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ORIGINAL PAPER

Short-Term Eucalyptus and Phragmites Biochar's Efficiency in Mineralization of Soil Carbon

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Abstract

Investigations of carbon dynamics of Eucalyptus and Phragmites feedstock's made biochar amendments require laboratory soil incubations that provide controlled conditions. The aim was to evaluate the effects of two different biochar amendments on carbon mineralization potential of two different soils. Biochars were produced at 550 °C from the Eucalyptus and Phragmites feedstock materials and at 0, 10, 20, and 40 t ha^{-1} of doses were mixed with silty loam texture Balcalı and clay texture, Kızıltapır soils. The soil + biochar amendments were incubated under constant temperature (28 °C) and moisture (80% of soil field capacity) conditions for 48 days. In both treatments, the biochar doses significantly increased CO_2 emission After 48 days, both biochars increased cumulative carbon mineralization (Cmin) by more than 20% in Balcalı soil ($P < 0.001$). The two introduced biochar had a significant impact on Cmin at the end of the incubation period in Kızıltapır soil. Biochars, on the other hand, considerably reduced the rate of Cmin in both soils at a dose of 40 t ha^{-1}. Eucalyptus and Phragmites biochars prepared with concentrations of 10, 20, and 40 t ha^{-1} have varied effects on soil organic carbon mineralization for both Balcalı and Kızıltapır soils. In general, with increasing biochar doses addition, Cmin significantly increased.

Keywords Soil microbial respiration · Carbon sequestration · Eucalyptus · Phragmites · C mineralization rate

1 Introduction

The rate of mineralization of soil organic carbon (SOC) can be used to determine the impact of various organic and inorganic elements on soil characteristics (Hossain et al. 2017). Soil organic mineralization is caused by chemical, physical, and biological modification and breakdown while these processes increased CO_2 emission (Van Gestel et al. 1991). This accounted for up to 60% of total greenhouse gas emissions (Rastogi et al. 2002). Despite the fact that plants and soils serve as CO_2 sinks and storage (Franzluebbers and Doraiswamy 2007), its release has increased greatly in the last few decades (Terrer et al. 2021).

Many studies on the effects of temperature on SOC mineralization have been conducted, with the majority of them relying on laboratory incubations (Reichstein et al. 2000; Schutt et al. 2014). Throughout the experiment, the incubation temperature was maintained at a constant level. For effective prediction or/and estimation of SOC mineralization potential under field settings, it is necessary to understand the kinetics of SOC mineralization under constant temperature and moisture conditions. Since there are no stable carbon mineralization processes (Ortas and Bykova 2020), it was reported that there is no general consensus about the relationship between SOC mineralization and temperature variations (Zhu and Cheng 2011). On the other hand, it was claimed that in many soils in Turkey's Eastern Mediterranean Region, optimum microbial activity was maintained at 28 °C and 80% of field capacity moisture (Zengin et al. 2008; Kocak and Darici 2016; Cenkseven et al. 2017).

Amendments of biochar to the soils have been recommended for enhancement of SOC sequestration and decrease of greenhouse gas emissions (Woolf et al. 2010). Biochar is produced by the thermal breakdown of biologically organic substances in the absence of oxygen (Jeffery et al. 2011). It was reported that when agricultural fields were treated

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with biochar, 50% of labile carbon in plant tissues can be transferred to SOC pool and maintain SOC accumulation by pyrolysis (Steiner 2008). In addition, Wang et al. (2020) claimed that soil carbon mineralization was negatively affected by biochar that change microbial community structure across stages of plant growth. Bruun et al. (2014) found that biotic mineralization of biochar was seemed to be the main pathway for evolution of CO_2 and suggested that further investigations are needed for biotic mineralization of biochar. Kanouo et al. (2019) highlighted that using biochar at high application rates and assessing the carbon destiny of biochar could provide the groundwork for future soil research to better understand the potential for carbon sequestration.

