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Soil quality alteration and maize (*Zea mays* L.) yield after organic amendments application to a Pellic Vertisol in China

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Abstract

Maintenance of soil quality for sustainable crop production is a key factor in maximizing the potential of cropland in all climate zones. This field study evaluated the influence of biochar, maize straw (MS), mixtures of both, and poultry manure (PM) on soil properties and maize yield in an agricultural soil in northeast China. Seven treatments comprising CK, control; MS, 12.5 Mg ha^{-1} maize straw; B1, 12.5 Mg ha^{-1} biochar; B2, 25 Mg ha^{-1} biochar; SB1, 12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar; SB2, 12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar; and PM, 25 Mg ha^{-1} poultry manure were applied and replicated four times. Soil samples were collected at four depths 0–10, 10–20, 20–30 and 30–40 cm. Results showed that organic amendments reduced soil bulk density (BD), increased total porosity (TP) and soil moisture content across the top soil (0–20 cm) when compared with the control. Lowest soil BD (1.28 Mg m^{-3}) was recorded for B2 at 0–10 cm depth. Soil pH and soil organic carbon (C_{org}) were also increased by organic amendments across 0–40 cm depth relative to the control. A significant negative linear relationship was observed between soil BD and $C_{org.}$ across the 0–40 cm depth. Maize grain yield (5.3 to 24.2%) and total biomass yield (2.9 to 14.9%) were significantly improved by organic amendments, compared to the unamended control. Our study concludes that biochar, biochar-straw-based soil management approach, and poultry manure can improve soil quality, maize biomass and grain yields.

1. Introduction

Organic amendments are biodegradable materials that provide alternative sources of plant needed nutrients, improve the population of beneficial soil microbes and increase plant primary and secondary productivity (Bohktiar and Sakurai, 2005; Singh et al., 2020). Research on the application of organic amendments, such as manure, biosolids, green wastes, composts and biochar, in agricultural soils has received significant attention because of their potential to improve soil fertility and soil health, sequester carbon in the soil, reduce emission of greenhouse gases, and for regenerative agriculture (Paustian et al., 2016; Oldfield et al., 2017; Gravuer et al., 2019). Reduction in land area per capita and declining soil quality are contributors to the increase in the application of synthetic fertilisers in agricultural lands. However, the application of synthetic fertilizers alone is not a sustainable solution for improving soil fertility and maintaining crop yield. In addition, the application of excessive mineral fertilizers may lead to soil acidification (e.g., ammonium-N fertilizers), eutrophication (e.g., phosphorus fertilizers) and other environmental problems (Liu et al., 2010; Agegnehu et al., 2016). Therefore, the adequate application of organic amendments may be a sustainable means of improving soil quality and supplying plant needed nutrients with minimal undesirable environmental impacts (Fawzy et al., 2016).

Soil quality is the capability of the soil to interact with the ecosystem in order to maintain the biological productivity and the quality of other environmental compartments, thus promoting the health of plants and animals, including humans (Doran and Parkin, 1994). Organic amendments, for example green manuring and crop straw in-plow, have been widely recommended as practices that enhance crop yield while increasing soil quality (Shisanya et al., 2009; Huang et al., 2010). Also, continual application of organic amendments such as animal manure usually decreases soil bulk density, thereby enhancing soil porosity due to the dilution effect caused by the mixing of the added lighter organic material with denser fractions of the soil (Shepherd et al., 2002). Nyamangara et al. (2004) reported that cattle manure improved plant growth and yield through the improvement of soil aggregation, increased nutrient supply and increased soil water holding capacity. In a meta-analysis examining the global impact of animal manure on soil biochemical properties, Liu et al. (2020) noted that the optimal manure application rate of 25 Mg ha^{-1} per year was best for adjusting proper soil pH. Among organic manures, poultry manure is highly rich in nutrients (Santhi and Selvakumari, 2000). Poultry manure, compared to other animal manures, decomposes faster, thus, releasing nutrients more rapidly for plant uptake (Gowariker et al., 2009).

In recent years, biochar application to soil has emerged as a strategy for sequestering carbon and improving soil quality (Vaccari et al., 2011). Biochar is a type of charcoal with high aromatic and stable carbon-rich compounds produced by pyrolysis of plant and animal residues at relatively low temperature (< 700°C) under anaerobic or limited oxygen condition (Lehmann et al., 2006). It is known to improve soil chemical (pH, cation exchange capacity, and nutrient retention) and physical properties (aggregate stability, porosity, and water retention) over a long time (Mensah and Frimpong, 2018; Odugbenro et al., 2020; Singh et al., 2022; Edeh and Masek, 2022). Biochar may favourably compete with synthetic fertilizers in improving soil quality, especially in areas with well drained sandy loam soils. However, there is limited information on the use of biochar for soil quality improvement and crop production on a Pellic Vertisol. Vertisols are deep black soils that have ≥ 30% clay, and shrink-swell cracks that start at the mineral soil surface. A moist Munsell colour value of ≤ 1.5 in the surface 50 cm of the soil puts the soil of the experimental site in a group called Pellic Vertisol (Gizachew and Smit, 2008).

