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IMPACT OF RICE HUSK BIOCHAR AND INORGANIC NITROGEN FERTILIZER COMBINATIONS ON YIELD OF MAIZE IN COASTAL SAVANNAH OF GHANA

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ABSTRACT

The continuous soil fertility decline globally possesses a great threat to food security. Thus requiring fertilizer as well as other integrated soil fertility management options to improve the soil health and increase crop productivity. Biochar is considered a potential remedy to soil fertility loss. This study, therefore, provides a novel insight into the effects of rice husk (RHB) and N-fertilizer (urea) applications at different rates on grain yield, total above-ground biomass, and NUE of *Obatanpa* maize cultivar. The experiment was a factorial trials arranged in RCBD. Three levels of N fertilizer were applied (0, 45 and 90 kg ha^{-1}) with and without biochar (10 t ha^{-1}) on (*Obatanpa*) maize variety with 3 different planting dates. A total of 45 kg ha^{-1} of P and K in the form of Triple Super Phosphate (TSP) and Potassium Chloride (KCl) respectively were applied as basal application. Results revealed that the application of inorganic Nitrogen or in a combination of biochar significantly ($P < 0.05$) increased grain and biomass yields. Interaction between biochar and N fertilizer increased agronomic N efficiency at low N application rates (45N kg ha^{-1}) for all 3 planting dates. The results from this study suggest that rice husk biochar amendment and N fertilization have the potential to enhance soil nutrient availability and increase maize yield. The combined application of 10 t ha^{-1} BC and 45N kg ha^{-1} (urea) fertilizer is hereby recommended as a sustainable soil fertility management option for maize production in the coastal savanna region of Ghana.

INTRODUCTION

Low soil fertility and climate change have been observed as significant factors negatively influencing agricultural productivity in sub-Saharan Africa (Walka et al., 2018). However, in Ghana, soil fertility decline is reported as a major biophysical factor posing a great challenge to crop production (Tesfahunegn et al., 2021). This is because of the low water holding capacity, low soil organic carbon (SOC) content, high soil acidity, and poor agronomic activities resulting in soil fertility decline have increased over the years with its intending consequence on crop production (Breuning-Madsen et al., 2017; Kristensen et al., 2019). To come out from this menace, there is the need to face agricultural production in a very sustainable way through effective soil management practices that have the potential to increase soil water retention, pH, SOC, and nutrient which have long-term positive impacts on crop yield. The incorporation of crop residue into the soil is an essential source of soil nutrients and organic matter. Soil amendment either from organic or mineral sources, has come to stay as part of solutions to soil fertility decline.

Biochar has been in use (as soil amendment) for several decades as an alternative soil improvement input. Biochar is obtained through the thermo-degradation of organic materials in an oxygen-controlled environment with physiochemical features, which makes it ideal for use as a soil amendment and carbon sequester (Bouqbis et al., 2016). The benefits of biochar in improving soil productivity are so enormous that it continues to draw a lot of attention from researchers in recent years. Several findings support the fact that biochar can increase soil water and nutrient retention, improve crop growth and yield, and a pathway to sequester carbon to the soil (Jeffery et al., 2017; Bornø et al., 2018; Ramlow et al., 2019)

Additionally, biochar application to the soil has different effects on soil biota. Not only does it improve biological N fixation (rhizobia) (Rondon et al., 2007), but it also enhances mycorrhizal fungi colonization and soil microbial biodiversity, respectively (Van Zwieten et al., 2010; Luo et al., 2017). Thus, soil micro-organisms function effectively in neutral pH; therefore, increased alkalinity effect as a result of applied biochar provides favorable habitat hence the increase in the population of soil microbes and their inherent activities.

