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Effect of biochar type and rate of application on maize yield indices and water use efficiency on an Ultisol in Ghana

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Abstract

In an integrated approach to cut-down on inorganic fertilizer use by smallholder farmers for agricultural production through the use of biochar, a split-split plot experimental design with three replications was carried to determine the effect of biochar from three different feedstock (corn cob, rice straw and cocoa pod husk) applied at two different rates of the feedstock (2.5 t ha^{-1} and 5 t/ha) with three application rates of Nitrogen, Phosphorus and Potassium (N-P-K) as inorganic fertilizer (90-60-60, 45-30-30 and 0-0-0) on maize growth and yield as well as soil chemical properties. The main plots of the experimental design were allocated to the biochar types while the Sub-plot was allocated to the biochar rates. The Sub-sub-plot went for the inorganic fertilizer rates. The maize seeds were sown at spacing of 80 cm between rows and 40 cm between plants. Three seeds were sown per each stand which was later thinned to two plants two weeks after planting. Urea, Triple superphosphate and Muriate of Potash were used as the sources of inorganic nitrogen, phosphorus and potassium (N-P-K) respectively. The P and K were applied once two weeks after planting while the N was split applied. One third of the application rate of nitrogen was applied two weeks after planting and the remaining two thirds applied six weeks after planting. Soil samples were collected from 0-20 cm depth before planting (one composite sample from the experimental site) and at harvest (from each treatment plot) to evaluate the effect of the different amendments on different soil chemical properties notable N, P, K, CEC, and pH. The quantity of biochar application had pronounced effects on maize grain yields where higher application rates (5 t/ha) showed superior performance to 2.5 t/ha.

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Keywords: Biochar; maize grain yield; pyrolysis; ultisol; soil fertility.

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1. Introduction

Biochar is charcoal obtained from biomass meant to be incorporated into the soil [1]. In the past years, biochar grew into one of the great promises to improve soil fertility and, in addition, to mitigate climate change through carbon sequestration [2,3]. Biochar has received particular interest for improving the inherently poor soils in the humid tropics, where large amounts of fallow vegetation from shifting cultivation – at present usually burned – could be used as feedstock for charring.

However, although considerable research on biochar in recent years has yielded promising results, these are inconsistent and the mechanisms leading to better soil fertility and higher yields are not yet well understood [4,5,6]. The main hypothesis of the current study is that biochar feedstock type has the potential to improve maize grain yields when applied solely or in combination with inorganic fertilizers. As biomass resources are limited, there are inevitable trade-offs between different uses of biomass for energy or as biochar applied to soil. Nevertheless, there are opportunities for pyrolysis technology to enable win-win-solutions for improved livelihoods and natural resource management

2. Methods

The experimental design was a split-split plot design with three replications. The whole plots were allocated to the biochar type (No biochar, corn cob, rice straw and cocoa husk biochar), the Sub- plot to the biochar rate (2.5 t/ha and 5 t/ha) while the sub-sub plot was for the fertility level (NPK: 0-0-0, 45-30-30 and 90-60-60). The area of a whole plot used was 9.4 m x 12.8 m with 2 m alley each between whole plots and replicates. Each sub-sub plot measured 4.2 m x 3.6 m with 1 m alley between them. The biochar was applied to the soil by broadcasting and manually incorporated to the soil with a hoe to a depth of approximately 15 cm. The chemical composition of the biochar feedstock is presented in Table 1.

2.1. Planting and fertilizer application

The hybrid maize variety 'mamaba' was used as the test crop. Three seeds were planted per stand which was later thinned to two after two weeks from planting using a planting distance of 80 cm x 40 cm. Urea, Triple superphosphate and Muriate of Potash were the sources of N, P and K. The P and K were applied once at two weeks after planting while the N was split applied; one third of the N was applied two weeks after planting and the remaining two thirds were applied six weeks after planting. Weeding of the field was done on the second, fifth and eighth week after planting.

2.2. Soil analyses

Soil pH was measured in soil to water ratio of 1:1 [7]. The Walkley Black procedure was used to determine soil organic carbon [8]. Total nitrogen (N) was determined using the Kjedahl digestion and distillation procedure.

The cation exchange capacity (CEC) at pH 7 was determined by the NH_4OAc method. Calcium (Ca) and Magnesium (Mg) were determined by atomic absorption spectrophotometry while potassium (K) and sodium (Na) were determined by flame photometry.