Maize (*Zea mays* L.) is one of the four major single crops with the second largest global production in 2020 (FAO, 2021). Maize is consumed as food and feed and used in several industries. Maize protein belongs to prolamins which are the most abundant type of proteins stored in cereal seeds, like wheat, maize, sorghum, rice, and barley (Holding, 2014). It is also a major source of oil, gluten, and starch, which can be hydrolyzed and enzymatically treated to produce syrups (Gao et al., 2020). The use of organic amendments for maize production can reduce the application of mineral fertilizers which will largely reduce the production costs as well as increase soil fertility for high productivity (Islam et al., 2010). In this study, a field trial was conducted to determine the effect of different organic amendment inputs on the potential improvement of soil quality and maize yield. We hypothesized that biochar, maize straw, and poultry manure would improve some physical and chemical properties of a Pellic Vertisol, and increase maize biomass and grain yields.

Table 1
Basic physical and chemical characteristics of the studied top soil (0–20 cm)

Parameter	Value
pH (H_2O)	6.20
Total N (g kg^{-1})	0.42
Organic C (g kg^{-1})	24.0
Available P (mg kg^{-1})	29.60
Exchangeable K (cmol(+) kg^{-1})	0.2
Exchangeable Na (cmol(+) kg^{-1})	0.5
Sand (g kg^{-1})	400
Silt (g kg^{-1})	280
Clay (g kg^{-1})	320
Textural Class	Clay Loam
Bulk Density (Mg m^{-3})	1.55

Table 2
Properties of the organic amendments applied

Properties	Biochar	PM	MS
pH (H_2O)	9.89	6.80	7.40
Organic C (g kg^{-1})	415.3	195.0	394.5
Total N (g kg^{-1})	6.88	5.40	5.20
Total P (g kg^{-1})	10.23	5.30	4.12

Explanations: PM, Poultry manure; MS, Maize straw

2. Materials and Methods

2.1. Study area and materials

The experiment was conducted from 2015 to 2016 on a field in Harbin, Heilongjiang Province, China (45°41'N, 126°37'E). The experimental site has a monsoon-influenced, humid continental climate. The mean annual temperature is 3.4°C and the annual precipitation is 500–600 mm, with 90% of the precipitation between April and September. The predominant cropping system is monoculture (maize or wheat), and rain-fed agriculture is the usual system of production. The soil used is classified as Pellic Vertisol (IUSS Working Group WRB, 2022) and contains 40% sand, 28% silt and 32% clay (Textural Class; Clay Loam). The basic properties of the soil used in the present study are shown in Table 1.

The maize straw used was air-dried and chopped into 5-cm-long sizes. The biochar was sourced from Jin and Fu Agricultural Company, China. It was made from maize stover at a pyrolysis temperature of 450°C. The poultry manure used in this experiment was applied to the field plots at a single dose. The properties of maize straw, biochar and poultry manure are shown in Table 2. pH value of organic amendments was determined using a glass electrode (1:10 solid-water suspension) with a Mettler-Toledo pH meter. Organic carbon was determined by Walkley-Black procedure, total N by Kjeldahl method, and total P by molybdenum-blue colorimetry (Murphy and Riley, 2014). Maize variety, Heyu29 (HY29) with 105 days of maturity was used as the test crop.

2.2. Methods and Analysis

The experiment was arranged in a randomized complete block design (RCBD) with seven treatments, namely CK (control), MS (12.5 Mg ha^{-1} maize straw), PM (25 Mg ha^{-1} poultry manure), B1 (12.5 Mg ha^{-1} biochar), B2 (25 Mg ha^{-1} biochar), SB1 (12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar), SB2 (12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar). Soil samples were collected at four depths (0–10, 10–20, 20–30, and 30–40 cm). Organic amendments were applied manually once and evenly spread on the soil surface. They were later incorporated into the soil to a depth of 30 cm via harrowing, and left over the winter. The size of each plot was 20 m^2 (5 m × 4 m) and each treatment was replicated four times, making a total of 28 experimental plots. Maize was sown in late spring (May, 2016) by a mechanical planter at one seed per hole at a spacing of 70 cm × 20 cm.

