

Effects of land management practices on soil organic carbon, nitrogen, and carbon mineralization in the Tarsus–Karabucak Eucalyptus forest

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Abstract

Soil carbon mineralization is a key indicator for assessing how the soil carbon cycle responds to changes induced by land management practices in natural and managed ecosystems. This study aimed to determine the effects of different management practices on soil organic carbon (SOC) content, total nitrogen (TN) content, and carbon mineralization across seven periods over two years. Three land management practices were applied in *Eucalyptus camaldulensis* Dehn. plantations established on soils with high clay content in the Tarsus-Karabucak forests: uncut (UC), chainsaw cut without tillage (CNT), and chainsaw cut followed by tillage (CT). SOC content was significantly affected by land management practices and time periods. SOC content in CT was lower than in CNT and UC across all periods. In general, land management practices did not have significant effects on TN content. Cumulative carbon mineralization was significantly affected by land management practices and periods and ranged from 11.99–16.88 in CT, 13.63–18.52 in CNT, and 16.18–18.69 mg C (CO₂) 100 g⁻¹ soil in UC after 30 days of incubation. Cumulative carbon mineralization was highest in UC in all periods, while CNT was generally higher than CT (CT < CNT < UC). In conclusion, both cutting practices affected SOC, cumulative carbon mineralization, and the mineralization rate, whereas no effect on soil TN content was detected in the Tarsus-Karabucak Eucalypt plantation. Cutting trees followed by tillage or no-tillage has reduced soil microbial activity but has increased the rate of carbon mineralization.

Keywords: Alluvial soil, Carbon mineralization, Cutting, Soil microbial activity, Tillage

INTRODUCTION

Soil organic carbon (SOC) is Earth's largest carbon pool and plays a key role in regulating atmospheric CO₂ concentration (Meinshausen et al., 2009). SOC not only serves as a vital reservoir for carbon sequestration but also provides essential nutrients to plants and soil microorganisms through the mineralization of organic matter (Marinari et al., 2010; Kocak and Darici, 2016). The mineralization process is highly sensitive to environmental factors such as temperature, moisture, and land management practices (Kocak, 2022; Schlüter et al., 2022; Sharma et al., 2025). CO₂ efflux to the atmosphere is controlled by the mineralization of SOC, which determines changes in atmospheric CO₂ concentration; and it is believed to be closely associated with global warming (Burney et al., 2010; Bradford et al., 2016). Climatic parameters (e.g., precipitation and temperature), anthropogenic controls (e.g., land use and management practices), soil characteristics (e.g., texture, SOC, and TN), and biological characteristics (e.g., biomass production and microbial abundance) affect SOC storage processes and losses (Patel et al. 2021; Kocak and Darici, 2022).

The conversion of natural ecosystems to agricultural areas can decrease SOC and TN content due to land degradation. (Awoonor et al., 2022; Xiao et al. 2024). Maximizing belowground carbon storage in forest ecosystems through sustainable management practices requires an understanding of the relationships between management practices and soil biogeochemical processes (Chatterjee et al., 2008). Forest management practices could affect quantity and quality of SOC, ratio of carbon mineralization, as well as soil microbial community structure in a positive or negative way (Mayer et al., 2020). It has been reported that deforestation and agricultural management practices can reduce soil organic carbon by up to 50% in the topsoil (<30 cm) compared to undisturbed forest soils (Veldkamp et al., 2020). Also, Wisniewski and Marker (2021) reported that

