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Soil carbon sequestration and maize yields in Alfisols of Northern Nigeria amended with different rates of compost and co-composted biochar

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ABSTRACT

A greenhouse experiment was carried out to evaluate the effects of compost, biochar, co-composted biochar, and compost + biochar on soil carbon sequestration and yield of maize in Alfisols of the Northern Guinea Savanna of Nigeria. The experiment was conducted with three different rates (5.10 and 15 t/ha) along with sole NPK (recommended dose) and control (no fertilizer application). Each treatment combination was replicated 9 times. This gave rise to 126 experimental pots, sowed with SAMMAZ 16 variety of maize, which were laid out in a complete randomized design. Three replicates from each treatment were sampled at 4th, 8th and 12th week after sowing (WAS) and were analyzed for their pH and soil organic carbon. Meanwhile, maize grain yield and shoot dry weight were measured after harvest. The data collected were subjected to Analysis of Variance and the significant means were separated at $p \leq 0.05$ using Duncan Multiple Range Test. Soil pH, was substantially enhanced by 17.67, 14.95 and 27.03 % at 4, 8 and 12th WAS when 5 t/ha of compost was applied, compared to the control. The application of 10 t/ha of compost resulted to 46.43, 17.86 and 26.39 % increase in soil carbon sequestration at 4, 8, and 12th WAS, compared to the control. Maize shoot dry weight and grain yield were enhanced by 93.80 and 54.57 % using15 t/ha of compost. Application of 10 t/ha compost showed increased yield and showed for carbon sequestration compared to 5 and 15 t/ha.

Keywords: Carbon Sequestration, Maize yield, Compost, Biochar, Co-composted Biochar, Alfisols.

1. INTRODUCTION

The emission of greenhouse gases has worsened following the conversion of forests into agricultural land, urban development, and the adoption of unconventional practices (Nwite and Alu, 2017). Soil degradation and nutrient depletion have also threatened food security and means of survival of human beings due to low yields per unit area of farmland (Naba, 2018). Agricultural land has the potential to absorb and store about 10% of the current annual emissions of 8-10 Gt/year Hansen et al., (2013), resulting in the sequestration of CO2 in terrestrial ecosystems (Stockmann et al., 2013). Soil application of organic amendments allows the mineralization of just 10 % of the global soil organic carbon pool, which is equivalent to the emission caused by mankind in approximately 30 years (Kirschbaum, 2000).

Therefore, soil application of compost (CMP), biochar (BCH), co-composted biochar (C-BCH) and compost + biochar (CMP + BCH) is essential in enhancing soil organic matter Lal, (2004) and carbon sequestration thereby enhancing the productivity of soil while mitigating climate change. The organic amendment, CMP, is made from organic material that undergo a controlled process with oxygen. When a matured CMP is applied to soil, it positively enhances soil properties. The application CMP decreased soil bulk density (Db) and increase soil carbon sequestration, grain yield of maize, total porosity (TP), hydraulic conductivity (Ks), and aggregate stability compared to the use of mineral fertilizer. The application of CMP provides labile organic matter for crop use; however, its effectiveness is limited due to the rapid decomposition of its organic matter content.

The pyrolysis of biomass materials under limited oxygen supply results to BCH International Biochar Initiative, (IBI, 2014). Application of BCH on degraded soils reduces soil Db and soil penetration resistance (SPR) Negis et al., (2019) while increasing TP and water holding capacity, soil carbon sequestration Lehmann and Joseph, (2015), soil pH and organic carbon (OC). Combined application of BCH and CMP is either through co-composting or mixing of the prepared amendments (Naba et al., 2020). Larney and Angers, (2012) reported that increasing rates of C-BCH resulted in increased soil TP, which in turn affected soil saturated hydraulic conductivity, moisture content and SPR. Maize is a staple food for millions of people worldwide, particularly in Sub-Saharan Africa, Latin America, and parts of Asia. It serves as a primary source of calories and nutrition, providing carbohydrates, dietary fiber, and various essential vitamins and minerals.

