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Determination of The Effects of Different Silvicultural Treatments on Soil Respiration, Temperature and Moisture Properties in The Skidding Trail Depending on Topographic Factors

Çiğdem ÖZER GENÇ*, Hasan Kürşat KARAYİĞİT

Kastamonu University, Faculty of Forestry, Kastamonu, TÜRKİYE
*Corresponding Author: cozer@kastamonu.edu.tr

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Abstract

Aim of study: This study investigates how silvicultural treatments and skid trails influence soil respiration in relation to soil moisture, temperature, and topographic factors within forest ecosystems.

Area of study: This study was carried out depending on topographical factors (slope, aspect, elevations) as a result of silvicultural treatments in *Pinus nigra* stands in Kastamonu Forestry Regional Directorate Daday Business Directorate.

Material and method: Soil respiration, temperature and moisture measurements were made at different slope, elevation and aspect groups from the control points and skidding trail for regeneration and tending treatments.

Main results: Silvicultural treatments did not significantly affect soil respiration or moisture on skid trails, while soil temperature was influential in both treatments. Elevation was the most important topographic factor, affecting all soil properties. Slope influenced only soil moisture, whereas aspect affected respiration and moisture but not temperature.

Highlights: The study provides insights into how skid trails from different silvicultural treatments impact soil properties and underlines the importance of ecologically based approaches for sustainable forest management.

Keywords: Silvicultural Treatment, Topographic Factors, Skidding Trails, Soil Respiration

Topoğrafik Faktörlere Bağlı Olarak Sürütme Yolunda Farklı Silvikültürel İşlemlerin Toprak Solunumu, Sıcaklığı ve Nem Özellikleri Üzerine Etkilerinin Belirlenmesi

Öz

Çalışmanın amacı: Bu çalışmada, silvikültürel işlemler ve sürütme yollarının, orman ekosistemlerinde toprak nemi, sıcaklığı ve topoğrafik faktörlerle ilişkili olarak toprak solunumu üzerindeki etkileri incelenmiştir.

Çalışma alanı: Çalışma, Kastamonu Orman Bölge Müdürlüğü Daday İşletme Müdürlüğü'ndeki karaçam meşcerelerinde yapılan silvikültürel uygulamalar (bakım ve tensil alanları) sonucunda topoğrafik faktörlere bağlı olarak yürütülmüştür.

Materyal ve yöntem: Her bir silvikültürel müdahale için kontrol noktalarından ve sürütme yollarından farklı eğim, yükseklik ve bakı gruplarında toprak solunumu, sıcaklık ve nem ölçümleri yapılmıştır.

Temel sonuçlar: Silvikültürel işlemler, sürütme yollarında toprak solunumu ve nemi üzerinde anlamlı bir etki göstermemiştir. Ancak toprak sıcaklığı her iki işlemde de etkili bulunmuştur. Topoğrafik faktörlerden yükselti tüm toprak özelliklerinde belirleyici olmuştur. Eğim yalnızca toprak nemini etkilerken, bakı grupları toprak solunumu ve nem üzerinde etkili olmuş, sıcaklık üzerinde ise etkili olmamıştır.

Araştırma vurguları: Bu çalışma, farklı silvikültürel işlemler sonucu oluşan sürütme yollarının toprak özellikleri üzerindeki etkilerini ortaya koymakta ve sürdürülebilir ormancılık için ekolojik temelli yaklaşımların önemini vurgulamaktadır.

Anahtar Kelimeler: Silvikültürel Müdahaleler, Topoğrafik Faktörler, Sürütme Yolları, Toprak Solunumu

