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Influence of Poultry Litter Biochar on Some Properties and Carbon Mineralization in Acidic Soil

Kanatlı Altlığı Biyokömürünün İsidik Bir Toprağın Bazı Kimyasal Özellikleri ve Karbon Mineralizasyonu Üzerine Etkisi

Özet

Son yıllarda, çeşitli organik atıklardan biyokömür (BC) elde edilmesi ve tarım topraklarının özelliklerini iyileştirmek amacıyla kullanılması çok yaygın bir uygulama haline gelmiştir. Biyokömürün alkali toprakların iyileştirilmesinde kullanılması üzerine birçok araştırma bulunmasına rağmen, asidik topraklara olan etkisi ile ilgili çalışmalar sınırlıdır. Bu nedenle, kanatlı altlığı biyokömürünün (PLBC) asidik bir toprağın özelliklerine ve karbon (C) mineralizasyonuna etkilerini araştırmak için bir inkübasyon denemesi yürütülmüştür. Toprak örneklerine ağırlık esasına göre 0 (kontrol), %2 ve %5 oranlarında kanatlı altlığı biyokömürü (PLBC) ilave edilerek 27 °C'de 30 günlük sürelerle 120 gün süre inkübasyona bırakılmıştır. Toprak pH'sı PLBC uygulaması ile inkübasyon süresi sonunda 4.38'den 5.31'e yükselmiştir. Elektriksel iletkenlik (EC) değerlerinde de artış olmuştur. Kontrol ve PLBC uygulanan toprak örneklerinin her biri için inkübasyonun 30. gününde karbon dioksit (CO_2) emisyonu maksimuma ulaşmıştır. PLBC toprağın organik madde içeriğini önemli ölçüde arttırmıştır. Değerler kontrol, %2 ve %5 için sırasıyla %3.51, %4.70, %6.27 düzeyinde bulunmuştur. PLBC uygulaması toprağın C mineralizasyonu üzerinde artan bir negatif etki göstermiştir. Partikül organik madde (POM) değerleri PLBC uygulamalarının organik karbon depolanmasını arttırdığını göstermiştir. PLBC uygulamalarının toprakta karbon depolamasının yanı sıra toprak düzenleyici etkisi gösterdiği

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ortaya çıkmıştır. Kontrollü koşullar altında kısa süreli bir inkübasyon çalışması ile elde edilen bu sonuçların sera ve arazi çalışmaları ile desteklenmesi daha faydalı olacaktır.

Anahtar Kelimeler: Kanatlı altlığı biyokömürü, asidik toprak, karbon mineralizasyonu, partikül organik madde

Abstract

During the last years, biochar (BC) from various organic wastes and its application to soil to improve soil properties have been a very common treatment in agricultural soils. While many studies have been conducted on the effects of biochar on the improvement of alkaline soils, studies on acid soils are limited. An incubation experiment was conducted to investigate the effects of poultry litter biochar (PLBC) on acidic soil properties and C mineralization. Biochar derived from poultry litter (PLBC) through slow pyrolysis was mixed with soil in three different doses (0, 2, and 5%) and subjected to a 120-day incubation period. pH increased from 4.38 to 5.31 at the end of the incubation. Electrical conductivity (EC) values also increased. Carbon dioxide (CO_2) emission reached its maximum on the 30th day of the incubation in control and with PLBC applied to the soil. PLBC increased the organic matter (OM) content of the soil. Values were 3.51%, 4.70%, 6.27% for control, PLBC 2% and 5% treatments, respectively. PLBC does have an increasing negative priming effect on the carbon (C) mineralization of the soil. Particulate organic matter (POM) increased the storage of organic carbon (OC) in the POM fraction for both PLBC applications. It is revealed that PLBC showed soil conditioning effect as well as C storage in the soil. This study was on the short-term incubation under controlled conditions, varying results would be obtained in field conditions.

