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Full Length Research Paper

Improving soil productivity through biochar amendments to soils

Yeboah E.[1]*, Ofori P.[1], Quansah G. W.[1], Dugan E.[1], Sohi S. P.[2]

[1]Soil Research Institute, Academy Post Office, Kwadaso, Kumasi, Ghana.
[2]Rothamsted Research, Harpenden, Herts, UK.

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Biochar based soil management has not being fully exploited in the tropics. In a greenhouse study, two soil types (sandy loam and silt loam soils) and 6 treatments namely: 3t ha-l Biochar, 120 kg N ha-1, 120 kg N ha-1 + 3t ha-1 biochar, 4t C ha-1 cattle manure, 4t C ha-1 cattle manure + 3t ha-1 biochar and control un-amended soil were evaluated for soil productivity. The treatments were replicated 3 times. Maize variety “mamaba” was the test crop. Shoot dry weight ranged from 41 to 45 g pot -l at the sandy loam soil at Ayuom and 28 to 35 g pot-l at the silt loam soil at Kwadaso. Shoot dry weight was significantly ($P < 0.001$) higher at the sandy loam soil compared to the silt loam soil. Soil pH declined in both soils. Biochar resulted in N recovery of 4 and 5% in maize shoot and root respectively on the sandy loam soil but caused less N recovery at the silt loam soil. The results show that N recovery can be improved by biochar application to sandy loam soil but not silt loam soil suggesting soil textural effect in the effectiveness of biochar application for soil productivity.

Key words: Biochar, nitrogen use efficiency, soil texture.

INTRODUCTION

The decline in soil productivity as a result of continuous cultivation in sub-Saharan Africa has been identified as a major cause of food insecurity and poverty. A large part of the Ghanaian population makes their living from these marginal soils. Crop yields continue to decline on smallholder farmers fields and there is a huge gap between potential crop yields and actual crop yields. To achieve food sufficiency, there is the urgent need to address the soil infertility problem of tropical soils. Furthermore, improving crop productivity on these marginal soils is vital for socio-economic reasons. A number of intervenetions have been considered in the past but with limited success. The application of inorganic fertilizers though provides an option to overcome soil infertility, the removal of subsidies on fertilizers has rendered this option inaccessible by smallholder farmers. Additionally, the transportation of the fertilizers to farmer’s fields is a major problem as farmers fields are generally far from the homestead. The use of organic inputs to improve soil nutrients also had limited success. In addition to the bulkiness of the organic inputs, the amount of organics available for incorporation to the soil is limited. Again, they have alternative uses such as for fuel, for livestock feeding, building materials etc. The Integrated Soil Fertility Management (ISFM) which combines the application of inorganic fertilizers and organic fertilizers for crop production has been proposed (Vanlauwe et al., 2004). However, the quality of organic inputs in terms of N, lignin and polyphenols has been suggested to influence the decomposition of organic inputs (Palm et al., 2001). High quality materials are expected to decompose rapidly to release plant nutrients to synchronize with crop demands. Low quality materials on the other hand are expected to first immobilize soil nutrients and then subsequently release it gradually for crop demand. The decomposition of organic resources releases gases such as CO_2, methane, N_2O which are greenhouse gases. Global concerns for climate change thus necessitate the search for agricultural management practices that can be used to achieve food security and at the same time contribute to adaptation and mitigation of climate change. Biochar, a product obtained from pyrolysis of woody materials may provide such a management practice (Glasser et al., 2004). Applied as a soil enhancer, the

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***Corresponding author:** Email: eyeboah5@hotmail.com.

Table 1. Selected soil properties of the soils used.

Soil parameter	Ayuom	Kwadaso
pH (1:1 H_20)	5.64	4.22
Org C (%)	1.56	0.97
% N	0.23	0.20
Available P (mg/g)	5.58	7.11
Ca	5.34	1.60
Mg	1.60	0.53
Na	0.26	0.07
K	1.74	0.13
Available K	133.91	110.48
Exchangeable acidity	0.10	0.60
% Base saturation	98.89	79.52
Parent material	Granite	Phyllite
Classification (WRB)	Chromic Lixisol	Ferric Acrisol
% Sand	60.01	30.64
% Silt	36.61	53.29
% Clay	3.38	16.07
Textural class	Sandy loam	Silt loam

