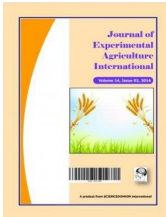

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Effects of Biochar, Rice Husk and Rice Straw on Productivity of Maize (*Zea mays* L.) and Sustainable Soil Fertility Restoration

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Authors' contributions

This work was carried out in collaboration between all authors. Authors IKD and OI designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Authors OI and IKA managed the analyses of the study. Authors IKD, OI and IKA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Integrated soil fertility management technology fits into the status of resource poor farmers in the Guinea savannah zone of Ghana. A field experiment was conducted at Nyankpala during the 2014 cropping season, to investigate the effects of Biochar, Rice husk and Rice straw and subsequently the residual impact on yield components and grain yield of maize. The study was a 3×3×3 factorial experiment consisting of three organic materials at three levels (2.5, 5 and 7.5 t ha^{-1} on dry matter basis) and three NPK rates (0-0-0, 45-30-30 and 90-60-60 kg ha^{-1}) laid out in a Randomized Complete Block Design with four replications. The highest grain yield was obtained with 7.5 t ha^{-1} biochar (4825 kg ha^{-1}) plus at 90-60-60 kg NPK t ha^{-1}, but 7.5 t ha^{-1} a biochar plus 45-30-30 kg NPK t ha^{-1} gave similar yield making the dose more acceptable. Longest cob was obtained with 5 to 7.5 t ha^{-1} of biochar (22.60 cm), or rice husk (20.69 cm), or rice straw (21.45 cm) plus at least 45-30-30 kg NPK $ha^{-1.}$ Shortest days to 50% flowering was found in 5 to 7.5 t ha^{-1} biochar (48.7), 5 to 7.5 t ha^{-1} rice husk (49.1) and 5 to 7.5 t ha^{-1} rice straw (49.6) plus at least 45-30-30 kg NPK ha^{-1} applications.

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Overall, organic materials supplemented with NPK fertilizer gave better results than sole organic materials or NPK fertilizer. The correlation coefficient of grain yield with stover weight and 100 seed weight were (r=0.757**) and 100 seed weight (r=0.678**) respectively. Organic materials plus at least 45-30-30 kg NPK ha^{-1} increased soil organic carbon content (72.8%), Nitrogen (95.6%), Phosphorus (54.6%) and Potassium (17.2%) for maize production.

Keywords: Biochar; rice husk; rice straw; maize; soil fertility restoration.

1. INTRODUCTION

Maize (*Zea mays* L.) is a key cereal crop of food and cash viability worth cultivation in sub-Saharan Africa (SSA). It is a rich source of food, fodder and feed for people and animals living in the rural and urban areas. Maize is processed into a wide range of foods and beverages, which are consumed as breakfast, main meals, or snacks. It has carbohydrate content of about 71%, but low in protein content. Maize production also serves as employment especially for the rural inhabitants of cottage industries.

Even though maize has the potential of eliminating poverty and hunger, its production is far below the recommended yield per hectare in SSA. Maize average yield reported by the Ministry of Food and Agriculture in 2010 was 1.9 t ha^{-1}, with an estimated achievable yield of about 4 t ha^{-1} [1]. In another study, the researchers noted soil fertility depletion in smallholder farms as the primary biophysical root foundation of diminishing per capita food production in Africa [2]. In addition, [3] and [4] recognized low inherent soil fertility as a major cause for low cereal yield in Ghana. On the other hand, [5] reported that maize grain yield is constrained by the inadequate supply of nitrogen caused by insufficient application of fertilizers that are found to be costly and unaffordable in smallholder farming.

Regional growth rates in fertilizer consumption have never been particularly high, partly because the real price of fertilizer is higher in Africa than in other developing/developed countries [6]. Smallholder farmers' application of fertilizer to food crops to maximize production has not often been profitable due to combination of high chemical fertilizer prices, low prices for food crops and high risk during production [2]. Even though chemical fertilizers significantly enhance crop production, [7] concluded that mineral fertilizers are very expensive and sometimes unavailable during peak demand periods in Ghana.

In a survey by [8], the authors reported on large quantities of good quality indigenous organic materials with widespread distribution in Ghana. The authors observed that using 3 t ha^{-1} of organic materials from crop residues with supplementary NPK fertilizer gave synergistic effect on soil fertility, soil chemical properties and soil buffer capacity, in lowland rice fields. Previously, [9] noted that there was good potential for organic-based rice farming with a combination of organic fertilizers to attain maximum yields. It was also observed that the sole application of organic materials or in combination with mineral fertilizer increased rice yields [7]. The use of locally available materials for crop improvement is an option that can be fully exploited as far as crop production by resource-poor farmers is concerned. In this study indigenous organic materials of biochar, rice straw and rice husk, as soil amendments for maize production were utilized in an on-station field trial. The objectives of the study were, to determine the appropriate organic material(s) in combination with inorganic N fertilizer for increased maize production in the Guinea savannah zone.