Key words: Poultry litter biochar, acid soil, C mineralization, particulate organic matter

Introduction

During the last decade, obtaining biochar (BC) from various organic wastes and its application to soil to improve soil properties have been a very common treatment in agricultural soils (Yan et al., 2020; Sarma et al., 2017; Kookana et al., 2011; Hossain et al., 2017). It has been proposed as a soil ameliorant for improving soil properties and functions due to its rich-carbon content, high adsorption capacity, and porous structure (Lehman et al., 2006, Chan et al., 2007, Verheijen et al., 2010; Lehmann and Joseph, 2015). Playing an active role in carbon storage in the soil, BC affects the physical, chemical, and biological properties of soils. Biochars of both plant and animal origin show a liming material effect in acidic soils, increasing pH, EC, and cation exchange capacity (CEC) (Jeffery et al., 2011; Chintala et al., 2014). Biochar shows low degradability due to its specific chemistry, which consist of aromatic ring structures (Haumaier and Zech, 1995; Glaser et al., 2000). Soil application of BC plays an important carbon storage role in soil due to its high carbon (C) content in the recalcitrant C form after biomass pyrolysis (Kuzyakov et al., 2014). It not only sequesters carbon in the soil but also ensures the return of OM removed by harvest from the soil (Jatav et al., 2020). Organic matter exists in soils as two types of organic C: recalcitrant and labile carbon. Labile C is unstable and includes particulate C, which is fast-cycling carbon (Six et al., 1999). Biochar application significantly increases organic C fractions (particulate C, easily oxidable C, and light fraction organic C) in soil (Yang et al., 2018; Cooper, 2020). Considering that BC provides a C pool with minimal microbial degradation in the soil due to its C structure, this permanent C pool can have a positive effect on soil structure, water holding capacity, and the nutrient cycle. The bulk soil C pool can be fractionated into POM and MAOM (mineral-protected and microbial-inaccessible) fractions (Averill and Waring, 2018).

Fresh or immature organic wastes are naturally biodegradable, but they create environmental pollution because of improper waste management. In order to minimize or eliminate possible adverse effects of the organic wastes, they have to be previously subjected to appropriate treatments such as composting or pyrolysis before application to the soil. These recycling technologies are aimed at increasing the maturity and stability of organic wastes to obtain valuable products for soil health and crop production (Mujtaba et al., 2021). Therefore, obtaining BC from various organic wastes such as agricultural crop residues, poultry litter, municipal waste, green, and food waste and applying it to soil have become more popular scientifically during the last decade (Kookana et al., 2011; Hossain et al., 2017; Sarma et al., 2017; Yan et al., 2020). Due to its mineral content and high pH, the use of poultry litter as a BC feedstock has been increased lately (Jeffery et al., 2011). Higher demand for protein supplies for people and rapid development in the poultry industry cause a huge increase in animal waste, leading to environmental problems. Storage or utilization of these wastes has become a trouble for the poultry industry (He et al., 2012). Regarding OM dynamics, organic soil amendments are essential for the sustainable productivity of soil. Not much is known about the effects of BC on acidic soils compared to alkaline soils. Acid soils consist of 30% of the world's soil, and soil acidity is a limiting factor for crop productivity (von Uexküll and Mutert, 1995). In these soils, low pH (<5.5 or 6.0) causes the toxicity of the elements to increase and the availability and amount of plant nutrients to decrease. Decreasing C mineralization as a result of the inhibition of microbial activity by acidic organic compounds may negatively affect productivity (Malchair and Carnol, 2009). Liming has been the most substantial approach for amending acid soil. Biochars of both plant and animal origin show a liming material effect in acidic soils, increasing pH, EC, and CEC (Jeffery et al., 2011; Chintala et al., 2014).

Annually, a large quantity of poultry meat (about 193 604 tons) is produced in Turkey (TUIK, 2021). An average of 60 kg of wet feces is obtained from a chicken in a year (Demirer et al., 2000). Most large quantities of poultry waste are used as organic fertilizer after composting. However, it is very difficult to deal with this huge amount of waste, which is still a problem. In acid soils, productivity is low because of the soils's low pH. Although plants such as the tea plant prefer acid soils to grow well, very low acid levels negatively affect the development and yield of the tea plant (von Uexkuell and Mutert, 1995). However, productivity can be increased through management practices.The aim of the study is to reveal the effect of poultry litter biochar (PLBC), on a wide variety of soil characteristics (pH, EC, OM, CO_2 respiration, C mineralization and POM) through a short-term soil incubation study.