Temperature, feedstock material, moisture, and carbon content of biochar all influence carbon mineralization. Also in the presence of plentiful organic C, labile and recalcitrant organic C are more effective in C storage and mineralization rate (Sultan et al. 2019).

Based on these studies, the objective of this work was to evaluate the effects of Eucalyptus and Phragmites biochar (produced at 550 °C) on organic carbon mineralization in a silty loam (Balcalı) and clay (Kızıltapır) soil series through an incubation period under constant temperature (28 °C) and moisture (80% of soil field capacity). Both Eucalyptus and Phragmites plant materials that have no agricultural economic value are growing in the coastal regions of Mediterranean. Instead of destroying the environment by burning these types of plant products, ecologically, it is predicted that the use of biochar as a feedstock for such plants will have a favorable impact on the growth of the soil organic carbon pool. It was hypothesized that different feedstocks used to make biochars, as well as biochar dosages, would reduce the rate of soil C mineralization.

2 Material and Methods

2.1 Collection of Feedstock and Biochar Production

Eucalyptus and Phragmites feedstocks were collected from Cukurova University Agriculture Research farm located at Southeastern of the Mediterranean part of Turkey. Air-dried feedstock materials were charred at 550 °C for 2 h in a closed container under oxygen-limited conditions in a muffle furnace (RD50, REF-SAN, Turkey). The biochars were milled by passing through a 2-mm sieve for further chemical analyses.

2.2 Biochar and Soil Analysis

The incubation experiment was conducted on two different soils such as Balcalı and Kızıltapır that was classified as calcic and located in Southeastern cost of the Mediterranean part of Turkey. Soil physical and chemical properties are given in Table 1. After removing recognizable plant debris, soil samples were air-dried and sieved through a 2-mm mesh sieve. The soil texture was determined with a Bouyoucos hydrometer, field capacity (%) with a vacuum pump at 1/3 atmospheric pressure, pH with a WTW, Inolab 720 pH-meter in 1:2.5 soil–water suspension, and $CaCO_3$ content (%) determined with digital calcimeter (Kacar 2009). Soils, feedstocks, and biochar were analyzed for organic carbon and total nitrogen with a CN Elemental Analyzer (Fisher-2000). Some chemical properties of biochars are presented in Table 2.

Table 1 Some physical and chemical properties of Balcalı and Kızıltapır soils used in the experiment of carbon mineralization

Soil properties	Balcalı soil	Kızıltapır soil
Clay (%)	7.9 ± 1.45a	48.16 ± 0.66a
Sand (%)	24.9 ± 0.2a	26.86 ± 0.03a
Silt (%)	67.16 ± 1.52a	24.93 ± 0.71a
Texture type	Silty loam	Clay
Field capacity (%)	39.13 ± 0.00a	35.83 ± 0.00b
pH	7.27 ± 0.04a	6.52 ± 0.52b
$CaCO_3$ (%)	19.53 ± 0.03a	0.43 ± 0.28b
C (g kg^{-1})	19.3 ± 1.4a	13.1 ± 0.3b
N (g kg^{-1})	1.8 ± 0.3a	1.3 ± 0.3a
C/N	10.9 ± 1.21a	10.35 ± 0.38a

Clay, sand, and silt; soil contents of clay, sand, and silt; *pH* soil pH; *$CaCO_3$* soil calcium carbonate (limestone) content; *C* soil organic carbon; *N* total nitrogen; *C/N* carbon to nitrogen ratio. Data are presented as mean ± standard error ($n=3$). Different small letters within a line indicate significant differences (Student's *T* test, $P \leq 0.01$)

Table 2 Organic carbon (C) and nitrogen (N) contents of Eucalyptus and Phragmites feedstocks and biochars used in the carbon mineralization experiment generated at 550 °C

Plants	Source	C (%)	N (%)
Eucalyptus	Feedstock	42.81 ± 0.12	0.59 ± 0.1
	Biochar	72.57 ± 0.53	0.81 ± 0.0
Phragmites	Feedstock	43.25 ± 0.92	0.40 ± 0.0
	Biochar	68.44 ± 0.75	0.44 ± 0.0

