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Biochar as a Soil Amendment Tool: Effects on Soil Properties and Yield of Maize and Cabbage in Brong-Ahafo Region, Ghana

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Abstract

Ghana's soil is continuously declining in fertility due to continuous cultivation and rapid mineralization of its soil organic matter. Previous studies have touted the potential of biochar to help improve soil properties and increase the yield of crops. This study investigated the effects of the application of biochar on physicochemical properties of soil and the yield of maize and cabbage in Ghana. The study indicated that application of biochar significantly increased soil organic matter (SOM) from 3.88% (for control) to 5.72% (for biochar application rate 20 ton/ha and 0 ton/ha of NPK). It also increased soil pH from 6.55 in (for control) to 7.30 (for biochar application rate 20 ton/ha) and 0 ton/ha of nitrogen (N), phosphorus (P) and potassium (K) which can help ameliorate the soil acidity problem of Ghanaian soils. This field study, demonstrated that addition of biochar from sawdust increased the yield (between the control (0 ton/ha of biochar, 0% of recommended dose of NPK) and 20 ton/ha, 0% recommended dose of NPK) of maize and cabbage by 6.66% and 7.57% respectively. This study concluded that application of biochar offers a great potential to improve soil quality and the yield of maize and cabbage in Ghana.

Keywords

Biochar, Physicochemical Properties, Soil Amendment, Ghana, Maize Yield

1. Introduction

In sub-Saharan African (SSA) countries, including Ghana, agricultural soil fertility has taken a nosedive over the years due mainly to continuous cultivation or over cropping, coupled with rapid organic matter mineralization [1] [2]. Additionally, as a result of continuous fertilizer use, high soil acidity has been identified as a major cause of food insecurity and poverty [2] [3]. In particular, agricultural systems in Ghana are characterised by low productivity, because they depend on low and erratic rainfall patterns, outdated agricultural practices and low application of inputs. Most of the sandy loamy soils in the country are highly weathered and characterized by poor fertility and high erosion rates. The loss in soil nutrients on croplands per hectare per year runs into several kilograms of fertilizers when quantified in terms of nitrogen, phosphorus and potassium and this has been a major limiting factor to crop production in tropical agro-ecosystem [4]. Therefore, farm practices that help to reduce nutrient depletion and leaching are required for sustained crop production and food security [5].

It has become even more important in recent times for people in agriculture to find new ways to enhance the sustainability of this all-important venture: agriculture [6] [7]. Interestingly, in the quest for more sustainable agricultural practices with regards to soil nutrient and water retention and pH regulation, growing attention is being given to biochar, as a soil amendment and a means for carbon sequestration [8] [9] [10] [11] [12]. Biochar refers to black carbon derived from biomass that undergoes pyrolysis [13]. Organic matter that undergoes slow pyrolysis leaves a carbon "skeleton" that is porous and resistant to decay, allowing biochar to accumulate in soils over time [14]. In addition to providing a stable store of soil organic matter, biochar increases soil pH and cation exchange capacity, improves soil structure and water retention capacity, and decreases nutrient loss through leaching and runoff [10] [11] [15] [16] [17]. These effects are especially well expressed in sandy soil [18]. The benefits of biochar are evident in the nutrient-rich Terra Preta (Dark Earth) soils of the Amazon basin [15] [19] [20] [21] [22].

Despite the fact that biochar has been proven to have many benefits on the world stage, the awareness and use of it in Ghana is very low. Akolgo *et al.* [23] found out that 83% of Ghanaians have no idea that charcoal (biochar) can be used as a soil amendment tool. And even though about 17% of Ghanaians are aware of the alternative use of charcoal as a soil conditioner, only 4% of Ghanaians actually use charcoal as a soil conditioner. It can therefore be stated that the effectiveness of biochar for the improvement of soil properties and crop yield in Ghana relies heavily on continuous testing, dissemination of results and education for stakeholders. According to Major [24], the efficacy of biochar must be shown in a variety of cropping systems, soil types and that the optimal application rates can only be determined after this has been done extensively. Wilson [25], stated that more and new tests on biochar need to be done, so that meaningful characterization of biochar and its benefits can be established. In the Ghanaian research space, Zolue [26] observed that biochar-based soil management is in its early stages and recommended that more studies should be done on the field to ascertain its effect on soil productivity by evaluating the growth and yield of test crops planted on biochar-added soils.