2. MATERIALS AND METHODS

2.1 Study Site

The trial was carried out at "Farming for the Future", University for Development Studies, Nyankpala Campus during 2014 cropping season. The site is located at latitude 9° 25' 14' N and longitude 0° 58' 42' W, with an altitude of 183 m above sea level. The area experiences uni-modal rainfall with an annual mean rainfall of 1000 to 1022 mm. The temperature distribution is fairly uniform with mean monthly minimum of 21.9°C and a maximum of 34.1°C with a minimum and maximum relative humidity of 46.0 and 76.8%, respectively. The soil at study site is ironstone gravel and ferruginized ironstone brash [10] and classified as a Haplic Lixisol [11] and locally referred to as the Tingoli series [12].

2.2 Experimental Design and Treatments

The trial was a 3×3×3 factorial experiment consisting of organic materials of biochar, rice straw and rice husk applied on dry a matter basis at 2.5, 5 and 7.5 t ha^{-1} with inorganic NPK fertilizer at 0-0-0, 45-30-30 and 90-60-60 kg ha^{-1}. The experiment was laid in a Randomized Complete Block Design (RCBD) with 4 replications. Plots of the 27 treatments measured 5 × 5 m with a plot size of 25 m^2. A 1 m alley was left between plots within a replication and 2 m alley between replications.

2.3 Experimental Materials

The organic materials were biochar, rice straw and rice husk. The rice straw was collected from farmers' fields at Bontanga, whilst the rice husk was obtained from the Savannah Agricultural Research Institute (SARI) rice milling site at Nyankpala. The biochar was made by subjecting rice husk to high temperature under high carbon dioxide and low oxygen levels (charring) using a local device called 'kuntan'. The organic materials were applied on dry matter basis at the rate of 2.5, 5 and 7.5 t ha^{-1}, 28 days before planting of the maize. Basal NPK application was done at the rate specified using fertilizer grade 15-15-15, 14 days after planting (DAP) and the remaining nitrogen for top dressing was applied with ammonium sulphate (21% N) at 43 DAP by band spot placement.

2.4 Weed Management

Prior to planting, glyphosate a pre-plant, non-selective herbicide was applied at 1.4 kg a.i.ha^{-1} to kill volunteer weeds before planting in order to achieve a stale seedbed to avoid early weed-crop competition. The hand weeding was conducted at 13, 40 and 72 DAP.

2.5 Soil Sampling and Analyses

Baseline composite soil samples were collected at random before planting at 0-20 cm soil depth to determine the initial soil physio-chemical properties (Table 1). Post-harvest soil samples were also collected in the same manner per plot basis for similar soil character measurements.

2.6 Data Collection

At 2 weeks after planting (WAP), 5 plants in the middle rows were randomly selected from each plot and tagged for the measurement of growth parameters at 3, 6 and 9 WAP. Leaf area index was measured at 6 and 9 WAP. Data was taken on days to 50% flowering and height of cob attachment. At harvest, data were collected on cob length, strawweight, 100 seed weight and grain yield.

2.7 Statistical Analyses

The data were subjected to analysis of variance using GenStat statistical package (11th Edition). Treatment means were separated using Least Significant Difference (LDS) at 5% significant level.

3. RESULTS AND DISCUSSION

3.1 Effect of Treatments on LAI and COB Attachment

The application of 5 and 7.5 t ha^{-1} of either biochar or rice straw produced the highest LAI, whilst application of NPK at 45-30-30 to 90-60-60 t ha^{-1} equally promoted the parameter (Figs.1 and 2). In addition, treatments of 2.5 to 7.5 t ha^{-1} of biochar or rice straw + 45-30-30 to 90-60-60 kg NPK/ha, 5 to 7.5 t ha^{-1} rice husk + 45-30-30 to 90-60-60 kg NPK t ha^{-1} maximized the height of cob attachment (Fig. 3). According to [13] and [14], they also observed increased crop growth with increasing amount of crop residues and inorganic fertilizer rate. Findings from the present study are consistent with [15] who reported that, organic manure in combination with inorganic fertilizer ensured increment in plant growth. Several researchers also reported that, soil amendment resulted in better crop establishment and increased crop growth rate and leaf area index [14,16].

Table 1. Important physicochemical basal soil properties of experimental site, 2014 cropping season

P^H in water (1:2.5)	% OC	% N	Mg kg^{-1} P	Mg kg^{-1} K	Mg kg^{-1} Ca	Mg kg^{-1} Mg	Texture g kg^{-1}		
5.54	0.117	0.0098	3.562	51.84	64.72	27.88	90.36	1.28	8.36