2. Materials and Methods

The soil classified as… according to FAO. A soil sample was taken from 0-20 cm of soil depth in a tea plantation (Rize-Güneysu Muradiye District) (40º 54' 18" N 40º 32' 47" E) which is located in the East Black Sea Region of Turkey. After drying, soil sample was passed through a 2 mm sieve, and the following parameters were analyzed. pH and EC (1:2.5 soil-water suspension), texture (Bouyoucos, 1951), organic matter (Nelson and Sommers, 1982), Total N (Bremner, 1965), C mineralization (Thomas, 1982), CO_2 evolution (Höper, 2006), particulate organic C (Cambardella and Elliott, 1992), and field capacity (Anonymous, 1954) were done. The feedstock was air- dried to approximately 10% before biochar production. Then, PLBC slow pyrolysis was done in an electric furnace at 300 °C with a heating rate of 10 °C min^{-1} for 120 min. pH of the PLBC was measured (1:20 water suspension) with a pH meter (Rajkovich et al., 2012), electrical conductivity (EC) was measured (1:20 water suspension) with an EC meter (Consort, multi-parameter analyzer, C3010). The ash and OM content of the PLBCs were determined by incineration at 550 °C (ASTM, 2007).

2.1. Incubation Experiment

PLBC was applied and mixed well with soil at rates of 0 (control), 2% and 5% (w/w) on a dry matter basis. PLBC rates were chosen to be 40 tones/ha and 100 tones/ha. Then the soil–PLBC mixtures, as well as the control 400 g soil on an oven-dry basis, were filled in 500 g pots and incubated at 27 °C for 120 days. The water content of the samples was kept at 70% of the field capacity during the incubation period. All treatments were triplicated. Samples were taken at 30, 60, 90, and 120 day intervals and analyzed for CO_2 respiration (Höper, 2006). pH, EC, OM, POM was analyzed only 0, and 120 days of the incubation period. The carbon mineralization rate (%) was calculated as described by Datta et al., (2019):

$$(CO_2\text{-C} / \text{applied C} + \text{soil C} \times 100) \quad (1)$$

Each treatment was replicated three times, and the experiment was carried out in a randomized plot design.

2.2. Statistical Analysis

An analysis of variance was performed on the data using MINITAB 17.1.0, and the significant differences among the treatment means were calculated by Duncan's multiple range test at $p<0.05$ using MSTAT-C.

3. Results and Discussion

3.1. Soil properties and biochar characterization

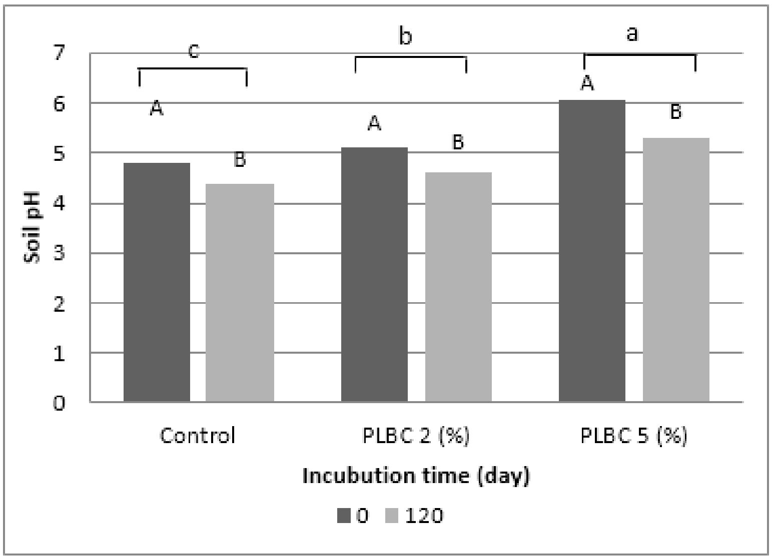
Some physicochemical properties of soil and PLBC are given in Table 1. Results were as follows: pH (1:2.5 soil: water) 4.79 (very strong acid), EC 0.046 dS m^{-1}, OM 3.45%, total nitrogen (N) 0.18%, texture sandy clay loam, and field capacity 42.4%. The results were consistent with the study of Ozdemir et al. (2020) for the eastern Black Sea Region's tea cultivated soils. Biochar characteristics were as follows: pH 10.1 (alkaline), EC 12.2 dS m^{-1}, OM 84.9%, total N 4.24% and ash 33.8%.