highly organic carbon-intensive biochar improves the structure, water retention capacity, fertility, and carbon sequestration of degraded soils. The enhanced nutrient retention capacity of the soil not only reduces the total fertilizer requirements**,** but also the environmental damage associated with fertilizers, including nitrous oxide emissions, phosphorus runoff into surface waters, and nitrogen leaching into groundwater. Further, and most importantly, biochar is relatively inert, with most of it remaining in the soil for orders of magnitudes longer than any other organic amendments. This means that biochar offers one of the few tools available for removing carbon from the atmosphere, making it one of the only carbon-negative renewable energy options at our disposal today (Lehmann, 2007). The use of biochar could allow the total soil organic carbon (SOC) sequestered in soils to be several magnitudes larger than is naturally possible. Again, it is relatively simple to verify for national carbon accounting and is more resistant to climate than the conventional SOC (Lehmann et al., 2006). Carbon trading that include agricultural soil sequestration will enable farmers to trade their sequestered biochar soil applications and facilitate the expansion of a range of new technologies that improve farm productivity, energy security, with potential for large positive environmental outcomes.

In Ghana, biochar-based soil management strategies are new and have not been evaluated in the context of Ghanaian agriculture. The study was to test the hypothesis that soil productivity is improved through biochar amendments but the extent of benefits is dependent on soil texture. The objectives of the study were:

- To enhance maize crop yield potential through biochar.
- Amendments with and without organic inputs on two contrasting but dominant soils in Ghana.
- To evaluate the effect of soil texture on biochar amendments for improving crop productivity.

MATERIALS AND METHODS

Soil sampling

Two dominant but contrasting soils in the semi-deciduous forest zone of Ghana were used for the study. Table 1 shows some selected physical and chemical properties of the soils. The top 0 - 15 cm was sampled from each site and all plant debris was removed. The samples were air- dried and sieved through a 2 mm mesh size. Pots were filled with 5 kg soil from each site.

Biochar

The biochar used in the study was obtained from EMBRAPA, Brazil. It was produced from savannah wood by local farmers under “hot tail” oven. The chemical composition of the biochar was: Org C, 38.8%; Total P_20_5, 1 gkg^{-l}; K_2O, 3.3 gkg^{-l}; CaO, 5.7 gkg^{-l}; MgO 1.1 gkg^{-l}, and C/N 68.2. The biochar was applied in powdered form and uniformly mixed with the soil before sowing the maize.

Nutrient uptakes

The nitrogen, phosphorus and potassium uptakes by the maize shoot and root were determined at the end of the 6 weeks growing season. Nutrient uptakes were calculated by multiplying the shoot and root yields with the N, P and K concentrations of the specific components. Maize shoot and stover yields in pots (g/pot) were converted to area basis (t/ha) by assuming planting distance of 0.75 * 0.25 m resulting in maize total plant population of 53333/ha.

Nitrogen use efficiency (NUE %)

The nitrogen use efficiency was determined as shown below:

NUE = (Maize N_F- Maize N_{0F} / N_{app}) *100 % …………………… (2)

Where Maize N_F is maize N uptake in the fertilized treatment, N_{0F} is the maize uptake in the control treatment and N_{app} is the amount of N applied in kg/ha.

Greenhouse study

The experimental design was completely randomized design and each treatment was replicated three times. The treatments were:

1. Control un-amended soil.
2. 3 t ha^{-1} biochar.
3. 120 kg N ha^{-1}.
4. 3 t ha^{-1} biochar + 120 kg N ha^{-1}.
5. 4t C ha^{-1} cattle manure.
6. 4t C ha^{-1} cattle manure + 3 t ha^{-1} biochar.

Phosphorus and potassium were applied as basal to all treatments at the rate of 30 and 60 kg K ha^{-1} respectively. Phosphorus was applied in the form of triple super phosphate while potassium was in the form of muriate of potash. The nitrogen source was urea. The amendments were thoroughly mixed with the soil. The soils were kept at filled capacity through out the period of the study. An N–efficient maize variety *Mamaba* was used as the test crop. The maize was planted at 3-seeds per pot and thinned to 2 one week after planting. Plant height was measured weekly for 6 weeks. At the end of the sixth week, the maize was harvested. The above-ground biomass was separated from the below ground biomass. All roots were removed from the soil and washed with distilled water. The fresh weights of both the above and below ground biomass were recorded and the samples were oven-dried at 60°C until constant dried weight was obtained. The above and below ground biomass was ground and analysed for N, P and K. Soil samples from each treatment were collected at the end of the sixth week for soil chemical analysis.