Maize-based diets have become integral to food security and nutrition in many regions. Maize requires fertile and adequately drained soil (Kamara et al., 2014). The short duration of maize allows it to effectively use fertilizer, resulting in a good amount of food grains per-unit area (Kamara et al., 2014). Decline in soil organic matter (OM) and fertility are becoming significant challenges to agricultural production. Poor soil conditions due to low soil OM, characterized by nutrient deficiencies and high acidity contributed to reduced maize productivity; hence, threatening global food security. Again, climate change, caused by global warming as a result of the accumulation of CO^2 in the atmosphere, poses a threat to almost the entire global ecosystem.

There is the need for the return of bio-materials into soils to sequester organic carbon. The sequestration of organic carbon in soil serve as a critical step in understanding and promoting sustainable land management practices. By elucidating the mechanisms underlying carbon sequestration and nutrients cycling potentials of organic amendments, this research can inform policy makers, land managers and farmers about its benefits agricultural systems. Ultimately, the findings of this study can contribute to the development of effective strategies for mitigating climate change and promoting sustainable agricultural practices. Therefore, this study aimed to evaluate the efficacies of compost, biochar, co-composted biochar and compost + biochar on carbon sequestration and yield of maize in Samaru Alfisols, Northern Nigeria.

2. MATERIAL AND METHODS

Geo-information of the Study Area

Samaru is located on the northern plains of Nigeria and lies between latitude 11^{o}00′ to 11^{o}28′ North and longitude 7^{o}30′ to 7^{o}52′ East. It lies at an altitude of about 686 m above sea level. It is within the Guinea Savanna with two distinct dry and rainy seasons. The long time (1968 - 2017) means annual rainfall of the study area is 1015.9 mm and is concentrated between the months of May and September (Yamusa and Abdukadir, 2020). The soils of the region are classified as Typic Haplustalf according to USDA Soil Taxonomy (Ogunwole et al., 2001). Dominant tree species found in the Zaria region are the *Isoberlinia doka, Terminalia avicennioides*, *Stereospermum kunthianum, Nauclea latifolia, Annona senegalensis* and *Dichrostachys cinerea* (Ogunwole et al., 2001).

Production of Biochar

The pyrolysis of biochar was carried out using maize cobs collected from a farm, within Industrial Development Center Samaru, located between latitude 11^o 9′13′′N and longitude 7^o 39′45″ E. The weighed cobs in stainless steel container was inserted into a sixty

(60) litter oven and it doors was locked. The pyrolysis process was carried out at 600 ^{0}C for a period of four (4) hours, as described by. After each turn, biochar produced was allowed to cool and its weight measured using a weight scale. The whole products after pyrolysis were stored in a plastic bag in preparation for laboratory analyses and soil application. The final yield of biochar produced was calculated as follow:

Yield (%) = weight of final product / weight of initials sample x 100 ....(1)

Production of Compost and Co-composted Biochar

Compost and co-composted biochar were produced using rice straw and dried Gmelina leaves (*Gmelina arborea)* as carbon sources. Meanwhile fresh mango (*Mangifera indica*) leaves was used as green material, and cow manure to further provide nutrients for microbial decompositions. Bio-materials were sourced from the Institute for Agricultural Research farm, IAR (Latitude 11^{o}14′14′′ N and Longitude 7^{o}38′65′′ E). The plants and animal materials were piled up in layers according to standard compost production protocol and left under a tree to provide shading. Each pile was covered with Polyethene sheets to conserve heat and moisture in the pile.

At two (2) weeks after pilling, 2.6 kg of phosphate rock (5 % phosphate rock w/w) was incorporated into the 52 kg pile, and the pile was divided into two equal portions (26 kg each). Following the procedure described by Zainudin et al., (2020), one portion was mixed with biochar (10 % biochar w/w) as co-composted biochar. Piles were left to mature by watering and turning up at two-week intervals until harvest. The prepared compost and biochar were mixed in equal proportion by weight as compost + biochar and was used as a treatment. Organic amendments used were analysed for nutrients in the laboratory and were augmented with mineral fertilizers to meet the 120: 60: 60 NPK recommended for maize.

