Ağaç ve Orman
Tree and Forest
https://dergipark.org.tr/tr/pub/agacorman

ISSN: 2757-5349
2023
4(1)
27-33
Araştırma Makalesi

Effects of pre-commercial thinning on soil respiration and some soil properties in black pine (*Pinus nigra* Arnold) stands

Karaçam (*Pinus nigra* Arnold) meşcerelerinde ayıklama kesimlerinin toprak solunumuna ve bazı toprak özelliklerine etkisi

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Gönderim Tarihi:
01/06/2023

Kabul Tarihi:
16/06/2023

Bu makaleye atıf vermek için:
Çömez, A., Kaptanoğlu, A. S. 2023. Karaçam (*Pinus nigra* Arnold) meşcerelerinde ayıklama kesimlerinin toprak solunumuna ve bazı toprak özelliklerine etkisi. Ağaç ve Orman, 4(1), 27-33.

Abstract
Forestry practices may cause significant changes in soil characteristics related to their properties and size. However, chemical attributes of the soil respond to the applications in the mid- or long-term while changes in soil respiration can react rapidly to forestry practices. Therefore, determining changes in soil attributes is needed to identify how the management practices would affect forest ecosystem function. Although there is much information on the effect of thinning practices on tree growth, there is a lack of knowledge on the impacts of pre-commercial thinning on soil properties, especially soil respiration. We aimed to determine pre-commercial thinning effects on some soil attributes in black pine sites. Four treatments with different intensities were applied to the stands studied. These practices were control (no pre-commercial thinning), 2000 (heavy), 4000 (moderate), and 6000 (light) individuals per hectare left. Measurements of soil respiration and soil temperature were carried out between 2014 and 2017 in the spring, summer, autumn, and winter months. Soil characteristics, including pH, organic matter, nitrogen, and phosphor content, were measured just after and three years after the thinning. As a result, thinning increased soil respiration rate and soil temperature while decreasing soil pH values. Results of the study showed that carbon balance in the ecosystem was significantly affected by thinnings, and adjusting the thinning intensity may be an efficient carbon management tool for reducing carbon emissions from the soil.

Key words: Carbon dioxide, emission, thinning, organic matter, nitrogen, phosphor.

Özet
Ormanlarda gerçekleştirilen teknik müdahaleler, özelliklerine ve boyutlarına bağlı olarak toprak özelliklerinde önemli değişikliklere neden olabilmektedir. Toprağın kimyasal özellikleri yapılan uygulamalara daha uzun sürede tepki gösterirken toprak solunumundaki değişim daha belirgin ve kısa sürede görülebilmektedir. Bu sebeple orman yönetim uygulamalarının orman ekosisteminin işlevlerini nasıl etkilediğinin ortaya konulması için toprak özelliklerindeki değişimin belirlenmesi gerekmektedir. Sözü edilen teknik müdahalelerden bakım kesimlerinin ağaç büyümesi üzerine etkisi konusunda çok fazla bilgi olmasına rağmen, toprak parametreleri, özellikle toprak solunumu üzerindeki etkileri hakkında bilgiler kısıtlıdır. Bu çalışma ile karaçam ormanlarında ayıklama kesimlerinin toprak özellikleri üzerindeki etkilerinin belirlenmesi amaçlanmış, 4 farklı şiddette ayıklama müdahalesi yapılmıştır. Bu müdahaleler sırasıyla kontrol (kesim yok), 2000 (kuvvetli), 4000 (orta) ve 6000 (zayıf) fert ha^{-1} kalacak şekilde uygulanmıştır. 2014-2017 yılları arasında örnekleme yapılmış ve ilkbahar, yaz, sonbahar ve kış aylarında her parselde toprak solunumu ve toprak sıcaklığı için 9 ölçüm yapılmıştır. Toprak özelliklerinden pH, organik madde, azot ve fosfor içerikleri ayıklamadan hemen sonra ve 3 yıl sonra ölçülmüştür. Çalışma sonucunda ayıklama kesiminin toprak solunumunu (Rs) ve toprak sıcaklığını arttırdığı, pH değerlerini ise azalttığı belirlenmiştir. Çalışma sonuçları orman ekosistemindeki karbon bilançosunun ayıklama kesimlerinden etkilendiğini ve topraktan meydana gelen karbon emisyonunun azaltılmasında ayıklama şiddetinin ayarlanmasının karbon yönetimi için önemli bir araç olabileceğini göstermektedir.