Soil analysis

The soil was analysed for texture using the method of Bouyoucos, (1962). Soil pH was determined in distilled water using a Glass electrode- Calomel electrode (McLean, 1982) MV Pracitronic pH meter. Soil pH was measured at a soil: solution ratio of 1: 2. Organic carbon was determined using the wet combustion method of Walkley and Black (1934).

Total N was determined using the method of Bremner (1965). Available phosphorus was determined using the method of Bray and Kurtz (1945). Exchangeable bases were extracted with 1.0 M NH_4OAc (pH 7.0) and Na and K in the extract determined by flame photometry (Chapman and Pratt, 1961) and Mg, Ca by EDTA titration method. Thomas' (1982) was used for the determination of exchangeable acidity. Soil ECEC was determined as sum of the exchangeable cations and acidic cations. Base saturation was determined as:

% BS = (Sum of exchangeable cations / CEC) *100 ………………………………Eq 1

Statistical analysis

The data were analysed using GenStat® (2007) and the ANOVA procedure (Payne et al., 2006). Each response variable (e.g. plant height, shoot yield, soil nutrients etc) was analysed with site as main effect and treatments as fixed effect. Site*treatment interaction was considered as well. The separation of means was tested using least significance difference with a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Effect of soil amendments on weekly plant height at Ayuom and Kwadaso

Table 2 shows the weekly plant heights at Ayuom and Kwadaso as influenced by soil amendments. At week 1, the influence of the soil amendments on plant height was marginally significant ($P < 0.05$). The difference in plant height between Ayuom and Kwadaso was significant ($P < 0.001$) with the Ayuom site showing significantly higher plant height than the Kwadaso site. The interaction between the site and the treatment (Site*Treatment) was also significant ($P < 0.03$). At Kwadaso, plant height ranged from 10.30 cm in the 3 t ha^{-l} Biochar treatment to 20.45 cm in the 4 t C ha^{-l} manure treatment. The manure treatment was significantly higher in plant height than the rest of the treatments suggesting rapid mineralization of the manure for plant growth. There was not statistical difference among the treatments at Ayuom.

At week 2, at Kwadaso, the 4t C ha^{-l} manure and the 4t C ha^{-l} manure + 3t ha^{-l} biochar treatments maintained their superiority over the rest of the treatments. Plant height ranged from 40.25 cm in the control treatment to 52.55 cm in the 4t C ha^{-l} manure treatment. The addition of biochar did not result in additional increase in plant height as the 4t C ha^{-l} manure treatment was significantly higher than the 4t C ha^{-l} Cattle manure + 3 t ha^{-l} Biochar treatment. At Ayuom at week 2, the 120 kg N ha^{-l} treatment showed significantly higher plant height than the rest of the treatments possibly due to readily available soil nitrogen for crop uptake. The difference in plant height among treatments was not significantly different from week 3 to week 6 at both sites. The increase in plant height between week 1 and 2 was rapid at both sites and least between week 5 and 6.

In general, plant growth was significantly higher ($P < 0.001$) at Ayuom than Kwadaso for each week suggesting a relatively better soil (Table 3) at Ayuom than Kwadaso for maize growth. An inherent soil property is therefore an important consideration for soil amelioration. The low growth at Kwadaso could be due to the acidic nature of this soil. It has been reported, in acid soils, efficiency of applied fertilizer is relatively poor, mainly because plant roots are unable to grow and function to their fullest extent in utilizing the soils available nutrients. At low pH, Al and Mn can become more available and toxic to plant growth. Also at low pH values, Ca, P and Mg are less available to the plant (Oades, 1988). Root growth greatly affects soil aggregate formation and breakdown through a suite of mechanisms related to root penetration, changes in soil water content, soil enmeshment, nutrient uptake, release of exudates, associated microbial activity and in situ production (Degens, 1997). We further

Table 2. Effect of soil amendments on weekly plant height at Kwadaso and Ayuom.

