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Research article

One-time application of biochar influenced crop yield across three cropping cycles on tropical sandy loam soil in Ghana

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ABSTRACT

The preparation and application of biochar by smallholder farmers is labour intensive hence an effective one-time application for multiple cropping seasons would be desirable by farmers and researchers. In this study, one-time biochar application as a soil amendment and its interaction with compost and NPK on yield performances of different crops was investigated across three cropping seasons. Treatments included biochar applied alone or together with compost, inorganic NPK fertilizer or both. Maize, okra and cassava were planted in succession and data was collected on their shoot N, P and K concentrations, yields as well as selected soil parameters (pH, exchangeable acidity, total exchangeable bases, effective cation exchange capacity, total N, total organic carbon, available phosphorus). Data was analyzed with GenSTAT and results were presented in tables and bar graph. Corn cob biochar applied solely did not significantly improve maize and okra yield in the first and second cropping season but increased yield of cassava significantly at the third cropping season. Yield increased in sole NPK, compost and NPK + compost treatments for all cropping cycles, but yields obtained from these treatments in the presence of biochar were greater than their corresponding treatments without biochar. The study also showed that biochar application together with compost, NPK or both, improved total organic carbon, total nitrogen, available phosphorus, total exchangeable bases, exchangeable acidity, effective cation exchange capacity and pH as well as tissue N, P and K of all crops.

Our findings demonstrated that a single application of biochar, particularly in the presence of compost, inorganic NPK fertilizer or both can increase yields across three cropping seasons and improve soil fertility.

1. Introduction

Biochar use for soil fertility improvement have become increasingly important in the global agricultural landscape, particularly amongst farmers (Steiner et al., 2018) and researchers (Mensah and Frimpong, 2018; Steiner et al., 2018). Biochar is a carbon rich material obtained when organic waste is subjected to relatively low temperature (<700 °C) and limited oxygen condition (Lehmann and Joseph, 2009). The pyrolyzed product can be applied to enhance the fertility of nutrient deficient soils and yield of crops (Crane-Droesch et al., 2013; Zhang et al., 2012), sequester carbon and attenuate emission of greenhouse gases (Van Zwieten et al., 2010; Zhang et al., 2012), remediate soil and water from trace metals or pesticide contamination (Beesley et al., 2010; Zhang et al., 2012). Most of these functions are possible due to biochar's large surface area and higher surface charges which develop from ionization of surface functional groups (Lehmann and Joseph, 2015). Additionally, Lehmann and Joseph (2015) reported that biochar carbon is largely recalcitrant and does not yield easily to microbial decomposition hence stays in soil for centuries or millennia. Biochar application to soil potentially leads to a long term benefit on soil fertility through improved soil exchange sites and enhanced nutrient retention capacity, gradual release of nutrients and hence their availability to plants, water availability to crops, and enhanced microbial functions (Lehmann and Joseph, 2015). Regardless of the enormous benefit derived from biochar, its sole addition to soil to enhance fertility and crop yield has limitations; particularly plant based biochar. Often, plant based biochar is deficient in nitrogen (Phares et al., 2020) as well as phosphorus (Zhang et al., 2016). It must therefore be co-applied with compost, manure or inorganic fertilizer (Adekiya et al., 2019; Phares et al., 2017).

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The utilization of compost to improve soil fertility and crop yield in previous studies showed positive results (Abdel-Mawgoud, 2006; Adugna, 2016; Barker and Bryson, 2006). Manure such as compost, however, mineralizes rapidly in tropical humid soils (Bol et al., 2000), compared to biochar, which has stable C (Kuzyakov et al., 2014). Due to rapid mineralization of compost, it is required that it is applied every season and in large amounts to sustain crop nutrient requirement (Inckel et al., 1996), which require extra labour and increased cost.

Although inorganic NPK fertilizer can supply readily soluble nutrients, it has a problem with leaching of N and K particularly in highly weathered soils (Baligar and Bennett, 1986). Some consequences associated with nutrient leaching include soil nutrient depletion, soil acidification, groundwater pollution, increased cost of farm operations and reduced yield of crops (Brady et al., 2008; Lehmann et al., 2003). Leaching results in nutrient losses from agriculture field and require extra input of nutrients which comes at a cost to the farmer. Acidification which results from leaching is often corrected by the farmer through liming, increasing cost and human drudgery associated with farm operations. We opined that, the positive synergy of applying biochar with either compost or inorganic NPK or both could reduce leaching and increase nutrient availability. Then again, it could result in the reduction in the application rates of both compost and inorganic fertilizer. When this happens, farmers are able to save money that would have been used to purchase the extra fertilizer. Thus, combined application of biochar with compost and/or inorganic fertilizer is potentially an economically prudent strategy for soil fertility management for smallholder farmers.