The argument that field-testing of biochar is needed in Ghana is strengthened by Duku *et al.* [1]. In their research, it was explained that farmers/researchers/extension officers in Ghana are likely to be motivated to use more of biochar if the benefits can be demonstrated explicitly in the field. The economic, agronomic and environmental benefits that could be derived from the production and application of biochar in soil should be evaluated using on-farm trials in Ghana [1].

Field-testing of biochar in Ghana has started albeit in a slow manner. Mensah and Frimpong [27] conducted an investigation on the effects of application of biochar (from corncobs) and compost on soil physicochemical properties, growth, and yield of maize on selected soils from the Rainforest and Coastal Savannah agroecological zones of Ghana. Amoakwah *et al.*, [28] studied how biochar from corncobs alters soil water retention, air flow and derived soil structure indices in a tropical sandy loam. Closely related to the study by Amoakwah *et al.*, [28] in terms of scope and time; Arthur and Ahmed [29] carried out a study to determine the effect biochar produced from rice straw on water retention, structure and gas transport of tropical soil. These field studies all concluded that the application of biochar improved the quality of soil and/or crop yield. The authors however recommended that more studies be done to assess and confirm the effect of application of biochar on the physicochemical properties of soil and yield of crops [27]. In view of this, this study seeks to examine the effect of application of biochar (produced from sawdust) on the physicochemical properties of soil and yield of maize and cabbage in Ghana. The findings of this study will help determine the efficacy of biochar as a soil amendment tool in Ghana.

2. Materials and Methods

2.1. Experiment Sites

The field experiments were conducted at Sunyani (7.3349˚N 2.3113˚W) and Dormaa (7.2671˚N 2.8677˚W) municipalities of the Brong Ahafo Region, on maize and cabbage respectively. The Brong Ahafo region is the food basket of Ghana because a greater amount of the national foodstuffs are produced in the region and supplied to other parts of the country. Also, the Brong Ahafo Region (and selected municipalities for that matter) is known to be a leading producer of maize [30] [31]. The climate of Brong Ahafo Region is classified by Köppen and Geiger as Aw (Tropical Savanna Climate).

2.2. Field Experiment

The field used for the maize trials was sprayed with sunphosate 41% non-selective herbicide and prepared (using no tillage method) before application of biochar and fertilizer. The no-tillage land preparation technique was used because maize farmers in the selected locations rely mainly on conservational (minimum tillage) methods for land preparation. Soil samples were taken with auger (0 - 30 cm depth) from each experimental unit before and after the experiment was carried out. Soil samples were air-dried, ground, well mixed and passed through a 2 mm sieved and analysed. All macro-nutrients, nitrogen, phosphorus and potassium (15:15:15 - NPK) and biochar amendments were applied in the respective experimental unit plots at different doses using the randomized complete block design (RCBD). Each experimental plot had a size of 10 m by 4 m (40 m^2). Treatments covered three different levels of biochar: B0 (0% of recommended dose), B1 (50% of recommended dose) and B2 (100% of recommended dose).The recommended dose of biochar for crop production is 20 ton/ha; therefore, B0 = 0 ton/ha, B1 = 10 ton/ha and B2 = 20 ton/ha. Three different levels of 15:15:15 NPK fertilizer were used: F0 = 0%, F1 = 50% and F2 = 100% of the recommended dose. All the possible combinations of fertilizer and biochar gave rise to nine treatments *i.e.* B0F0, B0F1, B0F2, B1F0, B1F1, B1F2, B2F0, B2F1 and B2F2. Each treatment combination was replicated three times.

The seedbed of the cabbage field was however prepared using hoes, mattock and rakes which is the common method for cabbage farmers in the selected locality. Soil samples were taken before seedbed preparation and after harvest for analysis. The soil was broken using hoe and mattock, and the biochar incorporated and mixed using the hoes and rakes at a depth of 15 cm. The planting distance of the maize and cabbage was 80 cm inter-row and 40 cm intra-row. Apart from the seedbed preparation, the treatments and experimental design were the same as in the maize field.

2.3. Biochar Production

Biochar was prepared by carbonizing sawdust in a multi-feed biomass gasifier at a temperature of 350˚C at the University of Energy and Natural Resources, Sunyani, Ghana. The biochar was put through a residence time of 4 hours per batch of production. At the end of each batch preparation, the charred sawdust was quenched with water and left to cool for six (6) hours before packaging. These samples were then packaged and transported to the experimental site.