Table 1: Chemical composition of biochar feedstock

Feedstock type	pH H_2O (1:5)	% Org.C	% N	C/N ratio	Ca $Cmol_c Kg^{-1}$	Mg [$Cmol_c Kg^{-1}$]	K $Cmol_c$ [Kg^{-1}]	Na [$Cmol_c Kg^{-1}$]	Avail. P [ppm]	Avail K [ppm]
Cocoa husk	10.4	17.4	1.08	16.11	18.6	17.09	13.5	4.5	263.31	6431.66
Corn cob	10.3	13.6	0.82	16.59	2.67	7.34	6.75	1.35	300.57	2890.21
Rice straw	10.4	4.41	0.83	5.31	2.14	18.69	16.88	3.15	343.62	3477.58

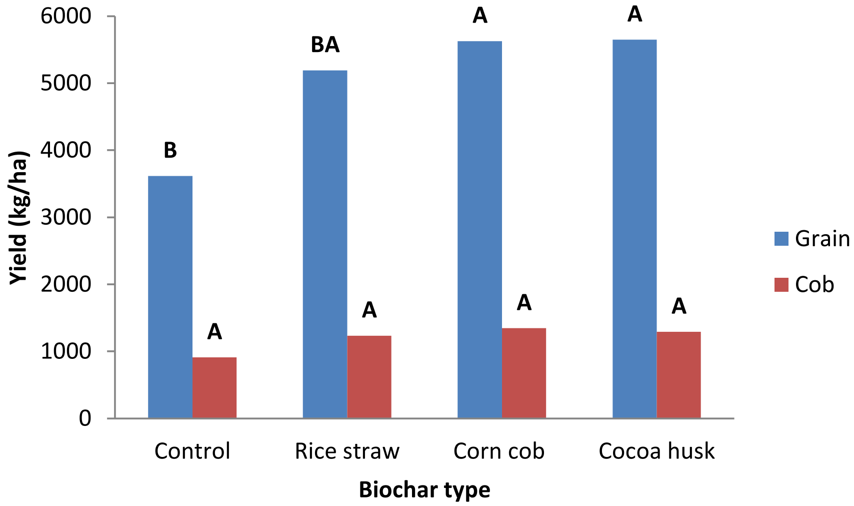

Fig. 1. Effect of biochar feedstock on maize grain and cob yields (Bar charts followed by the same letters are not significantly different at 5 % level of significance).

The effective cation exchange capacity (ECEC) was determined as the sum of exchangeable cations and exchangeable acidity. Exchangeable acidity (H^+ and Al^{3+}) was extracted with 1 M KCl and determined by titration with NaOH before and after addition of NaF [9]. Available phosphorus was determined using Bray No. I extraction solution [10]. Heavy metals were determined in 0.5 M EDTA soil extract on atomic absorption spectrophotometer model VGL Buck scientific

3. Results and discussion

3.1. Initial soil data

The soil was of loam texture (% sand 40.96, % clay 19.04 and % silt 40). The chemical characteristics were: pH H_2O (1:1) 6.10; % Org. C 0.78, % N 0.11, Ca 5.87 Cmol Kg^{-1}, Mg 0.53 Cmol Kg^{-1}, K 0.17 Cmol Kg^{-1}, Na 0.10 Cmol Kg-^{l}, Total Exchangeable bases 6.67 Cmol Kg^{-1}; Exchangeable acidity 0.15, Effective cation Exchange Capacity 6.82 Cmol Kg^{-1}, Base saturation 97.80 Cmol Kg^{-1}; Available Bray 1 Phosphorus 30.62 ppm, Available Bray 1 Potassium 79.02 ppm, Zn 41.60 ppm, Mn 37.20 ppm, Cu 101.60 ppm and Fe 464.20 ppm. The soil chemical composition reflects the generally low inherent soil fertility of tropical soils under continuous cultivation [11]. Agricultural intensification in African smallholder agriculture taking into consideration the combined application of inorganic fertilizer and organic inputs with improved germplasm and local adaptation is desirable.

