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Biochar application enhances soil nutrient availability and microbial biomass in Chernozemic soil

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Abstract

Field research was conducted for two years to evaluate the effect of corn straw biochar on soil chemical properties and microbial biomass of Chernozemic soil in Northern Province, China. The research set up was randomized complete block design with three replicates. A one-time application of biochar was done with the use of ploughing machine to a depth of 20 cm in the first year without further application in the second year. Each treatment plot size was 25 m^2. Biochar (BC) was applied at three doses: control (BC0), 15 (BC15), and 30 (BC30) t ha^{-1}. The doses of biochar significantly increased soil organic carbon (SOC), soil pH, the available nitrogen (AN), phosphorus (AP), and potassium (AK) as compared to the plots with no biochar additions (control) in 0-15 and 15-30 cm soil depth. Biochar at 30 t ha^{-1} (BC30) relatively increased soil organic carbon (SOC), available nitrogen (AN), phosphorus (AP), and potassium (AK) in 0-15 and 15-30 cm in both years than biochar at 15 t ha^{-1}(BC15). Soil pH increased in the first year compared to the control while no significant changes was noticed in the succeeding year. Biochar incorporation resulted in considerable increases in soil microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP) in 0-15 and 15-30 cm soil depth in both years. Overall, the results of this study suggested that highest dose of corn straw biochar (30 t ha^{-1}) could enhance restoration of soil health by boosting soil nutrients availability and enhancing microbial activities in Chernozemic soils.

Keywords: Biochar, available nutrients, microbial biomass pool, Chernozemic soil.

Introduction

Considerable attention has been given to the use of organic additives which is one of the known ways of improving soil health and promoting agricultural sustainability. These additives can enrich soil with nutrients and stimulate microbial activity, particularly in soils with low organic matter content (Khadem and Raiesi, 2017a). The organic additives like biochar, animal waste, homemade waste, green amendments and industrial waste have continuously become an indispensable source of nutrients in the soil (Mohanty et al., 2013; Ali et al., 2011; Quilty and Cattle, 2011). Their contributions have supported the increasing demand for global food to a reasonable extent. Among these, a carbon enriched product known as "biochar" continues to stand out as an amendment of potential multiple benefits (Song et al., 2018; Zhang et al., 2019). More so, its response to utilization can be related to production conditions and biomass source. The efficacy of biochar is generally reflected in its ability to improve soil properties (Luo et al., 2020). Unlike, other organic additives, the use of biochar has generated sustained interest over the years due to its long-term promising effects of C sequestration (Wang et al., 2017a,b). Periodically, it has mostly been presented to improve properties of various soils, including tropical sandy soils (Harter et al., 2014); chromic luvisol (Luo et al., 2013); albic soil (Joseph et al., 2019) and phaeozemic soil (Zhao et al., 2020). Furthermore, biochar contains essential nutrients including nitrogen (N), phosphorus (P) and potassium (K), which are gradually released into the soil (Ouyang et al., 2014). More so, its chemical and structural composition differs glaringly (Wu et al., 2019). Despite the component differences in biochar, assessible improvement has been

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uncovered in the utilization of biochar as soil amendment. The prolonged use of biochar has been linked to increased microbial biomass (Ameloot et al., 2013), improved soil quality (Sohi, 2012), greater nutrient availability (Herrmann et al., 2019), and also limit greenhouse gas emissions from the soil (Li et al., 2015). On the other hand, the usage of biochar to restore unhealthy soils is rising, availing more lands for cultivation (Alling et al., 2014; Berihun et al., 2017) and boosting crop yields (Barrow, 2012). Historically, the intensive pressure on agricultural lands has led to severe disruption in the soil system in many parts of the world (Xu et al., 2010). And drastically lower the total area of fertile lands, leading due to natural disasters and human-induced activities (Mulcahy et al., 2013). As foretold by Lal (2010), soil degradation might cause deterioration in food supply and trigger more competition for agricultural land.

Chernozemic soils, described by WRB (2015) as humus-rich, highly fertile black soils, are widespread in Northeast China and serve as a crucial agricultural base. However, their fertility has declined over time due to intensive farming and other human activities. While many studies have explored the effects of biochar on various soil types, its impact on Chernozemic soils remains limited (Zharlygassov et al., 2025). The aim of this study is to examine the effect of corn straw biochar on soil chemical and microbial properties of Chernozemic soil. We hypothesized that corn straw biochar at an increasing level would lead to enhanced soil nutrient availability, and improve microbial activities while maintaining soil health.