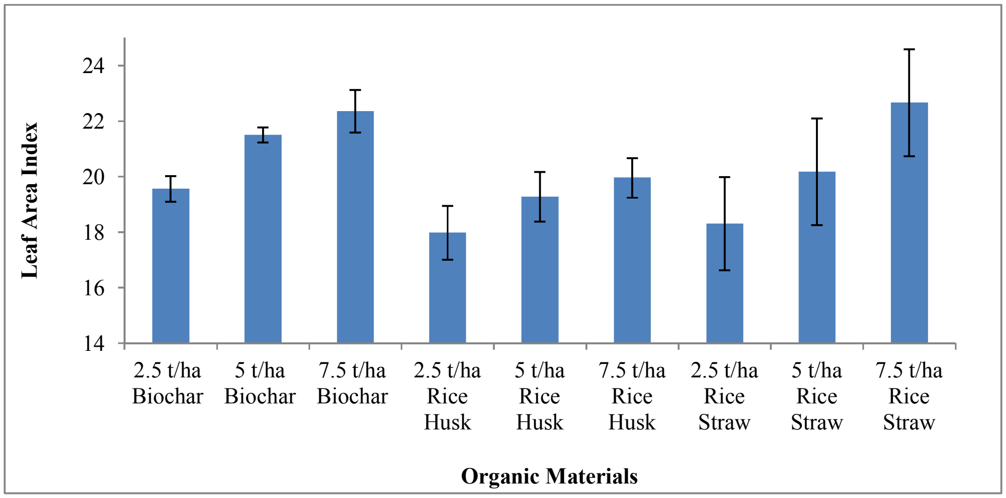

Fig. 1. The effects of organic materials on leaf area index of maize. Bars represent SEMs

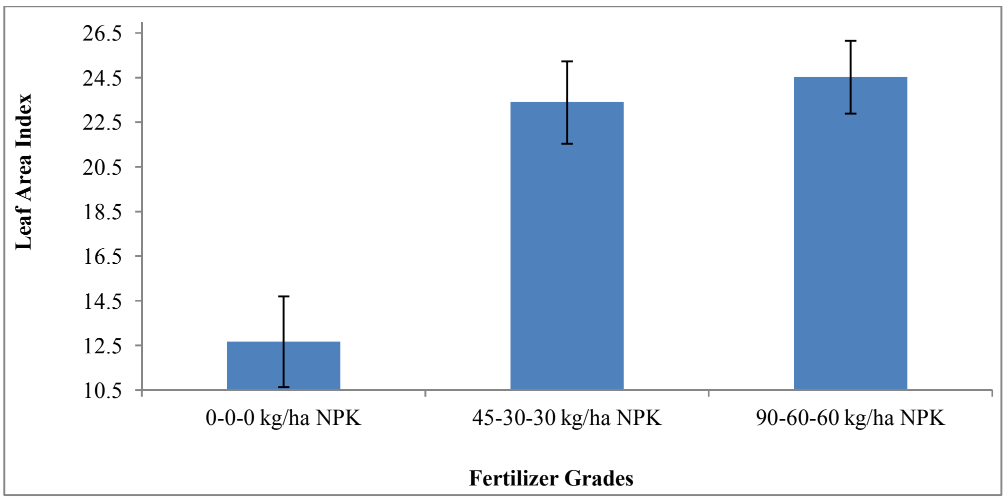

Fig. 2. The effects of inorganic fertilizer on leaf area index of maize. Bars represent SEMs

3.2 Days to 50% Flowering

Organic materials supplemented with NPK fertilizer gave earliest flowering 47 to 50 days with 2.5 to 7.5 t ha^{-1} of biochar, or rice husk or rice straw + 45-30-30 kg ha^{-1} to 90-60-60 kg ha^{-1} NPK (Fig. 4). Timely availability and adequate amounts of nutrients especially nitrogen from the organic sources with supplementary NPK fertilizer could have increased the dry matter accumulation and better crop growth positively supported the physiological functions of the crop to early flowering as reported by [17].

3.3 Cob Length

Cob length at harvest was significantly ($p<0.001$) affected by the application of the organic materials and NPK fertilizer. From this study, the outstanding treatments were attained with 5 to 7.5 t ha^{-1} biochar or rice husk or rice straw plus 45-30-30 to 90-60-60 kg NPK ha^{-1} (Fig.5). Lengthy cobs in organic amended plots might be attributed to higher growth rate due to nutrient availability, which led to high net assimilation ratio and dry matter accumulation. Timely availability of nitrogen from the organic sources could have increased dry matter accumulation and better crop growth that has positively changed the physiological functions of the maize crop. This is in line with [16] who noted that combination of organic and inorganic fertilizer promoted maize ear characteristics due to the incorporation of the organic material. On the other hand, [18] reported that the sustainable yield index of manure plus fertilizer almost doubled that of either organic manure or fertilizer alone.

3.4 Grain Yield

Grain yield of maize was overwhelmingly determined ($p<0.001$) by the combined application of organic materials and NPK fertilizer such that the highest (4825 kg/ha) was attained with 7.5 t ha^{-1} biochar of rice husk plus 90-60-60 kg NPK ha^{-1} (Fig. 6). However, application of with 7.5 t ha^{-1} biochar of rice husk plus 45-30-30 kg NPK ha^{-1} gave similar yield, organic matter alone supported very low grain yield (about 1052 t ha^{-1})

