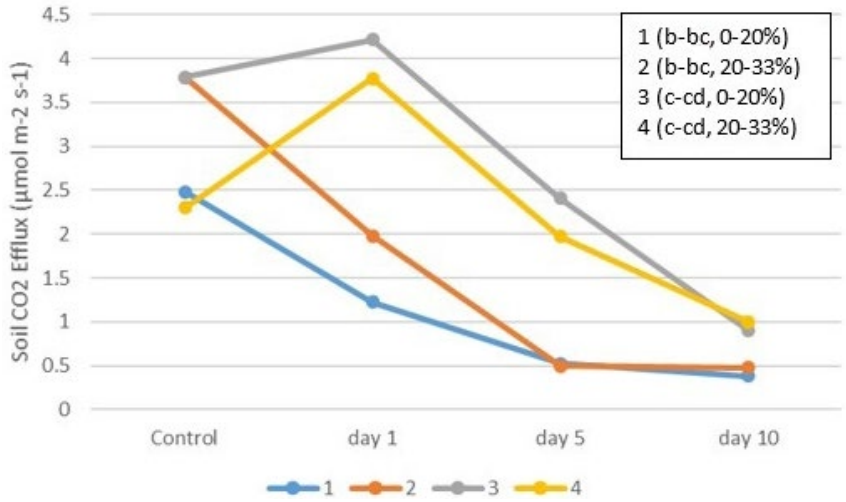

Figure 5: Impact skidding techniques on soil respiration in the skid trails and control area by days for suspended skidding (log track).

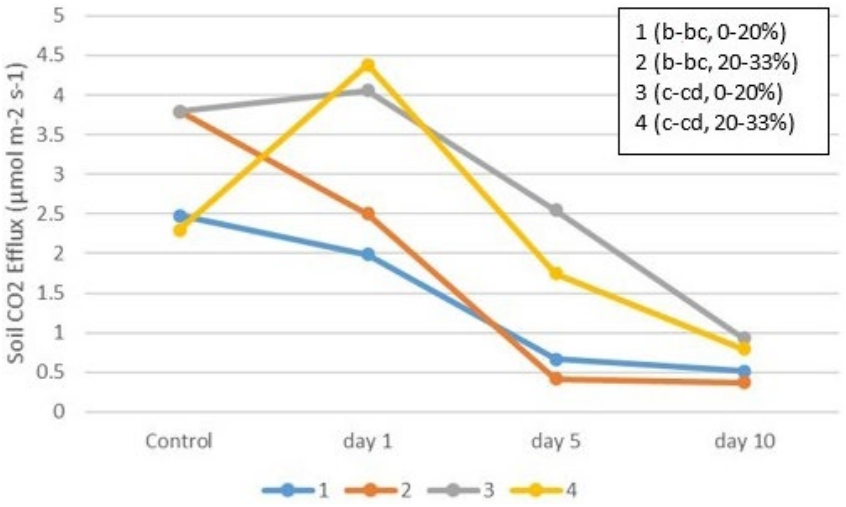

Figure 6: Impact skidding techniques on soil respiration in the skid trails and control area by days for suspended skidding (wheel track).

did not affect the pH values in the 20-33% slope group at the "b-bc" stand when compared to the control group, but there was a statistically significant difference between the techniques. It was determined that the skidding by using a skidding cone and cable-pulling techniques increased the pH value in the "b-bc" stand type by 33%< slope group, but the highest increase was due to the cable-pulling technique. There was no statistically significant difference between the techniques in the 0-20% and 20-33% slope groups at the "c-cd" stand type. It was determined that the techniques did not have a significant effect on pH in the slope group of the "c-cd" stand type of 33% (Table 3).

Soil moisture

It was determined that only the skidding by using a skidding cone technique statistically reduced the soil moisture value in the 0-20% slope group of the soil moisture values at the "b-bc" stand type, but the other techniques did not change the soil moisture value. In the 20-33% slope group, it was determined that all techniques reduced soil moisture at a statistically significant level, and it was revealed that the most moisture loss was in the cable-pulling techniques. In the "b-bc" 33%< slope group, it was determined that the soil moisture decreased after both the cable-pulling and skidding by using skidding cone techniques.