Following harvest (September, 2016), undisturbed soil samples at the depth of 0–10, 10–20, 20–30, and 30–40 cm were collected from each plot using soil core samplers to determine bulk density, total porosity and soil water content. The soil bulk density was determined using the gravimetric method, while total porosity (f) was calculated from the bulk density as shown below;

$$f = \left(1 - \left(\frac{\rho b}{\rho s}\right)\right) \times 100$$

Where ρb is the bulk density (Mg m^{-3}), ρs is the particle density (2.65 Mg m^{-3})

Soil moisture content (SMC) was calculated using the formula;

$$\text{SMC (\%)} = \frac{FC - DW}{DW - WC} \times 100$$

Where *FC* is the weight at field capacity in grams, *DW* is the oven dried soil weight in grams, and *WC* is the weight of soil core sampler in grams. Soil was oven dried at 105°C to a constant weight. *FC* was determined by placing the core samplers in a basin and de-ionized water added to a height of about 3 cm, and then allowed to stand for 24 hours. By this time, the soils in the core samplers had absorbed water by capillary rise, through soil pores. The saturated soil samples were then gently removed from the basin and allowed to drain for 72 hours (3 days) at temperature of 20°C when downward movement of water had stopped materially. Weight of the soil samples were measured and recorded as *FC*.

Disturbed soil samples from the depth of 0–10, 10–20, 20–30, and 30–40 cm were collected from the field plots after maize harvest to determine organic C and pH. The soil samples were air-dried and sieved separately with a 2-mm sieve to remove gravel, dead twigs and root residues. Soil organic carbon was determined by oxidizing organic matter in soil samples with $K_2Cr_2O_7$ in concentrated sulphuric acid for 30 min, after which the excess $K_2Cr_2O_7$ was titrated with ferrous ammonium sulphate (Walkley and Black, 1934). Soil pH (H_2O) was determined using a glass electrode (1:2 soil–water suspensions) with a Mettler-Toledo pH meter. The maize yield in terms of grain yield, total biomass yield, harvest index (Proportion of percentage of grain yield to total biomass), one hundred grain weight, ear length and ear circumference were measured after maize harvest.

Data collected were subjected to two-way analysis of variance (ANOVA) using GenStat Discovery Edition 4 software in order to evaluate the significance of treatment and depth on soil pH, organic carbon, bulk density, total porosity and soil moisture content. Maize yield parameters were subjected to one-way ANOVA. Means were compared using Least Significant Difference (LSD) test and Duncan's Multiple Range Test (DMRT) at the $P < 0.05$ level of significance.

3. Results and Discussion

3.1. Effects of different organic amendments on soil pH

Soil pH was significantly ($P < 0.01$) increased by all organic inputs except for straw at 0–10 and 30–40 cm soil depths (Fig. 1). The highest pH was recorded at the 30–40 cm depth, with B2 and SB2 showing the highest values 6.9 and 6.7, respectively. At 0–10 cm depth, CK and MS were significantly ($P < 0.01$) lower than SB1 while at 10–20 cm depth, MS, biochar and MS/biochar treatments were significantly ($P < 0.01$) higher than CK. Statistically significant ($P < 0.01$) differences were also observed at

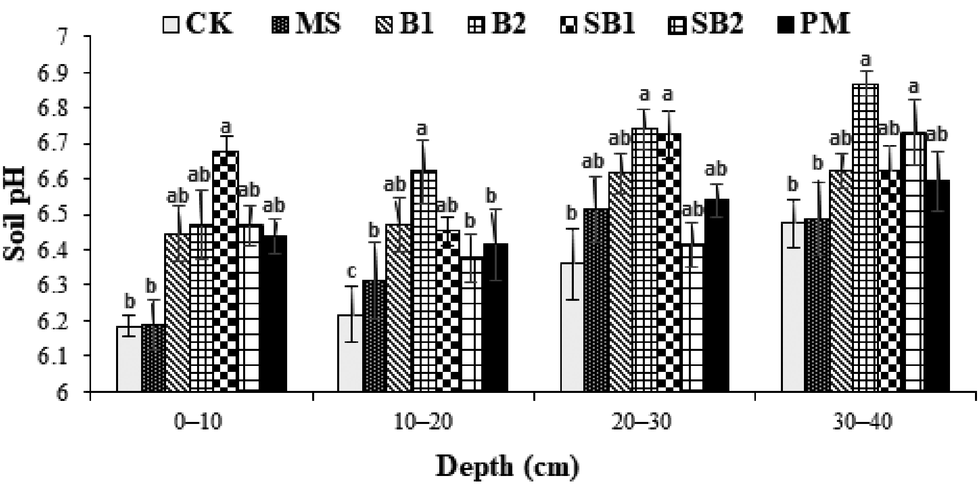

Fig. 1. Soil pH after maize harvest in the 0–10, 10–20, 20–30, and 30–40 cm depth following the application of organic amendments.