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SOC was significantly lower in agricultural soils than in forest soils. Low physical protection of soil organic matter by tillage can explain the degradation of SOC, as soil disturbance increases the exposure of previously protected organic matter to microbial decomposition, particularly in the forest floor and upper mineral soil layers (Balesdent et al., 2000; Murty et al., 2002; Mayer et al., 2020). Besides heavy soil tillage, also temperature and soil moisture can affect microbial population and activity with consequences on organic matter decomposition rates, eventually increasing or reducing CO₂ release to atmosphere (Gao et al., 2020; Sharma et al., 2025). Moscatelli et al. (2007) reported that the effects of land-use and land-management practices on TN and the soil C/N ratio varied; however, they found that land-management practices did not affect C mineralization. Tracy et al. (1990) compared no-tillage and conventional tillage to determine their impacts on C and N mineralization, and reported that tillage did not affect net C and N mineralization at soil depths below 5 cm. Beheshti et al. (2012) investigated the effects of lowland and upland farming on soil physical and chemical properties in forest ecosystems, including SOC and TN levels and their dynamics, and reported that forest clear-cutting and tillage practices decreased SOC and TN content. In contrast, Xu et al. (2009) conducted a laboratory incubation test to study organic matter mineralization in gray forest soils following land-use conversion and reported that conversion from wildwood land to farmland decreased SOC by 68.5% and 76.8% and TN by 40.5% and 44.4% in the 0–10 cm and 10–20 cm soil layers, respectively. The mineralization rate and cumulative carbon mineralization in farmland were 24.4%–43.2% and 9.20%–13.7%, respectively, of those in wildwood land.

Many studies have reported uncertainties in carbon stocks and decomposition and have indicated that deforestation, such as conversion of forests to farmland, is the most important factor driving carbon efflux into the atmosphere. It is known that carbon stocks held in trees through photosynthesis are greater than those in equivalent areas under arable crops, but 25–30% of the carbon in the soil is lost through land management practices compared with a natural ecosystem (Lal, 2005). In particular, the accuracy of the estimated terrestrial carbon balance is limited by uncertainties in the current rate of deforestation and the dynamics of areas not normally censused (Houghton and Goodale, 2013).

Current studies reinforce the understanding that land management practices, particularly those involving tillage, can significantly alter soil carbon dynamics. The balance between maintaining soil carbon stocks and meeting land-use demands requires carefully designed management strategies to mitigate adverse environmental impacts.

Three land management practices were applied in *Eucalyptus camaldulensis* Dehn. plantations in the Tarsus Karabucak forests: uncut (UC), chainsaw cut without tillage (CNT), and chainsaw cut followed by tillage (CT). Soil chemical and physical properties, including SOC, TN, and carbon mineralization, were measured every three months; sampling was not conducted in winter because of excessive drainage. The study aimed to assess the short-term effects of different management practices (clear-cutting with and without tillage) on SOC, TN, and soil carbon mineralization, an indicator of soil microbial activity, in *Eucalyptus camaldulensis* plantations in the eastern Mediterranean region of Türkiye. We hypothesized that clear-cutting with or without tillage would reduce SOC and TN by decreasing plant residue inputs and causing physical disturbances, leading to an increased rate of carbon mineralization.

MATERIALS AND METHODS

Study Area

The study was conducted in the *Eucalyptus* plantations of the Tarsus-Karabucak Forest Department (885 ha) located in Mersin, Turkey (36°53'N, 34°52'E). The study site is located at an elevation of approximately 10 m a.s.l. and is characterized by a humid Mediterranean climate. The site lies within a Mediterranean climate zone, with an average annual precipitation of 668.8 mm. July and August are typically the hottest months, with mean daily temperatures of 28.2 and 28.7 °C, respectively (Koc and Topaloglu-Paksoy, 2025). This climate type is characterized by extremely hot summers and mild winters. The study area is located on alluvial (azonal) soils. These are young AC-profile soils, formed on materials transported and deposited by rivers. The heterogeneity of their mineral content results from the lithological composition of the river basin and the erosion and deposition processes occurring during geological periods of soil development. Soil horizons in these profiles are absent or poorly developed. The alluvial soils in the study area are dark brown and mainly classified as the Karabucak series (Eutric Histosol). The area has drainage problems due to a high groundwater level (Dinc et al., 1995). Because of its economic and ecological properties and its rapid growth, *Eucalyptus* was chosen in the Mediterranean region of Türkiye for the restoration of degraded areas and for use in agroforestry systems. The Total eucalyptus plantation area in Türkiye was 2,419 ha as of the end of 2023 (FAO, 2024).