It was determined that the soil moisture values in the "c-cd" stand type 0-20% slope group decreased the soil moisture value of the log track statistically only in the suspended skidding technique, while the other techniques did not change the soil moisture value. It was determined that the soil moisture values in the 20-33% slope group at the "c-cd" stand type, and all techniques reduced the soil moisture values statistically. It was determined that the soil moisture values in the "c-cd" stand type were 33%< in the slope group, and all techniques significantly reduced the soil moisture value (Table 3).

According to the result of the Pearson correlation test, a positive relationship was found between soil moisture and days (soil respiration) ($p<0.01$). In other words, as soil moisture increases, soil respiration increases. Again, a significant relationship was found between pH and days (soil respiration) ($p<0.01$). The soil moisture was not significantly correlated with pH and EC ($p>0.05$). A positive relationship was determined between pH and EC ($p<0.01$) (Table 4).

Table 3: Variation of the effect of skidding techniques on pH, EC (Electric conductivity, µS/cm, soil moisture (%) depending on different slope, stand type (Ozer Genc, 2020).

	Stand type	Slope (%)	Control	Suspended skidding		Skidding by using a skidding cone	Cable-pulling	F value
				Log track	Wheel track			
pH	"b-bc"	0-20	5.048	5.415	5.185	5.049		1.293 ns
		20-33	5.762 ab	5.651 a	5.494 a	5.799 ab	6.429 b	2.768***
		33<	5.490 a			5.730 b	6.021 c	43.524***
	"c-cd"	0-20	7.125	7.215	7.260	7.175		0.731 ns
		20-33	6.090	6.410	6.210	6.060	7.420	1.625 ns
		33<	5.330			5.39050	5.290	0.153 ns
	F value		12.343***	19.001***	11.170***	27.161***	11.515***	
EC	"b-bc"	0-20	73.350 ab	74.150 ab	97.500 b	46.750 a		4.708*
		20-33	49.600 b	27.050 a	46.000 ab	108.450 d	87.000 c	27.690***
		33<	45.800			62.800	81.000	2.541 ns
	"c-cd"	0-20	202.500	260.500	248.000	215.250		0.746 ns
		20-33	62.700	104.250	218.150	38.150	213.500	2.833 ns
		33<	135.100			208.600	127.500	2.123 ns
	F value		4.712***	10.973***	2.852***	2.485**	4.314***	
Soil moisture	"b-bc"	0-20	16.7 b	13.2 ab	15.9 b	9.9 a		4.449*
		20-33	19.0 d	16.3 c	13.3 b	13.7 b	10.4 a	33.071***
		33 <	24.8 b			15.5 a	13.3 a	5.165*
	c-cd	0-20	36.4 b	23.9 a	39.9 b	30.4 ab		5.672*
		20-33	30.9 b	17.4 a	18.5 a	16.8 a	18.9 a	10.475***
		33<	18.4 b			8.8 a	12.9 a	10.892 **
	F value		7.908***	14.106***	20.255***	18.534***	3.893***	

Note: Different letters in Ph, EC, soil moisture indicate significant differences among skidding technique based on Duncan's test.

Table 4: Pearson correlations between soil properties.

	Soil moisture	pH	EC
Day 1 soil respiration	0.337**	0.307**	0.443**
Day 5 soil respiration	0.674**	0.564**	0.366**
Day 10 soil respiration	0.422**	0.304**	0.285*
Soil moisture		-0.018ns	0.017ns
pH			0.401**

DISCUSSION

Soil respiration

Soil respiration values generally decreased with the effect of compaction in the areas where skidding operations were carried out, and it was determined that the lowest soil respiration values were on the days 5 and 10. due to soil compaction over time. However, at some points, it is seen that the respiration values increased as of the 1. day compared to the control areas. The increased soil respiration is thought to be due to accelerated activity of the existing microbial population, possibly as a result of soil aeration due to skidding. However, at these points, it was determined that the respiration decreased with the soil compaction in the following days. Xu et al. (2011) stated that skidding operations in forestry can change soil respiration by causing changes in microorganism activity.

