Response of okra, *Abelmoschus esculentus* (L.) Moench, to biochar derived from cocoa pod husk and NPK fertiliser

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The potentials of biochar derived from cocoa pod husk are currently being explored to improve soil fertility, enhance crop production and prevent the deleterious effect of inorganic fertiliser on the environment. Field investigations were conducted to evaluate the effectiveness of NPK fertiliser fortified with biochar on the growth and yield performance of okra, *Abelmoschus esculentus* (L.) Moench, relative to inorganic fertiliser. Treatments involved NPK only applied at 30 and 60 kg N/ha, NPK at 30 kg N/ha together with biochar at 2.5 t/ha, NPK at 60 kg N/ha together with biochar at 5 t/ha and a control treatment, without fertiliser or biochar application, laid out in a randomised complete block design with three replications. Growth and yield parameters, plant height, number of leaves, fruit yield, nutrient uptake, post-cropping effects on soil properties were determined. Data were analysed using ANOVA. Growth and yields from the treatment with NPK at 60 kg N/ha, together with 5 t/ha biochar, were significantly ($P \leq 0.05$) highest, than other treatments, and partial budget analysis indicated highest marginal rate of returns for this treatment. Soil pH improvement underscored the beneficial effect of NPK fortified with biochar on the nutrition of okra plants, confirming that these materials could be utilised for crop production in the soil of the experimental site.

Keywords: Biochar-fortified NPK, cocoa pod husk, deleterious effect of inorganic fertiliser, growth and fruit yields, okra (*Abelmoschus esculentus*), partial budget analysis

Nutrients are required by plants for their growth either in organic or inorganic form. Inorganic fertilisers impose a threat to the ecosystem, while organic ones are eco-friendly. Due to deleterious effects of inorganic fertilisers, there is the need to explore the use of organic based fertilisers, which are environmentally friendly (Schnug and Silvia 1994). The need to improve soil fertility and enhance crop production has led to a renewed interest in the use of cocoa pod husk in the form of biochar as soil amendments on okra, *Abelmoschus esculentus* (L.) Moench, an economically important vegetable crop grown for its nutritional value. The fruit contains 7.6 g carbohydrate, 2.4 g protein, 31mg vitamin C, 0.32 g vitamin A and 0.7 g vitamin B_2. Okra is grown for its pods and fruits which are harvested in the immature stage and used fresh or powdered for cooking soup or stew. Large quantities of cocoa pod husk, which could be harnessed, are generated as wastes in cocoa farms. The resultant greenhouse gases emitted, through disposal in landfill, mulching, composting and burning, contribute to global warming. However, these organic materials could be used to produce biochar through pyrolysis thereby sequestering carbon, reducing global warming, as well as serving as a soil amendment (Ogunlade et al. 2011). Biochar is the solid residue obtained after pyrolysis, a process of combusting organic materials (biomass) under limited oxygen (Ogunlade et al. 2011). This process alters the molecular configuration of the organic material, making biochar more stable than the material from which it was derived, thus reducing its rate of decomposition (Lehmann et al. 2011), and it has a high residual effect on the soil, thereby making its nutrients available for years (Schmidt et al. 2002). Using different biomasses, it contains high amounts of carbon and biomass synthesised by this process of pyrolysis (Pessenda et al. 2001), (Hammes and