Soil Sampling and Analyses

Three land-management practices were chosen for 5-year-old *Eucalyptus* trees in this study: (1) Uncut (UC), (2) Chainsaw cut with tillage (CT), and (3) Chainsaw cut with no tillage (CNT). At the study site, 20 m × 20 m plots were established for each application, with three replicates. *Eucalyptus camaldulensis* was planted at 3.25 × 3.25 m spacing on a total area of 1 ha. Only CT was tilled at six-month intervals. Soil samples were collected at a depth of 0–20 cm in October (initial sampling), and subsequently in April, July, and October across seven sampling periods over two years. Because of severe drainage problems and high groundwater levels, soil samples could not be collected during winter. The collected samples were placed in plastic bags and transported to the laboratory, where roots, stones, and other extraneous materials were carefully removed by hand. The samples were then air-dried and sieved through a 2-mm mesh prior to physical and chemical analyses.

The following soil properties were determined according to Kacar (2016): Soil texture was analyzed using the Bouyoucos hydrometer method. Field capacity (%) was estimated at one-third of atmospheric pressure using a vacuum pump. Soil pH was measured potentiometrically in a 1:2.5 soil-to-water suspension, while the calcium carbonate (CaCO_3) content (%) of the soil was measured using a Scheibler calcimeter. Organic C and TN contents of soils were determined using a Thermo Scientific Flash 2000 CN Analyzer. All analyses were performed in triplicate. The initial values of soil carbon and nitrogen contents and other soil properties, of the Karabucak soil series were analyzed, and some chemical and physical properties are presented in Table 1.

Table 1. Some physical and chemical characteristics of soils under *Eucalyptus camaldulensis* plantations

	CT		CNT		UC	
Clay (%)	55.87	±0.52	58.23	±0.76	53.07	±1.24
Silt (%)	30.97	±0.47	27.83	±0.67	31.93	±1.37
Sand (%)	13.17	±0.23	13.93	±0.23	15.00	±0.32
Texture Type	C (Clay)					
FC (%)	52.96	±1.05	53.81	±1.19	44.30	±0.85
CaCO_3 (%)	15.07	±0.18	16.63	±0.09	18.76	±0.74
pH	7.83	±0.04	7.89	±0.06	7.87	±0.04
SOC (%)	2.65	±0.24	2.93	±0.08	3.16	±0.04
TN (%)	0.27	±0.04	0.30	±0.01	0.32	±0.03
C/N	9.91	±0.42	9.87	±0.16	9.93	±0.54

UC: Uncut, CNT: Chainsaw cut with no tillage, CT: Chainsaw cut followed by tillage, FC: Field capacity SOC: Soil organic carbon, TN: Total nitrogen C/N: Ratio of C/N

Soil Carbon Mineralization

Carbon mineralization was determined under controlled laboratory conditions by monitoring microbial CO_2 evolution following the respiration technique outlined by Schaefer (1967). Soil subsamples were incubated in airtight 750 mL glass jars. Prior to incubation, soil moisture was adjusted to 80% of each soil's field capacity, and samples were maintained at a constant temperature of 28 °C for 30 days. Microbially produced CO_2 was absorbed by 40 mL of saturated barium hydroxide [$\text{Ba}(\text{OH})_2$] solution, which was placed in an open container inside each incubation vessel. The accumulated CO_2 was quantified at 3-day intervals by titration with oxalic acid, using phenolphthalein as the indicator. Blank jars without soil were included to correct for background CO_2 . Carbon mineralization (%) was calculated as the proportion of cumulative CO_2 -C evolved during the incubation period relative to the initial soil organic carbon content.

Statistical Evaluation

All statistical analyses were performed using IBM SPSS Statistics v.19.0. A two-way analysis of variance (ANOVA) was used to test the effects of period, management practices (CT, CNT, UC), and their interactions on SOC, TN, and carbon mineralization. Tukey's honestly significant difference test was performed for multiple comparisons of means. Statistical differences were considered significant at $P < 0.05$. All results are presented in the figures as means $\pm$ standard errors calculated from three independent replicates.

RESULTS

Seasonal soil organic carbon and total nitrogen comparison in treatments

In CT, SOC and TN contents ranged from 2.12% to 2.77% and from 0.19% to 0.32%, respectively. No significant differences were found between the SOC content of CT and that of each period; however, for TN content, a significant difference was observed between Jul.10 and Apr.11 (Figure 1). In CNT, SOC and TN contents ranged from 2.66% to 3.73% and from 0.20% to 0.35%, respectively. Significant differences were found in SOC content between Oct.10 and Jul.11 and between Oct.10 and Oct.11, and in TN content between Apr.10 and Jul.11. In UC, SOC and TN contents ranged from 2.76% to 4.40% and from 0.18% to 0.33%, respectively. Statistically significant differences were observed in SOC content in Apr.10 compared with all months except Oct.10. Similarly, the TN content in Oct.10 differed significantly from that in Apr.11, Jul.11, and Oct.11. SOC and TN contents decreased in 2011 compared to 2009–2010, but the differences were not statistically significant (Figure 1).