Nevertheless, information on the interactive effect of biochar with compost and/or inorganic fertilizer under field conditions is rare; especially across multiple cropping seasons in Ghana. Studies on effect of biochar applied solely or co-applied with compost and/or inorganic NPK fertilizer have often been done as short term pot experiment, or one cropping season field work. Yeboah et al. (2016) interrogated the effect of biochar and inorganic NPK fertilizer on soil chemical properties and yield of maize for only a season. Frimpong et al. (2016) conducted a pot experiment involving the application of corn cob biochar and cow dung on soil properties and lettuce yield over one cropping season. Mensah and Frimpong (2018), investigated biochar and/or compost effect on soil properties of coastal savannah and the tropical rainforest agro ecological zones, and maize yield in a 40-day soil incubation experiment. Badu et al. (2019) studied one time biochar application with inorganic nitrogen fertilizer effects on maize (*Zea mays* L.), nitrogen use and yield in moist semi-deciduous forest zone of Ghana over two seasons (major and minor season). They reported positive effect of biochar on soil properties and yield of maize over the two seasons indicating that biochar effect was seen in both seasons.

There is paucity of information on the effect of one-time biochar addition on the soil properties as well as yields of multiple crops grown in 2 – year rotation. The research objective was to investigate the effect of biochar incorporated alone or co-applied with compost and/or inorganic NPK fertilizer on the yield of maize, okra and cassava in a 2 – year rotation.

2. Materials and method

2.1. Study site

The study was conducted at the A.G. Carson Technology Center of the University of Cape Coast, Ghana (5°07′54.2″N 1°17′41.7″W) during the major and minor seasons of 2016 and 2017 farming seasons, respectively. The area falls within Coastal Savanna Agroecological zone of Ghana and it is characterized by a bimodal rainfall pattern, with the major wet season between May and July while the minor season occurs between September and December. The area also experiences a short dry season in August and a longer one between December and April. The annual rainfall of the area ranges between 1150 - 1200 mm. The soil in the study area falls within the Benya series and classified as Haplic Acrisol (World Reference Base classification (WRB)). These soils are often characterized by low exchangeable bases and low pH (FAO and Working Group WRB, 2015).

2.2. Soil, biochar and compost preparation

Surface (0–20 cm) soil were sampled at 20 different points across a field of about 6000 m^2 and bulked to form a composite sample for initial soil characterization. Biochar used in the experiment was produced from corn cob using a locally manufactured kiln. To produce the biochar, corn cob pieces of varying lengths and diameters were laid in kilns and pyrolyzed at about 450 °C for up to 2 h. Biochar obtained was ground (using a pestle and mortar), and sieved to 0.5 mm size. Samples of the ground biochar was sent to the laboratory for analysis.

The compost was produced using the pit method (Edwards and Araya, 2011), at the University of Cape Coast Research and Teaching farm, Cape Coast, Ghana. The basic feedstock mixture of the compost was poultry manure (65% by mass) and maize straw (35% by mass).

2.3. Experimental setup

The experiment was conducted using completely randomized design with 4 replications. High-yielding varieties of maize (Obatampa), okra (Lady finger) and cassava (Capevars bankye), well adapted to the prevailing climatic and edaphic conditions were grown in rotation. The maize was grown during the major season: late March and harvested in July of 2016, followed by okra in the minor season (September to early December) of the same year. The cassava was grown across the major and minor seasons of 2017: early April to mid December 2017. The crops were selected because they are largely consumed by Ghanaians (SRID--MoFA, 2007).

2.4. Treatments input

The treatments were compost or biochar (applied singly at 10 t ha^{-1}); combined compost and biochar (each applied at 10 t ha^{-1}), with or without NPK fertilizer and combined compost and NPK. Treatments of fertilizer only and no amendment (control) were also included (Table 1).

Biochar was applied once, and only in the first cropping season, solely or in combination with compost or inorganic NPK fertilizer or both. In the second cropping cycle no amendments were added while only compost and/or inorganic NPK fertilizer were added during the third cropping season. During the maize production cycle, the inorganic NPK fertilizer was applied at 100 kg N ha^{-1}, 60 kg P ha^{-1} and 60 kg K ha^{-1}. However, P and K were in their oxide forms. No amendments were applied during the second cropping cycle where okra was grown. During the third cropping cycle, cassava received 100 kg N ha^{-1}, 60 kg P ha^{-1} and 80 kg K ha^{-1}, fertilizer input.

The biochar applied was C rich but nutrient poor. The compost was nutrient rich and contain high amount labile C, which could easily be lost through mineralization. Thus, biochar and compost, co-applied is expected to promote a double win of C sequestration and nutrient supply.