2.4. Physicochemical Characterization of Biochar

Moisture content of samples was determined based on mass loss after twenty-four hours at 105˚C. Volatile matter was determined by heating dried samples in the oven to 950˚C and recording the loss of the mass. Ash content of biochars was determined by heating the same samples to 750˚C in a muffle furnace for four (4) hours. Proximate analysis of the biochar was done using the ABNT NBR 8112 methods [32].

2.4.1. Particle Size Distribution

One hundred (100) grams of the biochar was weighed into 2.5 mm sieves which had been under laid with other sieves of decreasing diameter of 2 mm, 1 mm, 0.5

mm, 0.25 mm, 0.125 mm, 0.09 mm and 0.063 mm on a Retsch VS 1000 mechanical shaker. The biochar samples were then shaken continuously at 50 rpm for 5 min. The various size distributions of each of the three biochar samples were then weighed and expressed as a percentage of the total 100 g mass of biochar taken.

2.4.2. Bulk Density

Bulk density was estimated by determining the mass of the oven-dried biochar that could occupy a particular volume of container [33]. A quantity (20 g) of the biochar was oven dried at 105ºCtill constant mass was attained and kept in a desiccator to avoid absorption of moisture from the atmosphere. This took about 48 hours. Sample was poured to fill a 250 cm^3 measuring cylinder amidst intermittent gentle tapping to ensure good packing to the 250 cm^3 mark. The mass of the biochar filled in the 250 cm^3 was then determined by weighing. The bulk density was calculated from the mass of biochar divided by the total volume of biochar.

2.4.3. pH in Water

One gram of biochar was weighed into a beaker and 20 ml of distilled water added, to give biochar water ratio of 1:20. This ratio was used to ensure enough volume of supernatant for immersion of electrode. The mixture was stirred for about 30 minutes and left to stand for about an hour to settle most of the suspension and also to reach the room temperature. A glass electrode pH meter-CG818, Schott Great, was calibrated using two solutions of pH 7 and 9. The sample pH was then recorded. The test was carried in three replicates. The determination of pH of the samples was repeated using 1 M KCl solution according to the protocol outlined.

2.5. Soil Sampling

Soil samples were collected at a depth of 0 - 30 cm after crop harvesting at random from each treatment plot. The samples from each treatment plot were composited, placed in tagged plastic bags and dried at room temperature. These samples were taken to the soils laboratory at the Soil Research Institute of Ghana's Council for Scientific and Industrial Research in Kumasi for physio-chemical analysis. The soil samples were passed through the 2 mm sieve to obtain the soil fractions for the determination of soil textures. Total organic carbon (TOC), soil organic matter (SOM) and total organic nitrogen (TON) contents were determined by the dry combustion method using an N-C analyzer (Sumigraph NC-90A) as described by [34]. Exchangeable cations [calcium (Ca), magnesium (Mg), potassium (K), sodium (Na)] were first extracted with ammonium acetate (1.0 M NH_4OAc) and the contents were then determined by inductively coupled plasma-atomic emission spectroscopy. Exchangeable acidity was determined by first extracting with potassium chloride (KCl) and then titrating the extract with sodium hydroxide as described by McLean [35]. Cation exchange capacity (CEC) was calculated as the sum of exchangeable cations (Ca, Mg, K, Na) and exchangeable acidity.

2.6. Application of Biochar and Fertilizer

The amount of biochar and fertilizer required for each plot was determined based on the biochar application rate and plot size. The required quantity was weighed using a beam balance and incorporated into /mixed with soil using tools such as hoes, mattocks and rakes. The fertilizer was applied using the side dressing method.

2.7. Plant Sampling and Analysis

2.7.1. Maize Trial

The maize trial was done in the minor season: planting was done in August 2016 and harvesting was done in November of 2016. The plants were harvested 11 weeks after planting. The plants relied completely on rainfall for water. The harvest area within the plots was used to represent and determine the yield of the entire plot. Data collection and samples from the borders of the plots were discouraged as it may introduce boundary effect errors in the subsequent analysis.

The fresh weight was determined in the field. The samples of grains and straws were kept in an oven at 65˚C for 48 h, and then their dry weights were obtained and recorded.