Material and Methods

Research Site

The field research was conducted at the Heilongjiang Bayi Agricultural University Research Station, Daqing City, Heilongjiang Province, Northeast China (latitude 46° 58' N, longitude 125° 03' E). It is situated in the northern temperate continental monsoon climate. The annual mean temperature and precipitation is about 4.5 °C and 509 mm respectively. The soil properties prior to amendment show that soil is silty clay (26.2% sand, 31.4% silt and 42.4% clay) and Haplic Chernozem as per the soil taxonomy of World Reference Base for Soil Resources (WRB, 2015). The basic properties of soil are presented in Table 1.

Table 1. Prior soil measurements

Soil Depth (cm)	SOC (g kg^{-1})	AN	AP (mg kg^{-1})	AK	pH	Cu	Mn (mg kg^{-1})	Fe	Zn
0-15cm	17.51	1.51	50.08	112.86	8.2	1.82	1.88	2.24	1.05
15-30cm	15.31	1.33	48.21	105.12	8.0	1.91	1.12	1.56	0.89

*SOC= soil organic carbon; AN= available nitrogen; AP= available phosphorus; AK=available potassium; Cu=copper; Mn= manganese; Fe= iron; Zn=zinc

Experimental set up, Treatment application and Soil sample collection

The first experimental year was from April to October 2017 as well as the second year which was also from April to October 2018. The site was ploughed, harrowed and divided into plots. Three replicated plots of sizes 5 by 5 m^2 (25 m^2), with protective rows of 0.5 m in width and laid out in randomized complete block design. Thereafter, loads of biochar were spread on the surface at 0, 15 and 30 t ha^{-1}, and thoroughly mixed into the top 0-20 cm layer of the soil with the aid of a ploughing machine and with no supplementary additives in the following year. These treatments were assigned as control (BC0), BC15 (15 t ha^{-1}) and BC30 (30 t ha^{-1}) prior to maize planting (Maize ZD 958). The initial and post-harvest soil samples were randomly collected at the upper (0-15 cm) and lower (15-30 cm) soil depth using soil auger and core, packed in air-tight bags and taken to the laboratory. A part of the collected soil samples was immediately stored at 4 °C to determine the contents of microbial biomass C, N and P. Later, air-dried, passed through a 2 mm sieve and stored at room temperature for determination of physical and chemical properties.

Biochar

The corn-straw derived biochar utilized in this research study, pyrolyzed at 800 ºC using an industrial autothermic regulated pyrolyser with oxygen-limited conditions, was locally purchased from Sanli New Energy Company, China. Biochar characteristics were sorted by Bao (2000), and Jones and Willett (2006) procedures for pyrolyzed biomass. Carbon (C), hydrogen (H) and nitrogen (N) were determined by using Elemental Analyzer (EURO EA 3000). The biochar nutrient contents were: C (63.85%), H (2.76%), available nutrients N (1.57 %), P (1.89 %), K (1.32 %), and pH (10.09).

Analytical methods for soil samples

Soil organic carbon (SOC) was estimated by wet oxidation according to Walkley and Black (1934). The soil pH was measured by soil/water at 1:2 suspension using pH meter (Richards, 1954). Available Nitrogen (AN), Phosphorus (AP) and Potassium (AK) concentration were sorted by potassium permanganate method

(Subbiah and Asija, 1956), 0.5 M sodium bicarbonate (Olsen and Sommers, 1982), and 1 M ammonium acetate (Helmke and Sparks, 1996) methods, respectively. Soil texture was sorted by hydrometer method (Gavlak et al., 2003). Micronutrients was sorted by DTPA method (Lindsay and Norrvell, 1978).

Microbial biomass measurement

Soil microbial biomass carbon (MBC) and nitrogen (MBN) were measured using a chloroform fumigation direct extraction procedure (Brookes et al., 1985; Vance et al., 1987). Aliquot of extracts were analysed for MBC using an automated TOC Analyzer (Shimadzu, TOC-500 China) and MBN was determined using the Kjeldahl method. Microbial biomass Phosphorus (MBP) was determined with the anion exchange resin method (Kouno et al., 1995).