Anahtar kelimeler: Karbon dioksit, emisyon, sıklık bakımı, organik madde, azot, fosfor.

1. Introduction

Soil respiration (Rs) is one of the main sources which emits CO_2 to the atmosphere and is responsible for 25% of global CO_2 emissions (Schimel, 1995). Rs, which includes autotrophic and heterotrophic components and plays an essential role in the global carbon cycle (Schlesinger and Andrews, 2000), is the integrated result of underground processes and has been widely used to assess the effects of contribution to soil carbon pools (Keith et al., 1997; Concilio et al., 2005). Respiration of microorganisms, also called basal respiration, and plant roots living in the soil and the decomposition of organic substances cause the soil air to be enriched with CO_2 (Kantarcı, 2000). Rs is the release of carbon dioxide from plant roots and microbial activities into the atmosphere by changing under temporal and spatial factors (Akburak and Makineci, 2013). In many studies, the effects of soil environmental variables such as soil temperature and moisture, texture, pH, total carbon, and total nitrogen on soil CO_2 output have been well documented (Gough and Seiler, 2004). However, the effects of silvicultural treatments, such as thinning, are poorly understood.

Silvicultural interventions can significantly affect the forest ecosystem, changing the matter and energy flows. Therefore, Rs can be a valuable indicator of how forest management and practices affect forest ecosystem function (Bolat, 2019). Silvicultural thinnings increase throughfall, light, and temperature, affecting nutrient cycling in the forest ecosystem (Tolunay, 2003).

Rs rate varies among ecosystems and is often the dominant component of ecosystem respiration (Raich and Schlesinger, 1992). However, in arid and semi-arid ecosystems, it has been studied much less than in other ecosystems (Raich and Potter, 1995; Subke et al., 2006; Bond-Lamberty and Thomson, 2010), and therefore temporal and spatial Rs differences in these regions are less known. Irregular and low precipitation in arid and semi-arid regions has significant effects on Rs concerning seasonal and autotrophic-heterotrophic ecosystem processes, causing fluctuations in CO_2 release from soil to the atmosphere (Davidson et al., 1998; Rey et al., 2002, 2005; Jarvis et al., 2007). Other characteristics of arid and semi-arid regions are the wide spatial diversity and irregular distribution of resources, environmental conditions, roots, and microorganisms responsible for the decomposition of organic matter. All soil properties, such as rock fragments, earthworms, other micro and macro fauna, and biological residues, have significant effects on carbon dynamics (Rey et al., 2011).

The effects of tree harvesting from the ecosystem on Rs are inconsistent in the literature. Many authors reported that Rs increased as a result of thinning (Kaye and Hart, 1998; Selig and Seiler, 2004; Selmants et al., 2008), while others stated that it decreased (Kaye and Hart, 1998; Tang et al., 2005), or does not change (Toland and Zak, 1994). The inconsistency in Rs's response to thinning may be due to the nonsteady-state conditions of autotrophic and heterotrophic components (Yuste et al., 2007). For example, Rs may be decreased by thinning due to the death of respiratory tree roots (Pypker and Fredeen, 2003; Tang et al., 2005; Wiseman and Seiler, 2004) or increased with the rapid breakdown of these roots by soil microorganisms (Yuste et al., 2007) as well as the rapid root growth of new plants (Campbell et al., 2009). The decrease of stand density by thinning can affect the decomposition rate of organic matter and plant debris (Zhang and Zak, 1995, 1998) via changes in the microclimate conditions (Pang et al., 2013).

Massive carbon exchange occurs between terrestrial ecosystems and the atmosphere. Forests can mainly serve as pools for anthropogenic CO_2 emissions (Schimel, 1995). Much extensive research has been attempting to understand the carbon cycle and come up with the rising CO_2 level of the atmosphere. Several experiments on free-air CO_2 enrichment have been carried out over a wide range of ecosystems for more than 20 years. These researchers reported the increase in the carbon distribution in the underground depends on fine root growth (Matamala and Schlesinger, 2000; Zak et al., 2000), the increase in soil carbon inputs (Lichter et al., 2008), and the increase in Rs (Pregitzer et al., 2008).