Explanations: CK, control; MS, 12.5 Mg ha^{-1} maize straw; B1, 12.5 Mg ha^{-1} biochar; B2, 25 Mg ha^{-1} biochar; SB1, 12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar; SB2, 12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar; PM, 25 Mg ha^{-1} poultry manure. Different letters indicate significant differences ($P < 0.05$). Error bars indicate standard error, n = 4.

the 20–30 and 30–40 cm depths, confirming the effect of organic amendments on soil pH. This increase in pH following biochar application is consistent with other studies (Abrishamkesh et al. 2016; Parker et al., 2021), which could be attributed to the presence of alkali and alkaline metals in feedstocks that are not volatilized during pyrolysis (Yang et al., 2018). The effectiveness of biochar to increase soil pH is dependent on soil type, crops planted, and type of feedstock. The significant effect of straw-biochar combinations on soil pH could be due to the time of straw application, as there was about a year gap between the time for straw application and soil sample collection in this study. Also, the increase in soil pH with PM application could be due to ion exchange reactions which occur when terminal OH^- of Al^{3+} or Fe^{2+} hydroxyl oxides are substituted by organic anions, such as malate, citrate and tartrate, produced during the decomposition of PM (Dikinya and Mufwanzala, 2010).

3.2. Effects of different organic amendments on soil organic carbon

The Fig. 2 shows the effect of biochar, PM and MS on organic C. When studied as an individual factor, biochar significantly ($P < 0.01$) influenced organic C across the four depths, with biochar applied at the rate of 25 Mg ha^{-1} having the highest values. At 0–10 cm depth, the highest organic C value of 31.0 g kg^{-1} was recorded by B2, which indicated an increase of 37.5% when compared with CK. Biochar/MS combinations and PM also increased organic C across the soil depths. Organic C was found to decrease with depth as values from top soil (0–20 cm) was significantly ($P < 0.01$) higher than 20–30 and 30–40 cm.

Organic inputs increase labile organic C pool and promote the formation of new organic C due to microbial C assimilation with subsequent production of metabolic byproducts (Wu et al., 2019; Cui et al., 2020). The C-rich nature of biochar in the two levels of application (i.e., 12.5 Mg ha^{-1} and 25 Mg ha^{-1}) could have been responsible for the increase in organic C relative to the unamended soil at 0–10, 10–20, and 30–40 cm depths (Joseph et al., 2020). In addition, at 30–40 cm depth, organic C was significantly lower in the CK than in soil with organic amendments. PM and MS application also increased organic C content, with PM showing more prominence than MS, especially at the 10–20 cm depth, which could be as a result of the high turnover rate of PM than MS. Similar result was reported by Yeasmin et al. (2022) who found a more prominent increase in organic C with incorporation of poultry manure than rice straw. Crystal-Ornelas et al. (2021) also reported a 24% increase in soil organic C relative to conventional farming after the addition of organic amendments. The more prominent increase in organic C following PM addition could be due to the secondary effect of PM on improved maize growth and total biomass yield, with a resultant rise in soil organic C level. Therefore, application of organic amendments could be an effective way to sequester carbon in agricultural soils.

3.3. Effects of different organic amendments on soil bulk density, total porosity and moisture content

Soil bulk density (BD) under different organic matter treatments is presented in Fig. 3. Across the four soil depths, soil bulk density was lower with organic amendments than the control, but significant ($P < 0.001$) differences were recorded only at the top soil (0–20 cm) with B2, SB1 and PM. The lowest soil BD (1.28 Mg m^{-3}) was recorded with B2 at 0–10 cm soil depth, with a decrease of 14.7% relative to CK. Soil BD increased with depth, with the highest value (1.61 Mg m^{-3}) recorded at 30–40 cm depth for the control treatment. Several authors (Abel et al., 2013; Koide et al., 2015; Trifunovic et al., 2018) have reported a decrease in soil BD following increasing biochar application rates. A significant ($P < 0.001$ and $P < 0.05$) but negative linear relationship was observed between soil BD and soil organic C at all depths (Fig. 4) which showed that as BD decreased, soil organic C increased. The reduction of soil BD by biochar could be attributed to the creation of new pore spaces or enlargement of smaller pore spaces when biochar mixes with the soil to form aggregates (Verheijen et al., 2019). Similar effects as in the biochar on soil particle aggregation would be expected with PM addition in the soil, thus reducing soil bulk density.