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Introduction

Forest areas should be managed with sustainable forest management without harming other ecosystems at global, regional, and local levels in terms of their biological diversity, productivity, rejuvenation capacities, vitality and related ecological, economic, and social functions today and in the future (Anonymous, 1996; Türker, 2003). The ecological dimension of sustainable forest management ensures the continuity of the forest ecosystem by protecting vegetation, animals, microorganisms, minerals, hydrological and microclimatic features, forest soils, and their interrelationships. Forest ecosystems are dynamic and rich in biodiversity, drawing attention to their critical role in the carbon cycle worldwide (Değirmenci & Zengin, 2016). Soil respiration occurring in these ecosystems expresses the quantity of carbon dioxide (CO_2) released into the atmosphere as a consequence of the activities of both plant roots and microorganisms and constitutes a crucial factor in terms of the carbon budget of the ecosystem (Sasaki et al., 2016; Raison, 2024; Venn, 2023). Soil respiration is also an considerable ecological parameter reflecting forest soil's biological activity and health. However, this process can be directly affected by human-induced forestry activities, especially silvicultural treatments (Mishra & Agarwal 2024; Nance, 2023; Simmons et al., 2018b; Petrokofsky et al., 2015b; Dieler et al., 2017). Silvicultural treatments are applications carried out to ensure the continuity of forests, to rejuvenate them and to protect the ecological balance. Treatments such as regeneration (creation of clearings for natural rejuvenation) and tending can impact the structure and microclimate of the forest and lead to changes in soil properties (Sarıyıldız, 2024; Jandl et al., 2007; Dai et al., 2024). Skidding trails used during the removal of logs from the forest after the treatment can directly affect soil respiration by causing physical deterioration in the soil structure, the decline of organic matter and microbial activity (Küçük et al., 2007; Demir et al., 2009). Skidding trails used during these treatments can directly affect soil respiration by causing physical compaction on the forest floor, a decrease in organic matter and a decrease in microbial activity (Labelle & Jaeger, 2011). In addition to the transport of logs obtained because of different silvicultural treatments, intensive machine traffic also causes soil compaction on the skidding trails and negatively affects soil quality, plant growth and development. Therefore, soil compaction resulting from silvicultural works has a significant effect on forest sustainability as it impacts soil respiration (Girona et al., 2023; Jourgholami et al., 2024; Cole, 2023; Grünberg et al., 2023; Özer Genç & Arıcak, 2022). In forestry activities, skidding trails are important routes used to extract wood raw material from the forest (Eker, 2020; Sancal 2010). The construction and use of these trails can affect soil structure and ecosystem balance (Türk & Gümüş, 2015). More research on this topic is needed to better understand the influences of skidding trails on soil respiration, taking into account the density and diversity of silvicultural treatments applied. Such studies are important for minimizing the negative impact of forestry practices on the ecosystem and developing sustainable forestry methods. This study aims to investigate the impacts of silvicultural treatments carried out in tending and regeneration areas of *Pinus nigra* A. stands located in the northern part of Turkey in skid trails. Within the scope of the study, it was aimed to evaluate the effect of different silvicultural treatments (regeneration, tending) on soil respiration and the effects of temperature and moisture due to respiration on skidding trails in *Pinus nigra* A. Kastamonu Forestry Regional Directorate, Daday Forest Management Directorate in northern Turkey. The impacts of different silvicultural treatments on soil respiration, moisture, and temperature were assessed using different topographical characteristics (slope, aspect, elevation) in tending and regeneration stands. Soil respiration, moisture, and temperature were surveyed in the field using a LICOR 8100 gas analyzer (IRGA). This study, which aims to determine the impacts of different treatment levels and topographic factors on the ecosystem, will contribute to the development of scientifically based recommendations for the protection of ecosystem integrity.

Material and Methods

Introduction of the Study Area

The study was performed in Kastamonu Regional Directorate, Daday Forest Management Directorate, Yayla Forest Management Unit (Figure 1). Yayla Forest Management Unit is located in Kastamonu-E30c3, E30c4, F30b1, F30b2 plans and is geographically located between 33°15'18'' - 33°28'01'' east longitude and 41°24'52"-41°31'42" north latitude. The study area is characterized by typical mountainous forests of the Western Black Sea Region and generally has a sloping land structure. There are dense pure and mixed stands of *Pinus nigra* species forest trees in Daday Management Directorate. The study was carried out in June-July 2024, in 2 different slope, elevation and aspect groups, in order to assess soil respiration, temperature and moisture on the skid trails used during tending and regeneration operations (Table 1).