Data analysis

The collated data was first arranged in MS excel before been subjected to analysis of variance using GenStat software (version 10.3.0.0 VSN International Ltd). Tukey post-hoc test ($P < 0.05$) was used for comparison of means.

Results

Soil nutrient as affected by biochar

In the first year (2017), biochar increased soil organic carbon contents in accordance with increase in application doses of biochar additives. Treatment BC15 and BC30 elevated SOC in 0-15 cm soil depth compared with BC0 (control), whereas, at 15-30 cm soil depth, BC30 was significantly higher, followed by BC15 when compared with BC0 (Figure 1). In the second year (2018), similar case was observed at both 0-15 and 15-30 cm soil depths. BC30 was notably higher in soil organic carbon, followed by BC15 which were both significantly higher than BC0 respectively.

In the first year, BC15 and BC30 did not show significant effect but contributed increases to the soil pH in 0-15 cm soil depth compared with control, whereas, at 15-30 cm soil depth, similar resulting effects were observed (Figure 1). In the second year, and contrarily, BC15 and BC30 treatments did not contribute differences in 0-15 and 15-30 cm soil depth, compared with control.

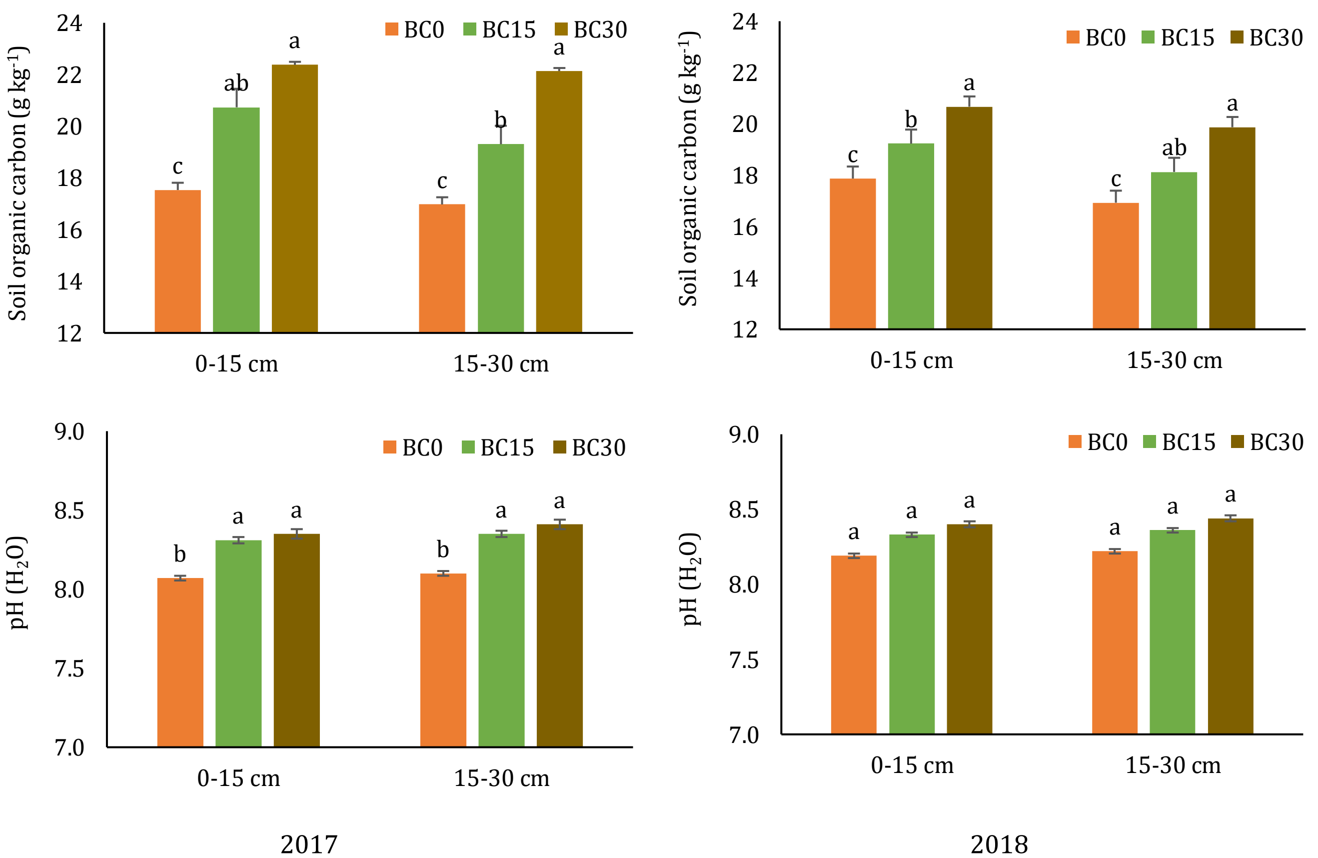

Figure 1. Effects of biochar on soil organic carbon and soil pH in 0-15 and 15-30 cm soil depth in 2017 (left) and 2018 (right). Different alphabets correspond to significant differences as regard Tukey post hoc test ($P < 0.05$).