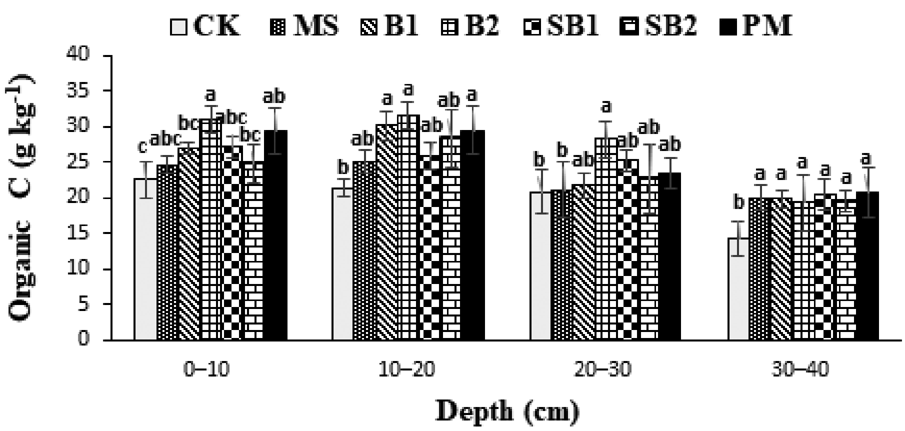

Fig. 2. Soil organic C after maize harvest in the 0–10, 10–20, 20–30, and 30–40 cm depth following the application of organic amendments.

Explanations: CK, control; MS, 12.5 Mg ha^{-1} maize straw; B1, 12.5 Mg ha^{-1} biochar; B2, 25 Mg ha^{-1} biochar; SB1, 12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar; SB2, 12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar; PM, 25 Mg ha^{-1} poultry manure. Different letters indicate significant differences ($P < 0.05$). Error bars indicate standard error, n = 4.

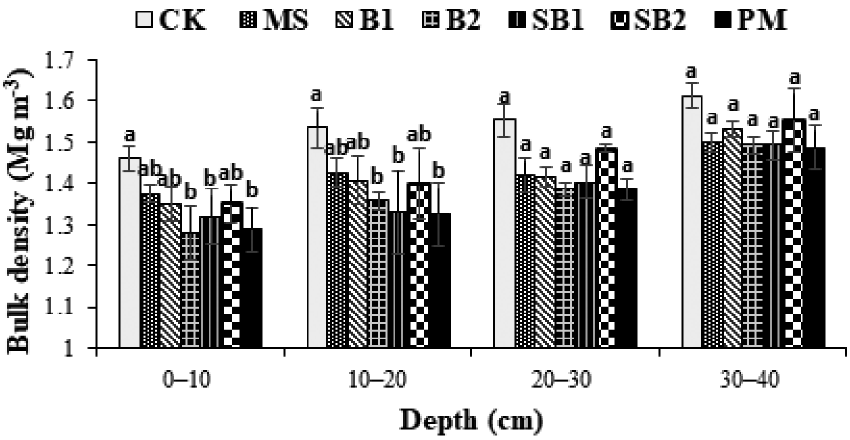

Fig. 3. Soil bulk density after maize harvest in the 0–10, 10–20, 20–30, and 30–40 cm depth following the application of organic amendments.

Explanations: CK, control; MS, 12.5 Mg ha^{-1} maize straw; B1, 12.5 Mg ha^{-1} biochar; B2, 25 Mg ha^{-1} biochar; SB1, 12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar; SB2, 12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar; PM, 25 Mg ha^{-1} poultry manure. Different letters indicate significant differences (P < 0.05). Error bars indicate standard error, n = 4.