Soil Sampling and Experimental Setup

Soil sample (1000 kg) for screenhouse experiment was destructively collected from 0 to 30 cm depth in a fallowed field at IAR Farm. IAR farm is within Northern Guinea Savanna of Nigeria on Latitude 11^{o}14′14′′ N and Longitude 7^{o}38′65′′ E, having altitude of 610 m above sea level. Undisturbed core soil samples were randomly collected from 0 – 30 cm depths in a 1,600 m^2 field, using core rings having heights of 98 cm^3 volume. The samples were covered with air-tight Polyethene sheets to prevent moisture loss and were taken to the laboratory. Disturbed soil samples were homogenized, air-dried and prepared for laboratory analyses and screenhouse studies.

The experiment consisted of three (3) rates of CMP, BCH, C-BCH and CMP + BCH (5, 10 and 15 t/ha). Each treatment was thoroughly mixed with 9 kg of prepared soil (Table 1). A total of 14 treatments combinations including a control and sole NPK, having 9 replicates, were obtained giving rise to 126 experimental pots which were laid in a Complete Randomized Design (CRD) in a screenhouse at Department of Crop Protection, Ahmadu Bello University, Zaria. The qualities of the organic amendments, with respect to available N, P and K, were determined with the view to calculating quantities of mineral fertilizers needed to supplement their nutrients supply capacities, to achieve a balanced nutrient supply for optimum productivity of maize, as follows:

Table 1 Treatments Combination

Treatment	Interpretation
CTL-	7 kg soil
NPK	0 g BCH + 9 kg soil + 7.5 g NPK 15:15:15
BCH1	23 g BCH + 9 kg soil + 4 g Urea + 1.3 g SSP + 3 g MOP = 5 t ha^{-1}
BCH2	46 g BCH + 9 kg soil + 2 g Urea + 0.7 g SSP + 2 g MOP = 10 t ha^{-1}
BCH3	69 g BCH + 9 kg soil + 1 g Urea + 0.4 g SSP + 1 g MOP = 15 t ha^{-1}
CMP1	23 g CMP + 9 kg soil + 3.1 g Urea + 2g SSP + 3.5 g MOP = 5 t ha^{-1}
CMP2	46 g CMP + 9 kg soil + 1.6 g Urea + 1 g SSP + 1.8g MOP = 10 tha^{-1}
CMP3	69 g CMP + 9 kg soil + 0.8 g Urea + 0.5 g SSP + 0.9 g MOP = 15 tha^{-1}
C-BCH1	23 g C-BCH + 9 kg soil + 3.2 g Urea + 1.14 g SSP + 2 g MOP = 5 t ha^{-1}
C-BCH2	46 g C-BCH + 9 kg soil + 1.6 g Urea + 0.7 g SSP + 1 g MOP = 10 tha^{-1}
C-BCH3	69 g C-BCH + 7 kg soil + 0.8 g Urea + 0.4 g SSP + 0.5 g MOP = 15 tha^{-1}
(CMP + BCH) 1	23 g CMP + BCH+ 9 kg soil + 3.6 g Urea + 1.6 g SSP + 3.2 g MOP = 5 t ha^{-1}

(CMP + BCH) 2	46 g CMP + BCH + 9 kg soil + 1.8 g Urea + 0.8 g SSP + 1.6 g MOP = 10 tha^{-1}
(CMP + BCH) 3	69 g CMP + BCH + 9 kg soil + 1 g Urea + 0.4 g SSP + 0.8 g MOP = 15 tha^{-1}

CMP= Compost, BCH= Biochar, C-BCH= Co-composted biochar, CMP + BCH= Compost + biochar, CTL= Control. 5, 10 and 15 represent 5, 10 and 15 t/ha of organic amendments.

Sowing of Maize and Post Treatment Soil Sampling

Maize (SAMMAZ 16) seeds, sourced from IAR seed unit were sown 3 cm below soil surface at three (3) seeds per hole after allowing saturated soil to drain over-night. Crops were thinned to one stand per pot at 10 days after sowing. Amended soils were sampled at 4, 8 and 12^{th} WAS by collecting disturbed and undisturbed sample, from 0 – 20 cm depth using three (3) replicates from each treatment, totaling 42 experimental units. Samples were used in the laboratory for chemical analysis.

