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Biochar Incorporation Zone Has an Effect on The Soil Carbon Dioxide Emission

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Abstract: Several factors are effective on soil carbon dioxide emissions caused by agricultural practices; soil organic matter contents, soil moisture and temperature, climatic changes, and tillage techniques are predominant. In recent years, as a CO_2 sequestration agent, biochar incorporation becomes a promising approach. Many studies show that biochar reduces soil CO_2 emissions; however, incorporation depth is not widely studied. A pot experiment was carried out to determine the effects of the incorporation zone of rose pulp biochar produced at 400 °C on carbon dioxide emission. Treatments were Z as without biochar incorporation (control), A, B, and C are the incorporation zone of 0-7, 0-14, and 0-21 cm soil layer. The measurements in the experiment last for about 2 months. Results revealed that mean CO_2 emissions for Z, A, B, and C treatments were 0.048, 0.052, 0.064, and 0.076 g $m^{-2}h^{-1}$, respectively. According to these results, it was determined that the biochar admixed in the C layer caused more soil CO_2 emissions, and there was no significant difference between the other treatments ($p>0.05$). The highest plant biomass development was obtained in the B treatment ($p<0.05$).

Keywords: Biochar, carbon dioxide emission, soil depth, plant development

Biyokömür Karıştırma Zonu Toprak Karbondioksit Emisyonu Üzerinde Etkilidir

Öz: Tarımsal uygulamalardan kaynaklanan toprak karbondioksit emisyonları üzerinde çeşitli faktörler etkilidir; toprağın organik madde içeriği, toprağın nemi ve sıcaklığı, iklim değişiklikleri ve toprak işleme teknikleri baskındır. Son yıllarda, CO_2 tutma ajanı olarak biyokömürün dahil edilmesi umut verici bir yaklaşım haline gelmiştir. Pek çok araştırma biyokömürün topraktaki CO_2 emisyonlarını azalttığını göstermektedir; ancak uygulama derinliği geniş çapta araştırılmamıştır. 400 °C sıcaklıkta üretilen gül posası biyokömürünün uygulama bölgesinin karbondioksit emisyonu üzerindeki etkilerini belirlemek amacıyla saksı deneyi yapılmıştır. Denemeler, biyokömür katılmayan Z (kontrol); A, B ve C, 0-7, 0-14 ve 0-21 cm toprak derinliklerinde gerçekleştirilmiştir. Deneme ölçümleri 2 ay sürmüştür. Sonuçlar Z, A, B ve C denemeleri için ortalama CO_2 emisyonlarının sırasıyla 0,048, 0,052, 0,064 ve 0,076 g $m^{-2}h^{-1}$ olduğunu ortaya çıkarmıştır. Bu sonuçlara göre C katmanına karıştırılan biyokömürün daha fazla toprak CO_2 emisyonuna neden olduğu, diğer uygulamalar arasında ise önemli bir fark olmadığı belirlemiştir ($p>0,05$). En yüksek bitki biyokütle gelişimi B uygulamasında elde edilmiştir ($p<0.05$).

Anahtar Kelimeler: Biyokömür, karbondioksit emisyonu, toprak derinliği, bitki gelişimi

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1. Introduction

Tillage practices on agricultural production stimulate greenhouse gas emissions. Agriculture-originated greenhouse gas sources are enteric fermentation in animal production, paddy cultivation, biomass management, chemical fertilizer applications, and soil cultivation practices. Soil CO_2 emissions show great variation depending on the cultivation techniques and methods chosen. For instance, reduced tillage systems decrease CO_2 formation and; therefore, lead to organic carbon accumulation (Akbolat et al., 2009). In addition, some soil conditioners are used to reduce carbon sequestration by reducing emissions in the soil. Biological coal (biochar), which is obtained by pyrolysis from vegetable wastes, is one of the options that can be used for many purposes. Biochar is recognized as an effective regulator for soil carbon sequestration and soil quality improvement (Yang et al., 2022). Straw may be converted into biochar, which can significantly lower carbon dioxide emissions than just returning it to agricultural land, according to Wang et al. (2020). Since the biochar application to the soil alters the chemical, physical and biological properties of the soil, it affects the C and N mobility in the soil (Van Zwieten et al., 2014). Several studies are available in the literature focusing on the type of biochar raw material (Spokas et al., 2009), the application doses to the soil (Alaboz and Isildar, 2018), and pyrolysis temperature. There are also studies showing that biochar reduces soil greenhouse gas emissions and provides carbon accumulation in the soil (Günal and Erdem, 2021). Memici and Ekinci (2020) reported that 30 tons ha^{-1} of biochar which is produced at low temperatures, incorporation into the 15 cm soil layer causes higher CO_2 emissions, but biochar that is produced at high temperatures reduces CO_2 emissions. In another study; it has been reported that biochar applications aid to decrease greenhouse gas emissions in general on a yearly basis, CO_2 and CH_4 emissions decreased compared to control with biochar applications, while N_2O gas emissions increased depending on the treatments tested (Saygan, 2017). More significantly, Jeffery et al. (2011) reported 80% less CO_2 emission. Researchers have reported that this decrease may be associated with stable carbon contents of the biochar that accumulated in the soil. Another greenhouse gas, N_2O also greatly influenced by biochar incorporation Laird et al. (2010) reported up to 51% less N_2O emission under maize cultivation. Biochar raw material and production methods are also detrimental to emissions that Woolf et al. (2010) reported greater carbon sequestration by wood debris than the rice straw. Biochar has an effect on enteric fermentation which added biochar on cattle feed ration reduces methane emission by up to 26% (Zhang et al., 2018). In general, according to Smith et al. (2016), biochar has the potential to recover up to 12% of global fossil fuel emissions.