	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
	Site		Site		site		site		site		site	
Treatment	Kwadaso	Ayuom	Kwadaso	Ayuom	Kwadaso	Ayuom	Kwadaso	Ayuom	Kwadaso	Ayuom	Kwadaso	Ayuom
Control	10.52	22.62	40.25	57.15	58.93	79.78	78.20	99.60	97.40	123.10	107.50	136.80
3t ha^{-1} Biochar	10.30	22.52	40.53	54.23	58.58	78.92	78.60	91.10	103.5	121.40	117.10	135.30
120 kg N ha^{-1}	14.97	24.35	41.25	58.70	59.93	81.25	75.40	96.30	94.50	118.00	122.60	136.40
3t ha^{-1} Biochar + 120 kg N ha^{-1}	12.10	21.95	34.35	55.75	46.10	82.18	56.60	100.40	76.30	122.50	106.80	139.20
4 t ha^{-1} Manure	20.45	21.93	52.55	57.37	68.46	80.03	88.90	97.10	111.10	119.90	121.80	134.10
4 t ha^{-1} Manure + 3t ha^{-1} Biochar	15.25	22.17	46.92	53.50	65.15	78.10	87.50	97.30	112.00	119.80	126.00	133.90
LSD (0.05)	3.44		4.42		6.78		10.24		13.33		8.20	
Site LS (0.05)	1.99		2.55		3.92		5.91		7.70		4.74	
Site x Treatment Lsd (0.05)	4.87		6.25		9.59		14.48		18.85		11.60	
CV	8		7.5		8.2		9.8		10.2		5.4	

Table 3. Shoot and root dry weight from the Ayuom and Kwadaso experimental sites at 6 weeks after planting.

	Site			
	Ayuom		Kwadaso	
	Biomass yield (g/pot)			
Treatment	**Shoot**	**Root**	**Shoot**	**Root**
Control	40.69	2.46	31.53	1.63
3t ha^{-1} Biochar	41.59	3.30	30.17	1.06
120 kg N ha^{-1}	41.25	2.06	29.94	1.52
120 kg N ha^{-1} + 3t ha^{-1}Biochar	44.98	3.03	28.10	0.77
4 t C ha^{-1} Cattle manure	42.25	3.50	33.57	2.01
4 t C ha^{-1} Cattle manure + 3t ha^{-1} Biochar	42.34	3.24	35.32	2.12
Lsd (0.05)	3.53	0.93	3.53	0.93
CV	8.0	35.2	8.0	35.2

hypothesize that soil pH directly affects soil aggregate formation and ultimately crop production.

Effect of soil amendments on shoot and root dry weight

Maize biomass yields were limited by deficient levels of available P, Ca and Mg. Shoot dry weight ranged from 41 to 45 g/pot at Ayuom and from 28 to 35 g/pot at Kwadaso. Shoot dry weight was significantly ($P < 0.001$) higher at the Ayuom site compared to the Kwadaso site. The amended soils at Ayuom did not show significant differences in shoot dry weight. The least shoot dry weight however, was observed in the control treatment and the highest from the 3 t ha^{-1} biochar + 120 kg N ha^{-1} treatment possibly due to improved nutrient retention from the biochar. Contrary to the Ayuom site, the least shoot dry weight was observed in the 3 t ha^{-1} biochar + 120 kg N ha^{-1} amended soil at Kwadaso. The lower pH (Table 4) following inorganic N application may explain this observation. The relatively higher exchangeable acidity from the Kwadaso site may be responsible for the lower crop production from this site. It has been reported that soil acidity is the main constraints for crop production in various parts of the world (Virupax, 2006). In acid soils, low nutrient use efficiency is associated with P immobilization, Al/H ion toxicity as well as low microbial activity. The low nutrient recovery efficiencies not only increase cost of crop production but also create environmental pollution. Therefore improving NUE efficiency in acid soils is desirable to improve crop yields, reduced crop production and maintenance of environmental quality. Results of the study support the view that biochar is relatively inert as in all cases, the performance of treatments with biochar was comparable with the treatments itself without the biochar.