Laboratory Analysis

The subsamples of organic amendments, soil samples before and after planting were passed through 2mm sieve and were analyzed for their chemical properties in the laboratory. Amended, un-amended soil samples and organic amendments were analyzed for their pH (in H2O), OC, available N and OM. Meanwhile, un-amended prepared soil samples were also analyzed for their available P and K content. Amended soil samples were also analyzed for their CEC. Organic amended, un-amended soils were analyzed for pH, OC, Available N. Amended soils were analyzed for ECE whereas un- amended soils were analyzed for P and K content. The CEC was measured following the procedure described by (Chapman, 1965). Available N was determined using macro Kjeldahl method as described by (Bremner and Mulvaney, 1982).

Soil OC was determined using Walkley – black dry combustion method as described by (Nelson and Sommer, 1982). Available P was measured using Bray-1 method (Jackson, 1958). Meanwhile available K was determined in an atomic absorption spectrometer. Saturated hydraulic conductivity was determined using a constant head permeameter method as described by (Reynolds et al., 2002). Moisture retention was measured using a pressure plate membrane as described by (Klute, 1986). Dry aggregate stability was determined following the protocol described by (Kemper and Rosenau, 1986). Bulk density was measured using the core method (Blake and Hartge, 1986). Particle density was determined following the procedure described by Blake, (1965) while total porosity was calculated following the order of (Obi, 2000).

Computation of Soil Organic Carbon Sequestration

Soil organic carbon stock (SOCS) of the bulk treated soil was calculated using the equation of Pluske et al., (2014) i.e.

$$SOCS = 100\rho dZC \qquad (2)$$

Where;

ϱd (Mgm-3) = Bulk density

Z (cm) = Soil depth

C (%) = Total soil organic carbon

Collection of Yield Data of Maize

The grain yield (GY) was obtained by collecting seeds from each cob and weigh using a balance scale. Yield of maize per hectare was computed from the grain yields. The shoot dry weight (SDW) was obtained by cutting the aboveground biomass of each plant and weighed, after sun- drying.

Statistical Analysis

Means and standard deviations were computed for the chemical properties and maize parameters. A one-way analysis of variance (ANOVA) was used to evaluate the effects of different application rates of the treatments on the measured soil and maize parameters, and differences between the treatment means was compared using Duncan Multiple Range Test (DMRT) at 5 % level. All statistical analyses were performed using SAS software version 9.4.

Properties of the Experimental Soil

The results of the properties of the experimental soil are shown in (Table 2). It showed that the soil had a loam textural class with the percentage of sand, silt and clay of 56.80, 28.30 and 14.90. Soil moisture content of the experimental soil at field capacity, permanent wilting and plant available water were 25, 14.10 and 10.09 %, respectively. The pH of the soil was found to be neutral (6.83) according to the ratings by (USDA, 1993). Meanwhile, the OC and total N obtained were low based on the standards by Udo et al., (2009) and Esu, (1991), respectively. According to the magnitudes of the soil available N, OC, P and K of the experimental soil made it of poor fertility. Therefore, management practice that enhances soil fertility, such as the application of CMP, BCH, C-BCH and CMP + BCH is essential in enriching the soil with essential plant nutrient elements.

Table 2 Pre-treatments Properties of Experimental Soil

Physical Properties			
Sand (%)	**Silt (%)**	**Clay (%)**	**Textural Class**
56.80	28.30	14.90	Loam
Db (Mg/g)	Dp (Mg/kg)	TP (%)	MWD (mm)
1.46	2.29	35.33	2.36
Ks (cm/min)	FC (%)	PWP (%)	AWC
1.73	25	14.10	10.09
Chemical Properties			
pH	OC (g/kg)	N (g/kg)	P (mg/kg)
6.83	5.90	0.80	1.70
K (mg/kg)	-	-	-
1.70	-	-	-

Db= Bulk density, Dp= Particle density, TP= Total porosity, MWD= Mean weight diameter, Ks= Saturated hydraulic conductivity, FC= Field capacity, PWP= Permanent wilting point, AWC= Available water content, OC= Organic carbon, N= Total nitrogen, P= Phosphorus, K= Potassium