Data are presented as mean ± standard error ($n=3$)

2.3 Soil Carbon Mineralization

One hundred grams of soil samples was placed in 750-mL incubation vessels. Biochar doses of 0, 10, 20, and 40 t ha^{-1} were calculated using three replicates based on field application dosages of 0, 10, 20, and 40 t ha^{-1}. Codes of biochar doses were used in figures as BE0, BE10, BE20, and BE40 for Balcalı Eucalyptus; BP0, BP10, BP20, and BP40 for Balcalı Phragmites; KE0, KE10, KE20, and KE40 for Kızıltapır Eucalyptus; and KP0, KP10, KP20, and KP40 for Kızıltapır Phragmites. The final moisture contents of soils were adjusted to 80% of their own field capacity before incubation at 28 °C over 48 days (Schaefer 1967).

The CO_2 produced from microbial activity was absorbed periodically in 40-mL saturated $Ba(OH)_2$ solution in small beakers, which were placed on the top of the soil in incubation vessels. Every 3 days, CO_2 produced by microbial respiration was measured by titration with oxalic acid in these closed vessels (Benlot 1977). For each treatment and control, cumulative C mineralization (Cmin, mg CO_2-C 100 g^{-1} soil) was calculated by summing up all measured 3 days CO_2 (3.day + 6.day + 9.day + …. + 48.day) until the end of incubation period, while their rates at 30th day, 30th–48th days, and 48th day were calculated by dividing cumulative mineralized C by its initial soil organic C content of control and all treatments (Kocak and Darici 2016).

2.4 Statistical Analysis

The collected data were statistically operated in SPSS 20.0. Student's *T* Test were used to show differences between Balcalı and Kızıltapır soils in physical (clay, sand, silt, and field capacity contents) and chemical (pH, contents of organic carbon and total nitrogen, C/N) properties. Tukey honestly significant differences (HSD) in one-way ANOVA test were only used to show differences between biochar doses in carbon mineralization of Balcalı and Kızıltapır soils for Eucalyptus and Phragmites biochars, separately. Three-way ANOVA was used to test the effects of soils, biochars, and biochar dosages on soil carbon mineralization. Results are given in figures as mean values ± standard errors of three replicates. Differences between treatments were declared as significant at the $P < 0.05$.

3 Results

3.1 Soil Physical and Chemical Properties

Soil properties of silty loam Balcalı and clay Kızıltapır soils were analyzed and the results are presented in Table 1. Organic carbon and nitrogen contents, pH, and $CaCO_3$ levels were higher in the Balcalı than that in the Kızıltapır soils. There were statistically significant differences between the two soils in terms of field capacity, pH, $CaCO_3$, and organic carbon ($P < 0.05$) but no significant difference was found in clay, sand, silt, nitrogen, and C/N.

3.2 Organic Carbon and Nitrogen Contents of Feedstocks and Biochars

Organic carbon and total nitrogen concentration of feedstock and biochars of Eucalyptus and Phragmites are given in Table 2. Carbon and nitrogen concentrations of feedstocks were 42.81% and 0.59% in Eucalyptus and 43.25% and 0.40% in Phragmites, respectively. Carbon and nitrogen concentrations of biochars were found 72.57% and 0.81 in Eucalyptus and 68.44% and 0.44% in Phragmites, respectively.

3.3 Effects of Eucalyptus and Phragmites Biochar in Balcalı Soil Carbon Mineralization

At the end of incubation period, cumulative carbon mineralization (mg CO_2-C 100 g^{-1} soil) was determined to be 17.35 for BE0, 21.09 for BE10, 20.32 for BE20, and 21.92 for BE40 (Fig. 1a). BE10 and BE40 significantly increased carbon mineralization in Balcalı soils for 21.6% and 26.3% compared to BE0 ($P < 0.05$). There was no significant difference in between BE0 and BE20 treatments.