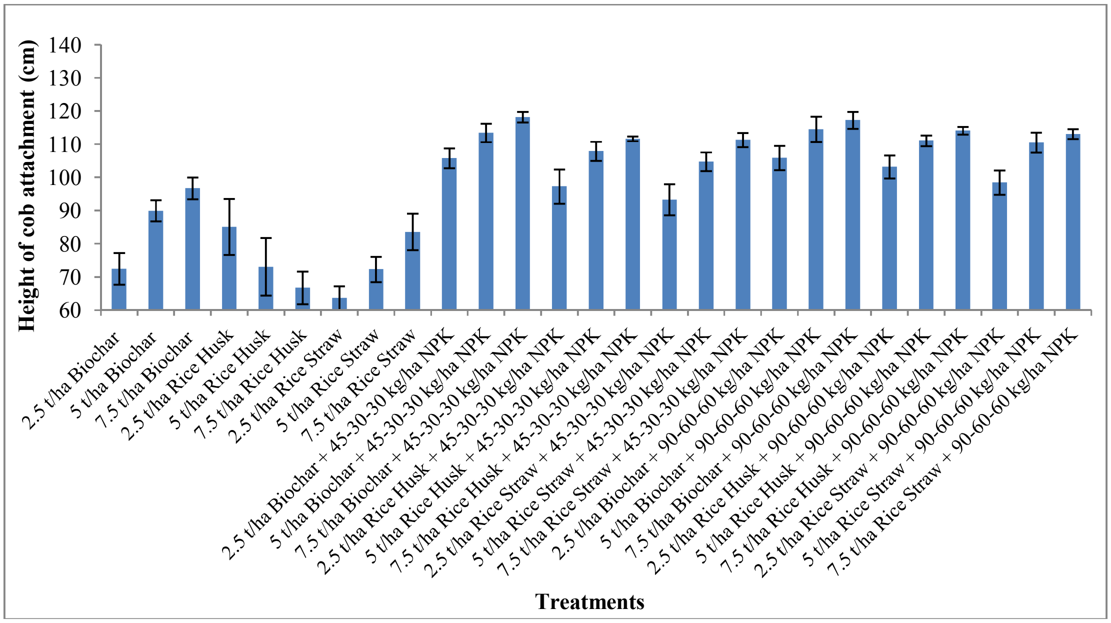

Fig. 3. Effects of organic materials by NPK on height of cob attachment of maize. Bars represent SEMs

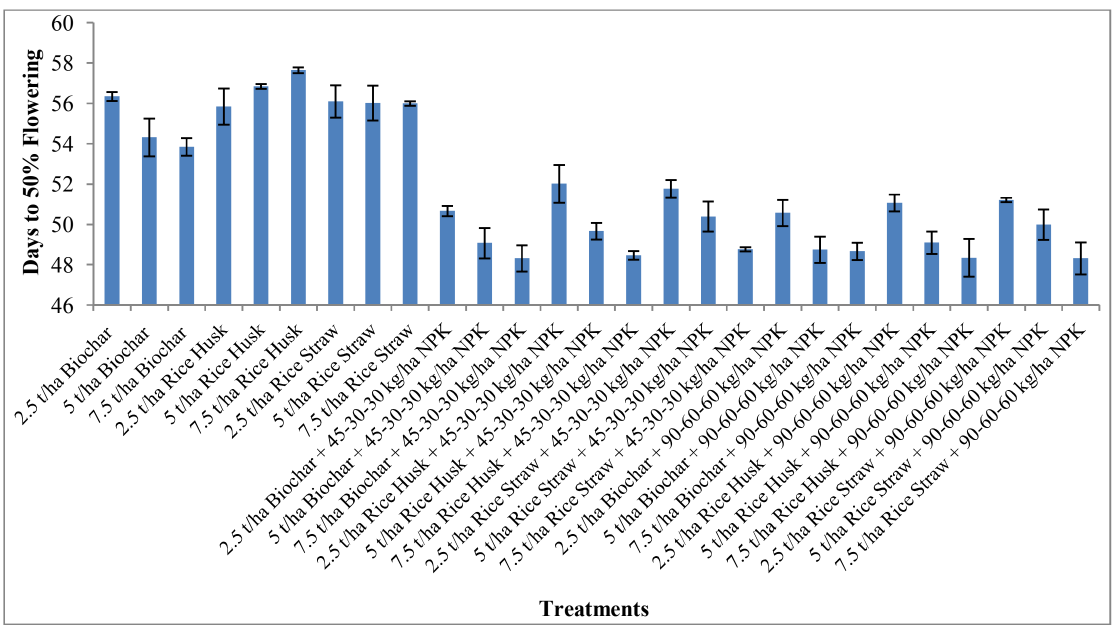

Fig. 4. Effects of organic materials and NPK fertilizer on days to 50% flowering of maize. Bars represent SEMs