Properties of organic amendments

The results (Table 3) of properties of the organic amendments showed that total N content was 7.80, 3.20, 5.60 and 6 g/kg in CMP, BCH, C-BCH and CMP + BCH respectively. The amendments were lower in N than those reported by (Glab et al., 2018). It is likely due to the volatilization of the element during BCH production, incases of C-BCH and CMP + BCH. The P contents ranged from 1.24 mg/kg in CMP + BCH to 8.60 mg/kg in BCH. BCH had the highest K value (1.80 mg/kg). It might be attributed to the volatilization of H, oxygen and N, resulting in a carbon –rich structure. Consequently, the concentration of K, which does not undergo volatilization, becomes relatively higher (Lehman and Joseph, 2015). With respect to OC content, it ranged from 95.70 in C-BCH to 167.60 in CMP. The amendments were lower in terms of OC compared to the report by (Mujtaba et al., 2021).

Table 3 Selected chemical properties of the organic amendments

Amendments	**N (g/kg)**	**P (mg/kg)**	**K (g/kg)**	**OC (g/kg)**	**pH**
CMP	7.80	1.61	0.43	167.60	8.16
BCH	3.20	0.86	1.80	99.80	10.81
C-BCH	5.60	1.94	0.56	95.70	8.70
CMP + BCH	6.00	1.24	1.12	103.20	9.71

CMP= Compost, BCH= Biochar, C-BCH= Co-composted biochar, CMP + BCH= Compost + biochar, N = Nitrogen, P = Phosphorus, K = Potassium, OC = Organic carbon, OM = Organic matter, C: N = Carbon to nitrogen ratio

The lower OC in the presence study might be attributed to the high pyrolysis temperature (600 ^{0}C) and the duration of pyrolysis (4 hours), which converted OC into its stable form. Soil OM ranged from 28.82 % in CMP to 16.47 % in C-BCH. The high OM detected in the CMP might be due to the fact that the OM present in CMP is easily decomposed by microbes, such as bacteria and fungi, which break down organic materials into humus. On the other hand, BCH and C-BCH are generally more recalcitrant and less readily decomposed compared to CMP (Lehman and Joseph, 2015). The pH of the organic amendments was 8.16, 10.81, 8.70 and 9.71 in CMP, BCH, C-BCH and CMP + BCH, respectively. The amendments were strongly alkaline (USDA, 1993).

3. RESULT AND DISCUSSION

Effect of Organic Amendments on Soil pH

The pH (Table 4) of soils amended with rates of CMP, BCH, C-BCH and CMP + BCH were significantly higher than the control and sole NPK fertilizer at all sampling periods in the present study. The pH of the amended soils was moderately acidic at 4 WAS, while at final sampling (12 WAS) it was neutral. Meanwhile, CMP amended soils were slightly acidic at first sampling and tended toward neutral at 12 WAS (USDA, 1993). Soil pH here tending towards neutrality and was similarly reported by who reported enhanced soil pH in a tomato field following the application of CMP derived from municipal solid waste. The significant increase might be attributed to the release of alkaline substances during the decomposition of organic amendments Guo et al., (2019) which offers a buffering capacity of the organic amendments against acidity, as well as increased microbial and enzyme activities.

Table 4 Effect of Organic Amendments on Soil pH

Soil pH			
Treatments (t/ha)	**4 WAS**	**8 WAS**	**12 WAS**
Control	5.03de	5.29d	4.84e
CMP5	6.11ab	6.22ab	6.77abc
CMP10	5.80abc	6.05ab	6.77abc
CMP15	6.43a	6.39a	6.77abc
BCH5	5.55bcd	6.10ab	6.88abc
BCH10	5.76abc	5.87bc	7.02a
BCH15	5.84abc	5.70c	6.64bcd
C-BCH5	5.26cde	6.04abc	6.38d
C-BCH10	5.97abc	6.21ab	6.65bcd
C-BCH15	5.89abc	6.24a	6.86abc
CMP + BCH5	5.30cde	6.17ab	6.53cd
CMP + BCH10	5.46bcd	5.87bc	6.64bcd
CMP + BCH15	5.64bcd	5.70c	6.91ab
NPK (Recommended)	5.09de	5.13d	5.20e
SE (±)	0.208	0.100	0.103

WAS = Week after sowing, CMP= Compost, BCH= Biochar, C-BCH= Co-composted biochar, CMP + BCH= Compost + biochar, SE = Standard error, subscript 5, 10 and 15 t/ha represent 5, 10 and 15 t/ha of organic amendments. Means followed by the same letter (s) within the same column and under the same week are not significantly different at .05 level of probability as determined by DMRT.