The available nutrient contents (AN, AP and AK) are delineated in Figure 2. In the first year, the biochar treatments (BC15 and BC30) slightly differ in concentration of AN in 0-15 cm soil depth, compared with control, whereas, at 15-30 cm soil depth, BC30 was greatly higher followed by BC15, compared with control. In the second year, BC15 and BC30 statistically differ compared with control, whereas, at 15-30 cm depth, the biochar doses did not exhibit any notable effect compared to BC0 (Figure 2).

In the first year, biochar with highest dose (BC30) influenced an increase in concentration of AP in 0-15 cm soil depth compared to the lower dose (BC15) and control (Figure 2), whereas, in 15-30 cm soil depth, the two doses of application did not differ statistically but emerged higher than BC0 (control). In the second year, BC15 and BC30 did not exhibit significant differences in 0-15 cm soil depth but higher than the control, whereas, at 15-30 cm soil depth, similar treatment pattern was noticed.

In the first year, BC15 and BC30 treatments showcased notable differences in concentration of AK in 0-15 cm soil depth, compared with control, whereas, in 15-30 cm soil depth, BC30 was significantly higher than BC15 compared with control (Figure 2). In the second year, both doses of biochar treatments significantly differ compared to BC0 in 0-15 cm soil depth, whereas, in 15-30 cm soil depth, BC30 emerged higher than BC15 compared with control.