After manual weeding and soil surface preparation, the experimental field was demarcated into 8 treatment plots with each plot measuring 4.4 m × 4.4 m (19.38 m^2) and 4 replications. Biochar was incorporated into the surface soil and manually mixed to ensure homogeneous distribution of biochar to about 20 cm depth. Biochar application was done only once during the 2016 major rainy season when the experiment was started. Compost was applied along with biochar two weeks before maize was sown. Compost was applied by broadcasting and incorporation into soil. NPK was split applied; at two and four weeks respectively after germination of maize using ring method (Adiaha and Agba, 2016). Similarly, NPK fertilizer was split applied, at one and three months after planting cassava, respectively (Biratu et al., 2018).

2.5. Planting and agronomic practices

Two weeks after biochar and compost application, the seeds of the maize were sowed using 4 seeds per hill at a spacing of 80 cm × 40 cm. The seeds were sowed on both amended and un-amended plots. The germinated maize was manually thinned to two seedlings per hill within 2 weeks. Thinning was done to ensure that plants left on the field had uniform growth. Each treatment plot had 11 rows, 10 plants per row and border of 20 cm.

Fertilizer application was done as described earlier and weeds growing on the plots were cleared by hand or with a hoe whenever necessary during each cropping cycle. Maize pest was controlled using the integrated pest management which involves the application of wood ash + neem leaf extract (Moyin-Jesu, 2010). Water was supplied to treatment plots using the handheld watering can, to field capacity every week. Loss in soil moisture is checked using time domain reflectometry (TDR) method prior to addition of water. Field capacity of the experimental field was estimated as described by Walker (1989).

Okra seeds were sown on the same plots after maize was harvested. The okra seeds were sowed at 4 seeds per hill at spacing of 60 cm × 60 cm, and thinned to 2 plants per hill within two weeks. Each plot had 6 rows, 12 plants per row and border of 20 cm. Here, no external inputs in the form of NPK or compost were added. Agronomic practices including weed control, diseases and pest management were carried out as described earlier (Afe and Oluleye, 2017).

Before cassava was planted, all the amendments except biochar were applied again at the rates described previously. Cassava was planted at spacing of 100 cm × 80 cm, with each plot having 5 rows and 4 plants per row. All necessary cultural and agronomic practices were carried out.

2.6. Laboratory analyses

2.6.1. Physical and chemical properties of soil

Soil sampled from the experimental field was analyzed before the start of the experiment and after harvesting of cassava. Soil physico-chemical properties (pH, available P, total organic carbon, total N, exchangeable bases, total exchangeable bases (TEB), effective cation exchange capacity (ECEC), exchangeable acidity, and bulk density) were determined using standard laboratory procedures at the Soil Research Institute, Kumasi, Ghana.

Soil pH was determined by immersing the glass electrode of a pH meter (*Suntex SP-701*) in a 1:2.5 soil: water (w/v) mixture. Modified wet oxidation procedure described by Nelson and Sommers (1996) was used to determine total organic carbon (TOC) content. Soil total nitrogen was determined by the micro Kjeldahl method (Allen et al., 1974). Available phosphorus (AvP) content was analyzed by the Bray-1 acid method (Maghanga et al., 2015). The ammonium acetate (at pH 7) extraction method was followed to determine the cation exchange capacity (CEC) (Dohrmann, 2006) while acid (KCl) titration was used to measure exchangeable acidity of soil (Anderson and Ingram, 1993). The hydrometer protocol was followed to determine the particle size distribution of the soil (Ashworth et al., 2001) and the USDA textural triangle used as a guide to establish the textural class.

2.6.2. Analysis of biochar properties

Biochar was analyzed for pH using the glass electrode method and biochar carbon was determined by the loss on ignition protocol by subjecting biochar to relatively high temperature (550 °C) for 4 h (Mikos-Szymańska et al., 2019). Micro Kjeldahl method was followed to analyse for total nitrogen in biochar (Allen et al., 1974) and ammonium phosphomolybdate protocol was used for total phosphorus determination (Motsara and Roy, 2008).

2.6.3. Compost analysis

Compost was characterized for pH, total N, total C, carbon: nitrogen ratio and total phosphorus. Briefly, a glass calomel electrode – MV Pracitronic pH meter (McLean, 1983) was used for pH determination in 1:5 compost: water (w/v) suspension. Total organic carbon of compost was determined by loss on ignition (Lord and Sakrabani, 2019). Total P was determined by the ammonium phosphomolybdate method (Motsara and

Table 1. Biochar, compost and NPK treatments and combinations.

Treatment		Rate of biochar (t ha^{-1})	Rate of compost (t ha^{-1})	Rate of NPK (Kg ha^{-1})
Control	Maize	-	-	-
	Okra	-	-	-
	Cassava	-	-	-
Biochar	Maize	10	0	0
	Okra	-	-	-
	Cassava	-	-	-
Compost	Maize		10	-
	Okra	-	-	-
	Cassava		10	-
Biochar + Compost	Maize	10	10	-
	Okra	-	-	-
	Cassava	-	10	
NPK	Maize	-	-	100:60:60
	Okra	-	-	-
	Cassava	-	-	100:60:80
Biochar + NPK	Maize	10	-	100:60:60
	Okra	-	-	-
	Cassava	-	-	100:60:80
Compost + NPK	Maize	-	10	100:60:60
	Okra	-		-
	Cassava	-	10	100:60:80
Biochar + Compost + NPK	Maize	10	10	100:60:60
	Okra			-
	Cassava		10	100:60:80

Roy, 2008), and total nitrogen was determined by the Kjeldahl method as described by Franke-Whittle et al. (2014).