The SOC content in CT was lower than in CNT and UC in each comparison among applications across all sampling periods, while significant differences between CT and CNT, and between CT and UC were observed only in Apr.10 and Oct.10. However, TN content remained stable across sampling periods, with no significant differences among periods (Figure 1).

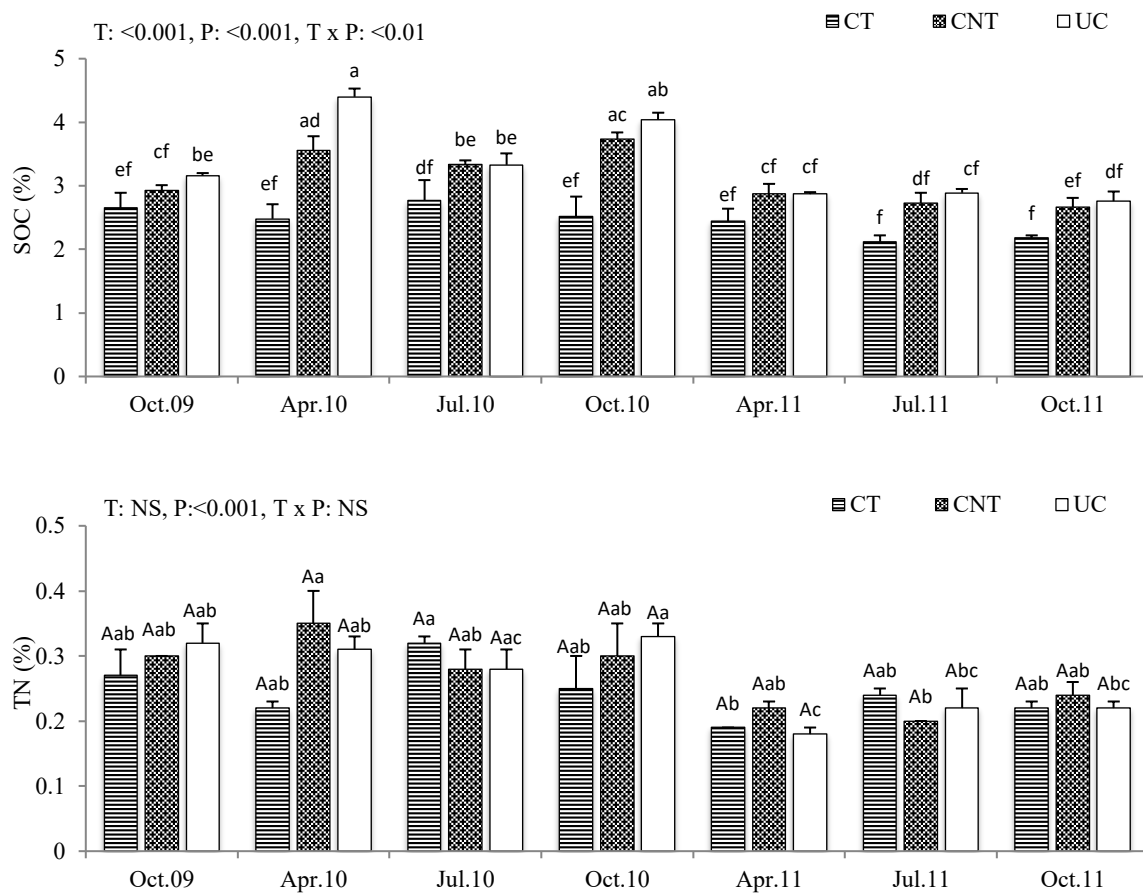


Figure 1. Organic carbon and total nitrogen of soils between Oct.09 and Oct.11. UC: Uncut, CNT: Chainsaw cut with no tillage, CT: Chainsaw cut followed by tillage, T: Treatment, P: Period. Different letters denote significant differences in SOC ($P < 0.05$). Different uppercase letters denote statistically significant differences among treatments, whereas different lowercase letters indicate significant differences between sampling periods for TN ($P < 0.05$). NS indicates non-significant differences. Values are expressed as means $\pm$ SE ($n=3$).