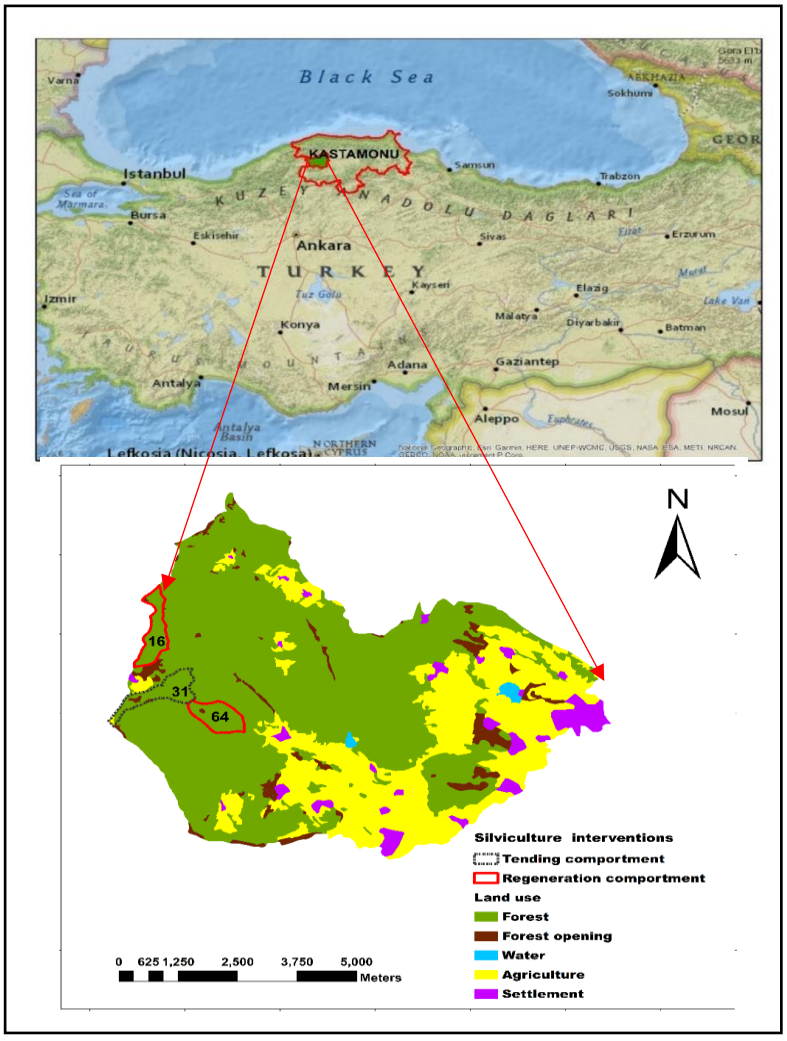

Figure 1. Location of the study area in Turkey

Topographic Factors

Topographic variables including slope, aspect, and elevation significantly effect soil temperature, moisture regimes, organic matter dynamics, and microbial activity; thus, they constitute critical determinants in explaining the spatial heterogeneity of soil respiration. Data made by taking these factors into account on skid trails allow for more accurate assessments in forest management and ecosystem carbon cycle studies. Therefore, it is important to consider these topographic factors to understand and manage soil respiration (Başaran et al., 2005; Gülenay, 2009; Dai et al., 2022; Wang et al., 2024).

Table 1. Work area plan

Topography Factors	Silvicultural Treatments: Tending	Regeneration
Slope (%)	0-33% 33%<	0-33% 33%<
Altitude (m)	0-900 900-1300	0-900 900-1300
Aspect	Sunny aspect Shady aspect	Sunny aspect Shady aspect

Slope, elevation and aspect maps were made within the study plan of Daday Forest Management Directorate, Yayla Forest Management Unit. In this context, 8.09 hectares of the management unit are in the 0-33% slope group, and 1.118 hectares are in the 33%< slope group. It was also determined that 5.58 hectares are in the sunny area and 3.62 hectares are in the shady area (Figure 2).