2.6.4. Tissue analysis

Shoot of maize, okra and cassava sampled were oven dried at 65 °C for 72 h, ground and sieved through 0.2 mm sieve. The sieved plant materials were analyzed for total N, P and K contents. Total P was determined by the ammonium phosphomolybdate method (Motsara and Roy, 2008), total N by Kjedahl method (Rowell, 1994) while total K was determined by atomic absorption spectrophotometer method as described by Eneji et al. (2003).

2.7. Yield and above ground biomass data collection

Dry maize cob was harvested 120 days after sowing, manually using the hand. The cobs were kept in separate jute bags to prevent mixing. The cobs were dried in the sun for 1 week and dehusked. The maize grains were shelled, sun dried and weighed and yield estimated in t ha^{-1} (Kugbe et al., 2019). Okra fruits were harvested from the 8th week till the 12th week after planting and average yield estimated as described by Mohammed and Miko (2009). Cassava was harvested 10 months after planting and yield estimated in kg ha^{-1} (Biratu et al., 2018). During harvesting, plants at the central row was harvested to avoid border effect.

2.8. Data analysis

All data collected were in triplicate and subjected to analysis of variance (ANOVA) using GenSTAT statistical software. The output was tabulated or presented as bar graph. Mean differences among treatments were established at $p < 0.05$ using Bonferroni test. Pearson correlation was carried out to determine the relationship between soil properties and yield at the terminal stage of the experiment.

3. Results

3.1. Characteristics of the soil, biochar and compost used in the study

Results of the initial analysis of the soil, biochar and compost used are as displayed in Table 2.

The soil used in the study was sandy loam with pH (6.01), available P (30.7 ug g^{-1}); total N (0.09) %; total organic carbon (0.53%) and bulk density (1.5 g cm^{-3}). The compost and biochar showed a basic pH of 8.4 and 9.2, respectively. Total N of the compost (1.3%), and that of biochar (0.70%) were high; total phosphorus of both compost (93.4 ug g^{-1}) and biochar (315.0 ug g^{-1}) were high; and total carbon in the compost and biochar were 31.9% and 79.8%, respectively. The property of the soil showed that, pragmatic management practices were required to make it productive.

3.2. Effect of biochar, compost and NPK on maize, okra and cassava yields

Table 3 present the results on the effect of biochar, compost and NPK on maize, okra and cassava yields, respectively.

Relative to the unamended plots, sole NPK, sole compost, combined biochar and compost and combined biochar and NPK treatments increased maize yields by 56.2 %, 69.8%, 75.3% and 87.0% respectively. Additionally, the application of biochar with compost + NPK, increased maize yield by 219%, compared to the control.

Although the treatments were not repeated prior to establishment of okra in the second cropping season, yield differences were observed among the treatment plots. Sole addition of biochar increased okra yield by 11.4%; biochar plus NPK by 73.5%; biochar and compost by 81.4%; NPK alone by 86.4%; compost plus NPK by 103.4%, compost alone by 135%; and biochar + compost + NPK by 145%, respectively.

At the third cropping cycle, fresh weight of cassava root, in all the amended soils were greater than the control. The highest yield ($P < 0.01$) was found in the biochar + compost + NPK treatment. However, cassava yield in the biochar + NPK treatment was similar to the compost + NPK amended soils. In comparison with the control plot, increases in cassava yields in the other treatments were as follows: sole biochar treatment (71.4%); sole compost (99.4%); biochar plus NPK (134.4%); NPK alone (153.1%); combined compost and NPK (155.9%); biochar and compost1 (72.6%); and biochar + compost + NPK (245.9%).

3.3. Aboveground N, P and K contents of the crops grown on biochar, compost and NPK fertilizer amended soils

The shoot concentrations of N, P and K in maize, okra and cassava are presented in Tables 4, 5, and 6, respectively.

Shoot N concentration of maize ranged from 1.11% to 3.14 % with the un-amended soil showing the least concentration while the biochar + compost + NPK treatment showed the highest (Table 4). Total N in okra shoot varied between 0.70% and 1.26% with the sole NPK amended soil showing the least concentration while the combined biochar + compost + NPK treatment showed the highest. The least total N concentration of 1.62% was recorded for cassava shoot from the unamended plot and the highest of 3.17% was recorded in shoot from the biochar + compost + NPK amended soil.