Carbon accumulation in forest soils can potentially balance the CO_2 concentration in the atmosphere. Soil organic carbon typically represents 50% of the total ecosystem carbon in forests (IPCC, 2001) and, in some cases, reaches three times the carbon stored above ground (Eswaran et al., 1993). As a result, soil organic carbon plays a crucial role in the natural global carbon cycle.

In this study, the effects of pre-commercial thinning on Rs and some soil attributes were investigated, and pre-commercial thinnings of different intensities were hypothesized to affect soil differently.

2. Material and Method

This study was conducted in a black pine stand, which was in the sapling stage with a mean diameter of 4 cm and a mean height of 3 m in 2014 in Kütahya province of Turkey (39º23′24″-39º23′40″N; 29º03′40″- 29º03′58″E), and with an altitude of 1240 m and an average slope of 25%. The aspect of the study area is north. The study area has a continental climate, with hot, dry summers and cold, wet winters. It receives an annual average of 820 mm of precipitation, according to the data of the nearest meteorology station in Simav-Kütahya. The mean temperature ranges from 2.4 ºC in the winter to 21.8 ºC in the summer (Table 1). Soil is a non-calcerous luvisol, according to IUSS Working Group WRB (2015), which developed from granite with well-drained, moderately deep sandy loam and loamy sand (Table 2) and covered by mull-type humus.

The dimensions of the plots were 10×10 m and 15×15 m, including a minimum of 40 individuals, with a 5 m buffer zone. The measurements were conducted on 12 plots with (4 treatments x 3 replications). The treatments included control (no thinning), 2000 (heavy), 4000 (moderate), and 6000 (light) individuals left per hectare, respectively. Field measurements and sample collection were carried out between 2014 and 2017, in 3-6 months interval, due to the restriction of reaching the study site by snow cover. During the data collection campaign, a portable thermometer was used to measure soil temperature (Ts) in 10 cm soil depth.

Soil samples were collected to determine the soil properties from the Ah and Ael horizons of the soil profile by a steel cylinder with a 100 cm^3 in volume. Particle size distribution of the soil was determined by the hydrometer method, EC, and pH by the electrometric method by an EC meter and pH meter following the standards of TS ISO 11265 and TS ISO 10390, respectively. The organic carbon content of the soil was determined by Walkley-Black wet digestion method, organic matter content was calculated by multiplying organic carbon by 1.72, while nitrogen was by Kjeldahl using a TekaFos N analyzer and phosphor by Bray and Kurtz No 1 method using a spectrophotometer (Kacar 2012).

Soil respiration was determined by the gravimetric soda-lime method (Monteith et al., 1964; Grogan, 1998, Tüfekçioğlu and Küçük., 2004). Three chambers were installed on each plot just after placing the soda-lime specimen. The soda-lime specimens were recollected 24 hours after the installation from May 2014 to November 2017, with a total of 9 occasions, 3-6 months intervals considering the reaching conditions to the study field due to snow cover.

Table 1. The average precipitation (Pr, mm) and temperature (T, °C) in the study area.

Years	Parameters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total Pr Mean T
1937-2017	Pr	126.5	106.9	86.6	71.7	48.3	28.1	15.2	10.7	24.5	49.2	94.3	157.6	819.6
	T	2.4	3.3	6.3	10.7	15.1	19.0	21.8	21.5	17.5	12.6	8.0	4.4	11.9
2014	Pr	38.8	18.2	23.4	56.2	62.6	90.8	2.2	1.2	57.0	57.0	37.6	93.2	538.2
	T	6.2	6.6	7.9	11.9	15.0	18.7	22.9	23.6	17.7	13.3	8.8	7.6	13.4
2015	Pr	99.0	65.8	60.2	41.8	54.1	60.6	20.5	45.6	15.0	32.6	49.0	1.8	546.0
	T	2.3	4.0	7.0	8.9	16.7	17.5	22.7	22.5	20.6	14.1	9.7	2.6	12.4
2016	Pr	149.2	34.8	75.2	16.2	42.0	15.8	0.0	52.4	29.6	5.0	75.4	4.8	500.4
	T	2.0	8.5	8.5	14.4	14.7	21.1	23.4	23.0	18.2	13.2	7.8	1.1	13.0
2017	Pr	113.6	30.2	36.2	69.4	67.8	77.8	1.4	35.4	3.4	44.8	53.8	66.8	600.6
	T	0.0	4.8	8.2	10.8	14.9	19.1	22.9	21.9	19.4	12.2	7.9	6.7	12.4