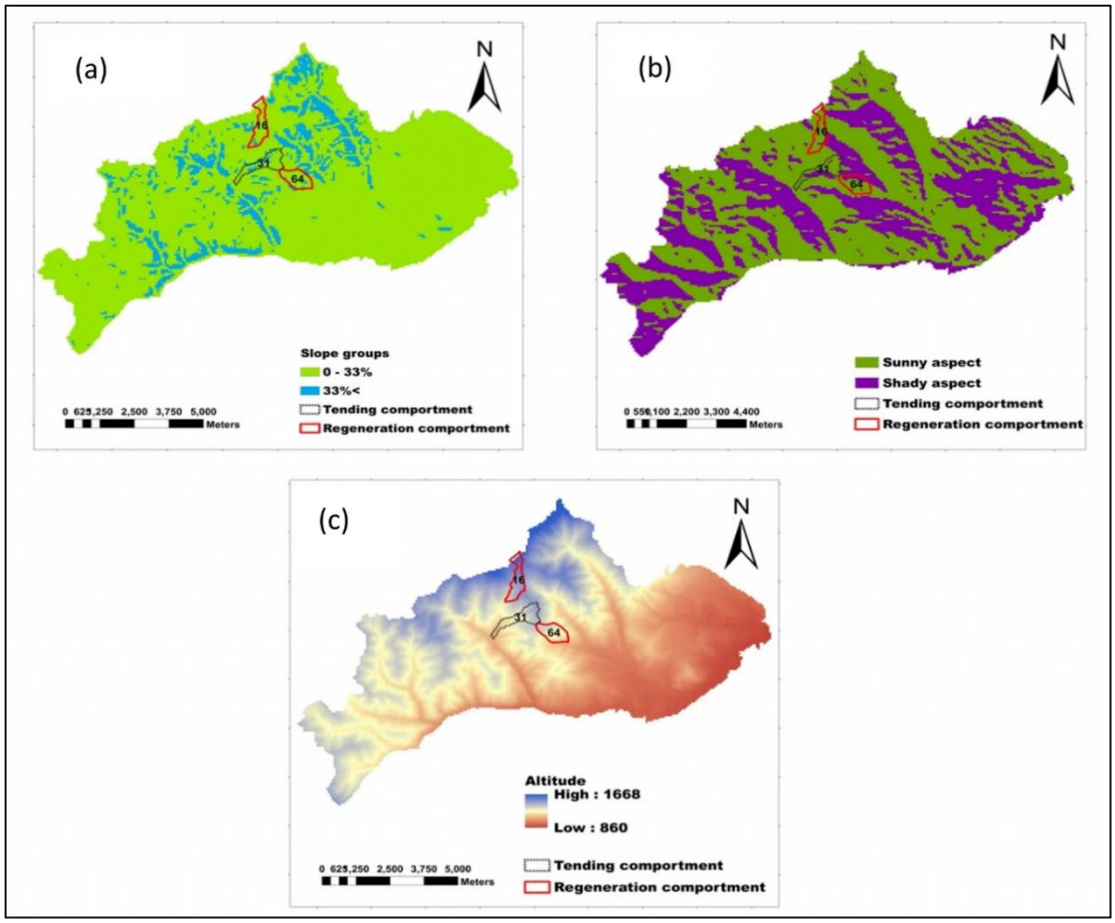

Figure 2. Yayla Forest Management Unit (a) slope, (b) aspect and (c) altitude maps

The study areas were selected according to the study plan on the skidding trails in the stands where regeneration and tending practices were carried out. In the research area, soil respiration measurements were made from 2 points in total 2 different points for control purposes from the area parallel to the skidding trail in the stands where the stands were regenerated. After the regeneration practices, soil respiration measurements were made from 2 different points in 2 replicates from 2 different points from the skidding trail. In the stand where tending practices were carried out, respiration measurements were made from 2 points parallel to the route where the logs were skidded for control purposes. Subsequently, soil respiration measurements were made from 2 different points of the skidding trail where the logs obtained from the tending stands were skidded with 2 repetitions. Soil respiration, temperature and moisture measurements were made from 2 different points at different slope, elevation and aspect

groups from the control points of the areas where 2 different silvicultural treatments were made and from 2 different points on the skidding trail where the logs were skidded after the treatments, with 2 repetitions (128 measurements in total, 2 slope x 2 elevation x 2 aspect x 2 silvicultural treatments x 2 control x 4 repetitions). In short, a total of 64 soil respiration and moisture temperature measurements were made on 8 skidding trails in the tending area and in the control area, and 64 soil respiration and moisture temperature measurements were made on 8 skidding trails and in the control area in the regeneration area. Soil respiration measurements were made in June and July, when vegetation and microbial activities are most active and rainfall is less than other months (Adachi et al., 2009; Shi et al., 2011). Soil respiration was carried out with a soil respirator with IRGA device (LICOR soil CO_2 release meter) (Figure 3).