Overall maize shoot P concentration ranged from 0.11 % to 0.41 % (Table 5). Compared to the control, the sole biochar, sole compost and sole NPK treatments increased shoot P by 45%, 100% and 45%, respectively; shoot P concentrations in biochar applied with compost or NPK

Table 2. Properties of the soil, compost and biochar used in the study.

Parameter	Soil	Compost	Biochar
pH	6.01	8.4	9.2
Total Nitrogen (%)	0.09	1.3	0.70
Available Phosphorus (ug g^{-1})	30.7	-	-
Total Phosphorus (%)	-	93.4	315.0
Total Carbon (%)	-	-	79.8
Total organic carbon (%)	0.53	31.9	-
C/N ratio	5.9	24.5	114
Bulk density (gcm^{-3})	1.5	-	-
Sand (%)	80.0	-	-
Clay (%)	8.0	-	-
Silt (%)	12.0	-	-
Textural class	Sandy loam	-	-

Each value is an average of 3 replicates of laboratory determination.

Table 3. Yield of maize, okra and cassava affected by biochar, compost and/or NPK applications.

Treatment	Maize (t ha^{-1})	Okra (t ha^{-1})	Cassava (kg ha^{-1})
Control	1.62 ± 0.03a	4.99 ± 1.45a	6.91 ± 1.53a
Biochar	1.65 ± 0.10a	5.56 ± 0.69ab	11.85 ± 0.85b
Compost	2.75 ± 0.19c	11.77 ± 2.63c	13.78 ± 0.74c
Biochar + Compost	2.84 ± 0.15cd	9.05 ± 1.03bc	18.84 ± 0.42e
NPK	2.53 ± 0.15b	9.30 ± 2.21c	17.49 ± 1.09de
Biochar + NPK	3.97 ± 0.02e	8.66 ± 3.67bc	16.20 ± 1.19d
Compost + NPK	3.03 ± 0.02d	10.15 ± 1.66c	17.68 ± 0.74de
Biochar + Compost + NPK	5.17 ± 0.05f	12.23 ± 0.50c	23.90 ± 1.70f
P value	<0.001	0.003	<0.001

Values shown in the table are average ±standard deviation. Values in columns differently lettered are significantly different (P < 0.05, Bonferroni test).

increased by 209% and 181%, respectively; and shoot concentration in the biochar + compost + NPK treatment was 272% higher than the control. The sole application of biochar, compost and NPK respectively resulted in 26%, 7% and 56% higher okra P concentration than the control. In the biochar plus compost or NPK treatments, okra P increased by 63% and 130%, respectively compared to the control while combined application of compost, NPK and biochar increased okra P concentration by 159% compared to the control. Cassava shoot P concentration also increased by 193% and 77% respectively in sole compost and NPK amended soil but was reduced by 20% in biochar amended soil compared with the un-amended soil. Biochar applied together with compost or NPK increased cassava shoot P concentrations by 225% and 245%, respectively while combined biochar, compost and NPK treated plot showed a 354% higher cassava shoot concentration than the control.

Regarding shoot K concentrations (Table 6), the biochar + compost + NPK treatment increased shoot K concentration by 202% above the control; biochar plus either NPK or compost increased shoot K by 150% and 103%; whereas sole compost and sole NPK additions increased shoot K concentration by 122% and 75%, respectively. Overall, okra shoot K concentrations ranged from 0.3% to 1%, with the un-amended control and biochar + compost an + NPK treatments showing the least and the highest, respectively. Biochar, compost and NPK applied solely increased okra shoot K concentrations by 144%, 273% and 167% respectively while biochar applied with compost or NPK increased okra shoot K concentrations by 337% and 301%, respectively. Similarly, cassava shoot K concentrations in all the amended soils were higher than the un-amended soils. Combined application of biochar with either compost or NPK showed superior cassava shoot K concentrations that were up to 50 % higher than when each amendment was added singly.

Table 4. Shoot N (%) of maize, okra and cassava in response to the amendments.

Treatment	Maize	Okra	Cassava
Control	1.11 ± 0.04a	0.81 ± 0.10a	1.62 ± 0.03a
Biochar	1.21 ± 0.02a	1.23 ± 0.04c	1.65 ± 0.10a
Compost	2.75 ± 0.19c	1.05 ± 0.03b	2.75 ± 0.19c
Biochar + Compost	2.84 ± 0.15cd	1.20 ± 0.01c	2.84 ± 0.15cd
NPK	2.38 ± 0.04b	0.70 ± 0.07a	2.53 ± 0.15b
Biochar + NPK	2.94 ± 0.02de	1.06 ± 0.02b	2.97 ± 0.02de
Compost + NPK	3.09 ± 0.07ef	0.96 ± 0.17b	3.03 ± 0.02de
Biochar + Compost + NPK	3.14 ± 0.11f	1.26 ± 0.05c	3.17 ± 0.05e
P value	<0.001	<0.001	<0.001
LSD (0.05)	0.17	0.013	0.191

Values shown in the table are average ±standard deviation. Values in columns differently lettered are significantly different (P < 0.05, Bonferroni test).