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Schmidt 2009; Lehmann et al. 2011). The biochar has beneficial effects on the soil (Hammes and Schmidt 2009; Lehmann et al. 2011); it increases the soil organic matter (Verheijen et al. 2009) and it improves soil pH, which increases the cation exchange capacity and is beneficial for the growth of plants (Verheijen et al. 2009). Biochar enhances soil by converting agricultural wastes into a powerful soil enhancer that holds carbon and makes soil more fertile as reported by Lehmann (2007a). It is important to understand that biochar is not an actual fertiliser, it is an amendment tool which plays the role of or enhances fertiliser properties, depending on the feedstock and pyrolysis conditions. Biochar is a cheap source of fertiliser compared to others and as well as for the purpose of increasing productivity in agriculture, application of biochar may also result in reduced nutrient leaching, restoration of degraded land and sequestration of carbon from the atmosphere (Lehmann 2007a). Thus, biochar can be more helpful than inorganic fertilisers to plants. Organic fertilisers improve soil fertility by activating soil microbial biomass (Ayuso et al. 1996), and they sustain cropping systems through better nutrient recycling (El-Shakweer et al. 1998). This present work compared the effectiveness of adding biochar organic fertilizer, derived from cocoa pod husk, alone with inorganic fertilizer, in the production of okra at the experimental location.

Materials and methods

Experimental site and climate

The field experiment was conducted at the Cocoa Research Institute of Nigeria, Ibadan, (Latitude 7º 13’ N longitude 3º 52’ E at an elevation of 360 m above sea level. The rainy season generally starts in March, becoming fully established in May, and ends in October. There is a bimodal rainfall pattern, with peaks in June and September. Temperature varies between a maximum of 36ºC and minimum of 21ºC, the low extremes coinciding with the rains and the cold dry harmatan winds, between July and October.

Field experimental design and sampling

A plot of 12 x 7 m was cleared and divided into three blocks each of 12m x 1.5m with 1 m distance between blocks. There were five treatments (fertiliser NPK 20-10-10 and biochar) replicated three times in a randomised complete block design: (1) Control (2) NPK/ha 30 kg N/ha (3) 60 kg N/ha (4) NPK/ha 30 kg N/ha + 2.5 t/ha biochar (5) NPK/ha 60 kg N/ha + 5 t/ha biochar.

Three seeds of okra, (47-4 variety), were planted per hole, later, thinned to one plant per hole, spaced 50 by 30 cm; 50 cm achieving a population of 25 stands per plot. Plants were grown for 16 weeks. Growth parameters: stem girth, leaf number and plant height, were taken on a weekly basis from 2 - 8 weeks, while fresh fruit weight and biomass yield were collected between 8-16 weeks after planting. At each period, plant samples were weighed fresh, chopped and then dried in an oven at 70ºC to constant weight. The dried samples were ground using a Cyclotec 1093 mill and analysed for N, P and K using the Chapman and Parker (1961) dry ash procedure. Uptake was calculated by multiplying respective contents with the dry matter yields.

Laboratory analysis

Composite soil samples (0 – 20 cm depth) were collected, bulked, air dried, crushed, thoroughly mixed, passed through a 2 mm sieve and subjected to routine laboratory analysis as described by Moormann et al. (1975). Soil pH (1:1 soil/water suspension ratio) was measured using a pH meter with glass electrode, particle size analysis was by the hydrometer method Bouyoucos (1962), total N by the micro-Kjeldahl method Jackson (1958), organic C by the wet dichromic acid oxidation (Walkley and Black 1934) and organic matter was estimated by multiplying organic C with a factor of 1.729. Available P was extracted using the method of Bray and Kurtz (1945). K and N were determined by flame photometry and Ca, Mg and extractable micro-nutrients (Mn, Fe, Cu and Zn) by atomic absorption spectrophotometry.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using SAS (1992) and means were separated using least significant difference (LSD 0.05%) and Duncan Multiple Range Test. Partial budget was carried out for economic analysis.

Biochar cocoa pod husk production

Cocoa pod husk biochar production was done through pyrolysis thermal decomposition of cocoa pod husk without oxygen at the University of Ibadan, Department of Mechanical Engineering. The pyrolyser used in producing the biochar has three compartments: an insulated metal box with a cover, an inner cylinder with a separate cover and a lower lid where the charred product comes out. The dried cocoa pod husks were fed into the inner cylinder and tightly sealed. A prepared burning charcoal was then fed into the space around the cylinder after which the reactor was covered. The timer was set at this stage to determine how long the biomass would take to char in the reactor. The charring process took about 4 hours from start to completion. The materials remaining in the cylinder after the content were smoldered and charred are referred to as biochar. The biochar was released into the lower lid, drawn out from the bottom after which water was sprinkled on the hot char to prevent complete combustion. The biochar was air dried for 2 weeks before use.