Figure 3. Study areas and measurement of soil properties

Soil respiration was measured using a LI-8100 device and a soil CO_2 flux chamber (11 cm in diameter and 5 cm in height), which was carefully positioned on the soil surface (Figure 3). In order to prevent air leakage, the chamber was pressed about 3 cm into the ground. The changes in CO_2 concentration were then recorded for two minutes. Measurements were made at intervals between 10.00 and 15.00 hours at each station. The rate of CO_2 evolution was stated in µmol m^{-2} s^{-1}. Soil moisture and temperature were monitored through the use of a thermocouple penetration probe (LI-8100-201), which was thrown away the soil at a constant depth of 10 cm near the soil respiration chamber and 3 measurements were carried out simultaneously. The soil moisture sensor and temperature probe have stainless steel tips and measurements are made by inserting the entire steel section into the soil. These probes are connected to the device console via cable. Measurements were carried out on-site. The device has powerful data analysis software, wireless connection and LAN connection. It has an automatic closing chamber and a wind and rainproof unit (When the weather is very hot, the pump in the control unit protects the device from pressure and prevents excessive heat from damaging the gas analyzer).

Statistical Analysis

'Kolmogorov-Smirnov' (K-S) one sample test, a normal distribution test, was performed on the data obtained in the study. Nonparametric tests were preferred because the parametric test assumptions were not met with the data obtained to examine the effects of silvicultural treatments, topographic factors including slope, elevation and aspect on the variables (Göl, 2022). The Kruskal-Wallis H test was applied to assess the differences on the variables of silvicultural treatments, slope, elevation and aspect. To identify the source of the differences, the Mann-Whitney U test, which is appropriate for comparing data that do not show normal distribution or have small sample sizes, was used (Kim et al., 2023; Siswo et al., 2023). In this regard, this test was used to evaluate the effects of silvicultural treatment, slope, elevation and aspect factors on respiration, temperature and moisture values. Statistical analyses were performed with the help of SPSS (version 22) package program.

Results and Discussion

To determine whether the data obtained in this study were normally distributed, the 'Kolmogorov-Smirnov (K-S) one-sample test' (p>0.05) was employed for further analysis. (p>0.05) (Table 2). As a result of the analysis, it was found that respiration, temperature and moisture values did not show the normal distribution and the control of the difference between silvicultural treatments and soil respiration, temperature and moisture values was evaluated with the nonparametric test 'Kruskal-Wallis H'. As the Mann-Whitney U test is suitable for comparing non-normally distributed data or small sample sizes between two independent groups, it was applied in this study to assess the effects of silvicultural treatment, slope, elevation, and aspect on respiration, temperature, and moisture values..

Table 2. Kolmogorov-Smirnov Test normality test

Variables	N	Mean	Std. Deviation	Minimum	Maximum	P*
Soil respiration (μmol m^{-2} s^{-1})	128	4.22	1.82	1.29	9.66	0.000
Soil temperature (C^0)	128	20.42	3.40	15.35	31.11	0.009
Soil moisture (%)	128	0.09	0.069	0.006	0.456	0.000

To determine whether slope, aspect and altitude factors affected soil respiration, temperature and moisture values, the Mann-Whitney test was used (Table 3).

Table 3. Significance relationship of variables with land slope elevation and aspect

Factors	Variables	Soil respiration			Soil temperature			Soil moisture		
		N	Mean Rank	P	N	Mean Rank	P	N	Mean Rank	P
Slope groups (%)	%0-33	64	67.69	0.331	64	65.25	0.819	64	54.84	0.003
	%33<	64	61.31		64	63.75		64	74.16	
Altitude gropus (m)	900-1100	64	72.13	0.020	64	78.22	0.000	64	55.28	0.005
	1100-1300	64	56.88		64	50.78		64	73.72	
Aspect groups	Sunny	64	73.13	0.009	64	70.88	0.052	64	56.66	0.017
	Shady	64	55.88		64	58.13		64	72.34	

Table 3 shows that there was not a statistically significant difference between the slope groups on soil respiration values (p>0.05), while there was a statistically significant difference between the elevation and aspect groups (p<0.05). While there was no statistically significant difference between slope and aspect groups on soil temperature values (p>0.05), results showed a statistically significant difference between altitude groups (p<0.05). It was observed that slope, elevation and aspect groups had statistically significant differences on soil moisture values (p<0.05).