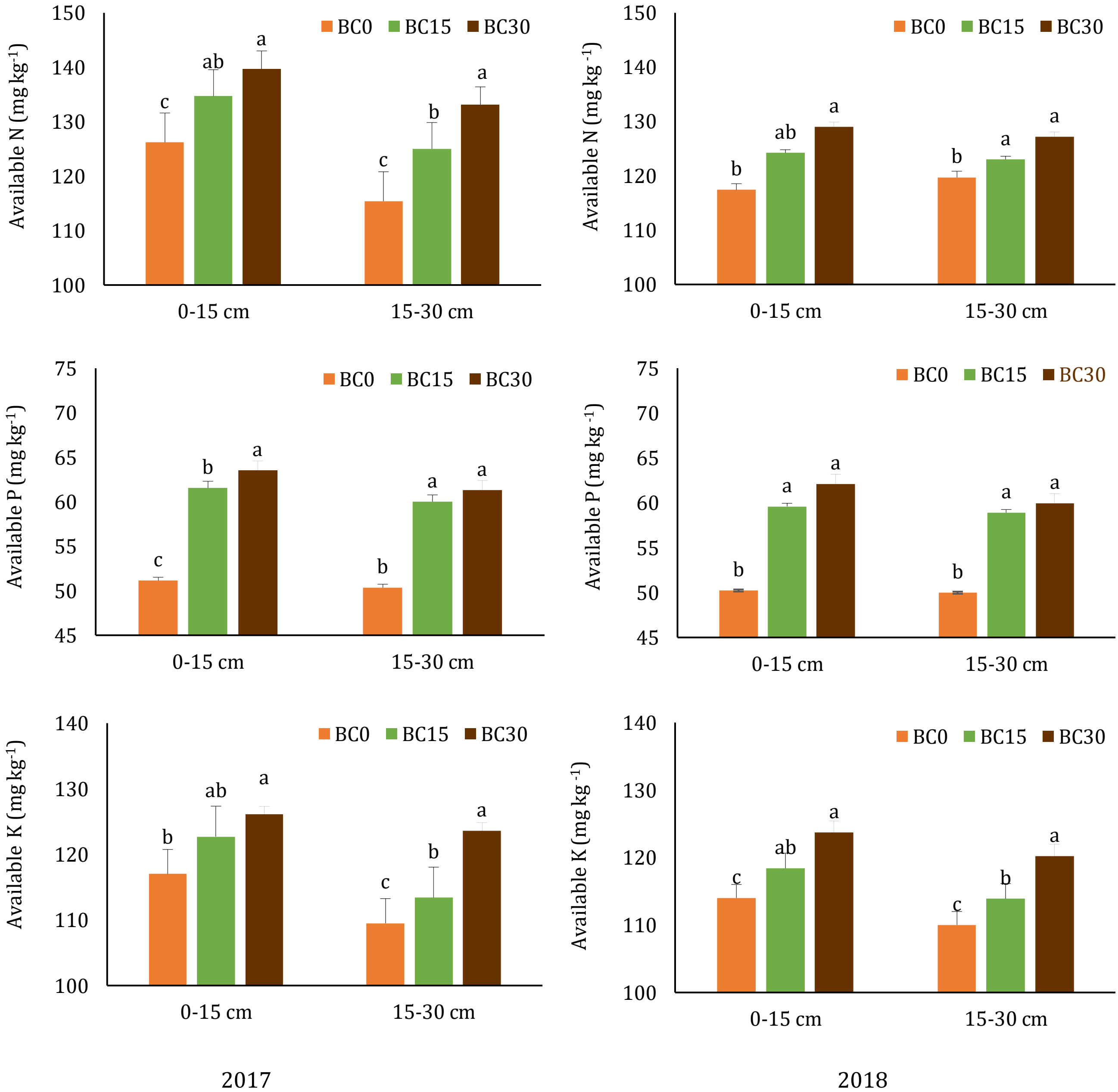

Figure 2. Effects of biochar on soil in 0-15 and 15-30 cm soil depth in 2017 (left) and 2018 (right). Different alphabets correspond to significant differences as regard Tukey post hoc test ($P < 0.05$)

Changes in soil microbial biomass

In the first year, BC15 and BC30 biochar treatments statistically surpassed control (BC0) in 0-15 cm soil depth, for MBC (Figure 3), whereas, in 15-30 cm soil depth, the highest dose exhibited (BC30) a statistically higher value than the reduced dose of biochar treatment (BC15) in 0-15 cm soil depth compared to control. In the second year, both doses of treatments (BC15 and BC30) showcased higher differences for MBC, in 0-15 cm soil depth, compared with control. Similarly, in 15-30 cm soil depth, pattern of treatment exhibition did not differ.

In the first year, the highest and lowest dose of biochar (BC30 and BC15) statistically increased MBN in 0-15 cm soil depth, compared to BC0, respectively (Figure 3) whereas, in 15-30 cm soil depth, treatment BC30 emerged higher, and followed by BC15, compared with control. In the second year, BC15 and BC30 did not differ but was significantly higher in MBN compared with control in 0-15 cm soil depth, whereas, in 15-30 cm soil depth, the highest addition of biochar dose (BC30) was greatly higher, followed by BC15, compared with control.

In the first year, BC15 and BC30 doses did not significantly differ but both higher in MBP, in 0-15 cm soil depth, compared with control (Figure 3), whereas, in 15-30 cm soil depth, BC30 surpassed BC15, compared with BC0. In the second year, BC15 and BC30 was higher in 0-15 cm soil depth, compared with control, whereas, in 15-30 cm soil depth, BC30 significantly increased than BC15, compared with control.