Cumulative soil carbon mineralization and their rates

Cumulative carbon mineralization ranged from 11.99 (Jul.10) to 16.88 (Oct.10) in CT; from 13.63 (Jul.10) to 18.52 (Apr.10) in CNT; and from 16.18 (Jul.10) to 18.69 (Oct.10) in UC (Figure 2). In general, CT had the lowest and UC had the highest cumulative carbon mineralization across all periods, whereas CNT had higher cumulative carbon mineralization than CT and were similar to UC ($CT < CNT < UC$).

Seasonal comparisons for each application within their respective periods were as follows: In CT, Jul.10 differed significantly from all other months, and Jul.11 differed significantly from Oct.10. In CNT, Oct.09 and Apr.10 were significantly higher than in all other periods, while no significant differences were found among months. Jul.10 was the lowest among the periods, and there were significant differences between Jul.10 and all periods except Apr.11. Significant differences were found between Jul.11 and Oct.11. In UC, significant differences were found between Jul.10 and all periods except Apr.11, while significant differences were found only between Oct.10 and Apr.11.

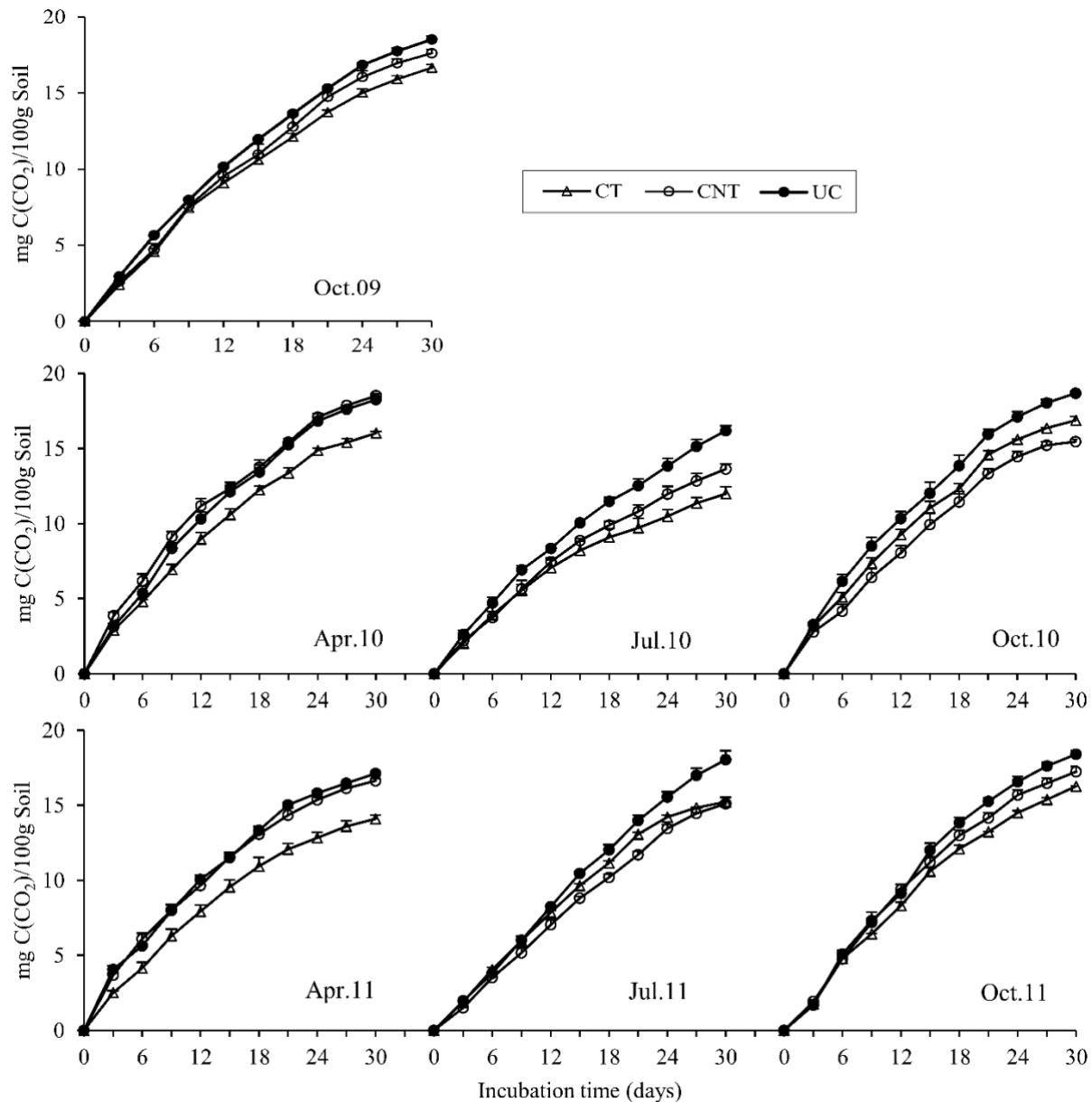


Figure 2. Cumulative carbon mineralized in the all applications (UC: Uncut, CNT: Chainsaw cut with no tillage, CT: Chainsaw cut followed by tillage) for each period (mean value $\pm$ SE, n=3)