Table 2. Some soil characteristics of the study site in 2017.

Horizon	Bulk Density ($g\ cm^{-3}$)	Texture	pH	Organic Matter (%)	EC ($mS\ cm^{-1}$)	Nitrogen (%)	Phosphor ($mg\ kg^{-1}$)
Ah	1.00 ±0.20	Sandy loam- Loamy sand	5.71±0.14	5.44 ±1.55	0.04 ±0.01	0.18 ±0.04	52.54 ±29.10
Ael	1.14 ±0.14	Sandy loam- Loamy sand	5.68 ±0.12	3.62 ±1.16	0.03 ±0.01	0.13 ±0.04	66.42 ±44.27

The effects of pre-commercial thinning applied at the different intensities on respiration and the time-dependent changes was evaluated by repeated measure ANOVA. Treatments were evaluated as a between-subject factor in repeated measures ANOVA to determine the differences within the thinning intensity. The mean annual respiration rates of the treatments were calculated by the mean of the periods. The mean respiration rates of the treatments for each year were evaluated by one-way ANOVA. All respiration data showed normal distribution. Therefore, no data transformation was needed. According to ANOVA results, the means separation test of the Duncan test was used for variables that were found to have a treatment effect, and the results were evaluated differently at the $\alpha = 0.05$ level (Özdamar, 2002).

3. Results

The highest Rs were observed in moderate thinning, except for November, September and November in 2015 and September in November 2017. Soil respiration changed from 0.35 g C m^{-2} d^{-1} in moderate thinning in September 2017 to 4.43 g C m^{-2} d^{-1} in June 2015. Variation in Rs among the measurement terms and treatment was significant at a level of $P<0.001$ and $P<0.05$, respectively. A decreasing trend was observed for Rs along the study period (Figure 1). Rs in the spring (in May or June) were higher than in the autumn and winter (in November and February) (Table 3). Soil temperature increased with thinning with a significant increase in May 2016, September 2016, and May 2017, with the lowest values in control (Table 3). The mean annual soil respiration rate changed between 4.85 and 6.02 t C ha^{-2} $year^{-1}$.

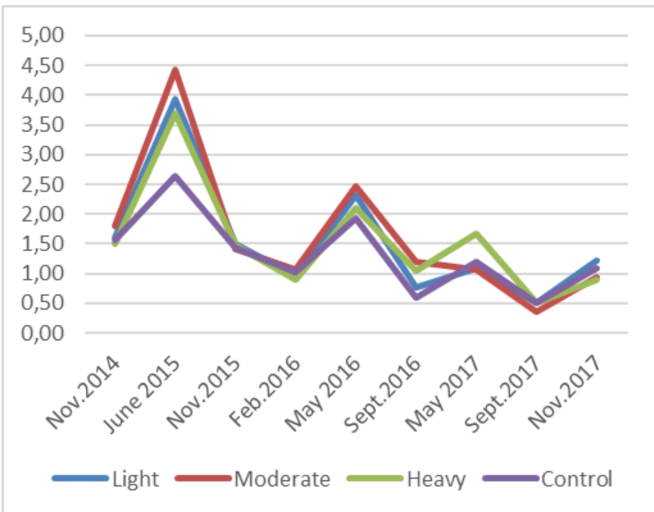

Figure 1. Soil respiration rates of the treatments. Changes in soil respiration (g C m^{-2} day^{-1}) among the measurement terms is significant at a level of $P< 0.001$.