DeArmond et al. (2023) and Babur (2022) determined that compaction affects soil respiration by directly affecting soil moisture, temperature, litter biomass, and stand cover. Soil microbial respiration mean values around the skidding were higher than the soils around the control. They determined that this was because microbial organisms survive by breathing more heavily due to moisture loss in soil exposed to direct exposure to external inspection, such as sunlight after skidding. Microbial respiration directly affects the carbon storage capacity in terrestrial ecosystems as it affects all organic matter of the soil and other microbial parameters (Mahmoodi et al., 2023).

EC

In the study, Table 3 shows that the EC values of the "b-bc" stand type were generally lower than the "c-cd" stand type at the control points. It was determined that different slope groups did not affect the EC values at a statistically significant level. As a result of the techniques applied in the "b-bc" stand type, it was observed that the EC values did not change or increase the EC values compared to the control group. In the "c-cd" stand type, it is seen that the techniques generally do not affect the EC value.

Jourgholami et al. (2020) was determined that there is no significant difference in EC values between slope classes. Demir et al. (2007) determined the electrical conductivity values as 86.57 µhos/cm and 88.35 µhos/cm at 0-5 cm soil depth level for the control areas and the areas that were interfered with and those that were not, in their study to evaluate the effect of harvesting activities on the soil. In the 5-10 cm soil depth level, it was determined as 60.05 µhos/cm and 67.18 µhos/cm, respectively, and as a result, it was determined that there was no difference between the values of electrical conductivity at both depths with disturb and undisturbed.

pH

The pH values of the "c-cd" stand type were higher than the "b-bc" stand type. In general, it can be said that the techniques do not affect the pH values statistically significantly. In skidding operations, pH didn't affect soil properties, but it had a significant effect on the pH values of the slopes of the study areas (Venanzi et al., 2016; Jourgholami, 2020). Naghdi et al. (2016) reported that the pH value did not change at a statistically significant level in different slope groups and the number of passes. In this study, since pH values were a chemical property that changes in the long term, it was expected that no difference would be observed immediately after harvesting.

Soil moisture

It is seen that the soil moisture decreased as a result of the techniques applied in both stand types. In the 0-20% slope group, it stands out that the skidding by using a skidding cone technique had the highest decrease in soil moisture. According to the 20-33% slope group, it was determined that the highest decrease in soil moisture was in the cable-pulling and the skidding by using a skidding cone technique. In the 33%< slope group, it is seen that the skidding by using a skidding cone and cable-pulling techniques caused almost the same level of soil moisture loss. Considering the control groups as a result of the applied techniques, it can be said that the stand type with the highest soil moisture loss was from the "c-cd" stand type and 33%< slope group. It is seen that the soil moisture decreased after skidding operations. When the samples taken from the disturbed areas and the undisturbed areas are compared, the soil compaction increases and the soil moisture values decrease accordingly (Croke et al., 2001; Demir et al., 2007). Makineci et al. (2007) determined the values of moisture content to be 21.26% in the skid trail and 27.22% in the undisturbed area.

CONCLUSIONS

This study was conducted with the overall objective to assess the impacts of ground-skidding techniques on soil respiration at different slope classes and stand types. Soil respiration appeared to increase immediately after skidding techniques. Due to soil compaction (due to logs and traffic-heavy machines) the respiration tract may be reduced in the following days. Skidding operations have also reduced soil respiration, possibly due to the following operations.

As a result, the effects of three different skidding techniques on forest soil respiration for two different soil stand types and slope classes were investigated in detail. It is seen that slope and stand type are not important factors in soil respiration. However, the days were found to be effective on soil respiration for all three different skidding techniques. Also, soil moisture, pH, and EC have been determined to be effective in soil respiration. When considering all stand types and slope groups, it was determined that the method that most affected soil respiration was the suspended skidding technique (90%). It was determined that the method that affects soil respiration less is skidding by using a skidding cone technique (64%). The use of a skidding cone in areas was the recommended technique because it caused less change to the soil respiration.

AUTHORSHIP CONTRIBUTION

Project Idea: ÇÖG; BA

Funding: ÇÖG; BA

Database: ÇÖG; BA

Processing: ÇÖG; BA

Analysis: ÇÖG; BA

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