Results and discussion

Pre-cropping soil characteristics and chemical properties of cocoa pod husks biochar

The soil characteristics of the experimental site are shown in Table 1 (Ogunlade et al. 2011). Based on established nutrient critical levels (Sobulo and Osiname 1981), it was evident that the location soils were low in organic C, exchangeable acidity, deficient in total N and exchangeable K, but high in available P. The soil is of medium acidity (Table 1), which made soil amendment necessary. Reports revealed the benefits and influence of biochar on plant growth and development. Biochar is low in organic C, N, P and K, but high in Ca (Table 2). It influences plant productivity directly due to its nutrient content, and indirectly, due to its ability to retain nutrients, increase soil pH, cation exchange capacity (CEC), soil water retention and alteration of soil microbial populations and functions, as explained by Ogunlade et al. (2011). Biochar significantly ($P \leq 0.05$) improved soil fertility, it influenced soil structure, texture, particle size distribution, porosity and density (Artiola et al. 2012).

Table 1: Characteristics of the soil used for the studies

Properties	Values
pH H_2O (1:1)	6.1
Organic C (g/kg)	3.1
Soil organic matter (g/kg)	5.33
Total N (g kg^{-1})	0.6
Av. P Bray 1 (mg/kg)	16.2
Exchangeable cations (c mol/kg)	
K	0.06
Ca	0.35
Mg	1.89
Na	0.61
Exchangeable acidity	0.05
Effective cation exchange capacity	2.96
Base saturation %	90.3
Extractible micronutrients (mg/kg)	
Cu	1.67
Zn	3.45
Mn	39.47
Fe	65.35
Particle size (g/kg)	
Sand	615
Silt	212
Clay	173
Textural class	**Loamy sand**

Table 2: Chemical properties of cocoa pod husks biochar

Parameter	Values
pH	7.9
Organic C (%)	0.70
Nitrogen (%)	0.46
Phosphorus (mg/kg)	0.5
Potassium (c mol/kg)	0.66
Calcium (g/kg)	2.89
Sodium (c mol/kg)	0.64

Effect of biochar and inorganic fertiliser on plant growth development of okra

Plant height

The treatment of NPK at 60 kg N/ha + 5 t/ha biochar produced the highest plant height during the growth period (Figure 1). At 2 weeks the height of NPK 60 kg N/ha + biochar (5 t/ha) was 8.32cm, this was followed by NPK 60 kg N/ha with 7.37cm. The shortest height at 2 weeks was 6.86 cm recorded with 30 kg N/ha NPK. There was a significant increase in the heights of the plants from 2 - 8 weeks. This indicated that each treatment released nutrients that enhance the plant height of okra (Akoroda 1982). The okra plants responded favourably to the biochar fortified NPK treatments, this may suggest that the organic residue may have improved soil fertility, influenced soil structure, texture, particle size distribution, porosity and micronutrients. This observation agrees with that of Lehmann (2007a) who reported that the residual effect of organic fertiliser increases results in enhanced height of crops.