Table 5. Shoot P (%) of maize, okra and cassava in response to the amendments.

Treatment	Maize	Okra	Cassava
Control	0.11 ± 0.03a	0.09 ± 0.02a	0.08 ± 0.02a
Biochar	0.16 ± 0.02a	0.11 ± 0.03a	0.07 ± 0.02a
Compost	0.22 ± 0.03abc	0.10 ± 0.01a	0.24 ± 0.06bc
Biochar + Compost	0.34 ± 0.07cd	0.15 ± 0.04abc	0.27 ± 0.05cd
NPK	0.16 ± 0.02a	0.14 ± 0.02ab	0.15 ± 0.03ab
Biochar + NPK	0.31 ± 0.04bcd	0.21 ± ±0.04bc	0.29 ± 0.03cd
Compost + NPK	0.21 ± 0.03ab	0.16 ± 0.03abc	0.23 ± 0.01 bc
Biochar + Compost + NPK	0.41 ± 0.07d	0.23 ± 0.04c	0.38 ± 0.05d
P value	<0.001	<0.001	<0.001
LSD (0.05)	0.073	0.023	0.0503

Values shown in the table are average ±standard deviation. Values in columns differently lettered are significantly different (P < 0.05, Bonferroni test).

Table 6. Shoot K (%) of maize, okra and cassava in response to the amendments.

Treatment	Maize	Okra	Cassava
Control	0.63 ± 0.14a	0.27 ± 0.05a	0.15 ± 0.09a
Biochar	1.19 ± 0.09bc	0.66 ± 0.08 b	0.45 ± 0.04a
Compost	1.40 ± 0.07cd	1.01 ± 0.09 cd	1.23 ± 0.12b
Biochar + Compost	1.58 ± 0.06d	1.18 ± 0.08d	1.34 ± 0.11b
NPK	1.11 ± 0.02 b	0.72 ± 0.15b	1.07 ± 0.05b
Biochar + NPK	1.28 ± 0.04bc	1.08 ± 0.07d	1.31 ± 0.04b
Compost + NPK	1.15 ± 0.02bc	0.76 ± 0.06 bc	1.04 ± 0.04b
Biochar + Compost + NPK	1.90 ± 0.14e	1.13 ± 0.02d	2.13 ± 0.23c
P value	<0.001	<0.001	<0.001
LSD (0.05)	0.147	0.141	0.209

Values shown in the table are average ±standard deviation. Values in columns differently lettered are significantly different (P < 0.05, Bonferroni test).

3.4. *Response of soil physical and chemical properties to biochar, compost and NPK fertilizer application*

Results of soil pH, exchangeable cations, total exchangeable bases, exchangeable acidity, effective cation exchange capacity determined after harvesting cassava are presented in Table 7. Here also we present results of TN and TOC under Figure 1 and available P under Figure 2.

Total organic carbon content was significantly ($p < 0.05$) higher in the treated plots above the control (Figure 1). The increases in SOC ranged from 16.7% to 63.6%, respectively, with combined biochar, compost and NPK treatment recording the highest increase.

Available phosphorus contents also increased significantly in the amended soils above the control except in the sole biochar amended soil, which was similar to the control. The increases in soil available P varied from 14% to 92%, with the combined biochar, compost and NPK treatment still showing the highest increase in soil available phosphorus.

In sole biochar amended soil, total nitrogen content was similar to the control but all other amendments significantly recorded higher values than the control. Relative to the control, the least increase of 28.6 % in total N concentration was observed in sole biochar amended soil and the highest increase of 382.6% in total N concentration was found in the combined biochar, compost and NPK treatment.

Soil pH increased in all the amended soils compared with the control, except for NPK amended soil. The sole application of biochar increased soil pH by 3.16%; sole compost addition by 3.32%; and their combined application increased soil pH by 9.8%. Although the sole application of NPK reduced soil pH, when it was combined with compost or biochar, soil pH increased by 2.32% and 3.49%, respectively. The application of biochar, compost and NPK together, resulted in the highest soil pH increase of 13.1%.

Exchangeable acidity in the control was significantly ($p < 0.05$) greater than all the amended soils. The decrease in exchangeable acidity followed the order; biochar < compost = biochar + compost + NPK < biochar + compost = NPK + compost < biochar + NPK < NPK.

Total exchangeable bases content increased significantly ($p < 0.05$) in all the amended soils above the control except in NPK amended soil which recorded a lower (12.5%) T.E.B than the control. Percentage increases in T.E.B ranged between 48% to 186%. Biochar and compost applied separately increased total exchangeable bases by 48% and 81.4%, respectively, but when biochar was applied together with NPK or compost, total exchangeable base increased by 54.3% and 117%, respectively. When biochar, compost and NPK were co-applied, an increase in T.E.B. by 186.6% above the control, was obtained.