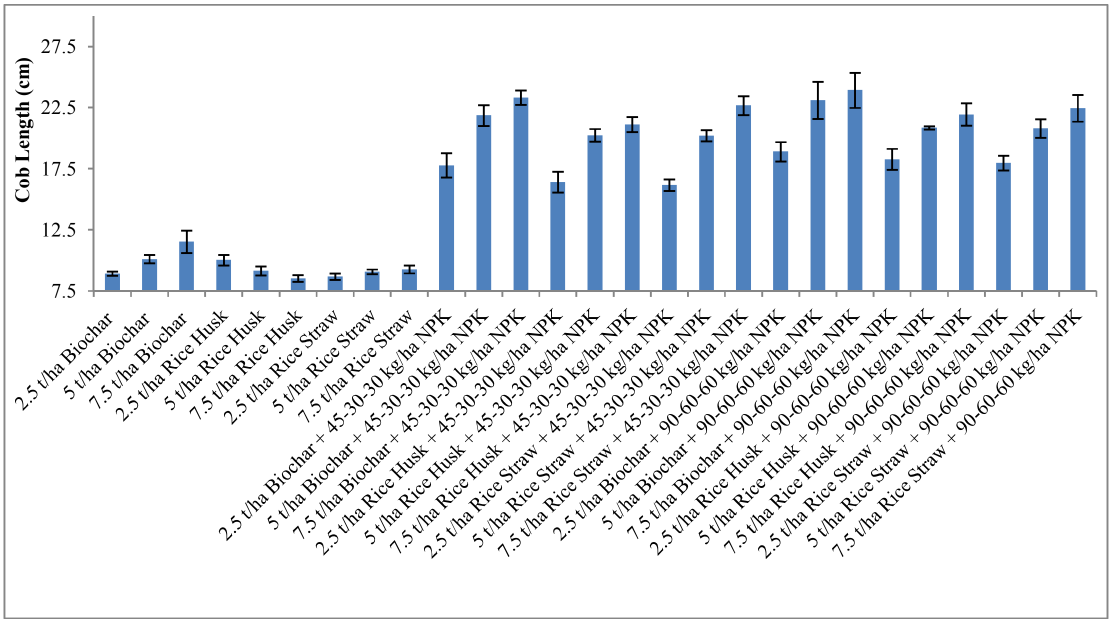

Fig. 5. Effect of the organic materials and NPK fertilizer on cob length of maize. Bars represent SEMs

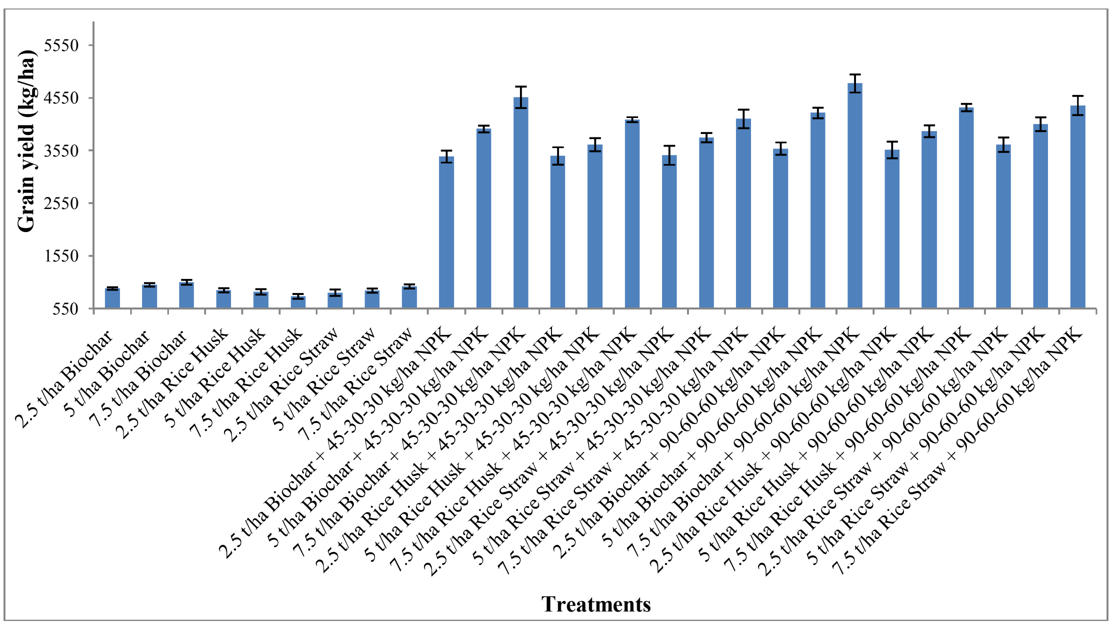

Fig. 6. The interaction effect of organic materials and NPK fertilizer on grain yield of maize after harvesting during the 2014 cropping season. Bars represent SEMs

compared to the integration of both organic and inorganic sources of nutrients. Possible explanation for outstanding grain yield under the integration, could be due to the synergistic effect of the organic materials on soil physicochemical properties like enhanced water holding capacity, increased cation exchange capacity (CEC) and provision of a medium for adsorption of plant nutrients and improved conditions for soil micro-organisms and direct nutrients from NPK [19]. The increase in maize grain yield could be attributed to the overall improvement in soil chemical, physical and biological properties [20]. Similarly, [21] also attributed the build-up of soil organic carbon, moisture retention as well as enhanced nutrient availability to the cumulative effect of manure application. Timely nutrients availability (mainly nitrogen) from the organic materials and inorganic fertilizer enhanced better crop growth, increased the dry matter accumulation and subsequent grain yield. This is in line with the report of [22] and [14] that organic soil amendments recorded the highest yield with chemical fertilizer.

3.5 100 Seed Weight

Hundred grain weight differed significantly (*p<.001*) due to the application of the treatments singly and in combinations at harvest. The outstanding amendments are: 5 t ha^{-1} to 7.5 t ha^{-1} Biochar + 45-30-30 to 90-60-60 kg NPK ha^{-1}, 2.5 to 7.5 t ha^{-1} Rice Husk + 45-30-30 to 90-60-60 kg NPK ha^{-1} and 5 t/ha to7.5 t ha^{-1} Rice Straw + 45-30-30 to 90-60-60 kg NPK ha^{-1} (Fig.7).