Table 1. Some physicochemical properties of materials

Parameters	Soil	PLBC
pH (w/v)	4.79	10.1
EC (dS m^{-1})	0.046	12.2
Organic matter (%)	3.45	84.9
Total N (%)	0.18	4.24
Texture	SCL	-
Field Capacity (%)	42.4	-
Ash (%)	-	33.8

3.2. The effect of PLBC on pH

PLBC treatments affected soil pH significantly, and soil pH increased ($p<0.01$) (Figure 1). While pH decreased in the control soil, PLBC treatment increased soil pH during incubation. pH changed from 4.79 (strongly acidic) to 4.38 (extremely acidic) in the control soil at the end of the 120th day of incubation. This change may be explained by the mineralization of OM by microorganisms releasing CO_2 and increasing carbonic acid (H_2CO_3) concentrations that affect soil pH.



*Different capital letters indicate significant difference between different incubation times ($p < 0.01$)

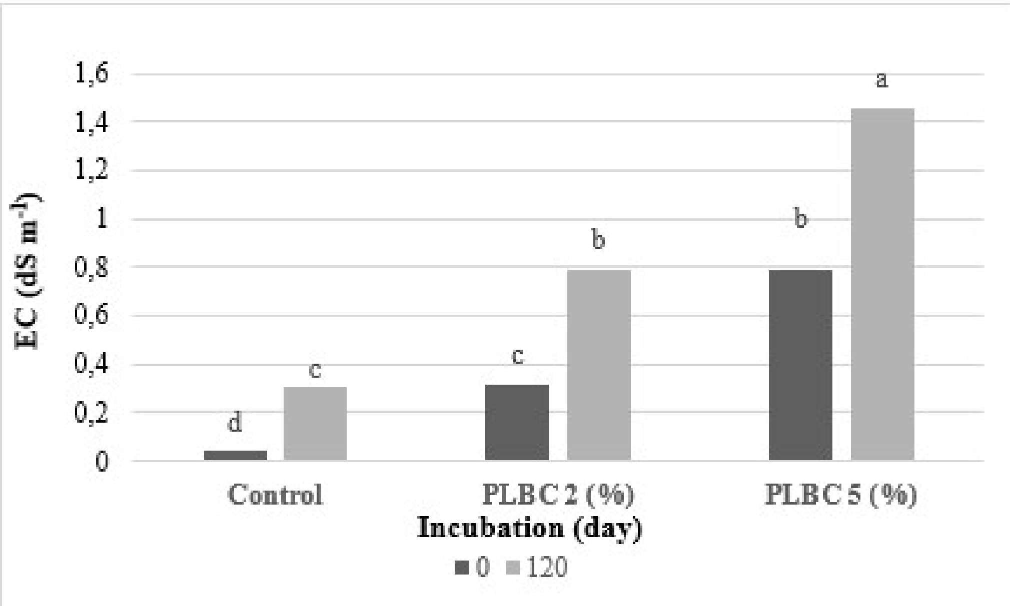
**Different lower-case letters indicate a significant difference among different biochar applications ($p<0.01$)

Figure 1. Effect of PLBC on soil pH

The difference was quite low (0.23 unit) between PLBC 2% treatment and control soil. After incubation, maximum increase was observed at PLBC 5%; the pH changed by about 0.93 pH units and increased from 4.38 to 5.31. This means that soil pH increased from very strongly acidic to strongly acidic Zang et al., (2019) reported that PLBC application increased soil pH between 0.5-1 units in acid soils, which is consistent with our results. This increase might arise from the high pH and ash content of PLBC, releasing basic cations (Chintala et al., 2014). Although they are obtained from different feedstocks and pyrolysis temperatures, most studies showed that PLBC generally increases soil pH (Van Zwieten et al., 2010; Chintala, 2014; Halim et al., 2018; Ren-yong et al., 2019). Naramabuye and Haynes (2006) also indicated that due to the alkalinity, PLBC can be used as a liming material. The findings in this study were similar to the results of other studies (Kishimoto and Sugiura, 1985, Mbagwu and Piccolo, 1997).