Biochar production and application in soils have a very high potential for the expansion of sustainable agricultural systems in Ghana (Mensah and Frimpong, 2018). This is because combined applications of biochar and chemical fertilizers have been shown to increase agronomic benefits (Lashari et al., 2015). For example, a combined application of biochar and N fertilizer has been found to have positive impacts on soil functions and crop N uptake and productivity (Lori et al., 2013 singh et al., 2018). Steiner et al. (2008) reported a doubling of maize grain yield on plots using a combination of NPK fertilizer with charcoal compared to the use of NPK fertilizer alone. Also, Oguntunde et al. (2004) studied the maize yield of a charcoal production site and adjacent fields and reported a 91% yield increment in the charcoal production site compared to the control. This evidences, therefore, suggest that rice straw-derived biochar do not only have a great positive impact on crop performance but more effectively when applied in combination with inorganic N fertilizer to support crop productivity (Manpreet et al. 2018). The increases observed in crop yield with biochar application could be attributed to the potential increase of nitrogen utilization from the fertilizer applied (Widowati et al., 2011). Despite the enormous benefits biochar possess as soil amendment material, its effectiveness is dependent on biochar type and application rate, biochar aging in soil, soil type, and environmental conditions (Lori et al., 2013; Olmo et al., 2016) as well as its combination with N rates (Manpreet et al., 2018). These variations present the issue of ambiguity and limitation to the general use of biochar as soil amendment material in agriculture. This is further exacerbated by a report of Haefele et al. (2011), who suggested that the effects of rice residue biochar addition on soil fertility and crop yield will depend on site-specific conditions. For now, studies on biochar, nitrogen fertilizer, and its combined effects on maize yield, soil nutrient status, and nitrogen use efficiency are quite scanty in the coastal savannah zone of Ghana. There is therefore the need to address the research gap in this area of study. This study was therefore carried out to (i) assess the impact of rice husk biochar on yield and TBM of maize, (ii) evaluate N (urea) fertilizer rates and rice husk biochar interaction on yield/TBM of maize, and (iii) evaluate the interactive effects of rice husk biochar and nitrogen fertilizer application on agronomic nitrogen use efficiency.

2. Materials and methods

2.1. Experimental site characteristics

The study was conducted at the University of Ghana, Soil and Irrigation Research Centre (SIREC) at Kpong in the Eastern Region of Ghana during the 2014 cropping season. The site is located on latitude 6^{o} 09'N and longitude 00^{o} 04'E at an altitude of 22 m above mean sea level. The land slopes gently with slopes between 1% and 5 %. It is 80 km N.E of Accra and 3km off Tema- Akosombo High way. The centre is within the coastal savanna agro-ecology of Ghana which is characterized by a bimodal rainfall pattern. Annual precipitation ranges from 600 to 1200 mm with a minimum and maximum annual temperature of 22.1^{o}C and 33.3^{o}C, respectively (SIREC, 2014)

The soil of the study area is classified as Calcic Vertisol according to the FAO-UNESCO system (FAO-UNESCO, 1990). Locally, it is tropical black clay and belongs to the Akuse series (Amatekpor and Dowuona, 1995). The vertisols of Accra Plains occupy a total area of about 0.163llion hectares (Brammer, 1967) and the textural classification is clayey. The soil has a pH of 6.5-8.5 with CEC ≥ 3.0 per kg clay. Dominant bases in the soil are Ca and Mg with clay ≥35%. Vertisol is a dark-colored soil containing a large amount (35-40%) of expansive clay minerals known as (montmorillonite). It is expansive; it swells and becomes sticky when wet, shrinks when dry, becomes very hard and, cracks extensively. Vertisols are highly prone to waterlogging during the peak of the major rainy season because of their low saturated hydraulic conductivity of high smectite content (Dudal and Bramao 1965; Coulombe et al., 1996).

Fourteen days to planting, soil samples were collected at five random spots across the diagonal of the site at depths of 0–15, 15–30, 30-45, 45-60, 60-75, and 75-90, and 90-100 cm. The samples collected were homogenized and ground to pass through a 2-mm sieve. These were analyzed for pH using a ratio of 1.2 ml water to 1 g soil (McLean, 1982); SOC using the procedure of Walkley and Black (1934); total N content by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984); OM content was determined by the use of dichromate-acid oxidation technique; available P and K using the Bray-I method (Bray and Kurtz, 1945); exchangeable cations and CEC was determined using ammonium acetate method (Black, 1965) at the University Ghana, Legon Ecological laboratory (ECOLAB. Table 1 shows the chemical characteristics of the trial soil before 1st, 2nd & 3rd planting.