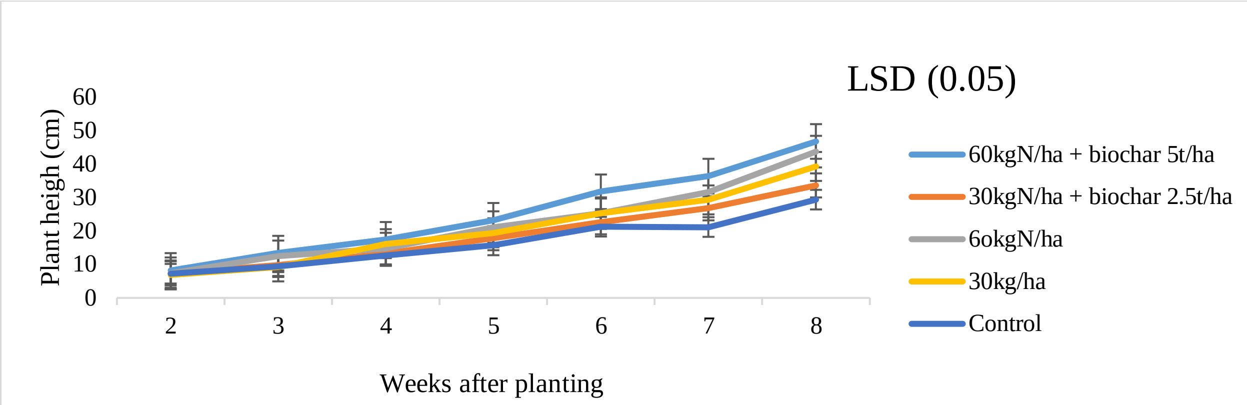

Figure 1: Effect of biochar and inorganic fertiliser on plant height of okra

Number of leaves

The treatment of NPK at 60 kg N/ha + 5 t/ha biochar significantly (p<0.001) out yielded the other treatments in the number of leaves during the growth period (Figure 2). There was a significant increase in the number of leaves of the plants from 2 - 8 weeks, with the control giving the least. This indicated that each treatment released nutrients that enhanced the number of leaves of okra (Akoroda 1982). As reported earlier, the addition of biochar derived from cocoa pod husk (organic source), suggested that the organic residue may have improved soil fertility and crop productivity.