In a related study, assessed the effects of BCH on soil pH and showed that application of BCH increased soil pH, due to the release of organic acids due to increased concentration of acetic, citric and oxalic acid in the soil, thus neutralizing soils, subsequently improving soil pH. The pH of the rates of the organic amendments in the present study increased with increasing sampling periods. reported a similar trend following the application of BCH to acidic soil, and attributed it to the release of basic compounds, such as calcium carbonate and magnesium carbonate from the BCH during decomposition which raised the soil pH over time. Similarly, the application of wood ash to acidic soil increased the soil pH due to its high buffering capacity, which helped to counteract the acidity and raise pH over time according to. These imply that soil application of the organic amendments is a reliable tool for raising soil pH.

Effect of Organic Amendments on Soil Carbon Sequestration

Results of soil organic carbon stock (SOCS) given on Table 5 ranged from 13.35 Mg ha-1 in sole NPK fertilizer to 38.50 Mg ha-1 in soil supplied with 15 t/ha of CMP, at 4 WAS. Meanwhile at 8 WAS, 10 and 15 t/ha of all the organic amendments were statistically higher ($p \leq 0.05$) than the control and sole NPK in SOCS. Apart from 10 and 15 t/ha of all the organic amendments, the remaining rates of organic amendments were comparable to the control in SOCS. At 12 WAS, it ranged from 10.87 Mg ha-1 in sole NPK to 20.36 Mg ha^{-1} in soils treated with 15 t/ha of both C-BCH and CMP + BCH. Results of the present study are in agreement with the report of who reported that the application of CMP enhanced SOCS by 35 % in a sandy loam soil.

Table 5 Effect of Organic Amendments on Soil Organic Carbon Stock

Soil Organic Carbon Stock (Mg ha^{-1})			
Treatments (t/ha)	**4 WAS**	**8 WAS**	**12 WAS**
Control	14.17c	15.08de	13.19cd
CMP5	18.53bc	17.83bcd	14.72bc
CMP10	26.45b	18.36bc	17.92ab
CMP15	38.51a	22.03a	20.01a
BCH5	19.00bc	17.77bcd	14.43bc
BCH10	16.57bc	18.03bc	14.92bc
BCH15	22.50bc	22.59a	17.58ab
CMP + BCH5	21.02bc	15.66cde	17.72ab
CMP + BCH10	21.68bc	18.32bc	17.93ab
CMP + BCH15	20.69bc	19.82ab	20.36a
NPK (Recommended)	13.35c	13.76e	10.87d
SE (±)	3.549	0.900	1.058

WAS = Week after sowing, CMP= Compost, BCH= Biochar, C-BCH= Co-composted biochar, CMP + BCH= Compost + biochar, SE = Standard error, subscript 5, 10 and 15 represent 5, 10 and 15 t/ha of organic amendments. Means followed by the same letter (s) within the same column and under the same week are not significantly different at .05 level of probability as determined by DMRT.

Similarly, observed a 27 % increase in SOCS following the application of CMP in a clayey soil and attributed it to increased input of soil OM, which promotes microbial activity and soil aggregation, thereby protecting SOC from microbial decomposition. According to the findings of Zhang et al., (2016), the application of BCH increased SOCS by 26 % in a loamy sand soil. Similarly, a study by Lehmann and Joseph, (2015) observed a 33 % increase in soil OCS after the application of BCH to sandy soil. The authors further reported that BCH enhances soil OCS by providing a recalcitrant form of carbon that is resistant to decomposition, thus promoting long-term carbon sequestration in the soil. Overall, the SOCS of the amended soil decreased with increasing sampling periods in the present study. The decrease might be due to increased soil pH and reduced OM with sampling times in the present study.