Table 1. Pre-planting soil chemical properties of the study site at SIREC

Soil depth (cm)	pH (1:2) Soil: H2O	S.O.C	Total N	O.M	Avail. P (cmg kg^{-1})	CEC (cmol kg^{-1})	K (cmol kg^{-1})
		-----------------	%	----------------			
0-15	6.71	0.85	0.08	2.47	4.54	38.21	0.27
15-30	7.20	0.77	0.07	2.12	4.25	39.30	0.19
30-45	7.30	0.66	0.06	1.87	3.48	35.60	0.09
45-60	7.38	0.54	0.05	1.56	3.22	34.21	0.09
60-75	7.41	0.48	0.04	1.35	3.22	35.42	0.07
75-90	7.40	0.45	0.03	0.66	3.09	33.70	0.05
90-100	7.40	0.41	0.03	0.51	2.53	33.31	0.05
Lsd (<0.05)	0.034	0.011	0.006	0.008	0.007	0.071	0.007

S.O.C – Soil organic carbon; N - Nitrogen; O.M-organic matter, P – Phosphorus; CEC- cation exchange capacity, K- Potassium

2. 2 Biochar preparation and analysis

Rice husks for biochar production were obtained from the SIREC rice mill located within the research center. Preparation of rice husk biochar (RHB) was carried out under a limited supply of oxygen (controlled pyrolysis) under open environmental conditions near the experimental site following the drum method (Srinivasarao et al. 2013). A drum was partially filled with the rice husks and charred at 350 °C with a residence time of 60 minutes. The drum was cooled under ambient air, and RHB was collected. The biochar pellets were homogenized, powdered, and passed through a 2 mm sieve for use. The biochar material was analyzed for chemical properties (Table 1) according to the International Biochar Initiative (IBI, 2011) procedures at the University of Ghana, Legon ECOLAB.

Table 2. Chemical properties of RHB used in the soil amendments before planting

Sample	pH (H2O)	O.C (g kg-1)	N (g kg-1)	P (g kg-1)	K (g kg-1)	CEC (cmol kg-1)
Biochar	7.01	57	0.8	0.09	0.53	20.4

O.C - Organic carbon; N - Nitrogen; P - Phosphorus; K - Potassium; CEC – Cation exchange capacity.

2. 3 Experimental set-up and procedure

After manual stump removal, tractor-mounted disc plowing and disc harrowing was done to fine-tune the land for sowing. The experiment was a 3 factorial trial laid out in a Randomized Complete Block Design (RCBD). The treatment consisted of 3 levels of Nitrogen (N) fertilizer applications (0, 45, and 90 kg/ha^{-1}) with and without biochar (10 t ha^{-1}) were evaluated on one maize (*Obatanpa*) variety on three different planting dates. In all, there were six treatments (biochar only, 0N, 45N only, 45N + biochar, 90N only, and 90N + biochar) replicated three times. The experiments were conducted simultaneously three times on 26/06/14, 06/09/14, and 26/09/14 (1st sowing-S1, 2nd sowing-S2, and 3rd sowing-S3). Treatment plots size measuring 6 m x 6.4 m was laid at the experiment site. In between each adjacent plot, a spacing of 0.5m was allowed to provide access pathways and reduce the lateral movement of irrigation water and biochar between plots. A total of 45 kg ha^{-1} of P and K in the form of Triple Super Phosphate (TSP) and Potassium Chloride (KCl) respectively were applied as basal application together with half of the N rates at 14 days after emergence. After the treatment plots were laid, RHB was evenly incorporated manually into the top 0.25 m of the soil at the same rate (10 t ha^{-1}) except the control. An improved planting stock of the maize variety *(Obatanpa*) was used as a test crop: a variety widely grown by Ghanaian farmers (Poku et al., 2018). *Obatanpa* is a medium maturity white quality protein maize variety (QPM), developed in Ghana under the Ghana Grains Development Project (GGDP) and promoted extensively by the Sasakawa Global 2000 (SG 2000) program.