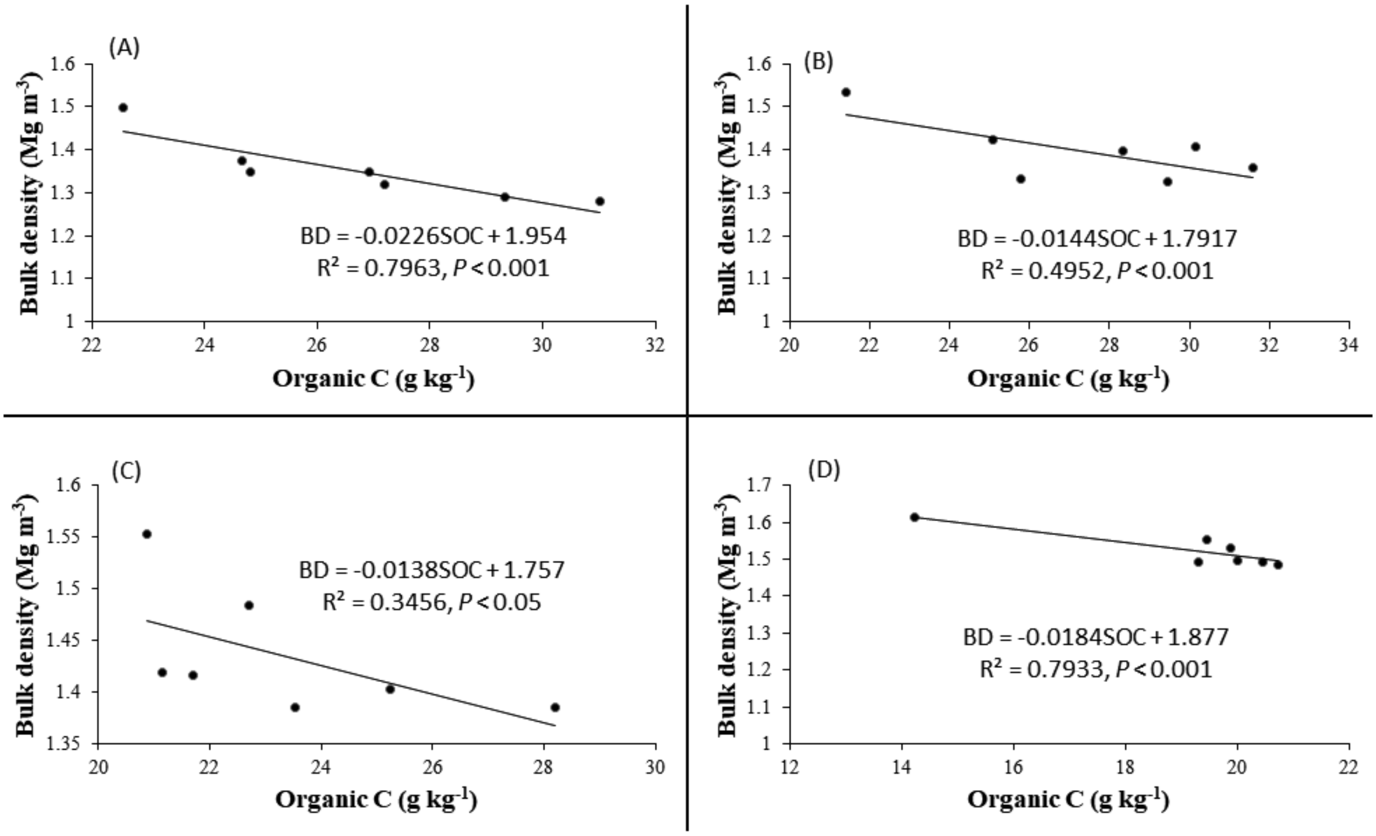

Fig. 4. Relationship between Bulk density and Organic C at (A) 0–10 cm (B) 10–20 cm (C) 20–30 cm and (D) 30–40 cm depth.

Compared to the unamended control, soil total porosity (TP) increased with the application of the organic amendments but decreased with depth (Fig. 5). Significant (P < 0.001) differences were observed with B2, SB1 and PM relative to CK at 0–10 and 10–20 cm soil depths. The highest TP value (51.7%) was recorded with B2 at 0–10 cm soil depth, showing an increase of 19.1% when compared with CK, while the lowest value (39.2%) was recorded with CK at the 30–40 cm soil depth. Total porosity (TP), which is the maximum capacity of the soil to hold air and water is inversely related to BD. Similar result was reported by Adekiya et al. (2019) who found that biochar and poultry manure reduced BD and increased TP. The increased TP and decreased BD following biochar and manure additions may be ascribed to the contribution of extra air-filled pores or formation of pores by the organic amendments to modify the pore system (Dokoohaki et al., 2017). Also, the addition of organic amendments is believed to have improved the coherence of primary soil particles, which made the soils with relatively high clay content behave like sand with regard to the movement of air and water.