In Ghana, maize may be harvested mechanically or by hand harvesting. The hand harvesting technique was adopted in this case because there were few maize plants for collection. Thirteen (13) out of 125 plants were harvested from each of the plots in the field by cutting randomly from the two middle rows in a 4-row plot. The entire plants were cut just above the brace root and brought to a common point to collect the dehusked ears. The work was supervised thoroughly to ensure that ears from one plot were not mixed with those from nearby plots whilst biomass from respective plots were properly bagged and labelled for lab analysis.

The corn ears with their biomass were labelled same as the designated plot names on the field for easy identification. Other relevant ear and biomass data collection procedures were carried out in the laboratory to record the weight of harvested ears, grain moisture content at harvest, the kernel and cob parameters and the dry weights of the combined chopped husk, leaves and stem were taken from each plot. The average ear weights, the number of rows on each ear and the kernels on a row were determined before manual shelling. The grains were dried from a moisture content of 24.6% to 13% with the cob before their dry weights were taken. The dry matter was chopped into small pieces, enveloped and kept under constant pressure at 80˚C. After 72 hours, the biomass had fully dried and the dry weights were recorded accordingly. The following yield data were taken:

- **EAR WEIGHT (kg):** the fresh weight of the ear without its stover were measured and the mean weight of ears from thirteen (13) randomly selected plants from the middle rows were used to compute the score for each plot;

- **EAR LENGTH (cm):** the ear length was recorded and the mean length of ears from thirteen (13) randomly selected middle row plants were used to compute the score for each plot;
- **EAR DIAMETER (mm):** this was taken as the diameter of the ear without stover measured at two ends and the middle part of the ear from thirteen (13) plants randomly selected from the middle rows of each plot and used to compute the mean ear diameter score for each plot;
- **WEIGHT OF 100 SEEDS (kg):** the weight of 100 seeds dried to 13% moisture content was weighed and recorded. Four replicate samples of 100 seeds per ear were measured to obtain the mean weight per ear. The mean 100 seed weight from the thirteen (13) randomly selected plants from the middle rows were used to compute the score for each plot;
- **GRAIN YIELD PER PLOT:** the total grain yield from all the thirteen (13) plants in the middle rows of each plot that were carefully harvested and threshed for full yield recovery was used to compute the grain yield which were dried to 13% moisture content and recorded in kilograms per plot based on the plant population used in this study. The estimation is expressed as shown in Equations (1) and (2).

$$GY = Mp \times P \quad (1)$$

$$Hy = GY \times \frac{10000\ \text{m}^2}{40\ \text{m}^2} \times \frac{1}{1000} \quad (2)$$

where,

GY = Grain yield per plot (kg)

Mp = Average grain yield per plant (kg)

P = Plant population per plot

Hy = Yield per hectare (ton/ha)

2.7.2. Cabbage Trial

The cabbage trial was done in the minor season: trans-planting was done in September, 2016 and harvesting was done in December of 2016. The plants were harvested after 9 weeks after transplanting. The plants watered partly by rainwater and supplemented by irrigation. Cabbage was harvested at maturity. Harvesting was done by hand with a knife. The crops were cut together with the large open wrapper leaves meant for protecting the heads in order to have the actual fresh weight of the cabbage. The practice reduced bruising of the heads that could have made the cabbage unattractive and receptive to deterioration. The roots and the stem were not included in the data collection.

Two cabbages out of twenty plant in each plot were randomly selected from every plot and weighed instantly to determine the fresh field weight of the cabbage. The labelled and packaged crops were transported from the field to the laboratory for additional data collection.

2.8. Statistical Analysis

Statistical analysis was done by subjecting the data to analysis of variance (ANOVA) using the Statistical Package for Social Scientists (SPSS). The normality of the data was checked using the explore function of the SPSS and TOC, TON, SOM, pH and Yield of Maize were all normally distributed. The ANOVA was used to determine if there is significant difference (at $p < 0.05$) between the means of the various factors. The Tukey HSD posthoc test was used to isolate the means with significant differences at confidence level of 95%.

3. Results and Discussion

3.1. Particle Size and Bulk Density of Biochar Produced from Sawdust

The largest proportion (55.7%) of the sawdust biochar was in the coarser size regime between 500 µm and 2500 µm. The smallest size fractions between 63 and 125 µm was 12.9%. The sawdust biochar had about 41.4% of its particles between 125 µm and 250 µm. The bulk density of the biochar was found to be 0.25 mg/m^3. Proximate analysis of the biochar showed 25.6% moisture content, 25.3% ashes, 53.8% volatiles and 20.9% fixed carbon. Generally, biochar was light and therefore as soil amendment, will have to be incorporated and mixed very well with the soil to avoid losses through water and wind erosion. The size range indicates that there is no need for further grinding of the sawdust biochar before incorporation. Surface application will not be ideal as they will float on water should the soil be irrigated and/or even rainwater.