This observed heaviest grains can be attributed to high nitrogen levels from the organic and inorganic sources, which led to optimum maize growth and the formation of assimilates for healthy grains. In a study conducted by [17], the researchers reported that lower nitrogen level in the soil resulted in lighter grain weight due to less available nitrogen for the optimum plant growth and formation of assimilates for healthy grains.

3.6 Stover Weight

Stover weight was highly enhanced (*p<0.001*) by the treatments singly and in combination, with maximum obtained with the applications of 2.5 to 7.5 t ha^{-1} biochar, rice husk, or rice straw + 45-30-30 to 90-60-60 kg NPK ha^{-1} ha, (Fig.8). Organic amended plots resulted in better crop establishment and positively increased crop growth rate and net assimilation rate which resulted in higher corn productivity [16].

3.7 Correlation Analysis

Stover weight correlated (0.757**) with grain yield followed by 100 seed weight (0.678**), confirming the strong relationship of the parameters with grain yield (Table 2).

3.8 Soil Analysis after Harvesting

Soil analysis after harvesting indicated that all the treatments had influence on the physio-chemical properties of the soil. The soil amendments altered the pH of the soil. The soil amendments also increased the organic carbon content and the major plant nutrient elements (nitrogen, phosphorus, potassium, calcium and magnesium) of the soil. The table below depicts the effects of the treatments on the chemical properties of the soil after harvesting in 2014.

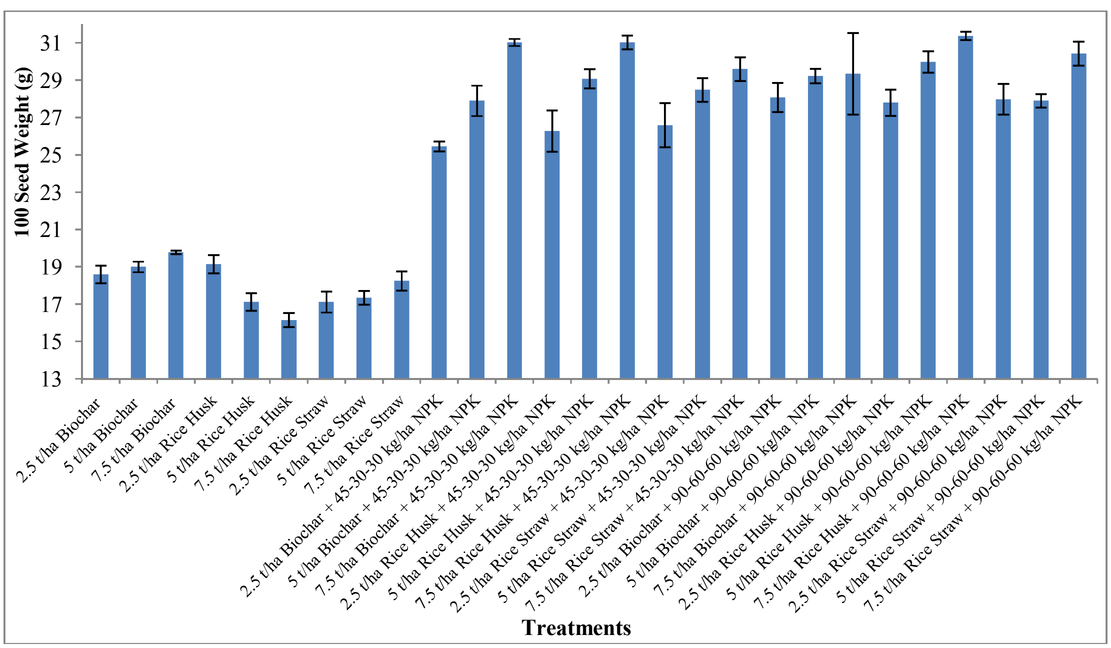

Fig. 7. Effects of organic materials and NPK fertilizer on 100 seed weight of maize. Bars represent SEMs