The first planting was done during the major growing season from June to September and the other two during the minor growing season from September to December with twenty (20) days interval (28th June, 6th and 26th September 2014). Four (4) seeds were planted per hill at 0.8 m x 0.4 m. and thinned to two (2) plants per hill after two weeks of planting. The N was split applied at approximately 14 days after germination and the remaining halve applied 45 days after germination.

Supplemental irrigation was applied to avoid water stress on plants since precipitation was not sufficient to meet fully crop needs throughout the growing season. About 54 mm of water was applied (55 mm x 4 = 220 mm) at each time of irrigation. Planting was done three times to obtain better data for analysis.

2. 4 Sampling and measurements

The plants were closely monitored for data collection. The phenological stages were noted when at least 50% of the plant population attained that stage. The grain yield and total biomass were measured from an area of 3.84m^2 consisting of 24 plants. Biomass yield was split into stovers and grain. The harvested plants were then separated into ears (cob + grains) and total stover (stem, leaves, and husks). The ears were separated into cobs and grains by hand shelling. They were weighed and results recorded as fresh weights. Sub-samples of the various plant parts were oven-dried to 70 ^{0}C for 72 hours to estimate dry matter yield. Grain and Stover yields were estimated per hectare, with grain at a moisture content of about 15 %. The stover and cob were added to obtain total above-ground biomass. The agronomic nitrogen use efficiency (NUE) as affected by nitrogen and biochar treatments was computed as

$$\mathrm{NUE} = \frac{\text{Grain yield}_N\ (\text{kg/ha}) - \text{Grain yield}_{\text{control}}(\text{kg/ha})}{\text{Amount of N fertilizer applied (kg/ ha)}}$$

Where;

Grain yield$_N$ and Grain yield$_{\text{Control}}$ are yields obtained under N kg ha^{-1} of N fertilizer applied and yield obtained with no fertilization respectively.

2.5 Statistical analyses

Data collected from the experiment were analyzed using GenStat (9th Edition) and Microsoft Excel (version 2010). All data subjected to statistical analysis were first entered in Microsoft excel and further exported into GenStat. Analyses were carried on the entire field data collected for the three planting dates. ANOVA was used to determine significant differences between soil chemical properties at different soil depths and yields under different treatments. The least significant differences was considered at p = 0.05 in all cases.

3. Results

3. 1 Initial soil and biochar properties

The initial soil pH can be described as neutral, with values ranging from 6.7 at the topsoil and increased down the profile to a pH of 7.4 (Table 1). OC content was moderately high (0.85%) at 0-15 cm and decreased to 0.41% at 90- 100cm of soil depth. Percentage OM was moderate (2.47%) at the topsoil (0-15 cm), decreasing to very low 0.51% at 90-100 cm depth. The CEC values were very high with 39.3 cmol kg^{-1} being the highest for 15-30 cm depths and the least of 33.3 cmol kg^{-1} at 90-100 cm depths. The N content was considered low at all soil depths since less than 0.1% was recorded, indicating that results obtained in the study would project the true response of maize cultivar to inorganic N applied. The texture of the soil at the study site was sandy clay loam at 0-15 cm depth, with the rest of the soil depths being clay. Generally, differences occurred in chemical properties of soil at different depths. However, they were not statistically significant (P>0.05) (Table 1). The pH of rice husk biochar was 7.01 (Table 2), which could be described as neutral. Also, CEC of the rice husk biochar was 20.4cmol kg^{-1}. OC and nitrogen content of biochar in this study were 57g kg^{-1} and 0.8 g kg$^{-1,}$ respectively. Total N in biochar was 0.8 g kg^{-1} (0.08 %). Percentage P and K in biochar were 0.09 and 0.53 g kg^{-1} respectively.