3.2. Maize grain yield indices as affected by biochar type, biochar application rate and inorganic fertilizer application rate

The influence of biochar feedstock type, biochar application rate on maize grain yield indices is presented in Figure 1 and Figure 2. Maize grain yield ranged from 3615.5 Kg ha^{-1} to 5648.3 Kg ha^{-1} in the Control no amended treatment plot to Cocoa husk treatment plot indicating 56% superiority of the cocoa husk treatment to the control plot. There were no significant differences ($P < 0.8058$) between biochar feedstock types suggesting that biochar irrespective of the feedstock type, can have profound effect on maize grain yield. The results are in agreement to earlier findings where biochar application in agriculture have been found to increase crop yields at least over the first few seasons [12,13]. In sub Saharan Africa, crop residues and many forms of biomass have value such as

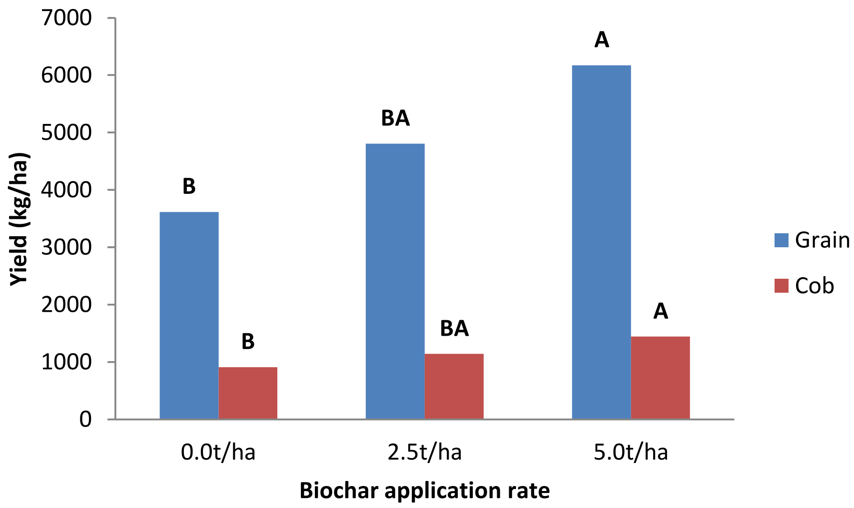

Fig. 2. Effect of biochar application rate on maize grain and cob yields (Bar charts followed by the same letters are not significantly different at 5 % level of significance).

fodder, fuel or direct application to soil as amendment. Thus, there will often be an opportunity cost if biomass is converted to biochar production. In drier areas, biomass availability is less and the opportunity cost of charring biomass is likely to be higher. In other situations, the opportunity costs of using

available biomass for biochar production will be much lower and in cases where the feedstock is an unwanted waste product, its use for biochar production might reduce disposal costs. Considering the low use of inorganic fertilizers in Africa, smallholder farming systems and the potential availability of biomass waste, there is huge potential for pyrolysis of biomass for soil fertility improvement. This huge benefit is not yet exploited. The application rate of biochar showed no significant differences between 2.5 t/ha and 5 t/ha but the control and the 5 t/ha were significantly different. The agronomic efficiency of biochar was higher at 5 t/ha application rate (51 %) compared to 2.5 t/ha (48 %). Lower application rates of biochar can still be applied by smallholder farmers to have almost 1.2 t/ha additional maize grain yield. A predictive understanding of higher application rates of biochar on short term as well as long term benefits on soil and crop productivity is needed to guide soil management decisions of the smallholder farmer in sub-Saharan Africa. Fertilizer application rate of 90-60-60 and 45-30-30 were statistically comparable in maize grain yield and showed superior performance to control no amended treatments. The interactive effect of biochar type and fertilizer rates were not significant. Nitrogen fertilizer use efficiency was higher at 45 kg N ha^{-1} (45 %) compared to 90 Kg N ha^{-1} (33 %). Substantial potential exists in the use of biochar within the Integrated Soil Fertility Management (ISFM) paradigm of the Alliance for a Green Revolution in Africa (AGRA) Soil Health Program towards greater yields and higher input use efficiencies.

4. Conclusions

The superior performance of maize under the biochar treatments provides great opportunities to improve maize grain yield on smallholder farmers' fields. The quantity of application has a pronounced effect on maize grain yields where higher application rates (5 t/ha) showed superior performance to 2.5 t/ha. Where availability of feedstock is limited on smallholder farmers' fields, lower application rates can be used with 45-30-30 NPK fertilizer application to improve maize grain yield. The choice of biochar for charring to improve soil fertility should be guided by the availability of feedstock. In order to upscale the biochar technology, the process of charring (pyrolysis equipment) and the feedstock should be appropriate to the smallholder farmers' circumstances. Maize grain yield can be improved with combined application of inorganic fertilizer (half of the recommended rate of inorganic fertilizer application i.e. 45-30-30) and biochar 2.5 t/ha. New policies on sustainable use of biochar to improve improved food security and energy access are needed. Such policies will provide the integration of biochar into the development processes.

Other comments: The study contributes to African-European Partnership on biochar research such as SIANI biochar expert group; biochar plus, globe urban food plus and African Biochar Platform

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