3.3. The Effect of PLBC on Soil Salinity (EC)

Increasing rates of applied PLBC affected soil EC significantly (p<0.01) (Figure 2). Depending on the incubation time, control soil's EC increased from 0.05 dS m^{-1} to 0.31 dS m^{-1}. At the beginning, EC values were 0.31 dS m^{-1} and 0.78 dS m^{-1} for 2% BC and 5% BC applications, respectively. After 120 days, EC values reached 0.79 and 1.46 dS m^{-1}. The increases were 2.6- and 4.7- times higher than those of control soil. Despite this increase, there was no change in the soil salinity classification. High EC values most likely resulted from easily soluble salt ions in PLBC. The findings are in agreement with a study where the addition of PLBC with highly soluble salts resulted in a higher EC value in soil (Chintala et al., 2014). Reported values in previous studies showed that the pH, salinity, and N values of BCs produced from animal origin wastes were higher than those of vegetable origin wastes (Scott et al., 2014; Jassal et al., 2015; Akça et al., 2021). PLBC has higher EC values than BCs of vegetable origin, varying between 5.66 and 33.7 dS m^{-1} (Clemente et al., 2018; Evans et al., 2017). Sikder and Joarder (2019) also determined high pH, EC, and organic C values for PLBC in their study. The results obtained in this study are in line with those of other studies. Since it is seen that the effect on soil salinity is highly dependent on the amount of PLBC incorporated into the soil, PLBC application may result in an increase in soil salinity.

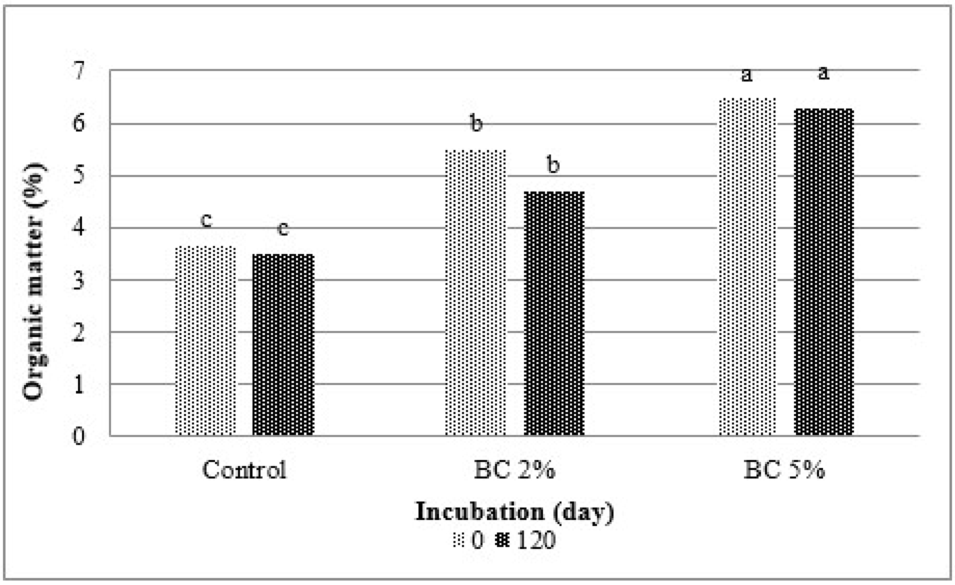


*Different lower-case letters indicate a significant difference among different biochar applications (p<0.01)

Figure 2. Effect of PLBC on electrical conductivity

3.4. The Effect of PLBC on Soil Organic matter

At the beginning of the incubation, the OM contents of the control soil and PLBC treated soils (2% and 5%) were 3.67%, 5.49% and 6.46%, respectively. PLBC applications significantly increased the OM content of the soil (p<0.01) (Figure 3). Incubation time affects were not statistically significant. At the end of the incubation period (120th day), the control, PLBC 2% and PLBC 5% values were slightly decreased (3.51% for control, 4.70% for 2% PLBC and 6.27% for 5% PLBC) compared to the beginning of the incubation due to the decomposition of the OM. PLBC applications provided increases (1.339 and 1.786 fold) in soil OM content compared to the control soil. Results are consistent with some other studies (Spokas et al., 2013; Zhang et al., 2014; Zhao and Nartey, 2014).