Biochar itself could not be considered as soil organic matter due to many reasons; however, its organic matter-like effects are an important feature of the area which has very low organic matter contents due to the semiarid climate condition. According to measurements taken 4 years after applying biochar to the soil, mineralization declined with depth; therefore, the soil organic matter contents (SOC) increased by 10.7% and 24.9% for 0-20 and 20-40 cm (Ma et al., 2023).

Numerous studies have been conducted on a variety of topics, including the production of biochar at various temperatures, the types of plant waste used in the process, the impact on soil CO_2 emissions, and potential uses as soil conditioners. There is, however, a lack of adequate study on the best method for combining biochar raw material, various environmental circumstances, and the incorporation depth of biochar. In some researchs biochar and the soil mixed in different depths; however, it wasn't specific aim for selecting those depths. For instance, while Memici and Ekinci (2020), and Schnell (2012) were chosen a 15 cm soil layer for mixing depth in their studies, Joseph et al, (2020) mixed biochar to 20 cm soil depth in his/her experiment. Another researcher (Eastman, 2011) reported that he mixed the soil mixing depth with a rotary tiller throughout the tillage depth. The findings of the study discussed above show that no studies have been achieved in which the biochar application depth is considered a primary issue. For this reason, there is a need for a study in this direction to determine the working depth of the equipment to be used, especially in cases where the large-scale biochar application is targeted. This study aims to determine the effects of rose pulp biochar produced at 400 °C on soil CO_2 emissions and the growth of maize plants grown in these soils after two month of measurement period. The study, it was also aimed to determine the plant water consumption values.

2. Material and Method

Biochar used in the experiment was produced by a self-constructed from the rose pulp unit at 400 °C. The pyrolysis time was determined by monitoring the gases coming from the exhaust, after about 12 hours, the combustible gases were exhausted and pyrolysis was terminated. Obtained biochar passed through the 2 mm sieve by hand force before incorporation into the soil. Some selected properties of the soil used are presented in Table 1.

Table 1. Selected properties of the experimental soil (Akbolat and Coskan, 2021)

Texture	pH (1:2.5)	EC (1:2.5; dS m^{-1})	$CaCO_3$ (%)	Organic matter (%)
Silty loam	7.7	0.248	27	1.76

mg kg^{-1}

P	K	Ca	Mg	Fe	Zn	Mn	Cu
12.2	936	18200	1413	18.4	4.1	45.6	5.06

The experiment was carried out in size 8 pots which a depth of around 21 cm and a capacity was 4500 g of soil. Soil water content adjusted to field capacity by adding to tap water. To determine the field capacity of the soil, 50 g of soil was placed in a funnel with filter paper and added

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water until drainage was observed. 60% of the water content of saturation is considered as field capacity. The water-holding capacity of the biochar was also determined and taken into consideration. For each pot, 9 g of biochar which is equivalent to 5000 kg ha^{-1} was weighed. The weighed biochar was incorporated homogeneously to 0 to 7, 0 to 14, or 0 to 21 cm soil layer for A, B, and C applications, respectively. After that, all pots were adjusted to field capacity moisture content with tap water. The CO_2 emissions from pots were measured once every 3 days. Before the 7th and 11th measurements, pots were weighed and water contents re-adjusted. After adding the water, it waited for 4 hours for the water to spread into the soil evenly. Waiting also prevents measurement errors caused by the abrupt release of carbon dioxide that occurs as the pores fill with water. The CO_2 measurements were done by a Soil CO_2 flux system developed by PP Systems, Hitchin, UK (Akbolat et al., 2009). The system has a built-in CO_2 analyzer, soil evaporation probe, CFX-2 respiration chamber, and temperature probe.