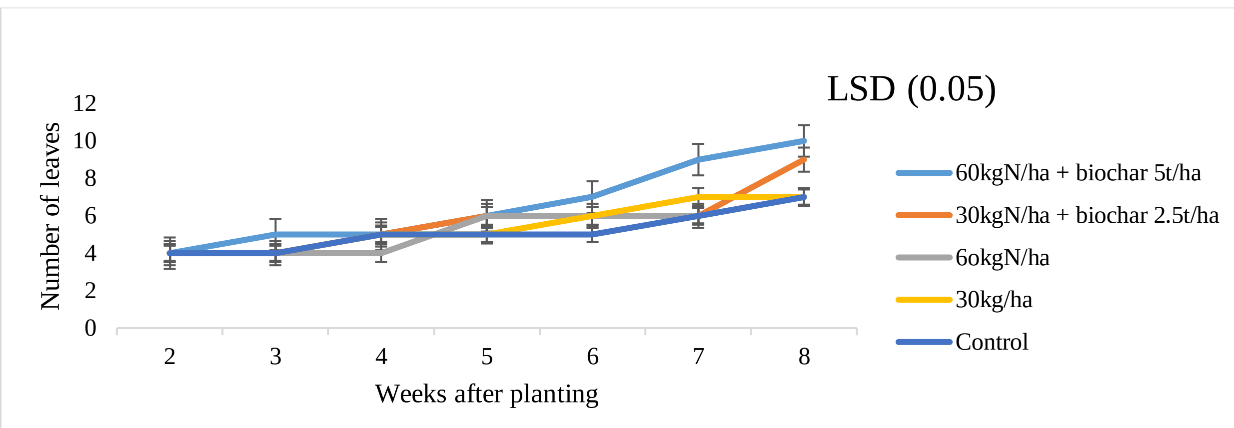

Figure 2: Effect of biochar and inorganic fertiliser on number of leaves of okra

Nutrient accumulation

Previous research revealed that the use of organic fertiliser alone has been ineffective in the maintenance of soil fertility in Nigeria (Ogunlade et al. 2011). This could be attributed to low CEC of most of the soil, which implies low nutrient holding potentials. In this study 60 kg N/ha + 5 t/ha biochar consistently significantly ($P \leq 0.05$) improved NPK accumulation at 4 weeks after planting (27.47, 4.47, 5.13 kg/ha) for N, P and K respectively (Table 3) better than other treatments, except 30kg N/ha + 2.5t/ha biochar. This might be due to reduced nutrient leaching when mineral fertiliser is applied in combination with biochar (Lehmann et al. 2007a). The effect of biochar on soil is estimated to run from hundreds to thousands of years. Application of biochar is a strategy to prolong carbon sequestration. Studies have demonstrated that biochar application can significantly improve crop productivity (Cheng 2011), improve soil conditions and increase the efficiency of fertilisers (Bishwoyog et al. 2015). The findings of this study agree with Uzoma et al. 2011, who reported biochar application rates of 15 to 20 t/ha increased maize grain yield by 150 and 98% respectively, under sandy soil conditions.

Table 3: NPK uptake by okra as influenced by fertiliser sources at 4 weeks after planting

Fertiliser sources	Rate	Uptake (kg/ha)		
		N	P	K
Control	0	9.3b	1.87b	2.73b
NPK	30 kgN/ha	10.37b	2.13b	3.33ab
NPK	60 kgN/ha	16.17b	2.97ab	4.83ab
NPK + biochar	30 kg N/ha + biochar 2.5 t/ ha	18.23ab	2.90ab	4.6ab
NPK +biochar	60 kgN/ha + biochar 5 t/ha	27.47a	4.47a	5.13a

Means with the same letter(s) in each column are not significantly different at $P \leq 0.05$

Okra fruit yield

After 16 weeks of growth the fresh fruit yield of okra obtained from treatment 60 kg N/ha + biochar 5 t/ha was significantly ($P \leq 0.05$) higher than other treatments (Table 4). The resultant effect of biochar addition with mineral fertiliser is noticeable in the improved fruit yield.

Table 4: Okra fruit yield as affected by fertiliser sources at 16 weeks of growth

Fertiliser sources	Rate	Okra fresh fruit yield (kg/ha)
Control	0	9,077c
NPK	30 kgN/ha	12,911bc
NPK	60 kgN/ha	14,423b
NPK + biochar	30 kgN/ha + biochar 2.5 t/ha	9,599c
NPK + biochar	60 kgN/ha + biochar 5t /ha	25,707a

Means with the same letter(s) in each column are not significantly different at $P \leq 0.05$

Variation in post-cropping nutrient content with fertiliser sources

Generally there were appreciable increases in nutrient content post-cropping with NPK fortified with biochar than treatments with NPK alone. Soil post-cropping nitrogen for the control and NPK fertiliser alone were lower while fertilisers in combination with biochar resulted in higher soil total nitrogen values compared with the initial soil nitrogen value (Table 5). The treatment of 60 kg N/ha +5 t/ha biochar resulted in the highest soil pH increase. Soil pH improvement underscores the beneficial effect of biochar-fortified NPK on the nutrition of okra plants.

Table 5: Variation in post-cropping nutrient content with fertiliser sources

Fertiliser sources	Rate	Mg Pre	Mg post	Ca Pre	Ca post	K Pre	K post	P pre	P Post	N Pre	N post	pH pre	pH post
Control	0	1.89	0.81	0.35	4.95	0.06	0.43	16.2	14.3	0.6	0.3	6.08	6.07
NPK	30 kgN/ha	1.89	3.22	0.35	5.27	0.06	2.24	16.2	17.4	0.6	0.5	6.08	6.08
NPK	60 kgN/ha	1.89	2.03	0.35	5.08	0.06	1.09	16.2	20.2	0.6	0.4	6.08	6.09
NPK+ biochar	30 kgN/ha + biochar 2.5 t/ha	1.89	2.87	0.35	6.49	0.06	2.85	16.2	21.1	0.6	0.7	6.08	6.72
NPK+ biochar	60 kgN/ha + biochar 5t /ha	1.89	2.98	0.35	8.12	0.06	2.85	16.2	21.4	0.6	0.7	6.08	6.67