No significant variation in soil chemical parameters measured was found among the treatments, except the pH of Ael horizon. Lower pH values were measured in the treatment parcels compared to the control (Figure 2).

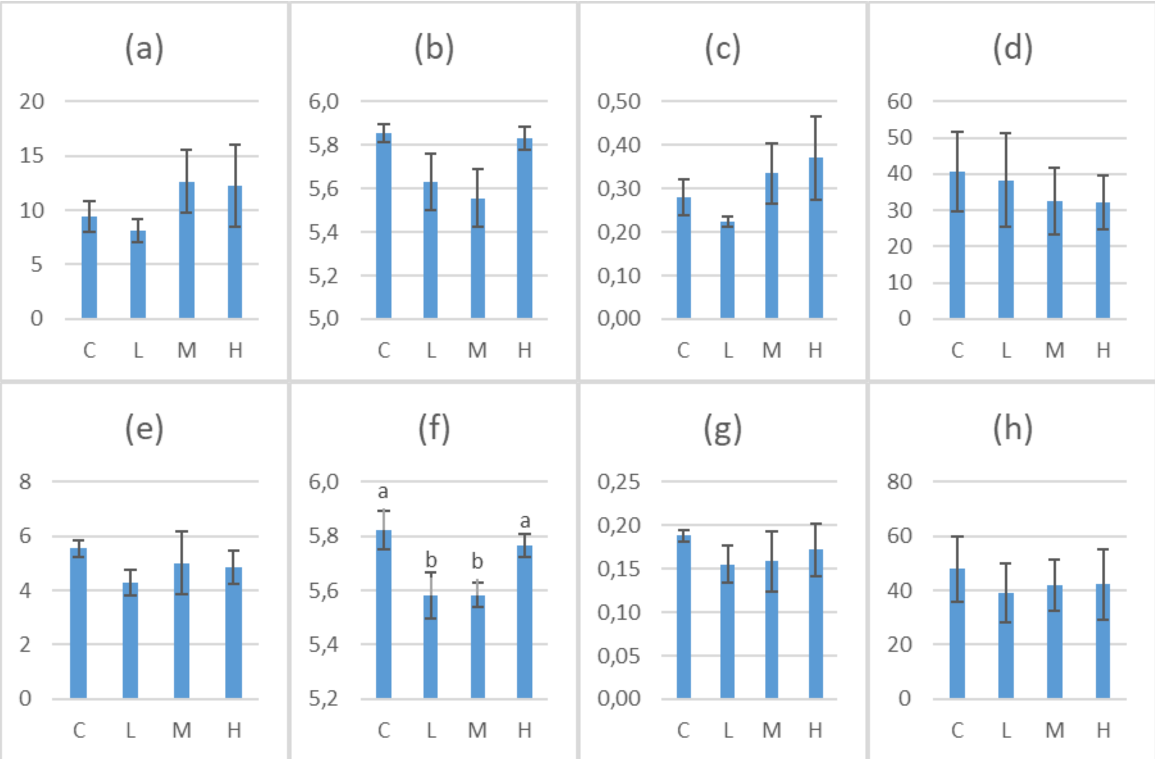

Figure 2. Some soil chemical attributes of the treatments. C, L, M, and H in the X-axis donate control, light thinning, medium thinning, and heavy thinning, respectively. (a) Organic matter content of Ah horizon (%), (b) pH of Ah horizon, (c) Nitrogen content of Ah horizon (%), (d) Phosphor content of Ah horizon (mg kg^{-1}), (e) Organic matter content of Ael horizon (%), (f) pH of Ael horizon, (g) Nitrogen content of Ael horizon, (%) Phosphor content of Ael horizon (mg kg^{-1}). The difference in pH of the Ael horizon was significant at a level of 0.05 and different groups were shown with different letters. Error bars indicate the standard error of the mean.

Table 3. ANOVA results for the thinning effects on soil respiration rate (Rs) and soil temperature (Ts) (Means ± se).