Some topographic changes, such as aspect and slope especially in mountainous areas, can effect soil moisture and temperature by altering solar radiation and rainfall (Berryman et al., 2015; Tian et al., 2019; Kang et al.,

2003). In our study, the slope factor did not affect soil respiration and temperature values but affected soil moisture values. Accordingly, it was determined that the 0-33% slope group had higher moisture values than the 33%< slope group. Soil moisture plays a critical role in hydrological processes by influencing infiltration, evaporation, erosion, and surface runoff, (Zhang et al., 2019) and it is also central to land management strategies addressing soil and water loss, geomorphological dynamics, and environmental conservation. Its spatial variability is largely shaped by climatic conditions, land use and vegetation cover, topography, and soil characteristics. On sloping land, surface runoff of water increases, which can lead to a decrease in soil moisture (Guo et al., 2020; Liu et al., 2019). As a result, although land slope does not directly affect soil respiration, it indirectly shapes soil respiration due to its effects on factors such as soil temperature, moisture, organic matter accumulation and erosion (Macit et al., 2021; Altunsu et al., 2021; Özbayram, 2006; Semercioğlu et al., 2023). This is thought to be due to the fact that in areas with low slopes (0–33%), the surface flow of water is slower, and rain and snow water can infiltrate the soil more and are retained in the soil for a longer time, resulting in higher soil moisture. Altitude groups were determined to affect soil respiration, temperature and moisture values. It was founded that respiration and temperature values were higher in the 900-1100 m elevation range than in the 1100-1300 m elevation group, while moisture values were higher in the 1100-1300 m elevation group. Land elevation is an important determinant of soil temperature and the processes occurring in the soil necessary for plant growth, and temperature values change with elevation (Onwuka & Mang, 2018; Wang et al., 2011). Elevation changes, vegetation composition, nutrients, soil properties, soil fauna and microbial activity influence soil respiration variation. In general, studies concur that soil respiration increases with altitude and that these results are an impact of increasing temperature. Typically, temperature decreases with altitude, so the altitude factor is widely used to assess the response of soil respiration to temperature (Rodeghiero & Cescatti, 2005). Studies indicate that CO_2 exchange between the soil and atmosphere varies with climate change, and that soil respiration's temperature sensitivity changes with elevation (Zhang et al., 2015; Luo et al., 2014). Finally, the aspect factor was effective on soil respiration and soil moisture. In the Northern Hemisphere, south-facing slopes receive more sunlight, which increases soil temperature (Shang & Liu 2024). Similar to our study, Keith et al. (1997) expressed in their study higher temperatures increase microbial activity and soil respiration but this increased the evaporation rate, leading to a decline in soil moisture.

The relationship between the silvicultural treatments (before/after tending, before/after regeneration) and the silvicultural treatments was determined by analyzing the data of soil respiration, temperature and moisture variables in the skidding trails with Kruskal Wallis test (Table 4).

Table 4. Significance relationship of variables with silvicultural treatments

Silvicultural treatment	Measuring points	Soil respiration				Soil temperature				Soil moisture			
		N	Mean Rank	df	P	N	Mean Rank	df	P	N	Mean Rank	df	P
Tending	Control	32	71.75	3	0.225	32	44.75	3	0.001	32	61.69	3	0.229
	Skidding trail (disturbed)	32	62.56			32	66.31			32	57.13		
Regeneration	Control	32	54.19			32	64.81			32	75.56		
	Skidding trail (disturbed)	32	69.50			32	82.13			32	63.63		

According to Table 4, it was determined that there was no statistically significant difference between silvicultural treatments and soil respiration and soil moisture

(p>0.05), while there was a statistically significant difference between them and soil temperature (p<0.05). Moroni et al. (2009) showed in their study that silvicultural treatments affect soil temperature, moisture and respiration rates. However, he stated that soil moisture levels (3.5-9.5 cm depth) are less important in explaining soil respiration rates because they do not change widely. This suggests that the effects of silvicultural treatments on soil respiration and moisture are limited. The significant relationship between the soil temperature values before and after the applied silvicultural treatments on the skidding trail is given in Table 5.