Partial budget analysis of production of 1 ha of okra using biochar derived from cocoa pod husk and NPK fertiliser

Partial budget analysis indicated highest marginal rate of returns for NPK at 60 kg N/ha + 5 t/ha biochar (133.3) treatment, then NPK at 30 kg N/ha N + 2.5 t/ha biochar (39.2) treatment, relative to NPK at 60 kg/ha NPK with no biochar addition (11.6) and 30 kg/ha NPK (12.7) (Table 6). This indicated the economic advantage of the addition of biochar in this experimental location.

Table 6: Partial budget analysis of production of 1 ha of okra using biochar derived from cocoa pod husk and NPK fertilizer

		1. Control	2. NPK 30 kgN/ha	3. NPK 60 kgN/ha	4. NPK 30 kgN/ha + biochar 2.5 t/ha	5. NPK 60 kgN/ha + biochar 5t/ha
Gross farm gate benefits						
Average field yield (t/ha)		9.08	12.91	14.42	9.60	25.71
Gross farm gate benefits (N/ha)		2,270,000	3,227,500	3,605,500	2,400,000	6,427,500
Variable input costs (N/ha)						
NPK fertiliser		0	30,000	60,000	30,000	60,000
Biochar		0	0	0	0	0
Okra seeds		119,048	119,048	119,048	119,048	119,048
Land clearing		125,000	125,000	125,000	125,000	125,000
Field layout		50,000	50,000	50,000	50,000	50,000
Planting		40,000	40,000	40,000	40,000	40,000
Weeding		225,000	225,000	225,000	225,000	225,000
Fertiliser application		0	40,000	40,000	40,000	40,000
Harvesting		80,000	80,000	80,000	80,000	80,000
Salesmanship		48,000	48,000	48,000	48,000	48,000
Transportation		64,000	64,000	64,000	64,000	64,000
Total variable input costs (N/ha)		751,048	821,048	851,048	821,048	851,048
Net benefit (N/ha)		1,518,952	2,406,452	2,754,452	1,578,952	5,576,452
Change in net benefits between two consecutive treatments (N/ha)			887,500	348,000	-1,175,500	3,997,500
Change in total variable input costs between two consecutive treatments (N/ha)			70,000	30,000	-30,000	30,000
Marginal rate of return			12.7	11.6	39.2	133.3

N450 = US$1
Okra fresh fruit was valued at N250/kg,
Change in benefits between treatments 2 and 1 is 2,406,452.38 – 1,518,952.38 = 887,500
Change in net benefits between treatments 3 and 2 is 2,754,452.38 – 2,406,452.38 = 348,000
Change in benefits between treatments 4 and 3 is 1,578,952.38 – 2,754,452.38 = -1,175,500
Change in net benefits between treatments 5 and 4 is 5,576,452.38 – 1,578,952.38 = 3,997,500.
Change in total variable input costs between treatments 2 and 1= 821,047.62 – 751,047.62= 70,000
Change in total variable input costs between treatments 3 and 2=851,047.62 – 821,047.62= 30,000
Change in total variable input costs between treatments 4 and 3=821,047.62 – 851,047.62= -30,000
Change in total variable input costs between treatments 5 and 4 = 851,047.62 – 821,047.62 = 30,000

Conclusion and recommendation

The results of this investigation indicated high potentials of NPK fortified with biochar. The growth and yield of the test crop fruits obtained where NPK at 60 kg N/ha in combination with 5 t/ha biochar was significantly ($P \leq 0.05$) higher than what obtained in other treatments. This showed the superior effectiveness of the addition of biochar to the mineral fertiliser. The economic analysis for this treatment showed a higher marginal rate of return than the other treatments. Hence, from the performance of the biochar fortified NPK relative to NPK only, this is recommended for okra production in the experimental location.

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