*Different lower-case letters indicate a significant difference among different biochar applications (p<0.01)

Figure 3. Effect of PLBC on soil organic matter

3.5. Carbon Dioxide Emission and C Mineralization

The interaction between PLBC applications and CO_2 evolution was found statistically significant (p<0.01). PLBC applications increased the mineralized CO_2 values in the soil at the beginning of incubation (0. day) compared to the control soil (Figure 4). CO_2 emission loss was 0.70 for control, 1.51 for PLBC 2%, 2.99 for PLBC 5% CO_2/100g/day (p<0.01). CO_2 emission reached its maximum on the 30th day of the control and PLBC applications, but there was no statistical difference between the applications. Values were as 4.74, 4.67, 4.57 mg CO_2/100g/day for control, PLBC 2%, and PLBC 5%, respectively. Hossain et al. (2017) reported that approximately a 30-day incubation period is required for the maximum microbial decomposition of organic materials added to the soil, and then CO_2 emission shows decrease.

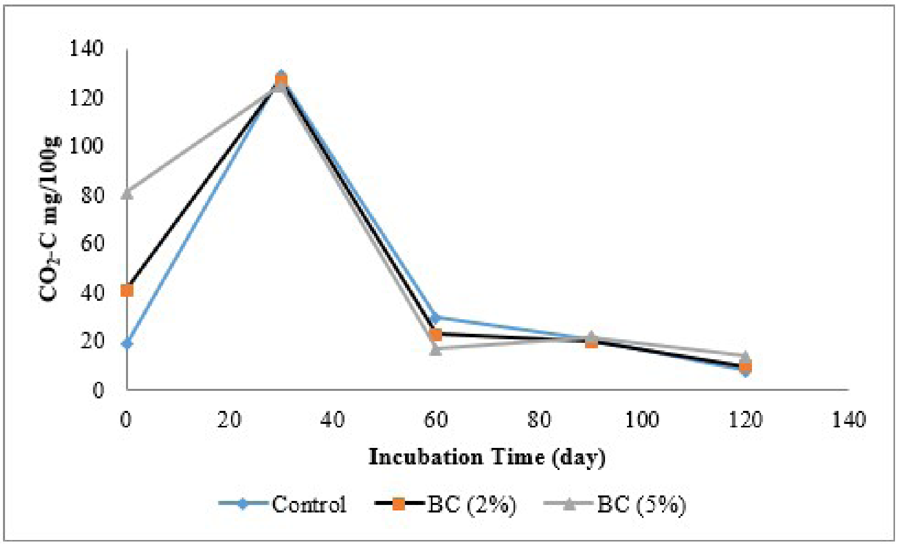
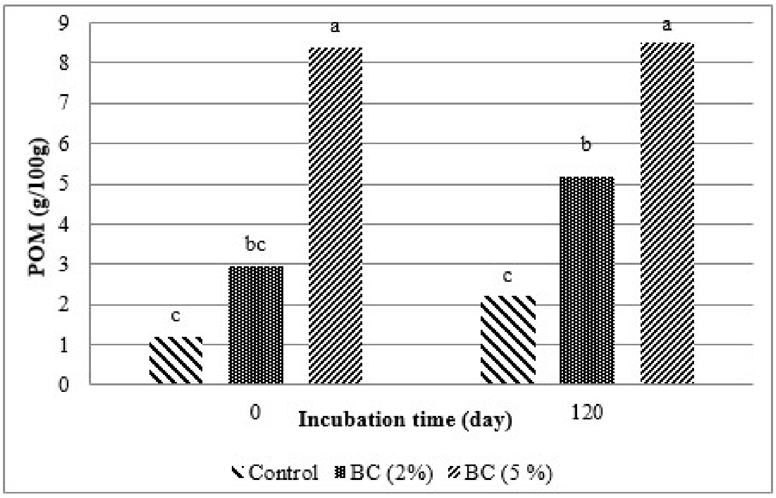