Acidic soils (low pH) tend to have lower soil OCS compared to neutral or alkaline soils (higher pH). This is because acidic soils often have reduced microbial activity, leading to slower decomposition of OM and the accumulation of SOCS over time. On the other hand, neutral or alkaline soils support more active microbial communities, thereby promoting the decomposition of OC and resulting in reduced OC accumulation over time. It was observed in the present study that SOCS increased with increasing application rates of organic amendments. The increase in application rates might be due to an increase in OM, which results in direct increase of OC input and an indirect increase in plant production due to higher doses of organic amendments (Lugato et al., 2010). Therefore, soil applications of CMP, BCH, C-BCH and CMP + BCH showed positive effects on soil carbon sequestration.

Effect of Organic Amendments on Shoot Dry Weight and Grain Yield

Results of shoot dry weight (SDW) of SAMMAZ 16 (Table 6) indicated that soil supplied with 15 t/ha CMP had the highest value (4301 kg ha^{-1}) while the least was in the control (1954 kg ha^{-1}). Reported that organic amendments enhanced the SDW of maize in Zaria, Northern Guinea Savanna agro-ecological zone of Nigeria. They accorded the observed positive effects to improvement in soil fertility parameters, including organic matter content, nitrogen content, and phosphorus content following the application of farmyard manure, CMP and vermicompost. Grain yield of SAMMAZ 16 (Table 6) responded positively to the various application rates of the organic amendments in the present study.

Table 6 Effect of Organic Amendments on Shoot Dry Weight and Grain Yield of Maize

Treatments (t/ha)	Shoot Dry Weight (kg/ha)	Grain yield (kg ha^{-1})
Control	1954e	334h
CMP5	3021bcd	4148cd
CMP10	3501b	5386a
CMP15	4301a	5190ab
BCH5	2897bcd	2684e
BCH10	2826bcd	1528f
BCH15	2150de	1226fg
C-BCH5	2488cde	3043e
C-BCH10	3341bc	4531bcd
C-BCH15	2772b-e	3875d
CMP + BCH5	2332bcd	3839d
CMP + BCH10	2879bcd	4815abc
CMP + BCH15	3217bc	4672abc
NPK (Recommended)	2506cde	590gh
SE (±)	266.158	228.561

WAS = Week after sowing, CMP= Compost, BCH= Biochar, C-BCH= Co-composted biochar, CMP + BCH= Compost + biochar, SE = Standard error, subscript 5, 10 and 15 represent 5, 10 and 15 t/ha of organic amendments. Means followed by the same letter (s) within the same column and under the same week are not significantly different at 0.05 level of probability as determined by DMRT.

The GY ranged from 334 kg ha^{-1} in the control to 5386 kg ha-1 in soil supplied with 10 t/ha of CMP. The results showed that all the levels of the organic amendments were significantly higher ($p \leq 0.05$) in GY than the control. The increase in GY observed in the present study might be attributed to the enhanced soil fertility following the use of organic amendments. CMP, BCH, C-BCH and CMP + BCH enrich the soil with essential nutrients, including N, P, and K, which are important for maize growth and development. Results from the present study are similar with the reports of with application of vermicompost, a nutrient-rich organic amendment, who observed increase in the yield of maize through improved soil fertility.

4. CONCLUSION

The study assessed the effect of compost, biochar, co-composted biochar and compost + biochar on carbon sequestration and yield of maize from a northern guinea savannah Alfisols. Results showed that soil organic carbon stock and maize yield were enhanced following the application of organic amendments with rates of compost amendments performing better than the remaining treatments. Application of compost at a rate of 10 t/ha optimally increased the soil carbon stock and the final grain yield of maize after harvest. Therefore, it is recommended for adoption by farmers to boost farm productivity. Further study in field conditions in mid to longer duration is recommended to better understand the efficacies of the organic amendments on carbon sequestration and maize yield as a climate change mitigation strategy.

Authors' contribution

Angyu MD: Designing of experiment, execution of research, data collection and analysis and interpretation; Abdulkadir A: Research supervision and manuscript proofreading; Garba J: Research supervision and manuscript proofreading.

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Informed consent
Not applicable.

Conflicts of interests
The authors declare that there are no conflicts of interests.

Ethical approval
The ethical guidelines for plants & plant materials are followed in the study for plant materials collection & identification.

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Data and materials availability
All data associated with this study are present in the paper.

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