4. Discussion

In the first and second seasons, sole biochar application showed insignificant yield increase in maize and okra. In the third year, significant yield response was observed for cassava. The dynamics in the yield obtained indicates that, the effect and benefits of biochar is realized over time (Adekiya et al., 2019). Biochar basically is recalcitrant, and contain negligible amount of labile nutrients which is released into soil in the first and second cropping season (Glaser et al., 2002; Lehmann et al., 2003). However, the improved yield of cassava in the 3rd season could be related to considerable nutrients released from enhanced biochar decomposition, particularly in the third season (Glaser et al., 2002; Lehmann et al., 2003).

Table 7. Soil properties after harvesting cassava.

Treatment	Exchangeable cations (c mol_c kg^{-1} soil)				T.E.B (c mol_c kg^{-1} soil)	Ex. Acidity (c mol_c kg^{-1} soil)	ECEC c (c mol_c kg^{-1} soil)	pH
	Ca	Mg	K	Na				
Control	1.60 ± 0.03a	1.74 ± 0.03b	0.11 ± 0.03a	0.06 ± 0.01ab	3.51 ± 0.04b	0.29 ± 0.02c	3.80 ± 0.02b	6.02 ± 0.02b
Biochar	3.28 ± 0.10e	2.23 ± 0.05c	0.24 ± 0.04b	0.04 ± 0.01a	5.79 ± 0.06e	0.10 ± 0.02a	5.89 ± 0.04e	6.23 ± 0.02e
Compost	2.93 ± 0.02d	2.77 ± 0.11d	0.22 ± 0.02b	0.15 ± 0.03 e	6.07 ± 0.14f	0.11 ± 0.02a	6.18 ± 0.14f	6.20 ± 0.02d
BC + CM	3.05 ± 0.05d	3.71 ± 0.10e	0.31 ± 0.02c	0.12 ± 0.02d	7.20 ± 0.09g	0.12 ± 0.01a	7.31 ± 0.09g	6.60 ± 0.01f
NPK	1.56 ± 0.02a	1.36 ± 0.08a	0.13 ± 0.03a	0.07 ± 0.01abc	3.12 ± 0.07a	0.22 ± 0.03b	3.33 ± 0.04a	5.97 ± 0.06a
BC + NPK	2.72 ± 0.10c	2.18 ± 0.07c	0.24 ± 0.05b	0.09 ± 0.01bc	5.22 ± 0.11d	0.15 ± 0.02a	5.37 ± 0.12d	6.23 ± 0.01e
NPK + CM	2.43 ± 0.07b	2.27 ± 0.04c	0.23 ± 0.02b	0.10 ± 0.02cd	5.03 ± 0.10c	0.12 ± 0.02a	5.16 ± 0.11c	6.15 ± 0.02c
BC + CM + NPK	4.79 ± 0.12f	4.13 ± 0.09f	0.33 ± 0.04c	0.13 ± 0.03de	9.39 ± 0.12h	0.10 ± 0.01a	9.49 ± 0.11h	6.81 ± 0.02g
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Values shown in the table are average ±standard deviation. Values in columns differently lettered are significantly different (P < 0.05, Bonferroni test).
BC: biochar, CM: compost.

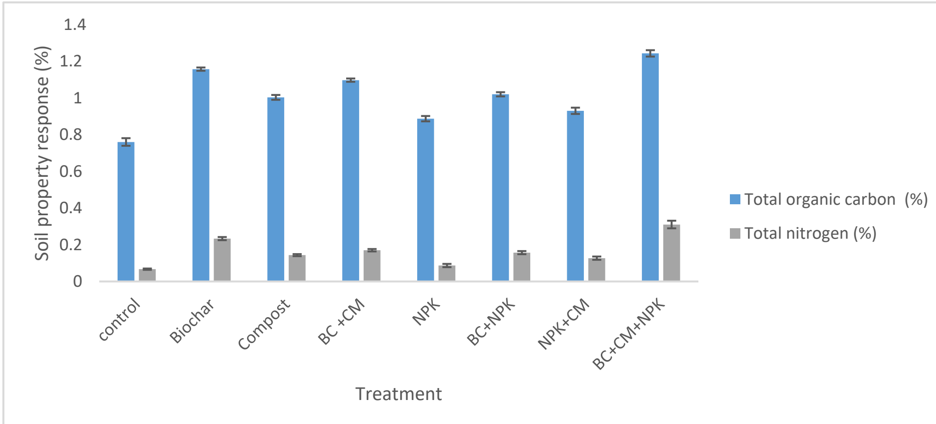

Figure 1. Total organic carbon (%) and total nitrogen (%) contents in soils amended with biochar, compost and NPK solely or in combination. BC: biochar, CM: compost, NPK: inorganic fertilizer.