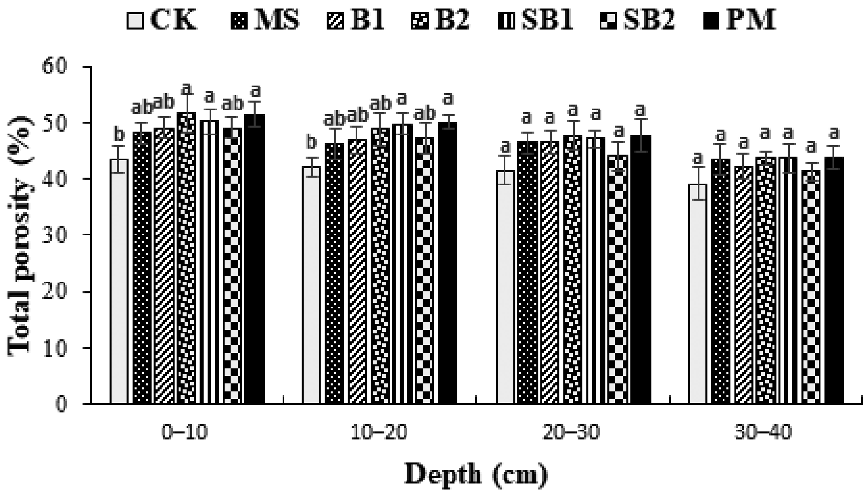

Fig. 5. Soil total porosity after maize harvest in the 0–10, 10–20, 20–30, and 30–40 cm depth following the application of organic amendments. Explanations: CK, control; MS, 12.5 Mg ha^{-1} maize straw; B1, 12.5 Mg ha^{-1} biochar; B2, 25 Mg ha^{-1} biochar; SB1, 12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar; SB2, 12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar; PM, 25 Mg ha^{-1} poultry manure. Different letters indicate significant differences (P < 0.05). Error bars indicate standard error, n = 4.

Statistically significant (P < 0.01) differences were observed in soil moisture content in respect to the added organic amendments at 0–10 and 10–20 cm soil depths (Fig. 6). At 0–10 cm soil depth, soil moisture content with B2 (44%) and MS (40%) were significantly higher than the control without amendment (30%), with an increase of 46.7% and 33.3%, respectively. At 10–20 cm soil depth, B2 (38.4%) and PM (35.4%) were significantly higher than CK (27.9%) and other treatments, with an increase of 37.6% and 26.9%, respectively relative to CK. However, there were no differences with MS, B1, SB1, SB2 compared to the control. It is believed that the stabilization of soil structure and increased porosity following addition of organic inputs to the soil contributed to the increase in soil moisture content. Similar result was obtained by Zhou et al. (2020) who reported that the addition of manure or straw significantly increased soil moisture holding capacity by 11.6–40.3%. Saffari et al. (2021) also reported increased soil moisture retention following biochar addition due to its large surface area. Furthermore, fine biochar particles could have facilitated the formation of micropores, which serve to retain capillary water.

3.4. Assessment of maize yield parameters

The yield parameters of maize under biochar, MS and PM treatments are presented in Table 3. Application of PM, biochar, MS and biochar/MS combinations had positive influence on most of the measured maize yield parameters. B2 recorded the highest grain yield (9.35 Mg ha^{-1}) followed closely by SB2

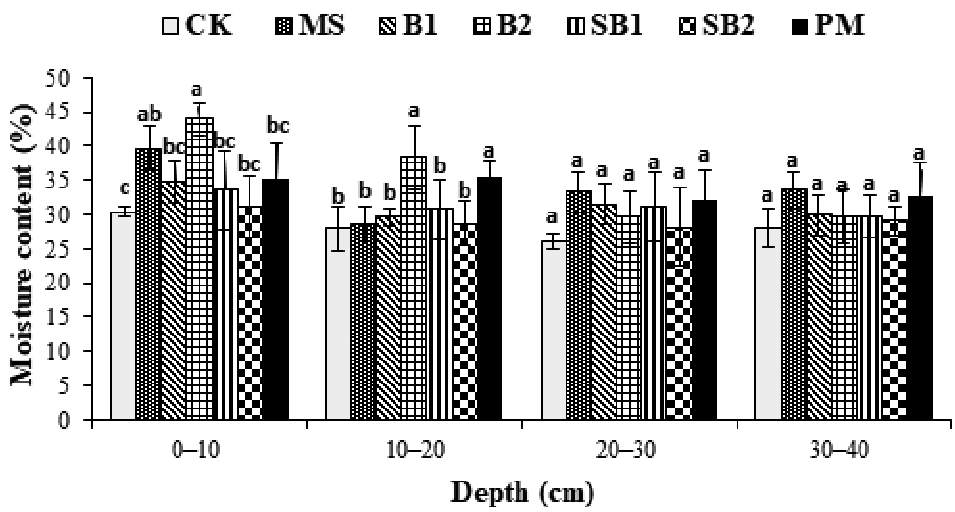

Fig. 6. Soil moisture content after maize harvest in the 0–10, 10–20, 20–30, and 30–40 cm depth following the application of organic amendments. Explanations: CK, control; MS, 12.5 Mg ha^{-1} maize straw; B1, 12.5 Mg ha^{-1} biochar; B2, 25 Mg ha^{-1} biochar; SB1, 12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar; SB2, 12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar; PM, 25 Mg ha^{-1} poultry manure. Different letters indicate significant differences (P < 0.05). Error bars indicate standard error, n = 4.