After 30 days of incubation, the rates of Cmin (%) were found to be 0.50% for BE0, 0.52% for BE10, 0.53% for BE20, and 0.63% for BE40 while no significant differences were found in between treatments (Fig. 2a). These rates were 0.29% for BE0, 0.34% for BE10, 0.36% for BE20, and 0.38% for BE40 between 30 and 48th days (Fig. 2a) while only significant difference was found between BE0 and BE40 ($P < 0.05$). At the end of incubation period, Cmin rates were 0.79% for BE0, 0.86% for BE10, 0.90% for BE20, and 0.99% for BE40 (Fig. 2a). Only significant difference was found in between BE10 and BE40 treatments ($P < 0.05$).

Cumulative carbon mineralization (mg CO_2-C 100 g^{-1} soil) were measured and found 17.35 for BP0, 22.59 for BP10, 20.99 for BP20, and 21.34 for BP40 (Fig. 1b). Carbon mineralization was significantly increased by addition of BP10 for 30.2%, by BP20 for 21.0%, and BP40 for 23.0% compared to BP0 after 48 days of incubation ($P < 0.05$).

Rates of Cmin (%) were 0.52% for BP0, 0.68% for BP10, 0.57% for BP20, and 0.48% for BP40 after 30 days of incubation (Fig. 2b) while BP10 was significantly higher than BP0 and BP40 ($P < 0.05$). These rates between 30 and 48th days of incubation were 0.38% for BP0, 0.39% for BP10, 0.34% for BP20, and 0.32% for BP40 (Fig. 2b) while BP0 was significantly higher than BP40 ($P < 0.05$). At the end of the incubation period, Cmin rates of biochar were found 0.90% for BP0, 1.07% for BP10, 0.91% for BP20, and 0.80% for BP40 (Fig. 2b). BP10 treatment was found that there is the highest Cmin rate ($P < 0.05$) among treatments.