Root yield trend was similar to shoot yield. Differences in root yield were observed between sites where Ayuom site significantly resulted in higher root yields than Kwadaso. Within sites, there were not differences in root yield across treatments. At the Ayuom site, with the exception of 4t C ha^{-l} cattle manure + 3t ha^{-l} biochar treatment, biochar tended to enhance root biomass production. At the Kwadaso site however, biochar amended soils generally produced less root biomass except in 4t Cha^{-l} cattle manure + 3t ha^{-l} biochar treatment where bio-char addition resulted in 6% more root biomass produc-tion.

Soil chemical properties at the end of the first cropping

Table 4a and 4b shows some selected soil chemical properties of the soils used for the study after 6 weeks. In general, after 6 weeks of plant growth, soil pH de-clined in both soils. Oguntunde et al., (2004), reported similar observation in the forest savanna transition zone in Ghana. The decline was more rapid at the Kwadaso site compared to Ayuom site. Among the treatments, 120 kg N ha^{-1} and 120 kg N ha^{-1} + 3t ha^{-l} Biochar showed the least pH. This observation was consistent at both Kwadaso and Ayuom sites. The decline in pH was of the order: 120 kg N ha^{-1} = 120 kg N ha^{-1} + 3t ha^{-l} biochar < control = control + 3t ha^{-l} Biochar < 4t C ha^{-l} cattle manure = 4t C ha^{-l} cattle manure + 3t ha^{-l} biochar. The low pH observed is due to acidification resulting from dissociation of urea to produce H^{+} ions. The results show that 120 kg N ha^{-1} is too high an application rate for the soils studied. At low pH, P fixation is enhanced resulting in low plant growth. The high cost of inorganic fertilizers and the low biomass yield from high inorganic N application indicates that such application rate is not economical. Besides smallholder farmers are not in a position to apply at such rate. The application of lime may be neces-sary to increase soil pH under such management sce-nario. Resource poor farmers in developing countries however, cannot apply adequate amount of lime. Under this condition, the use of limited amount of lime along with nutrient efficient and elemental toxicity resistant plant species or genotypes within species is a compli-mentary solution for improving crop productivity on acid soils.

Soil org C at the Ayuom site was generally higher and significantly different ($P < 0.01$) from Kwadaso site. It ranged from 1.2 to 1.34% at Ayuom and 0.90 to 1.01% at Kwadaso. At both sites, there were no significant treatment effects on soil organic carbon. The total N was significantly higher ($P < 0.002$) at the silty loam soil at Kwadaso relative to the sandy loam site at Ayuom. There was no statistical difference within the treatments at both sites. The total N ranged from 0.16% in the control unamended treatment to 0.20 in the 3t ha^{-l} biochar + 4t C ha^{-l} Cattle manure treatment at Ayuom and from 0.18 to 0.25% in the control and biochar treatments respectively at the Kwadaso site.

At Ayuom, 3t ha^{-l} Biochar and 3t ha^{-l} Biochar + 120 kg N ha^{-l} resulted in significantly higher ($P < 0.004$) exchangeable Ca contents than the rest of the treatments while 3t ha^{-l} Biochar + 120 kg N ha^{-l} was the only treatment that showed significantly higher exchangeable Ca contents on the silty loam soil at Kwadaso. The Ayuom site generally showed significantly higher ($P < 0.001$) soil exchangeable Ca contents (3.29 to 5.07) than the Kwadaso site (1.25 to 4.94). The exchangeable Na did not show statistical significance between sites ($P < 0.495$) and ranged from 0.07 to 0.11. Base saturation was generally higher at the Ayuom site and ranged from 93.99 to 98.66. The difference between sites was significant ($P < 0.001$). The Base saturation at the Kwadaso site was ranged from 73.81 in the 120 kgN ha^{-l} amended treatment to 90.06 in the 3t ha^{-l} Biochar + 120 kg N ha^{-l} treatment.