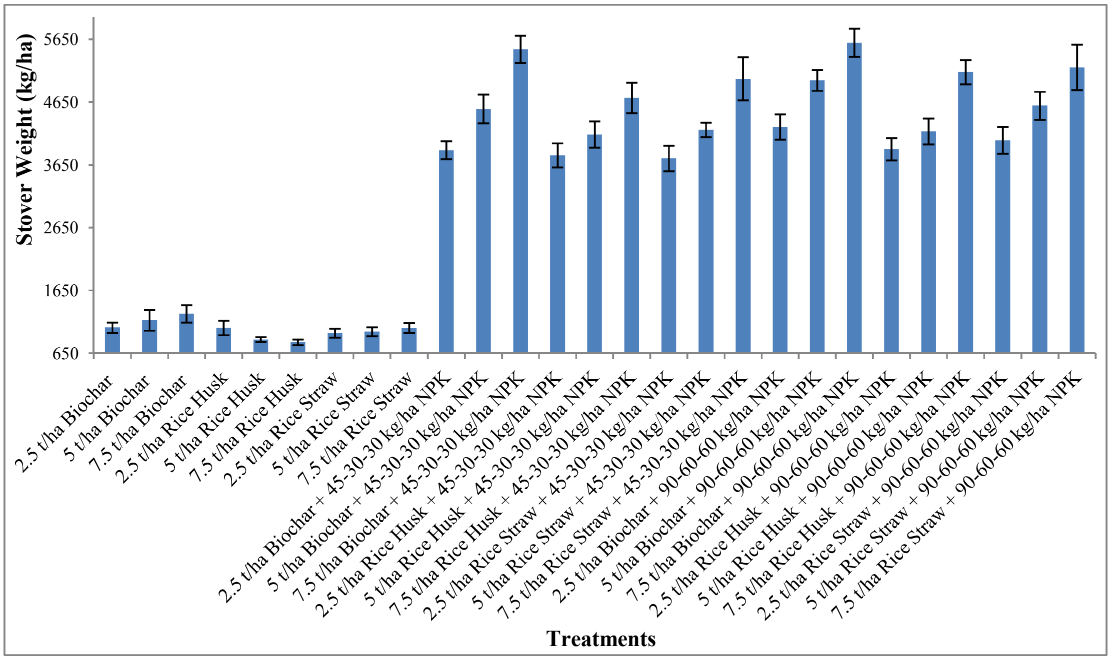

Fig. 8. The interaction between the organic materials and NPK fertilizer on stover weight of maize cultivated in the Guinea savannah zone of Ghana. Bars represent SEMs

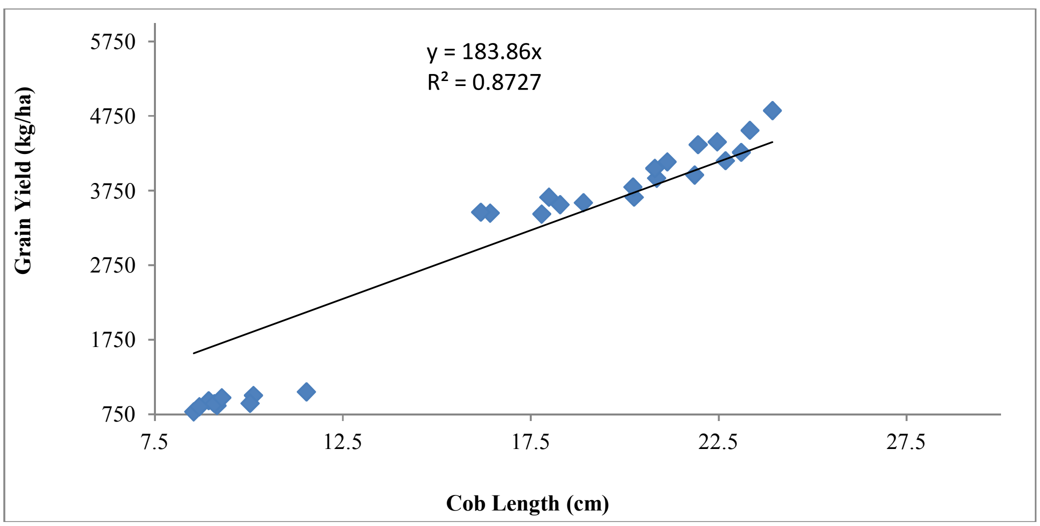

Fig. 9. Linear relationship between grain yield and cob weight of maize

Table 2. Correlation between grain yield, cob length, cob weight, stover weight and 100 seed weight of maize cultivated in the Guinea savannah zone of Ghana

	Grain yield	Cob length	Seed weight	Stover weight
Grain yield	1			
Cob length	0.154	1		
Seed weight	0.678**	0.268	1	
Stover weight	0.757**	0.396*	0.680**	1