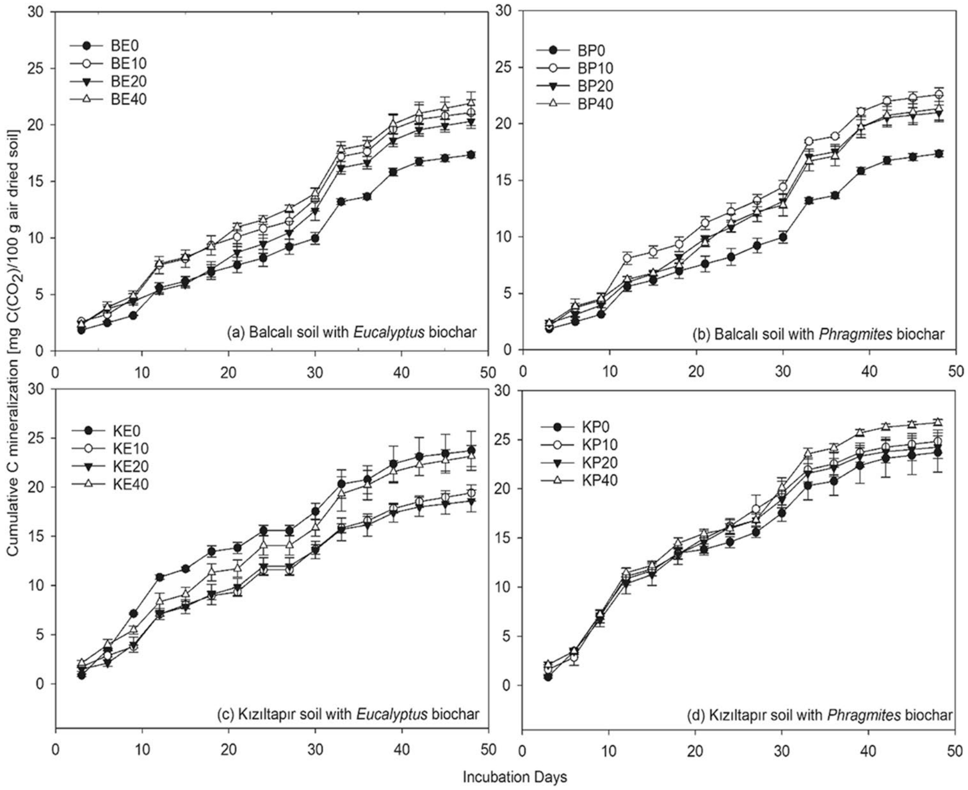

Fig. 1 Cumulative carbon mineralization of biochars generated from Eucalyptus and Phragmites to Balcalı and Kızıltapır soils after 48-day incubation for all treatments: **a** Balcalı soil mixed with Eucalyptus biochar at the doses of 0; BE0, 10; BE10, 20; BE20 and 40 t ha^{-1}; BE40; **b** Balcalı soil mixed with Phragmites biochar at the doses of 0; BP0, 10; BP10, 20; BP20 and 40 t ha^{-1}; BP40; **c** Kızıltapır soil mixed with Eucalyptus biochar at the doses of 0; KE0, 10; KE10, 20; KE20 and 40 t ha^{-1}; KE40; **d** Kızıltapır soil mixed with Phragmites biochar at the doses of 0; KP0, 10; KP10, 20; KP20 and 40 t ha^{-1}. Vertical bars represent the standard error of the mean (*n* = *3*)

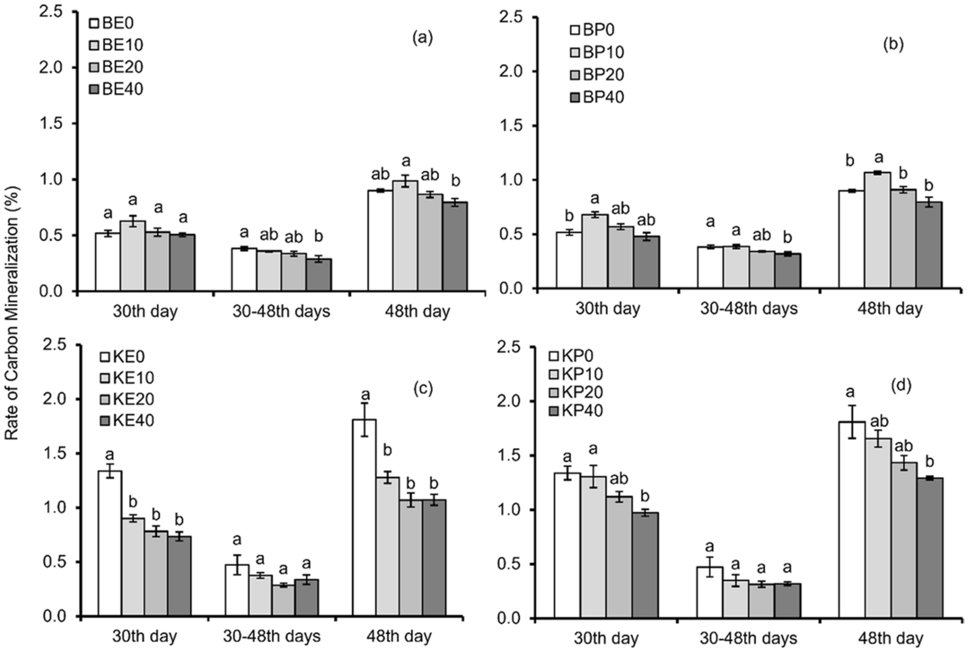

Fig. 2 Rates of carbon mineralization rates (%) of biochars generated from Eucalyptus and Phragmites to Balcalı and Kızıltapır soils after 30th day, between 30 and 48th days and 48th-day incubation for all treatments. **a** Balcalı soil mixed with Eucalyptus biochar at the doses of 0 (BE0), 10 (BE10), 20 (BE20), and 40 (BE40) t ha^{-1}; (**b**) Balcalı soil mixed with Phragmites biochar at the doses of 0; BP0, 10; BP10, 20; BP20 and 40 t ha^{-1}; BP40; (**c**) Kızıltapır soil mixed with Eucalyptus biochar at the doses of 0; KE0, 10; KE10, 20; KE20 and 40 t ha^{-1}; KE40; (**d**) Kızıltapır soil mixed with Phragmites biochar at the doses of 0; KP0, 10; KP10, 20; KP20 and 40 t ha^{-1}; KP40. Vertical bars indicate the standard error of the mean (*n* = 3). Different lowercase letters above the columns indicate significant differences between the treatments for each incubation time, separately (Tukey's HSD test, $P < 0.05$)