Comparisons of all applications within each period were as follows: In Oct.09, UC was significantly higher than CT. In Apr.10, CT was significantly lower than CNT and UC. In Jul.10, CT and CNT were significantly lower than UC. In Oct.10 UC was significantly higher than CT and CNT. In Apr.11, CNT was significantly lower than UC. In Jul.11, CT and CNT were significantly lower than UC. In Oct.11, CT was significantly lower than UC. (Figure 3).

Carbon mineralization rates ranged from 0.45% (Jul.10) to 0.75% (Oct.11) in CT, from 0.41% (Jul.10) to 0.65% (Oct.11) in CNT, and from 0.42% (Apr.10) to 0.67% (Oct.11) in UC. In all applications, rate of carbon mineralization were highest in Oct.11, and CT was higher than CNT and UC in all periods (Figure 3). Seasonal comparisons of carbon mineralization rates were as follows: In CT, Jul.10 was significantly lower than all other months. In CNT, Oct.09 was significantly higher than Jul.10 and Oct.10, while Oct.11 was significantly higher than Oct.10. In UC, Apr.10 was significantly lower than Jul.11 and Oct.11. Comparison of carbon mineralization rates of applications within each period were as following: CT was significantly higher than CNT and UC in Apr.10 and Oct.10 while no significant differences were found between CNT and UC in Apr.10.