Plant uptake

The N, P and K uptakes were generally low reflecting the

Table 4. Influence of soil amendments on soil chemical characteristics after 6 weeks of plantin.g
a. Ayuom

Treatment	Soil pH	Orgc. C	%N	Na	K	ECEC	Ex Acidity	TEB	BS
Control	5.49	1.23	0.16	0.09	0.16	4.99	0.12	4.87	97.20
Control + 3t ha^{-l} Biochar	5.49	1.33	0.18	0.10	0.18	7.41	0.10	7.31	98.63
120 kg N ha^{-1}	5.22	1.26	0.19	0.09	0.16	6.83	0.18	6.66	97.57
120 kg N ha^{-1} + 3t ha^{-l} Biochar	5.23	1.34	0.18	0.11	0.20	7.76	0.25	7.51	96.78
4 t ha^{-l} Manure	5.53	1.23	0.20	0.08	0.16	6.83	0.09	6.74	98.63
4 t ha^{-l} Manure + 3t ha Biochar	5.54	1.26	0.18	0.09	0.13	6.09	0.25	5.84	92.99
LSD	0.11	0.09	0.04	0.02	0.05	1.81	0.14	0.92	6.39
CV	1.9	6.5	16.5	18.5	30.9	27.9	29.6	31.6	6.0

b. Kwadaso

Treatment	Soil pH	Orgc. C	%N	Na	K	ECEC	Ex Acidity	TEB	BS
Control	3.95	0.99	0.18	0.09	0.08	2.79	0.65	2.14	76.61
Control + Biochar	3.90	0.98	0.25	0.08	0.13	4.49	0.63	3.86	80.68
120 kg N ha^{-1}	3.73	0.97	0.23	0.09	0.09	2.88	0.75	2.13	73.81
120 kg N ha^{-1}+ Biochar	3.63	0.90	0.22	0.07	0.11	7.90	0.78	7.12	90.06
4 t ha^{-l} Manure	3.92	1.01	0.20	0.10	0.13	4.27	0.57	3.70	84.51
4 t ha^{-l} Manure + 3t ha^{-l} Biochar	4.06	0.09	0.24	0.11	0.12	3.03	0.48	2.54	84.03
LSD	0.11	0.09	0.04	0.02	0.05	1.81	0.14	0.92	6.39
CV	1.9	6.5	16.5	18.5	30.9	27.9	29.6	31.6	6.0

inherently low nutrient contents of the soils used for the study (Table 5). In N, P and K uptakes were higher at the sandy loam site at Ayuom relatively to the silt loam site at Kwadaso. The differences in N, P and K uptakes were signifycantly higher at Ayuom than at Kwadaso. In each, soil, the order of nutrient uptake was of the order N>K>P.

Nitrogen use efficiency (NUE %)

The efficiency of the applied urea was poor in both soils (Figure 1). This could be due to the short duration of the experiment (42 days). Peak N demand for maize is expected during grain formation but in this study, the plants were harvested before this period. As expected, the efficiency was relatively poor in the acidic soil (Kwadaso site) compared to the moderately acidic soil at Ayuom. The NUE % was negative at both sites; -1.4% at Ayuom and compared to -4.10% at Kwadaso. Application of biochar however resulted in positive NUE % (4.33%) at the sandy loam site at Ayuom but resulted in low N recovery on the silty loam site at Kwadaso (Figure 1a). The positive NUE% on the sandy loam site may be due to improved nutrient retention, reduced leaching, volatilization and denitrification following the biochar addition on the sandy loam soil at Ayuom. The NUE % at the silty loam site was more than three times as low as that of the sandy loam site. This low NUE % could be due to high denitrification under heavy textured soils. This observation is consistent with the findings of Maria et al*.*, 2007 who found clayey soils to have higher denitrification rates than silty soils. Biochar addition to inorganic N showed higher root N recovery (~5%) on the sandy loam site at Ayuom but resulted in less nutrient recovery on the silty loam site at Kwadaso. The root N reco-