3.4 Effects of Eucalyptus and Phragmites Biochar in Kızıltapır Soil Carbon Mineralization

Cumulative carbon mineralization (mg CO_2-C 100 g^{-1} soil) were calculated 23.71 for KE0, 19.42 for KE10, 18.60 for KE20, and 23.16 for KE40 at the end of incubation period (Fig. 1c). Less significant differences were found in between all treatments interaction (Table 3). Rates of Cmin (%) were investigated 0.74% for KE0, 0.78% for KE10, 0.90% for KE20, and 1.34% for KE40 after 30 days of incubation (Fig. 2c) while Cmin rates of all biochar treatments were significantly higher than KE0 ($P < 0.05$). These rates were 0.29% for KE0, 0.34% for KE10, 0.38% for KE20, and 0.47% for KE40 between 30 and 48th days while no significant differences were found in between treatments (Fig. 2c). At the end of incubation period, Cmin rates were 1.81% for KE0, 1.28% for KE10, 1.07% for KE20, and 1.07% for KE40 (Fig. 2c). Cmin rates of all biochar treatments were significantly lower than that in KE0 ($P < 0.05$).

Cumulative carbon mineralization (mg CO_2-C 100 g^{-1} soil) for KP0, KP10, KP20, and KP40 treatments was 23.71, 24.83, 24.24, and 26.73, respectively (Fig. 1d). Rates of Cmin (%) were 1.34% for KP0, 1.31% for KP10, 1.12% for KP20, and 0.97% for KP40 (Fig. 2d). After 30 days of incubation period, with increasing level of biochar, Cmin ratio was significantly decreased. In between 30 and 48th days, statistically, there were no significant differences in between both biochar treatments (Fig. 2d). At the end of the incubation period, Cmin rates of biochar statistically significantly ($P < 0.05$) were decreased with increasing biochar dose addition (Fig. 2d).

4 Discussion

Soil carbon mineralization has a direct link to the supply of macro- and micro-nutrients, release of greenhouse gases into the atmosphere, and a significant impact on soil quality regulation (Spokas et al. 2009). Introduction of biochar to the soil can modify carbon cycle in the soil (Wang et al. 2021). The following is how biochar's fate in the soil carbon cycle was explained: biochar may contribute in the breakdown of native soil organic carbon (SOC) by decreasing the mineralization of SOC in the long term through the protection mechanisms of the addition of new C to soil (Weng et al. 2017). Low soil C mineralization was shown to be driven by an increase in biochar C/N rate, pyrolysis time, and clay content of soils, as well as a drop in soil C/N, while the most important driver for biochar effect on soil C cycling was incubation conditions (Ding et al. 2018). Soils with low biochar concentration exhibited higher rates of C mineralization than soils with higher biochar content, according to research (Liang et al. 2010; Sultan et al. 2019).

Phragmites biochar had lower carbon and nitrogen concentrations than Eucalyptus biochar, according to the findings. Increasing doses of Eucalyptus biochar boosted C mineralization in Balcalı soil (silty loam) and lowered it in Kızıltapır soil (clay). When compared to BE0 treatment, BE40 treatment has the highest mineralization rate (26.3%).