*NB: *, ** Significant at 0.005 and 0.01, respectively*

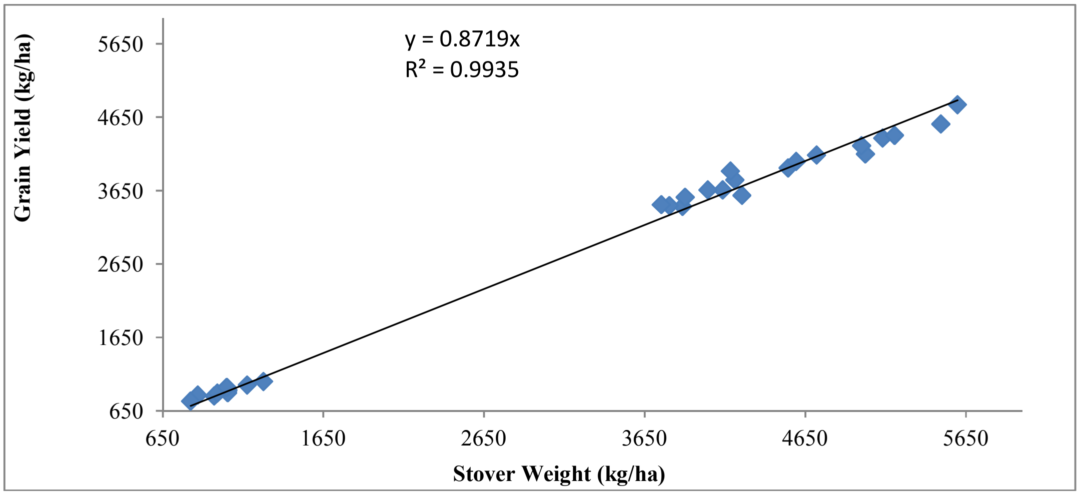

Fig. 10. Linear relationship between grain yield and stover weight of maize

Table 3. Soil chemical properties after harvesting in 2014

Treatment	pH	% OC	% N	Mg/kg P	Mg/kg K	Mg/kg Ca	Mg/kg Mg
2.5 t/ha Biochar	5.32	0.84	0.07	5.8	74	114.6	78.7
2.5 t/ha Biochar + ½ NPK	5.26	0.99	0.09	8.7	105.6	143.7	44.8
2.5 t/ha Biochar + FULL NPK	4.94	1.48	0.13	13.6	142.8	163.5	89
5 t/ha Biochar	5.27	0.7	0.07	5.8	69.7	167.5	75.7
5 t/ha Biochar + ½ NPK	5.33	0.89	0.08	7.5	98.6	197.9	87.8
5 t/ha Biochar + FULL NPK	5.07	0.68	0.06	8.7	60.8	163.9	72.5
7.5 t/ha Biochar	5.4	1.57	0.15	11.9	59.4	174.7	73.5
7.5 t/ha Biochar + ½ NPK	5.37	0.84	0.08	7.7	51.8	118.7	62.8
7.5 t/ha Biochar + FULL NPK	5.14	0.9	0.09	8.9	114.3	147.8	68.5
2.5 t/ha Rice Husk	5.47	0.7	0.06	7.0	61.3	124.5	44.0
2.5 t/ha Rice Husk + ½ NPK	5.19	0.92	0.09	7.9	52.7	153.8	52.8
2.5 t/ha Rice Husk + FULL NPK	4.84	0.5	0.05	5.4	55.0	88.8	34.0
5 t/ha Rice Husk	5.43	0.7	0.07	5.0	58.6	117.6	34.7
5 t/ha Rice Husk + ½ NPK	5.07	0.44	0.04	4.6	59.4	82.7	32.7
5 t/ha Rice Husk +FULL NPK	4.94	0.35	0.03	3.8	51.8	76.0	28.3
7.5 t/ha Rice Husk	5.12	0.74	0.07	6.0	114.3	134.3	42.3
7.5 t/ha Rice Husk + ½ NPK	5.07	0.68	0.06	5.5	98.5	118.8	35.3
7.5 t/ha Rice Husk +FULL NPK	5.25	1.07	0.10	7.0	61.3	157.1	47.1
2.5 t/ha Rice Straw	4.82	2.89	0.27	8.5	52.7	198.8	61.7
2.5 t/ha Rice Straw + ½ NPK	5.22	3.09	0.30	12.7	55.0	247.5	74.8
2.5 t/ha Rice Straw + FULL NPK	5.27	3.01	0.29	11.7	58.6	221.6	67.1
5 t/ha Rice Straw	5.12	3.09	0.29	11.1	59.4	235.0	73.0
5 t/ha Rice Straw + ½ NPK	5.07	3.03	0.29	9.8	51.8	212.2	66.1
5 t/ha Rice Straw + FULL NPK	4.94	3.33	0.32	15.6	114.3	254.1	84.9
7.5 t/ha Rice Straw	5.12	2.89	0.28	9.7	98.5	199.7	62.5
7.5 t/ha Rice Straw + ½ NPK	4.97	3.01	0.30	12	61.3	216.2	64.0
7.5 t/ha Rice Straw +FULL NPK	4.85	3.17	0.31	13.8	52.7	244.2	73.8

NB: ½ NPK = 45-30-30 kg ha^{-1} NPK and FULL NPK = 90-60-60 kg ha^{-1} NPK

The present study is consistent with [23] who reported on the improvement of soil properties with organic soil amendment applications while [24] also reported that rice straw incorporation increased soil organic matter content. In addition, [25] observed that the interaction between the application of organic fertilizers and inorganic fertilizers (nitrogen, phosphorus and potassium) influenced organic carbon content and soil cation exchange capacity.

4. CONCLUSION

The results of this study showed that, combination of the organic and inorganic materials enhanced maize grain yield, 100 seed weight, stover weight, cob length and days to 50% flowering. The highest grain yield was obtained for 7.5 t ha^{-1} biochar (4825 kg ha^{-1}) plus 90-60-60 kg NPK t ha^{-1*-} but 7.5 t ha^{-1} biochar plus 45-30-30 kg NPK/ha gave similar yield making the latter dose more acceptable. Combining organic and inorganic fertilizers was advantageous because they supported maize growth and development and final grain yield. Rice husk and rice straw are available in large quantities in the Guinea savannah zone of Ghana and could be used as soil amendments for maize growth. Adoption of integrated soil improvement approaches remains the most feasible option for smallholder farmers to improve maize production on fragile soils as long as the prices of inorganic fertilizers remain unaffordable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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