Parameters	Practices	Nov 2014	Jun 2015	Nov 2015	Feb 2016	May 2016	Sep 2016	May 2017	Sep 2017	Nov 2017
	Control	1.57±0.06a	2.64±0.06b	1.44±0.13a	1.03±0.03a	1.92±0.13a	0.59±0.02c	1.19±0.08b	0.51±0.04a	1.10±0.09a
Rs	Light	1.61±0.08a	3.93±0.06a	1.49±0.08a	0.95±0.07a	2.31±0.25a	0.78±0.01b	1.08±0.04b	0.52±0.04a	1.23±0.20a
g C m^{-2} d^{-1}	Moderate	1.80±0.21a	4.43±0.66a	1.40±0.05a	1.08±0.12a	2.47±0.18a	1.19±0.10a	1.68±0.04a	0.35±0.03b	0.95±0.29a
	Heavy	1.50±0.07a	3.70±0.12ab	1.48±0.07a	0.90±0.02a	2.11±0.08a	1.04±0.03a	1.08±0.10b	0.51±0.05a	0.89±0.04a
	P	*>0.05*	<0.05	*>0.05*	>0.05	>0.05	<0.001	<0.001	<0.05	*>0.05*
	Control	2.87±0.19a	11.93±1.68a	6.87±0.15a	4.80±0.26a	9.27±0.13b	15.40±0.21b	10.13±0.26b	20.70±0.60a	2.30±0.15a
Ts ºC	Light	3.12±0.30a	13.80±0.17a	6.93±0.09a	4.77±0.12a	10.17±0.12a	15.33±0.23b	10.57±0.09ab	21.00±0.17a	2.33±0.18a
	Moderate	3.10±0.21a	13.97±0.24a	6.60±0.30a	4.53±0.48a	10.50±0.62bb	16.23±0.52ab	11.20±0.46a	20.40±0.31a	2.57±0.27a
	Heavy	2.87±0.32a	14.50±0.23a	6.63±0.03a	4.80±0.20a	11.50±0.25a	17.00±0.40a	11.40±0.06a	21.40±0.15a	2.33±0.30a
	P	*>0.05*	*>0.05*	*>0.05*	*>0.05*	*<0.05*	*<0.05*	*<0.05*	*>0.05*	*>0.05*

*Different letters on same columns show different groups

4. Discussion and Conclusions

Soil respiration results of the present study are comparable with the results reported by Akburak and Makineci (2013), who found a range of Rs of 0.39-2.24 $m^{-2}d^{-1}$ for a *Pinus nigra* plantation in İstanbul. On the other hand, Tüfekçioğlu and Küçük (2004) reported a relatively lower Rs in May for *Picea orientalis* stands in a humid region, with a range of 0.59 to 1.13 g C $m^{-2}d^{-1}$. However, their Rs values in August were similar to our results in November, likely due to the effect of climatic conditions. On the other hand, thinning resulted in an increase in Rs in June 2015 and September 2016 in the present study, as reported by Yang et al. (2022), who found soil respiration between 0.63 and 6.72 g C m^{-2} d^{-1} which is in line with the results found in the current study. In addition, Zhang et al. (2022) reported that thinning increased Rs by 32% in a C*unninghamia lanceolata* plantation in southeastern China, which is lower than the present study, with a mean increase of 66% in June 2015 as a result of medium thinning compared to the control.

Higher Rs in the treatments than the control might be attributed to the accelerated litter decomposition rate due to increased moisture and temperature in a forest stand. Thinning decreases the interception capacity of the tree canopy while increasing rainfall reaches the forest floor (Cheng et al., 2020). In a variety of development stages (young, pole, mature) of forests, maintenance treatments such as thinnings lead to an increase in rainfall, light, and the temperature reaching the ground, a decrease in water consumption, and thus a change in the humidity-temperature relationship in the soil (Tolunay, 2003). According to the findings of this study, heavy thinning was observed to be beneficial in keeping the CO_2 emission caused by soil respiration at the lowest level. A reduced live plant root due to thinning will lead to decreased root respiration in heavily thinned areas (Yuste et al., 2007), and soil respiration levels will close to the control site. It was reported that CO_2 emissions from the soil might be reduced by thinning due to the reduction in subsurface autotrophic respiration, which is greater than heterotrophic respiration (Sullivan et al., 2008; Ryu et al., 2009). In the present study, moderate and light treatments might encourage the formation of new plants, and their respiration levels that increase with root respiration were higher than those in control (Campbell et al., 2009).