After emission measurements were completed, corn seeds were sown in the same pots where the measurements were made and plant growth parameters were monitored in the short term (60 days). For this purpose, corn seeds were planted in pots, and the moisture contents of the all pots were adjusted to field capacity. The pots were irrigated once a week to add evaporated/transpired water. At the end of the experiment, the height of the plants was measured in meters, and the shoot cut 1 cm above the soil surface was dried at 80 °C and weighed by analytical balance.

Obtained results were subject to Tukey multiple comparison test ($p<0.05$) using the Minitab package program.

3. Results and Discussion

Experiments were carried out in laboratory conditions. Soil temperatures of the core of pots, one of the data determined during the experiment, depending on the applications from the rose pulp biochar mixed into different soil depths are presented in Figure 1.

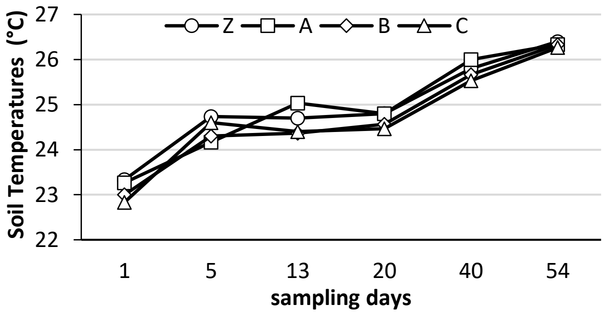


Figure 1. Soil temperature changes depending on sampling days

An increasing soil temperature trend was observed during the experiment where the temperature readings climbed during the measurement, from around 23 °C to about 26 °C (Figure 1). This situation is related to the increase in laboratory temperature due to seasonal change, and no additional heat treatment was applied to the pots. The response of the pots to the increasing ambient temperature was at different levels, and the adaptation to room temperature was slower as the depth of biochar mixing increased. Although the lowest temperature values were observed in the C treatment which the incorporation layer was 0-21 cm, there was no statistical difference between the applications in terms of temperature change ($p>0.05$). However, differences in temperature between the measurement days were significant ($p<0.05$).

The amounts of water added to the pots to re-adjust the field capacity are given in Figure 2. The differences in terms of added water amounts were not significant; however, within the measurement days, a great decreasing-increasing course was observed. There was no trend observed through evapotranspiration.

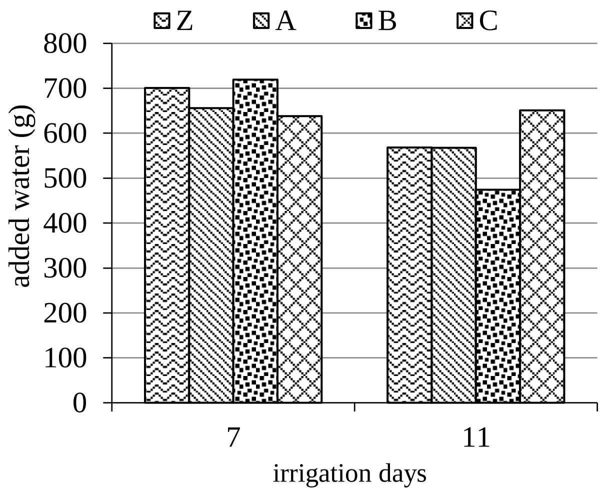


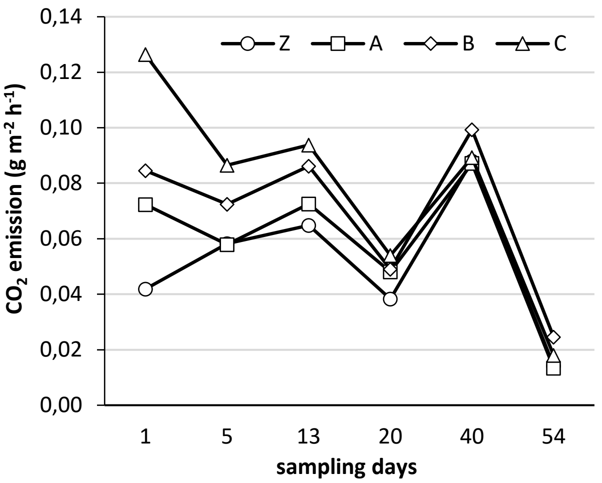
Figure 2. Added water amounts on irrigation days