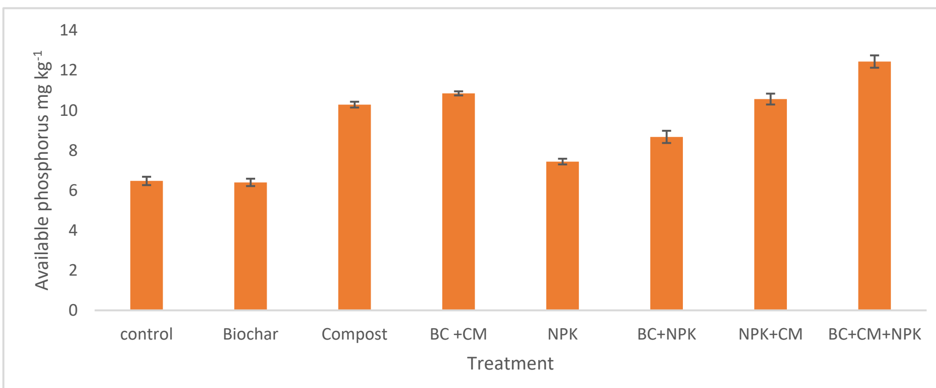

Figure 2. Available phosphorus content (mg kg^{-1}) of control soil and soils amended with biochar, compost and NPK solely or in combination. BC: biochar, CM: compost, NPK: inorganic fertilizer.

The increase in yield for all crops following the application of biochar together with compost and/or NPK could be as a result of additive effect resulting in the general improvement of soil properties (Table 7). In the present study, significant and positive correlation ($p < 0.05$) was found between soil properties and yield (Table 8). Additionally, it was evident in our study that, when NPK and/or compost was applied to plots that had earlier been treated with biochar, yield response was greater compared with plots with no biochar application. The persistent biochar effect was observed across the three seasons, which affirms the gradual biphasic decomposition of biochar (Cross and Sohi, 2011). The presence of biochar might have also stimulated microbial activity to gradually increase decomposition of native or added organic matter, releasing nutrients for plant uptake. This corroborates earlier studies that reported increased mineralisation of organic matter in the presence of biochar (Kuzyakov et al., 2000; Zimmerman et al., 2011).

Table 8. Pearson correlation matrix of selected soil properties and yield of cassava at the end of the experiment.

	Yield
AvP	0.80***
TN	0.87***
SOC	0.62**
TEB	0.67**
pH	0.70**

AvP = Available phosphorus, TN = Total nitrogen, TOC = Total organic carbon, TEB = Total exchangeable bases, ** = significant, *** = highly significant.

The increase in okra yield in the second season, is an indication that external inputs added during the first season extended its effects into the second season. This could be related to the presence of biochar in the treatment. Earlier suggestions indicate biochar has capacity to adsorb plant nutrients on its surface for gradual release (Kammann and Graber, 2015; Schmidt et al., 2015) and its effect persisted to increase yield in the second season. In the third season, cassava yield increased significantly possibly due to the fresh input of NPK, compost and soil conditioning effect of biochar. This also indicates a positive complementarity between biochar and organic or inorganic amendments, which could be exploited to increase crop yields in smallholder farming systems.

Total organic carbon, available phosphorus, total exchangeable bases as well as soil pH and exchangeable acidity were remarkably improved in amended soils. This is an indication that, the co-application of biochar, compost and or NPK conferred excess nutrients in treated plots and was not exhaustive hence contributing to crop yield. In our study, soil pH in NPK amended plot was lower than the control. This could be attributed to low basic cation content in and N transformation associated with application of N fertilizers. Unlike compost and NPK which increased available N when applied individually or in combination with biochar, sole biochar plots had low N which could be due to the limiting N content of biochar applied.

Tissue N, P, K of maize, okra and cassava were greatly improved which could be due to the enhanced soil nutrient content and supply to crops mediated by the presence of biochar (Gao and DeLuca 2016; Syuhada et al., 2016).

5. Conclusion

The findings of our study amply demonstrated that biochar effect in soil persisted and influenced crop yields across three cropping cycles. Further, the study showed that the effect of biochar on soil fertility was pronounced when it was applied in combination with compost, NPK or both, resulting in increased yields of maize, okra and cassava more than when biochar was absent. This finding would encourage farmers to include biochar in their soil management practices due to the enhanced crop yield observed in our study. The inclusion of biochar could potentially discourage smallholder farmers from practicing open-air burning of agricultural residues which has been implicated in global warming.

Declarations

Author contribution statement

Kwame Agyei Frimpong: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Christian Adler Phares: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Isaac Boateng: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Emmanuel Abban-Baidoo: Performed the experiments; Analyzed and interpreted the data.

Lenin Apuri: Performed the experiments.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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