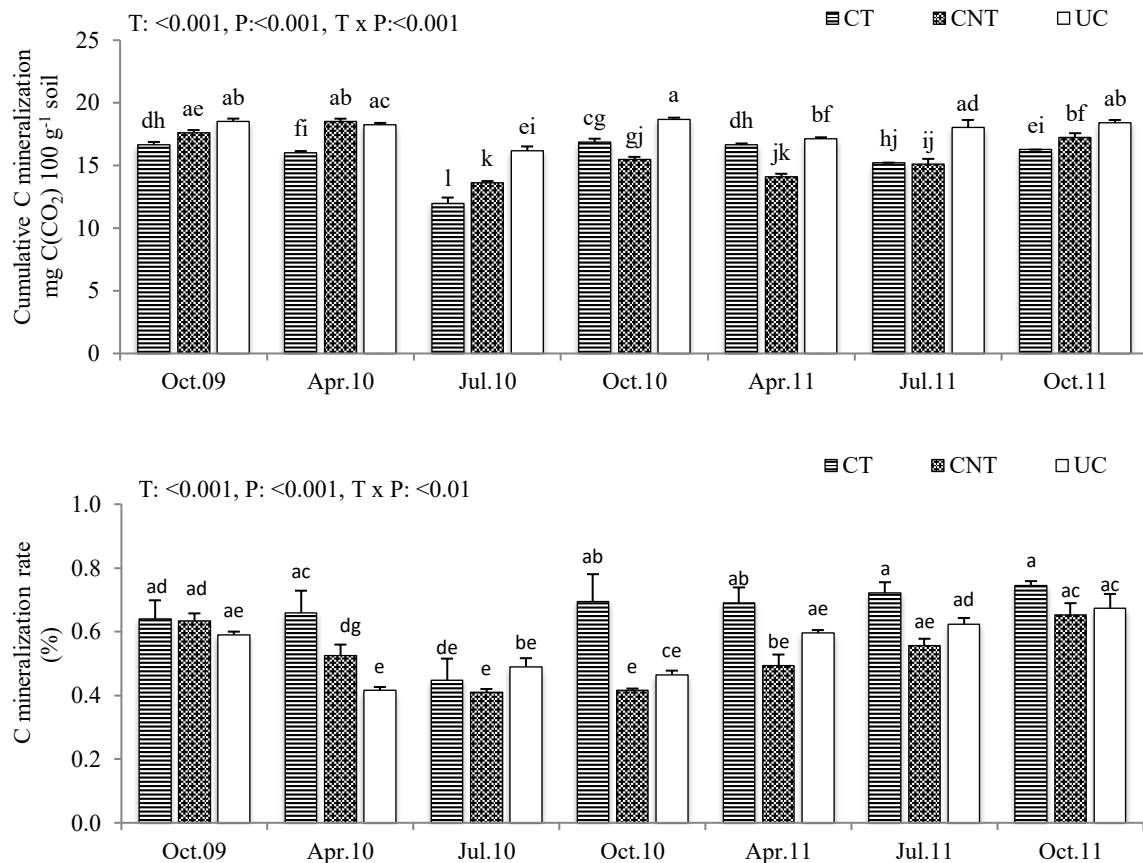


Figure 3. Cumulative C mineralization and the rate of C mineralization in all applications for each season at 28°C over 30 days. UC: Uncut, CNT: Chainsaw cut with no tillage, CT: Chainsaw cut followed by tillage. T: Treatment, P: Period. Different letters denote significant differences ($P < 0.05$). Each bar represents the mean value $\pm$ SE ($n = 3$).

DISCUSSION

Soil carbon, one of the main components of soil organic matter, plays a vital role in many physical, chemical, and biological processes in soil ecosystems (Gerke, 2022). Soil carbon storage in forest ecosystems contains 80% of aboveground terrestrial carbon and 70% of all soil organic carbon (Batjes, 1996). Therefore, Changing the amounts of detrital organic matter and soil respiration to the atmosphere through intensive management practices such as cutting and tillage may have important effects on ecosystem functions, atmospheric chemistry, and global climate (Jandl et al., 2007). Many studies have indicated that forest management practices affect only the surface soil and that soil carbon levels are balanced within 20 years after harvest (Buchholz et al., 2014).

In this study, SOC content was lower in both CT and CNT than in UC across all sampling periods, while TN content showed a stable trend across sampling periods in all land management practices. Wen et al. (2016) compared the effects of clear-cutting and uncut stands in *Pinus* plantations on SOC and TN dynamics and reported that SOC was higher in unharvested areas than in harvested areas, but soil TN was similar in both treatments. Their findings were consistent with the results of this study. A meta-analysis study determined that harvesting and biomass removal treatments significantly reduced SOC, and the effect of these treatments on TN was smaller than the effect on SOC (James et al., 2021). Dore et al. (2016) also reported that SOC was 26% lower in harvested areas than in uncut areas in the two years following clear-cutting. Maquere et al. (2008) investigated the effects of different management practices and land-use change in pasture and *Eucalyptus* plantations on SOC and TN stocks and reported that land-use change increased SOC stocks by 15–25% in the 0–30 cm soil layer. Tesfaye et al. (2016) compared carbon and nitrogen stocks across four land-use types, including natural forest, tree plantations, cropland, and degraded land. Their findings showed that, on average, native forests had 84.4%, 26.4%, and 33.7% higher carbon stocks, and 82.4%, 51.8%, and 27.1% higher nitrogen stocks than tree plantations, croplands, and degraded soils, respectively. Chatterjee et al. (2008) reported that different timber harvesting practices had no effect on the biogeochemical processes and microbial community structure associated with SOC. However, the latter study found that forest management practices have the potential to alter forest carbon dynamics and reported that heavy harvesting increased their SOC pool relative to unmanaged soils through incorporation of logging residues and forest floor materials into soil mineral horizons (Chatterjee et al., 2008). Groppo et al. (2015) determined the concentrations of several soil elements and

their stocks in native vegetation, pastures, and crop-livestock systems, and found that SOC and TN were higher in soils under native vegetation than in other systems.