(9.08 Mg ha^{-1}) and PM (8.88 Mg ha^{-1}) which were all significantly ($P < 0.001$) higher than CK. Compared to CK, grain yield was higher by 5.3, 9.6, 24.2, 10.9, 20.6 and 17.9% for S, B1, B2, SB1, SB2 and PM, respectively. The addition of MS did not have any significant effect on total biomass yield. However, B2, SB2, PM, SB1 and B1 were significantly ($P < 0.001$) higher than CK. Significant ($P < 0.001$) effect of organic amendment was recorded for harvest index (HI), with PM (44.92%) and SB2 (45.24%) recording the highest values. MS, B1, B2, SB1, SB2 and PM increased HI by 4.4, 6.4, 7.8, 6.4, 10.5, and 9.8%, respectively when compared with CK. PM and B2 recorded higher 100-grain weights than other treatments while there was no significant ($P > 0.05$) effect of treatment on ear circumference. Furthermore, for ear length, B1, SB2 and PM were significantly ($P < 0.05$) higher than other treatments. These improvements in crop performance following application of organic amendments are consistent with findings from Mekuria et al. (2014) and Zhang et al. (2016), and may be as a result of their increase of nutrients availability, soil moisture content, porosity, and reduction of bulk density. The increase in soil organic matter content as a result of organic inputs altered soil physical and chemical properties, which contributed to soil's productivity in terms of maize grain and biomass yield. Previous study reported that PM at the application rate of 15 Mg ha^{-1} increased maize grain yield of a sandy loam soil by 251% (Udom et al., 2019). Sharma et al. (2019) also reported a significant increase in maize grain yield and biological yield following PM application. Applying PM to soils as a source of crop nutrients serves as an important means of its safe disposal (Reddy et al., 2008). Findings from a 25-year study by Cai, et al. (2019) also indicated that manure inputs increased crop yields by strongly and positively increasing soil nutrients, soil organic C and soil pH. Furthermore, Liu et al. (2021) found that rice straw biochar applied at the rate of 20 Mg ha^{-1} increased maize grain yield and stalk biomass yield by 24% and 87.2%, respectively in the first year following its addition. Many studies from different climate zones have been performed on the influence of biochar on maize yield, with varying degrees of results which are dependent on biochar feedstock and type, application rate, soil type, climate, and time of application.

4. Conclusions

Findings from this research demonstrated that biochar, poultry manure (PM) and maize straw (MS) improved soil physical (reduced bulk density, increased total porosity and moisture content) properties, pH and organic C. However, their effects on measured soil physical properties were limited to the top soil (0–20 cm) which could be attributed to low root growth in the sub soil due to soil compaction. Organic inputs also increased maize grain yield and total biomass yield, with B2, SB2 and PM at application rates of 25 Mg ha^{-1} resulting in the highest maize grain yield. The results suggest that the addition of biochar, PM and MS by farmers at the appropriate dosage could be an effective soil management approach to improving soil quality and increasing maize biomass and grain yields.

Disclosure Statement

The authors declare no known conflict of interest

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Table 3
Changes in maize grain yield, total biomass yield and yield components following organic amendments application (n = 4, ±S.E)

Treatment	Grain Yield (Mg ha^{-1})	Total Biomass Yield (Mg ha^{-1})	HI (%)	HGW (g)	Ear length (cm)	Ear circumference (cm)
CK	7.53 ±0.09e	18.44 ±0.10e	40.90 ±1.24d	31.99 ±2.78bc	20.87 ±1.72ab	16.61 ±0.75
MS	7.93 ±0.13d	18.56 ±0.13e	42.69 ±0.87c	31.35 ±1.21bc	20.74 ±0.73ab	16.64 ±0.22
B1	8.25 ±0.12c	18.98 ±0.13d	43.51 ±1.85c	32.86 ±2.69bc	21.15 ±1.22a	16.66 ±0.53
B2	9.35 ±0.26a	21.18 ±0.26a	44.11 ±2.04b	33.13 ±3.40b	19.94 ±1.18b	16.98 ±0.63
SB1	8.35 ±0.07c	19.19 ±0.08d	43.48 ±1.54c	30.07 ±2.69c	19.56 ±1.67b	16.20 ±0.72
SB2	9.08 ±0.15b	20.08 ±0.17b	45.24 ±2.69a	32.69 ±1.54bc	21.79 ±0.36a	16.91 ±0.30
PM	8.88 ±0.14b	19.78 ±0.15c	44.92 ±2.48a	34.87 ±3.28a	21.31 ±1.10a	16.70 ±0.88

Explanations: CK, control; MS, 12.5 Mg ha^{-1} maize straw; B1, 12.5 Mg ha^{-1} biochar; B2, 25 Mg ha^{-1} biochar; SB1, 12.5 Mg ha^{-1} maize straw + 12.5 Mg ha^{-1} biochar; SB2, 12.5 Mg ha^{-1} maize straw + 25 Mg ha^{-1} biochar; PM, 25 Mg ha^{-1} poultry manure; HI, harvest index; HGW, one hundred grain weight. Different letters in the same column indicate significant differences ($P < 0.05$).

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