3.2. Soil Physical Properties

The statistical analysis of the soil data before and after harvesting showed that application of biochar significantly (as shown in **Table 1** and **Table 2**) increased total organic carbon (TOC), Soil organic matter (SOM) and soil pH. Application of biochar increased TOC from 2.25% for biochar rate of 0 ton/ha or control, to 3.32% for biochar application rate 20 ton/ha (see **Table 1**). SOM also increased correspondingly from 3.88% (control) to 5.72% (for biochar application rate 20 ton/ha). The increase in the TOC and SOM apparently helped to address the major soil nutrient deficiencies at the trial site, which is consistent with results found by past research works [36] [37]. TOC is an indicator of SOM quality, which aerates the soil and helps retain water and nutrients. SOM also provides substrate for soil microbial biomass, which in turn make nutrients much more readily available to plants. Studies have shown that a sandy soil amended by coconut shell biochars increased soil organic carbon (SOC) and persisted after the second crop harvest, while TOC in manure treated soil was not significantly different from the fertilizer-only treatment after the first and second maize harvest [38]. Recent studies have reported that TOC was significantly increased due to different biochar applications [39] [40] [41]. Soil TOC in this study was averagely above the recommended lower limits of 1.8%, whilst the average total

Table 1. Comparison of means of (a) Soil Organic Matter (b) Total Organic Carbon (c) Soil pH for all treatments to show their significant differences.

(a)

Treatment	N	subset for alpha = 0.05			
		1	2	3	4
B1F0	3	3.75			
B0F0	3	3.88			
B0F2	3	3.88			
B1F2	3		4.52		
B0F1	3		4.53		
B2F1	3			5.40	
B1F1	3			5.49	
B2F2	3				5.72
B2F0	3				5.85
Sig.		0.392	1.000	0.798	0.424

Means for groups in homogeneous subsets are displayed. Uses Harmonic Mean Sample Size = 3.000.

(b)

Treatment	N	subset for alpha = 0.05			
		1	2	3	4
B1F0	3	2.18			
B0F0	3	2.25			
B0F2	3	2.39	2.39		
B1F2	3		2.62		
B0F1	3		2.63		
B2F1	3			3.15	
B1F1	3			3.19	
B2F2	3			3.32	3.32
2F0	3				3.47
Sig.		0.155	0.088	0.388	0.541

Means for groups in homogeneous subsets are displayed. Uses Harmonic Mean Sample Size = 3.000.

(c)

Treatment	N	subset for alpha = 0.05				
		1	2	3	4	5
B1F0	3	6.5600				
B0F0	3	6.5667				
B0F2	3		6.8500			
B1F2	3			7.1200		
B0F1	3			7.1300		
B2F1	3			7.1300		
B1F1	3			7.1800	7.1800	
B2F2	3				7.2400	7.2400
B2F0	3					7.3000
Sig.		1.000	1.000	0.094	0.094	0.094

Means for groups in homogeneous subsets are displayed. Uses Harmonic Mean Sample Size = 3.000.

Table 2. The effect of Biochar Treatment on soil physicochemical properties at time of harvesting stage.

LABEL	pH H_2O 1:2.5	% TOC	% TON	%SOM	Exchangeable Cation (cmol/kg)				T.E.B	EX. ACIDITY	CEC	BASE SAT
					Ca	Mg	K		Na	cmol/kg		%
B0F0	6.85	2.25	0.19	3.88	9.88	3.35	0.09	0.06	13.38	0.10	13.48	99.26
B0F1	6.56	2.63	0.24	4.53	9.22	4.21	3.37	0.07	16.86	0.10	16.96	99.41
B0F2	6.55	2.25	0.19	3.88	9.35	2.67	3.69	0.05	15.75	0.13	15.88	99.21
B1F0	7.24	2.18	0.18	3.75	11.91	3.94	1.61	0.07	17.53	0.10	17.63	99.43
B1F1	7.13	3.19	0.24	5.49	12.12	5.74	2.15	0.04	20.04	0.13	20.17	99.38
B1F2	7.13	2.62	0.23	4.52	12.98	4.34	6.18	0.06	23.56	0.10	23.66	99.58
B2F0	7.30	3.47	0.20	5.98	17.21	2.67	1.50	0.09	21.47	0.10	21.57	99.54
B2F1	7.18	3.14	0.22	5.40	18.21	2.27	1.35	0.06	21.88	0.10	21.98	99.55
B2F2	7.12	3.32	0.24	5.72	16.21	3.61	1.13	0.05	20.99	0.10	21.09	99.53