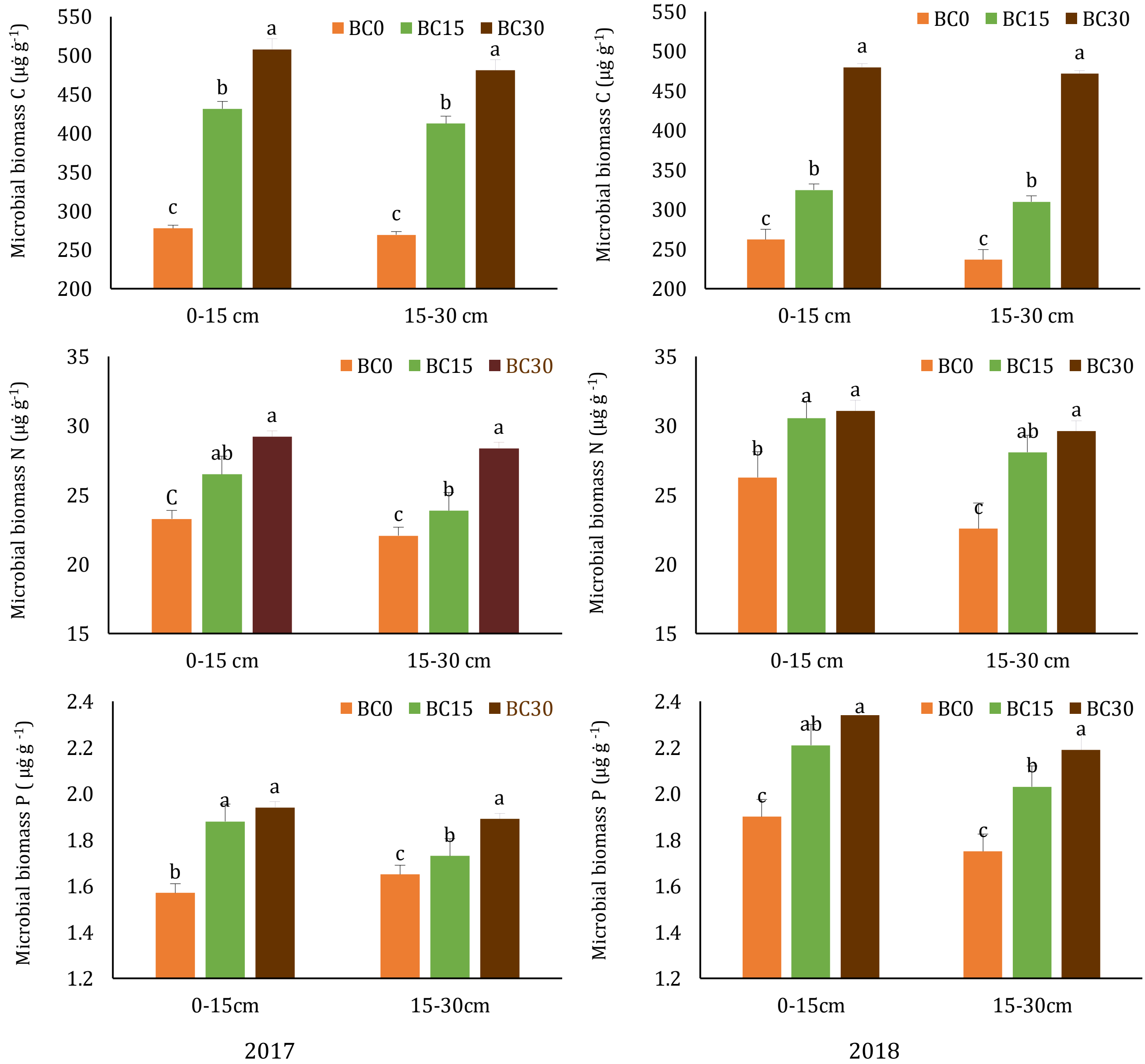

Figure 3. Effects of biochar on microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP) in 0-15 and 15-30 cm soil depth in 2017 (left) and 2018 (right). Different alphabets correspond to significant differences as regard Tukey post hoc test ($P < 0.05$)