Table 5. Pairwise comparison of soil temperature values as a result of silvicultural treatments Mann-Whitney U test

Silvicultural treatments	Measuring points	Mean rank	Sum of ranks	P
Tending	Control	38.75	1240.00	0.007
	Skidding trail (Disturbed)	26.25	840.00	
Regeneration	Control	41.13	1316.00	0.000
	Skidding trail (Disturbed)	23.88	764.00	

When the relationship between silvicultural treatments and temperature was evaluated, results showed a statistically significant difference between the skid trails (disturbed) and the control points in the tending stands (p<0.05). Similarly, A statistically significant difference was found between the skidding trails (disturbed) and the control points in the regeneration stands (p<0.05) (Table 5). Kovács et al. (2018) investigated the effects of different silvicultural practices (e.g. clear-cutting, gap cutting) on microclimate and soil conditions in oak-hornbeam forests. The results show that clear-cutting increases air and soil temperatures, affecting soil moisture and other microclimate factors. Similarly, Nazari et al. (2021) investigated the effects of soil compaction due to mechanized wood harvesting on the physical properties of forest soils. The results show that compaction reduces soil porosity, which can disrupt forest ecosystem functions. These changes can lead to increased soil temperature and disruption of moisture balance. It can be thought that these situations are related to the fact that the areas vacated due to silvicultural treatments are exposed to more sunlight and the shading decreases. Again, during the skidding of the logs, the soil is compressed (compaction) and the organic upper layer (litter layer) is destroyed. When this layer is removed, the soil becomes more open to sunlight.

It was determined that differences in soil temperature between the control groups (undisturbed) and skidding trails (disturbed) in both tending and regeneration stands. In both stands, soil temperature values in the control group were observed to be higher than those in the skidding trail. Nilsen & Strand (2008) found that thinning affects soil respiration by directly changing soil temperature and moisture. Soils in skidding trails had lower mean values of soil microbial respiration than control areas. This is because soil compaction is higher in the treated areas (on skidding trails), and porosity is reduced, which restricts the movement of air and water. Microorganisms are stressed, and their respiration decreases, leading to a decrease in soil temperature (Goutal et al., 2012).

Conclusions

This study aimed to evaluate the effects of tending and regeneration applications, which are carried out to ensure the healthy and productive development of forest ecosystems, on soil respiration, moisture and temperature characteristics depending on the changes in log density in the skid trails. The study examined the effects of the skid trails in both tending and regeneration areas on soil respiration, temperature and moisture among two different slope, elevation and aspect groups. The results show that the slope groups do not significantly affect soil respiration and temperature, but they affect the moisture values. On the other hand, it was observed that the elevation groups significantly affect soil respiration, temperature and moisture. It was revealed that the aspect groups have an effect

that affects soil respiration and moisture but does not cause any temperature change.

It was found that there was no difference between respiration and moisture values before and after the treatment of the tending and regeneration areas, but the temperature values changed. In the tending stand, the soil temperature was higher on the skidding trail, while the temperatures of the control points were higher within the regeneration areas. In short, it was determined that silvicultural treatments were not significant factors in respiration and moisture values on the skidding trail. However, soil temperature was determined to be an effective factor for both silvicultural treatments. At the same time, elevation is an important topographical factor for all three soil properties.

Soil compaction (volume differences of the transported logs - due to the log numbers and heavy machinery -wheel pressure) was the main reason for the skidding trails due to the narrowing of the respiratory tract. As a result of different silvicultural treatments applied in forests in our country, determining the effects of log transportation on skid trails on soil properties is an extremely important issue. This study has revealed that silvicultural treatments do not have a direct effect on soil respiration, but topographic factors generally affect soil properties. More detailed information can be obtained in the field of forestry management and sustainability with more comprehensive studies to be conducted on this subject in our country, and significant contributions can be made.

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: Ç.Ö.G ; Investigation: Ç.Ö.G. and H.K.K.; Material and Methodology: Ç.Ö.G.; Supervision: Ç.Ö.G.; Visualization: Ç.Ö.G. and H.K.K.; Writing-Original Draft: Ç.Ö.G. and H.K.K.; Writing review & Editing: Ç.Ö.G., H.K.K.; and the authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

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