TOC—total organic carbon; TON—total organic nitrogen; TEB—total exchangeable cation; CEC—cation exchangeable capacity; Base Sat—base saturation.

organic nitrogen (TON) content, although increased, were still below levels considered sufficient (0.25% for N), which may be due to high N uptake by plants, and high contents of above and below-ground plant residues. This research discovered that the soil of the study area (humid tropical Ghana) is sufficient in TOC but deficient in TON. The increase in pH has been isolated in the post hoc test (**Table 1(c)**) which shows that the rise in pH was mainly due to application of biochar not NPK. Previous studies by Vašák, *et al.* [42] revealed that application of NPK to soil reduces pH which goes to affirm the findings of this paper. The increase in pH with increase in dosage of biochar and fertilizer implies that application of biochar to agricultural soil in Ghana can help ameliorate the soil acidity problem identified by Dovana & Cassy [3]; Smith-Asante, [2]. In a similar study, Mensah and Frimpong [27] found that application of biochar with compost increased the soil pH. The increase in the pH could be attributed to the increase in available soil P due the presence of P in biochar [43] [44].

Soil pH was significantly (**Table 1** and **Table 2**) different among soil samples of different treatments. Highest soil pH (7.30) was found in the experimental unit having B2F0 treatment while the lowest was found in B0F2 (6.55) (**Table 1**). The pH increased due to the application of biochar implies that the acidic soil in Ghana can be amended using biochar.

Cation exchange capacity (CEC) increased with increase in the application rates. Highest soil CEC of 23.66 cmol/kg was observed in B1F2 and the lowest was in B0F0 of 13.48 cmol/kg. Soil amendment with biochar significantly improved the CEC, indicating that soil retention of non-acidic cations increased. CEC is an important parameter in retaining inorganic nutrients such as K^+ and NH_4^+ in soil [45], and biochar has been associated with the enhancement in

CEC of some biochar-amended soils [14] [46], thereby increasing the availability and retention of plant nutrients in soil and potentially increasing nutrient use efficiency.

Soil texture at the selected site varied from silt loam to sandy loam (**Table 3**) with visible contamination from construction materials both vertically in each profile and among the plots. The average soil texture was loamy sand (65.3% sand, 25.4% silt, 9.3% clay) in the profile. Soil texture is the most stable soil physical characteristic that has influence on a number of other soil properties including structure, soil moisture availability, erodibility, root penetration and soil fertility [47]. The coarse texture soil exhibited at the site controls the variability of nutrient storage capacity, limit the water holding capacity and increases permeability. Variability in soil texture was attributed to the complex nature of parent material as well as the past activities that have been carried out at the site (land use). The land area has been under cultivation for more than ten years with some history of construction activities. The high soil pH in control plots (**Table 1**) may therefore be as a result of previous liming.

3.3. Effect of Biochar Application on Crop Yield

The biochar amendments significantly ($p \le 0.05$) affected the yield of maize as shown in **Table 4**. The yield parameters such as cob length, grain dry weight, and stover dry weight of maize were significantly affected by the increase in dosage of fertilizer but showed marginal changes with biochar. The yield of dry grain generally ranged from 12.31 ton/ha for B0F0 (0 ton/ha of biochar, 0% of recommended dose of NPK) treatment to 13.13 ton/ha for B2F0 (20 ton/ha, 0% recommended dose of NPK) (**Table 4**, **Table 5** and **Figure 1**) representing 6.66%. These variations were probably due to variations of residual fertilizer in the different sections of test site. These results are consistent with a study conducted by Major *et al.* [24], which looked at maize yield and nutrition during 4 years after biochar application to a Colombian savannaoxisol. They observed that biochar application had no significant effect on maize yield in the first year after biochar application. However, in the subsequent years maize yield increased with increasing biochar application rate. The increased SOC influences many soil characteristics including colour, nutrient holding capacity (cation and

Table 3. Particle size analysis for the selected site.