After 48 days in Kızıltapır soil, the lowest and non-significantly lowered KE20 treatment was found to be 21.6% lower than KE0. In all days of the incubation period, the effects of different dosages of Eucalyptus biochar on C mineralization in Balcalı soil were as follows: Balcalı: BE0 < BE20 < BE10 < BE40. Phragmites biochar increased C mineralization in Balcalı and Kızıltapır soils and these stimulations were generally higher than Eucalyptus biochar. BP10 treatment was the highest and significantly increased C mineralization for 30.2% compared to BP0. KP40 was highest and no significant differences were found between all Phragmites biochar treatments at the end of incubation period. In contrast, it was reported that addition of 1% Phragmites biochar (produced at 500 °C) into a Plinthudult soil (contains high silt content) had caused a major decrease in the bacterial PLFA (phospholipid-derived fatty acids) concentrations compared to control soil. It is known that obtained information from the PLFA method is comparable to the ecological concept of functional groups and is particularly useful for studying soil C dynamics and soil C mineralization (Stemmer et al. 2007; Mellado-Vazquez

Table 3 Results of analysis of variance (*P* values) of the effects of soil type, biochar type and biochar dose, and their interactions on changes in cumulative carbon mineralization (Cmin) and its rate

Source of variation	Degrees of freedom	*P* value (Cmin)	*P* value (rate of Cmin)
Soil type	1	<.0001	<.0001
Biochar type	1	0.0007	<.0001
Soil type*biochar type	1	0.0051	<.0001
Biochar dose	3	0.0059	<.0001
Soil type*biochar dose	3	0.0013	0.0138
Biochar type*biochar dose	3	0.1088	0.5421
Soil type*biochar type*biochar dose	3	0.3855	0.0138

et al. 2019). Similarly Liu et al. (2020) reported that biochar additions could increase the abundance of several effective bacteria and have significant effects on mineralization.

Stimulation of Eucalyptus biochar, produced at 550 °C, was peaked out for 2–3 weeks in C mineralization of a low clay soil in the study of (Singh and Cowie 2014). It was reported that soil microbial activity was decreased by the presence of Eucalyptus biochar produced at 600 °C (Dempster et al. 2012). In contrast, over a 5-year period, Singh and Cowie (2014) found that Eucalyptus biochar produced at 550 °C accelerated C mineralization in a low clay soil. On the other hand, it was reported that cumulative CO_2 evolution from soil amended with Eucalyptus biochar at the dose of 5 t ha^{-1} was significantly lower than the dose of 0 t ha^{-1} with no difference between the 0 and 25 t ha^{-1} of biochar addition (Dempster et al. 2012). In contrast, Zhang et al. (2014) clearly indicated that biochar produced at 700 °C did not enhance soil microbial activity or biomass. Under laboratory circumstances, biochars generated at 550 °C generally boosted microbial activity in both soils.

Effects of Eucalyptus biochar doses on C mineralization in Kızıltapır were as following: KE20 < KE10 < KE40 < KE0. This situation was opposite in Balcalı soils mixed with Eucalyptus biochar. KE10 and KE 40 were only significantly higher than KE0 on day 3, and there were no significant differences between KE0 and other biochar doses after 9 days. Throughout the incubation period, all Eucalyptus biochar dosages were lower than KE0. In addition, at the end of incubation period, no significant differences were found in between treatments and this may indicate that there was suppression in microbial activity in Kızıltapır soil after 9 days. It is possible to conclude that all Eucalyptus biochar doses in Kızıltapır soil are not utilized as an energy source by microorganisms. This result may be consistent with the study of Singh and Cowie (2014) that Eucalyptus biochar produced at 550 °C resulted in an immediate (on day 1) suppression of native soil organic carbon mineralization ($P < 0.05$). Different effects of Eucalyptus biochar doses on soil C mineralization may originate from the different textures of soils in this study.

Effects of Phragmites biochar on C mineralization of Balcalı soil was as following: BP0 < BP40 < BP20 < BP10. No significant differences were found between treatments until 12th day. Also, no significant differences between treatments were found until 9th day while BP10 was significantly higher than BP0 between 12 and 48th days. It was reported that water-soluble carbon from Phragmites biochar was released when it was wetted and this biochar reduced all dissolved metal concentrations (Fe, Zn, and Mn) in the acid drainage (Mosley et al. 2015).