Figure 4. CO_2 emission from PLBC treatments during the incubation

The reason why determined CO_2 values with initial PLBC applications (day 0) were higher than the control soil can be explained by the fact that a part of the labile C in the PLBC is mineralized in a short time (Kuzyakov et al., 2009) and they stimulate the development of soil microorganisms (Quilliam et al., 2013). Although there was an increase in CO_2 output on the 30^{th} day, there was no statistical difference between the control and PLBC applications, and the differences among the applications in the later stages of the incubation were very low, indicating that the microorganism population used rapidly decomposing carbonaceous compounds as the C source (Gaunt and Lehmann, 2008). Some studies have indicated that the decomposable carbon compounds in BC can be used as a carbon source by microorganisms, but this may vary depending on the PLBC feedstock and pyrolysis temperature (Zimmerman et al., 2011; Troy et al., 2013). In addition, it has been revealed that the application of the material in powder or pellet form has a different effect on CO_2 emission. Sigua et al. (2014) stated that higher CO_2 values were obtained in soils where PLBC is applied in powder form compared to PLBC applied as pellets. In this study, although the addition of PLBC initially had an effect on the CO_2 activity, it was observed that the effect was low. In some cases, the application of BC can initially increase CO_2 emissions. PLBC applications may not have any impact on the soil, or vice versa, or even increase greenhouse gas emissions. Initial increases in CO_2 release from BC-added soils are due to both biotic and abiotic processes (Mukherjee and Lal, 2013). In humid climates with low pH, decomposition may not occur even with high OM as a result of acidifying compounds inhibiting microbial activity (Malchair and Carnol, 2009). There may be CO_2 outputs independent of organic material and water management (Rahman, 2014). Zimmerman et al. (2011) explained that there may be at least two types of interactions between PLBC-C and soil organic-C, that soil organic C may prevent BC decomposition at the beginning, while PLBC may be responsible for delaying soil organic carbon (SOC) decomposition at a later stage. Since PLBC is a recalcitrant material, therefore it may remain in the soil as a significant portion of the soil carbon fraction for a long time (Revell, 2011). The calculated C mineralization rate was 9.72%, 6.93%, and 6.89% for control, PLBC 2%, and PLBC 5%, respectively. As can be revealed, the mineralization rate in the control soil was higher than the PLBC applications. Biochar applications reduced the C mineralization rate in the soil. The fact that PLBC application does have an increasing negative priming effect on the mineralization of the soil, which can be considered positive in terms of C storage. The fact that the labile carbon from the structure of the BC is low and the environment is quite acidic suggests that the active microorganism activities in OM decomposition are insufficient. PLBC applications also seem to reduce OM mineralization in the soil. This situation can be attributed to the PLBC forming organomineral structures with the mineral parts of the soil. As a result of PLBC application, high respiration at the beginning and low respiration in the later stages of incubation may be attributed to the use of BC as an easily degradable C source by microorganisms. Then decrease may occur due to adsorption at later times (Pignatello et al., 2006). The findings are consistent with the results of Zimmerman et al. (2011).

3.6. Soil Particulate Organic Matter (POM)

POM increased the storage of OC in the POM fraction for both PLBC applications compared to the control soil ($p<0.01$). Statistically insignificant difference was found between the initial and final POM values in all applications. POM content of soil samples varied between 1.20-2.21, 5.02-5.15, and 8.39-8.51 g/100g for control, PLBC 2% and 5%, respectively (Figure 5).



*Different lower-case letters indicate a significant difference among different biochar applications ($p<0.01$)

Figure 5. Effect of PLBC on particulate organic matter

Particulate organic matter constitutes the most reactive fraction of SOM and reflects the degradation rate of readily decomposable constituents (Cambardella and Elliott, 1992). Incubation time did not affect the POM content of the soil. This indicates that C can be stored in the soil with PLBC applications.

4. Conclusion

Biochar from poultry litter (PLBC) can be used as a soil conditioner to increase the pH of acidic soils. On the other hand, PLBC can be applied to soils due to its effect of reducing carbon mineralization to ensure carbon storage in acidic soil. Thus, both poultry litter will be evaluated and benefit will be obtained for acidic soils from the poultry industry that cause environmental pollution problems on a large scale. However, it may be possible to observe an increase in soil salinity when using PLBC at rates higher than 5%. It should be considered during the application. This study was carried out as a short-term incubation experiment under controlled conditions, further studies would be conducted in the conditions of field to understand better the mechanisms of PLBC effect in acidic soils.

Author Contributions

This paper was prepared from Master Thesis of Yasemin Aktaş. The other authors supervised the research, structured the paper and edited the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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