Profile pit				
Depth of Soil	% Sand	% Silt	% clay	Texture
0 - 10	77.08	21.3	1.62	Loamy Sand
10 - 20	69.5	19.4	11.1	Sandy Loam
20 - 30	49.32	35.5	15.18	Loam
Average	65.3	25.4	9.5	Sandy loam

Table 4. Tukey HSD posthoc test of crop yield (ton/ha).

Treatment	N	subset for alpha = 0.05		
		1	2	3
B1F0	3	9.6877		
B0F0	3		12.1847	
B0F2	3		12.1875	
B1F2	3		12.1889	
B0F1	3		12.3120	
B2F1	3		12.5000	
B1F1	3		13.1250	13.1250
B2F2	3		13.4377	13.4377
B2F0	3			15.0000
Sig.		1.000	0.523	0.110

Means for groups in homogeneous subsets are displayed. Uses Harmonic Mean Sample Size = 3.000.

Table 5. Maize yield of trial treatments.

Label	Cob L (cm)	Cob FW (kg)	Cob DW (kg)	Grain FW (kg)	Grain DW (kg)	Ear FW (kg)	100 Kernels FW (kg)	Stover FW (kg)	Stover DW (kg)
B0F0	13.50	0.75	0.53	0.22	0.41	0.08	0.02	1.38	0.56
B0F1	13.50	0.72	0.52	0.20	0.39	0.08	0.02	1.18	0.56
B0F2	13.90	0.89	0.62	0.27	0.48	0.10	0.02	1.30	0.64
B1F0	13.00	0.59	0.70	0.19	0.31	0.07	0.02	0.905	0.48
B1F1	14.31	0.76	0.72	0.24	0.39	0.09	0.02	1.31	0.52
B1F2	14.91	0.80	0.64	0.27	0.43	0.09	0.02	1.49	0.71
B2F0	15.00	0.81	0.64	0.22	0.42	0.09	0.02	1.25	0.50
B2F1	14.50	0.77	0.65	0.32	0.39	0.09	0.02	1.57	0.74
B2F2	16.75	0.79	0.76	0.33	0.40	0.10	0.02	1.86	0.77

L—length; FW—fresh weight; DW—dry weight. All values are the average of 6 measures, except for 100 kernels FW, which are the average of 4 measures.

anion exchange capacity), nutrient turnover and stability, which in turn influence water relations, aeration and workability [48]. But SOC can significantly influence these soil characteristics after some form of decomposition and increase in microbial activities, both of which take several weeks to build up. This study therefore argues that the first season is used by microorganism to condition soil (with biochar as catalyst) for the observed yield increase in the subsequent years after application.

The biochar amendments however had significant ($p \leq 0.05$) effect on the yield of cabbage as shown in **Table 6** and **Figure 2**. The yield of cabbage was increased by 7.57% from 1.98 kg for B0F0 (0 ton/ha of biochar and 0% of recommended dose of NPK) to 2.13 kg for B2F0 (20 ton/ha of biochar and 0% of recommended dose of NPK). The observations in this study is consistent with a

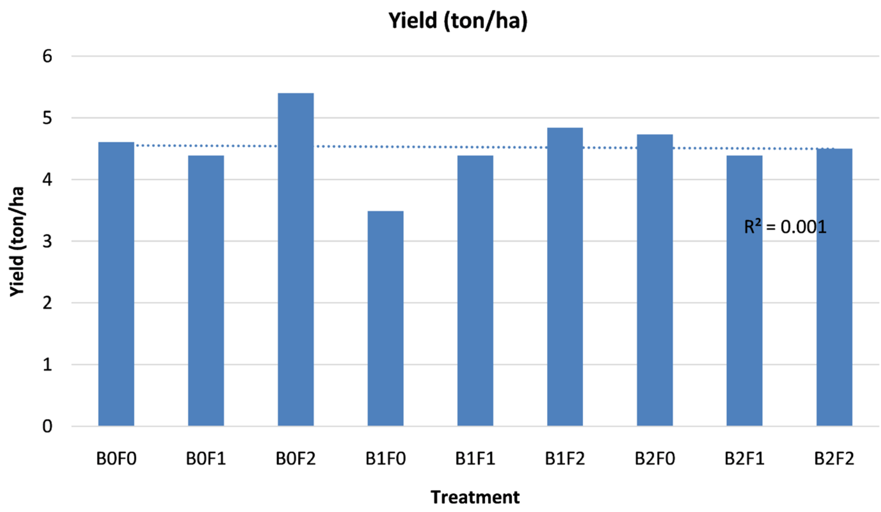

Figure 1. Effect of treatments on yield of maize.