3.2 Effect of biochar and N fertilizer on grain yield and total biomass

The responses of *Obatanpa* maize cultivar to different levels of nitrogen fertilizer to grain yield were significant ($P<0.05$). The highest ($P<0.05$) grain yield was obtained from plots treated with 90kgN ha^{-1} and the lowest ($P<0.05$) yield from control plots of 0kgN ha^{-1}. Sole biochar recorded yields of 2091, 1717, and 2067 kg ha^{-1} for the three planting dates respectively. Combined treatment 90N + 10t ha^{-1} biochar recorded the highest grain yield of 4937kg ha^{-1} while sole 90 N produced the highest grain yield of 4603kg ha^{-1}across the three sowing dates. Plots treated with 0kgN ha^{-1} produced the lowest grain yields (Table 3). The interaction between planting date, biochar, and N fertilizer on maize significantly ($P<0.05$) affected the grain yield (Table 3).

Table 3. Different levels of Nitrogen under biochar treatments in three different planting dates on yield of *Obatanpa* maize cultivar at SIREC

Planting date	**Biochar**	**Fertilizer**				**Mean**
		No fertilizer	**45 N**	**90 N**	**Mean**	
Date one	No Biochar	1983.3	3033.3	4408.3	3141.6	3251.4
	Biochar	2091.7	3483.3	4616.7	3361.1	
Mean		2037.5	3258.3	4572.5		
Date two	No Biochar	1700.0	3058.3	4603.3	3120.5	3303.9
	Biochar	1716.7	3808.3	4936.7	3487.2	
Mean		1708.4	3433.3	4770.0		
Date three	No Biochar	1941.7	3316.7	4453.3	3237.2	3402.5
	Biochar	2066.7	3758.3	4878.3	3567.8	
Mean		2004.2	3537.5	4665.8		
Mean		1916.7	3409.7	4669.4		

LSD ($P \leq 0.05$); Planting date = 37.63***** Fertilizer = 37.63***** Biochar = 30.73*****
Planting date × Fert. = 65.18*****, Planting date × Biochar = 53.22*****
Biochar × Fert. = 53.22***** Planting date × Biochar × Fert. = 92.18*****

* = significant at 5% probability level NS= not significant at 5% probability level

Total above-ground biomass (TBM) recorded for control across the three sowing dates was 4833, 5550, and 4550 kg ha^{-1} respectively with 2nd planting date recoding the highest. Sole biochar treatments produced the highest TBM of 6125kg ha^{-1} for 2nd planting with the least of 5575kg ha^{-1} for 3rd planting. Combined 90kgN ha^{-1}+10t ha^{-1} biochar treatment produced the highest TBM of 12712kg ha^{-1} for the 2nd planting date. Total biomass production of *Obatanpa* maize cultivar was significantly affected by planting date and fertilizer treatment interaction. Additionally, the interaction between the three factors (planting date, fertilizer, and biochar) significantly (P<0.05) affected the total biomass production (Table 4).

Table 4. Different levels of Nitrogen under biochar treatments in three different planting dates on total biomass of *Obatanpa* maize cultivar at SIREC

Planting date	**Biochar**	**Fertilizer**				**Mean**
		No fertilizer	**45 N**	**90 N**	**Mean**	
Date one	No Biochar	4833	8587	11366	8262	8661
	Biochar	5692	9484	12002	9059	
Mean		5263	9035	11648		
Date two	No Biochar	5550	8710	13056	9105	9507
	Biochar	6125	9992	13608	9909	
Mean		5837	9351	13332		
Date three	No Biochar	4550	8825	11850	8408	8792
	Biochar	5575	9424	12525	9175	
Mean		5063	9125	12188		
Mean		5387	9170	12401		

LSD ($P \leq 0.05$); Planting date = 122.4*****, Fert. = 122.4 Biochar = 100.0*****
Planting date × Fert. = 212.1***** Planting date × Biochar = 173.2*****
Biochar × Fert. = 1173.2***** Planting date × Biochar × Fert. = 299.9*****