Discussion

Soil nutrients dynamics

Amending soils with biochar has been helpful in overcoming nutrient shortages (Khorram et al. 2018; El-Naggar et al., 2019). Relative changes were noticed in the soil pH at both 0-15 and 15-30 cm soil depth due to biochar influence. This is congruent with previous studies that have reported biochar contains ash, especially cations which may offer an effective change in pH of biochar treated soils (Doan et al., 2015; Vaccari et al., 2015). In support, acidic compounds produced on biochar surface through the oxidation of biochar particles in the soil could also be a reason for the increase in soil pH as explained by prior research (Laghari et al., 2015; Griffin et al., 2017). As reported in this study, biochar added soils had elevated SOC contents in both 0-15 and 15-30 cm soil depth. This is applicable to a wide-range of experiments that reported SOC increases after biochar addition, improving soil quality in degraded soils (Brandão et al., 2011; Weng et al., 2017; Li et al., 2018). Corresponding findings by Jones et al. (2012) reported that biochar increases SOC contents after application at 25 t ha^{-1} and 50 t ha^{-1}. Also, it resonates with a report that biochar contributed to the organic C pool in the soil environment (Sohi, 2012; Simarani et al., 2018). Progressively, biochar addition relatively influenced the content of AN in-soil depth. This is in affirmation with prior studies that N concentration in soil was surged by the addition of biochar (Novak et al. 2010; Clough and Condron, 2010; Chintala et al., 2013). This result also tallies with Zhang et al. (2012) who reported that the inclusion of biochar at 20 and 40 t ha^{-1} accrued a significant increase in N concentration. Also, Haider et al. (2017), in a four-year field research observed biochar amendment increased soil mineral N at 0-15 cm soil depth while no impact was found at 15-30 cm depth. This simply implies that N retention in the soil may be related to the large surface area and high porosity of biochar providing adsorption sites (Singh et al., 2010; Bruun et al., 2012; Bhattacharjya et al., 2016). Biochar addition significantly contributed to increase in AP at both 0-15 and 15-30 cm soil depths. This aligns with a report by Farrell et al. (2014) who reported an increase in P concentration after biochar application. Besides that, Mahmoud et al. (2017) also found that P in soils increased when biochar was applied as soil amendments in degraded soil. In essence, P appears more available in soils to which biochar has been applied, both by acting as a source and by reducing losses of P and other cations from the system (Lehmann et al., 2011; Cui et al., 2011; Ameloot et al., 2013; Mukherjee and Lal, 2013). The available K (AK) was relatively modified by applied biochar in 0-15 and 15-30 cm soil depths. This coincides with that of El-Naggar et al. (2015) who reported biochar treatment had a positive influence on soil available K in the 0-30 cm soil depth. Also, Major et al. (2010) and Khorram et al. (2019) reported biochar increased available K in a long-term field study. This implies that considerable amount of K in biochar promoted changes in soil AK in this study. Prior studies have established that biochar amendment showed enhanced or no effects on soil K availability which might be due to use of different feedstock (Steiner et al., 2007; Gaskin et al., 2010; Lentz and Ippolito, 2012).

Soil microbial biomass

Biochar application could alter changes in soil microbial biomass pools (Teutscherova et al., 2017). Soil MBC increased with increasing biochar dose at 0-15 and 15-30 cm depth in both years. This is congruent with earlier reports that biochar application increased MBC at 0–30 cm soil depths (Paz-Ferreiro et al., 2012; Masto et al., 2013; Gomez et al., 2014; Noyce et al., 2015). The addition of biochar to soils has been suggested to provide more suitable environment for microbial activities and carbon mineralization (Liang et al., 2010; Lehmann et al., 2011; Dempster et al., 2012; Sun et al., 2015). The increased content of MBN at 0-15 and 15-30 cm depths in this study suggests high N turnover rate from organic N mineralization after biochar addition (Oladele et al., 2019). More so, biochar presence in soil accelerates microbial activities (Steiner et al., 2004; Kolb et al., 2009; Kuzyakov et al., 2009; Jones et al., 2012; Tang et al., 2013) which retains N through microbial cycling (Steiner et al., 2008). MBP has been considered as an important contributor of P in the soil (Redel et al., 2008). Biochar treatments increased MBP at both soil depths. Li et al. (2007) reported that addition of biochar increased MBP in a field experiment which implies biochar attributes to retaining P. Also, with the addition of biochar, increased MBP was mainly due to high P concentrations in the biochar and which provided P for the utilization of microbes (Zhai et al., 2015).

Conclusion

The 2 years field study showed that biochar application improved SOC, soil pH, available nutrients, and microbial biomass pools of Chernozemic soils. Higher biochar doses generally made way for greater effects across all measured parameters in both the upper and lower soil depths. The remarkable changes in soil carbon contents thus affirms biochar ability to increase soil carbon. Soil available nutrients remain positively influenced by biochar indicating that biochar can alter chemical properties of amended soil. The observed increases in microbial biomass pools coincides with the available soil nutrients generated from the use of biochar. This study indicates that biochar application is a credible practice for improving soil quality and enhancing microbial activities in studied soil. However, further research trials to elucidate the impact of other types biochar and its doses on Chernozemic soils is needed.

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