Table 6. Cabbage yield of field trial treatments.

Treatment	Fresh weight (kg)
B0F0	1.98
B0F1	1.92
B0F2	1.96
B1F0	2.0
B1F1	2.27
B1F2	2.17
B2F0	2.127
B2F1	2.29
B2F2	2.16

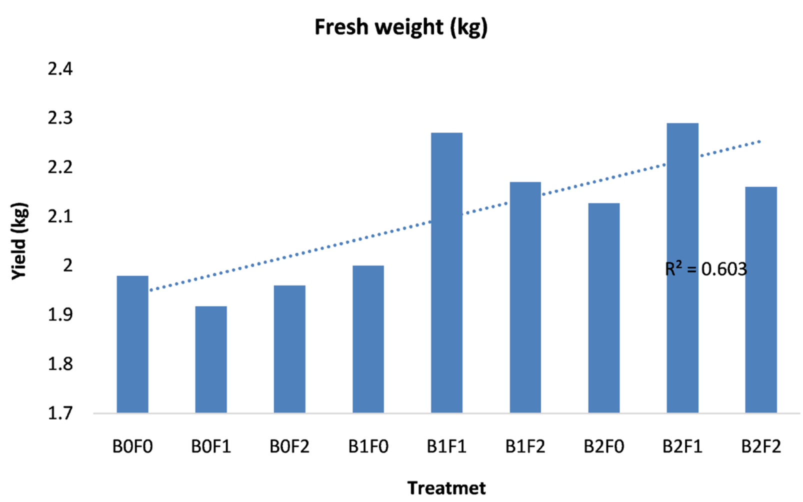

Figure 2. Treatments effects on the yield of cabbages.

study conducted by Tariku *et al.* [49] where different crops responded differently to the application of biochar. Carter *et al.* (2013), revealed that cabbage yield was maximum in the first crop season and lowest in the third crop cycle/season. Their finding was the reverse of finding of Major *et al.*, [24] cited earlier in this study. The variance in the yield responses to application of biochar by maize and cabbage could be attributed to variance in optimum growth condition of the two crops. According to Wunderground [50] and FAO [51], the maximum growing conditions for cabbage is pH of 5.3 - 8.0. However, for maize production (increase in grain yield) the most important factor is the ready availability of Nitrogen. The application of biochar was able to create the optimum growth condition of cabbage in the first season but needs more (at least a season more) time to establish that for maize [52].

4. Conclusions

This field study demonstrated that addition of biochar in combination with NPK has positive effect on maize and cabbage yield. The yield of maize and cabbage was increased by 6.66% and 7.57% respectively in sandy loam soil. The study showed that application of biochar significantly increased soil organic matter (SOM) from 3.88% (for control) to 5.72% (for biochar application rate 20 ton/ha) and soil pH from 6.55 in B0F2 to 7.30 inB2F0. The increase in pH through application of biochar can be used to cure the soil acidity problem which can enhance food security in Ghana. This research also, discovered that the soil of the study area (humid tropical Ghana) is sufficient in TOC but deficient in TON. Therefore, we suggest that successive applications of biochar (which make TOC and SOM persistent) in the soil, plus NPK or/and compost as a N fixing agent, can improve soil quality. The analysis revealed that 20 ton/ha dose of biochar is the optimum for maximum crop growth and good soil condition. This treatment will be beneficial to, over time, enhance the organic matter content, nutrient status, and yield of crops.

The positive effects of biochar application on soil physico-chemical properties, yield of maize and cabbage in Ghanaian soil go to strengthen the global assertion that biochar is a great tool for sustainable agricultural soil management. The findings of this study confirm that biochar works well for agricultural soils in Ghana as much as the case of the nutrient-rich Terra Preta (Dark Earth) soils of the Amazon basin (of Brazil). The study results indicate that the declining fertility and acidity levels of agricultural soils of Ghana can be ameliorated by the use of biochar.

Further study on the coupling of biochar amendment and soil management treatments such as compost and other inorganic fertilizers should be done for further understanding sustainable agriculture. Evaluation is needed to ascertain which combination of soil management types gives the optimal crop responses. Lastly, more tests should be conducted on other crops.

Data Availability

All relevant data used to support the findings of this study are included within the article.

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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