In general, SOC content was higher in UC than in other applications. In this study, high biomass inputs on the soil surface may have resulted in elevated SOC. In addition, it has been reported that the quality and quantity of biomass are important for the development of SOC pools (Gutierrez et al., 2021). Due to the potential for high organic matter input, carbon accumulation in UC was higher than in both CT and CNT. Soil nitrogen content may have varied seasonally. Thus, the applications in this study did not affect TN content. Carbon sequestration and soil carbon storage potential are dynamically influenced by numerous environmental factors. Tree species, their ages, parent material, soil texture, time, and variable environmental conditions affect the quality and content of SOC (Shi and Cui, 2010; Sagliker et al., 2018; Gencer et al., 2026). It has been reported that land management practices on natural vegetation affect the quality and distribution of SOC (Wan et al., 2023).

Soil carbon mineralization in UC was higher than in both CNT and CT, following the order $UC > CNT > CT$ in this study. However, the cumulative respiration curves were similar across all treatments (Figure 2). Increases and decreases observed in carbon mineralization curves provided insights into the quality of the organic matter remaining in soils during sampling periods. Similar increases and decreases in the curves were evident in CT and CNT soils, which can be explained by the tillage-dependent release and accelerated decomposition of organic matter, leading to decreases in soil microbial activity, and by increases in organic matter resulting from plant residue inputs, which led to increases in soil microbial activity (Figure 2). Soil microbial activity in CT and CNT was generally stable, and the observed increases in their curves may be due to random inputs of organic matter to the soils and/or the presence of annual plant materials. In summary, land management practices in this study had low impact on cumulative carbon mineralization, as results were similar to those from the natural area. On the other hand, Moscatelli et al. (2007) studied the effects of the land use on carbon mineralization in forest and agricultural fields and reported that there were differences in TN between the two soils and found that carbon mineralization was not affected by the management practices. Beheshti et al. (2012) reported no differences in cumulative carbon mineralization between forest and cultivated sites, and they indicated differences in SOC and TN. Xu et al. (2009) studied the carbon mineralization in forest soils after land use and they reported that in the conversion from wildwood land to farmland, cumulative carbon mineralization in farmland were decreased than in wildwood land.

Cumulative carbon mineralization in all soils was measured seasonally, and carbon mineralization was higher in autumn and spring than in summer. This situation reflects a favorable soil ecological balance. Autumn rainfall and regional temperature conditions were optimal for soil microbial activity and available and/or new input of easily decomposable organic matter were quickly mineralized but complex compounds and their subunits were maintained in soils which were observed and occurred in spring and summer pass (Avalos et al., 2007).

CONCLUSION

In general, this study showed that management practices, including cutting trees with or without tillage, had no significant or negative effects on soil organic carbon, and total nitrogen was not affected by these practices in the eucalyptus plantation at the Tarsus-Karabucak Forest. The rapid growth of eucalyptus trees and their litter inputs may have contributed to the restoration of soil carbon and nitrogen equilibrium within two years. In contrast, these management practices generally had significant impacts on soil carbon mineralization. After 30 days of incubation, the practices significantly decreased cumulative carbon mineralization. However, the rate of carbon mineralization remained highest in CT soils throughout all periods. Overall, this study provides insight into the processes that occurred during organic matter mineralization under different land management practices, as reflected by SOC levels and their mineralization. It reinforces the understanding that land management practices, particularly those involving tillage, can significantly alter soil carbon dynamics. The balance between maintaining soil carbon stocks and meeting land use demands requires careful management strategies to mitigate adverse environmental impacts.

Conflict of Interest

The authors declare that they have no competing interests.

Author Contributions

Sahin Cenkseven: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Visualization, Writing-original draft, Writing-review and editing; Cengiz Darici: Supervision, Conceptualization, Methodology, Writing-review and editing; Ibrahim Ortas: Writing-review and editing.

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Thesis Statement

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