Soil CO_2 emission values (Table 2 and Figure 3) revealed that there was a great influence of biochar on CO_2 formation. For the first measurement day, the greatest influence occurred on CO_2 which was increased with all biochar applications. The highest value was at C treatment as 0.126 g CO_2 m^{-2} h^{-1} which was followed by the B, A, and Z treatments with the values of 0.084, 0.072, and 0.042 g CO_2 m^{-2} h^{-1}, respectively. The CO_2 emission values at the first 3 measurement days were distinctly different from each other; however, the gap between treatments was getting closer at the last measurement days. Mean CO_2 values (Table 2) revealed that all treatments significantly triggered CO_2 flux, where the lowest emission was observed in the control (Z) treatment. These results indicate that the application of biochar increases the CO_2

emission of the soil. Lehmann and Joseph (2009) also reported such a result, but stated that in the long run, the net emission will be negative as a result of biochar application; in other words, biochar is still an effective method for carbon sequestration. Although it was aimed to determine the effect of biochar on CO_2 emission in this study, the main issue is to reveal whether the mixing depth has a special role in emission. In general, the findings showed that the mixing depth is effective, and that near-surface application should be preferred instead of deep application, provided the doses remain the same, to reduce CO_2 production. The observed differences within treatments may be since with deep mixing, the same amount of biochar creates more contact with the soil, which creates different effects on microorganisms. One of the factors affecting soil carbon dioxide emission is soil evaporation (H_2O emission) but none of the treatments results from significantly higher evaporation ($P>0.05$).

Table 2. The mean CO_2 emission values of treatments

Treatments	Mean CO_2 emission (g CO_2 m^{-2} h^{-1})
Z	0.048^{c} ±0.027
A	0.052^{bc} ±0.024
B	0.064^{ab} ±0.032
C	0.076^{a} ±0.038



After emission measurements are completed, the maize plant was cultivated on the same pots, and the plant development parameters such as plant height and shoot dry weight are determined (Figure 4). Determined parameters are significantly influenced by treatments ($P<0.05$). Increasing the depth of the biochar incorporation zone increased plant growth regularly until application B. In the C application observed rising trend disappeared, and both plant height and shoot dry weight values dramatically dropped in the Z application.

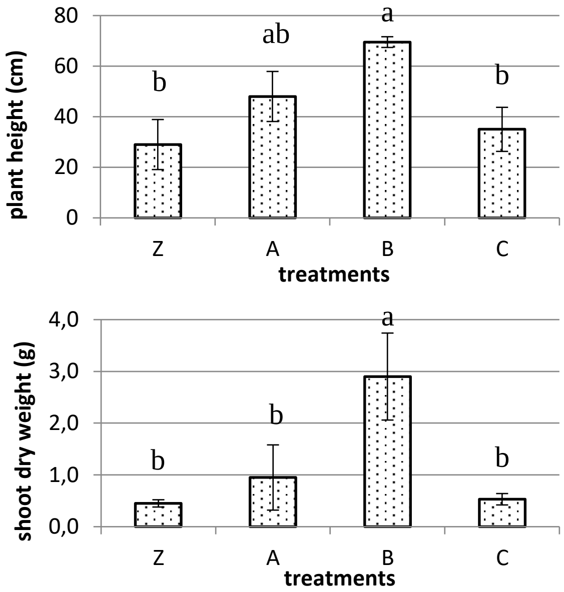


Figure 4. Plant height and shoot dry weight of maize

4. Conclusions

The results obtained from this study showed that the depth of biochar application affects both CO_2 emission and plant growth. All applications increased CO_2 emissions, the lowest increase was observed in the narrowest layer (0-7 cm) and the highest increase was observed in the widest application layer (0-21 cm). When the results in terms of CO_2 emission are considered, it is concluded that close-surface biochar incorporation may provide more carbon sequestration leading to less CO_2 return to the atmosphere. When the treatments were compared, it was determined that the most suitable mixing depth in terms of vegetative parameters was a 0-14 cm layer. When the depths were compared in terms of vegetative parameters, it was determined that the most convenient mixing depth was a 0-14 cm layer. Significant positive effects were not observed at other incorporation zones.

Author Contributions

Authors equally contributed for the preparation to this paper.

Conflict of Interest

As the authors of this study, we declare that we do not have any conflict of interest statement.

Ethics Committee Approval

As the authors of this study, we declare that we do not have any ethics committee approval.

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