Akburak and Makineci (2016) found that thinning had an effect only in the first year on soil respiration in a hornbeam forest in Istanbul. This change is in the direction of increasing soil respiration by removing trees from the system, as in our study. Thus, high respiration levels in the thinned plots might follow a decreasing trend over the years in this study. With an increase in thinning intensity, soil respiration may decrease with the death of breathing tree roots (Yuste et al., 2007). Still, it may increase with the rapid breakdown of these roots by soil microorganisms or the respiration of the fast-growing small roots of new plants (Campbell et al., 2009; Yang et al., 2022). On the other hand, as the stand canopy grows more rainfall and sunlight would be captured by the tree crown, which in turn, causes to decrease in microbial activity, one of the main sources of soil respiration, due to less temperature and moisture.

Global soil respiration rates correlate positively with annual temperature and precipitation (Raich and Schlesinger, 1992). The results of the present study confirmed that relationship. The increase in the soil temperature with thinning is likely because of the canopy reduction, thus more energy and rainfall reaching the forest floor, notably in the spring and autumn months (del Campo et al., 2022).

The minimum levels of Ts were observed in control areas. As the litter layer acts as a buffer in control areas, soils in the release cut area will likely not have warmer and drier conditions than those under control (Callaham et al., 2004; Epron et al., 2004). The respiration rate correlation with soil temperature was consistent with the literature (Yilmaz and Bilgili 2018).

Again, it is possible to make some generalizations about annual soil respiration. When evaluating the study results annually, the highest emission levels were produced from moderate (6.02 t C ha^{-1} $year^{-1}$) thinning, while the heavy thinning had the lowest emission after control plots (5.6 t C ha^{-1} $year^{-1}$). Although Zhang et al. (2022) reported a higher soil respiration rate with a mean of 13.9 t C ha^{-1} $year^{-1}$ for an unthinned conifer forest in China, our results were close to global soil respiration data of 6.8 t C ha^{-1} $year^{-1}$ for temperate conifer forests, reported by Raich and Schlesinger (1992).

Thinning affected only the pH of mineral soil significantly in the current study. Other chemical properties were not affected evidently in a three-year period. However, differences in the organic matter, nitrogen, and phosphor content indicated that the effects of thinning on soil chemical properties would become more evident in the longer term. Soil pH of the Ael horizon was decreased significantly by thinning, which may be related to the increase in rainfall reaching the floor resulting in the leaching of cations from the soil (Kantarcı, 2000). Heavy thinning increased pH compared to light and moderate thinning, likely due to higher organic matter mineralization. Similarly, Lin et al. (2022) reported that soil pH value increased with an increase in forest canopy openness in *Cunninghamia lanceolata* (Lamb.) Hook.) plantations in China.

As a result, to minimize CO_2 emissions from soil respiration, heavy pre-commercial thinning may be an effective tool for forest sites in ecological conditions similar to our study site for carbon-focused forest management. However, heavy thinning may reduce aboveground biomass, decreasing total carbon stock in the ecosystem. Although a decline in biomass carbon pool occurs just after the cutting, logging residues left at the site and growing trees may somewhat compensate for this decline. Nevertheless, there is a need for further research on the loss and gain in carbon stock.

In this study, Rs measurements were carried out for extended periods due to climate limitations. Shorter sampling intervals along the year would likely reduce the uncertainty of the annual CO_2 emission. Furthermore, the role of the soil microbial community on Rs remained unclear in this study. Therefore, the effects of temperature rise due to thinning on soil enzymes, microbial carbon, and fauna diversity should be investigated to understand better the factors behind the changes in CO_2 flows in the ecosystem. On the other hand, this study was carried out in a sapling stage forest. Therefore, the results might not be generalized to further stages of the stands, indicating another research need for future changes in Rs and other soil properties.

Acknowledgement: This study was supported by the General Directorate of Forestry, Research Institute for Forest Soil and Ecology within the project numbered ESK-22(6317)/2014-2017/2018.

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