Effects of Phragmites biochar on C mineralization of Kızıltapır soil were as following: KP0 < KP20 < KP10 < KP40. No significant differences between all Phragmites biochar treatments were found in the all measured days of incubation period. These results indicated that Phragmites biochar had no negative effect on microbial activity in Kızıltapır soil. In contrast, it was reported that biochar mineralization could be affected by both temperature and clay content while biochar was protected from mineralization by its own stable chemical and physical nature as well as by physical protective mechanisms during the early periods of incubation (Bruun et al. 2014).

The effects of various biochars and biochar dosages on soil organic carbon mineralization were statistically significant (Table 3). According to research, the impacts of soil, biochar, and dosages, as well as their interactions, have a major impact on mineralization. However, there is a few work related the significant interaction in between soil-biochar-doses application. It was indicated that over the long-term incubation, biochar can persist in soil on a centennial scale and decreases the turnover of native SOC (Fang et al. 2019).

After 48 days of incubation period, 20 and 40 t ha^{-1} doses of Eucalyptus and Phragmites biochars had no significant effect on rate of C mineralization in Balcalı soil compared to their control treatments, while only significant difference was found between BP10 and BP0 ($P < 0.05$) (Fig. 2a and Fig. 2b). All Eucalyptus biochar doses and KP40 significantly decreased mineralization rate in Kızıltapır soil ($P < 0.05$, Fig. 2c and Fig. 2d). In general, all 40 t ha^{-1} biochars significantly decreased this rate only in Balcalı soil ($P < 0.05$) between 30 and 48th days. Kanouo et al. (2019) reported that application of Eucalyptus biochar (produced at 300 °C) at 15 t ha^{-1} on clay loam soil did not have any important effect on physical properties of soil but significantly increased soil organic carbon and soil pH. Addition of Eucalyptus biochar at the application rate of 10, 20, and 40 t ha^{-1} may have increased soil organic carbon in clay Kızıltapır soil as well as these doses significantly decreased the mineralization of soil organic carbon. On the other hand, Zhu et al. (2017) reported that a rate of 4% biochar had no significant effect on CO_2 emission rate compared to its control in a silty loam soil after 60 days of incubation. After 48 days of incubation, results are shown that 20 and 40 t ha^{-1} biochar additions had no significant effect on C mineralization rate in Balcalı soil.

The effects of different soils, biochars, and biochar doses applications on Cmin were statistically highly significant (Table 3). The impacts of various soils, biochars, and doses, as well as their interactions and interactions between soil-biochar-doses, are statistically significant.

In general, rate of C mineralization was less affected by both biochars in Balcalı soil and was significantly decreased by both biochars at 40 t ha^{-1} in Kızıltapır soil after 48 days. For further research, during the incubation period, the destiny of biochar mineralization should be assessed using various temperature and moisture regimes. The texture of the soil could be a key element in determining the impact of different biochars on carbon mineralization.

5 Conclusions

This incubation study demonstrated that biochars (Eucalyptus and Phragmites) and their doses addition to Balcalı and Kızıltapır soils significantly increased Cmin. For both Balcalı and Kızıltapır soils, 10, 20, and 40 t ha^{-1} biochar doses have varied effects on soil organic carbon mineralization. Under both biochars incubation carbon mineralization significant decrease over 40 t ha^{-1} dose application.

Both biochars have varied effects on cumulative carbon mineralization in Balcalı soil. Results revealed that Eucalyptus biochar decreased cumulative carbon mineralization compared to Phragmites biochar. Both biochars were beneficial to CO_2 emission in Balcalı soil. Further study is necessary to evaluate the effects of soil biological diversity on biochar carbon mineralization rate under long-term incubation period conditions.

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Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Ethics Approval The authors will follow the Ethical Responsibilities of Authors and COPE rules.

Consent to Participate On behalf of all co-authors, I believe the participants are giving informed consent to participate in this study.

Consent for Publication I, Burak Koçak, give my consent for a submitted manuscript to be published in the Journal of Soil Science and Plant Nutrition free of charge.

Conflict of Interest The authors declare no competing interests.

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