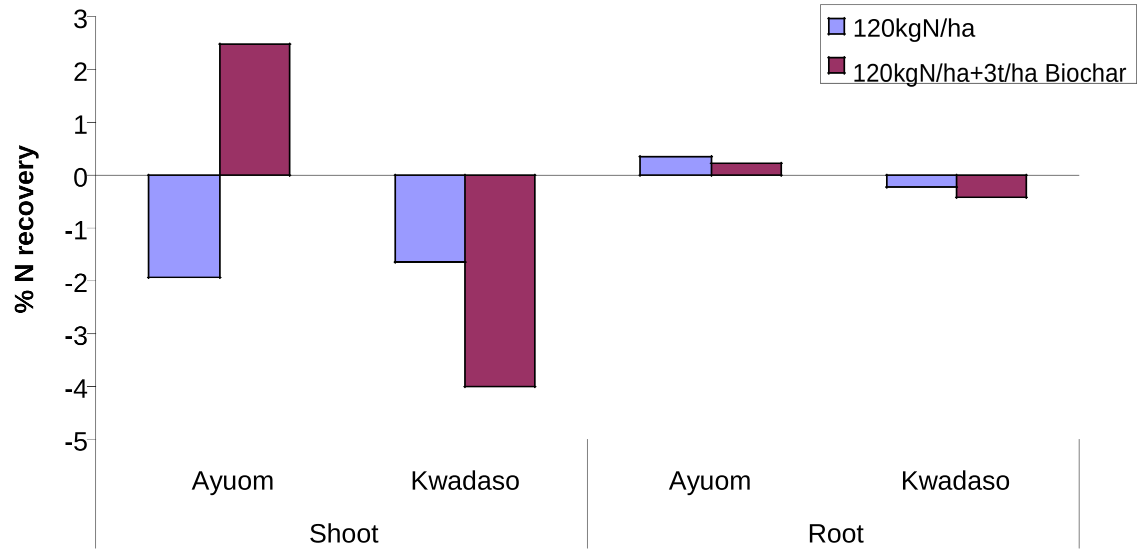

Figure 1. Shoot and root nitrogen recovery (NUE %) as influenced by soil amendments on a sandy loam (Ayuom) and a silt loam soil (Kwadaso) in Ghana.

Table 5. Soil nutrient uptakes at Ayuom and Kwadaso at 6 weeks after planting.

	N uptake (kg/ha)				P uptake (kg/ha)				K uptake (kg/ha)			
	Shoot		Root		Shoot		Root		Shoot		Root	
Treatment	**Ayuom**	**Kwadaso**	**Ayuom**	**Kwadaso**	**Ayuom**	**Kwadaso**	**Ayuom**	**Kwadaso**	**Ayuom**	**Kwadaso**	**Ayuom**	**Kwadaso**
Control	66.85	46.15	2.34	1.54	4.77	3.03	0.18	0.10	17.02	9.55	0.55	0.35
3t ha^{-l} Biochar	62.87	43.23	3.05	1.09	4.73	3.27	0.27	0.08	12.81	11.73	0.70	0.23
120 kg N ha^{-l}	65.19	41.27	2.2	1.28	4.25	3.04	0.15	0.11	15.58	14.34	0.41	0.32
3t ha^{-l} Biochar + 120kg N ha^{-l}	71.69	38.76	2.79	0.69	4.46	2.62	0.21	0.05	12.38	15.36	0.53	0.17
4 t ha^{-l} Manure	66.70	46.79	3.45	2.15	4.21	3.40	0.28	0.14	11.88	20.84	0.75	0.36
4 t ha^{-l} Manure + 3t ha^{-l} Biochar	65.45	42.84	2.95	2.10	4.43	3.51	0.25	0.14	12.68	19.03	0.81	0.39
LSD (0.05)	6.93		0.95		0.49		0.06		5.09		0.18	
CV	10.6		37.1		10.8		31.9		29.60		32.6	

very was higher than the shoot N recovery on the sandy loam site at Ayuom (Figures 1a and Figure 1b). The observation highlights the importance of below ground biomass to total soil nutrients.

Conclusion

The result of the study shows the benefits of combined application of cattle manure and biochar for better maize crop production. Application of 120 kg N ha^{-1} urea resulted in soil acidification on both soils which also affected maize biomass production. The effect of urea application on soil acidification was pronounced in the Ferric-Plinthic Acrisol than the Humi-Plinthic Lixisol. The application of biochar to organic fertilizers such as farm yard manure rather than inorganic fertilizers appears to benefit crop production in the short term. The results show that biochar enhanced crop growth better in a sandy loam soil compared to the silty loam soil suggesting soil textural effect in the effectiveness of biochar application for crop growth. Inorganic N application in the form of urea resulted in negative NUE % at both sites. Addition of biochar to inorganic N however, resulted in positive NUE % at the sandy loam site at Ayuom but exhibited a negative NUE% at the silt loam site at Kwadaso. The authors recommend further research into the use of biochar as a soil amendment for sustainably improving soil productivity in the tropics.

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