* = significant at 5% probability level NS= not significant at 5% probability level

Nitrogen use efficiency (NUE)

The agronomic N use efficiency in sole inorganic N fields recorded values that ranged from 11 kg grain kg^{-1} N at 45kg N ha^{-1} to 15 kg grain kg^{-1} N at 90kg N ha^{-1} over the three sowing periods. Thus NUE was generally high at high N application rates. Further, it was interesting to note that the NUE of maize with N + biochar combination ranged from 15 kg to 18 kg grains kg^{-1} N at 45 kg N ha^{-1} + 10t BC ha^{-1}. At 90N+ BC combination, values ranged from 13 to 15 kg grains kg^{-1} N at 90 kg N ha^{-1} + 5000kg BC ha^{-1}

4. Discussions

Findings from this study revealed that the application of inorganic Nitrogen or in a combination of rice husk biochar could significantly ($P < 0.05$) increase grain yield. In all the three sowing dates, though there were differences among control and sole biochar, these differences were not statistically significant ($P > 0.05$). On the whole, combined treatment 90N + 10 t ha^{-1} biochar recorded the highest grain yield of 4937 kg ha$^{-1,}$ with the control recording the lowest grain yield of 1700 kg ha^{-1} (Table 3). This means the interactive effect of Nitrogen and biochar produced yields which were significantly higher than sole biochar or inorganic nitrogen applications. This increase in grain yield with combined treatment of biochar and inorganic N was as a result of the positive effect biochar has on soil physicochemical properties such as a change in soil pH, BD(ρb), CEC, WHC and reduced soil strength (Luo et al., 2017). Also, the increase in yield confirms the assertion of Jeffery et al. (2017) and Bornø et al. (2018) that biochar incorporated into the soil provided a medium for adsorption of plant nutrients, particularly N, and improved conditions for soil micro-organisms resulting in increased yields.

Additionally, the total above-ground biomass production followed a similar trend as the grain yield. Biomass per treatment varied from 4550 kg ha^{-1} to 13608 kg ha^{-1} for the control and 90N + biochar, respectively over the three planting dates (Table 4). The application of Nitrogen or in a combination of RHB significantly influenced total above-ground biomass production. The increase in N rate with a corresponding increase in biomass observed affirms the claim of Segum et al. (2019) that a combination of biochar and N fertilizer has a significant interactive effect on grain and biomass production.

On average, agronomic nitrogen use efficiency across the three sowing dates was the same for both low and high N application rates. This result, however, disagreed with Zingore et al., (2007) who reported the highest agronomic NUE at low N rates applications. On the other hand, with N + biochar combination, NUE was generally highest at low N application rates in all the sowing dates. This was possible as a result of the positive impact biochar has on the soil chemistry. Biochar provides no significant source of plant nutrients. However, it can improve the efficiency of inorganic fertilizers (Ramlow et al., 2019), resulting in higher NUE at a low N application rate (45N Kg ha^{-1}) with biochar (10 t ha^{-1}) combinations as shown in this study. Also, the increased NUE of maize due to biochar and N interaction at a low N rate could also be the result of the improved soil physiochemical properties such as water-holding capacity, and nutrients availability within the biochar (Jeffery et al., 2017; Segum et al., 2019).

5. Conclusions

The results from this study demonstrated that the combined application of biochar and inorganic fertilizer could produce yields that were significantly higher than the sole application of either biochar or inorganic fertilizer. Similarly, nitrogen application or in a combination of RHB has a positive influence on total biomass production. Biochar improved the soil's physical, chemical, and biological properties, thereby improving the efficiency of inorganic fertilizer uptake resulting in a significant increase in yield and total above-ground biomass of maize. With the combined application of biochar with inorganic N fertilizer, agronomic N use efficiency (AEN) was generally highest at a low N application rate (45N +10 t ha^{-1} biochar).

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Conflict of interests

The authors declare no conflict of interest.

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