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Agronomic potential of maize stover biochar under cowpea–maize sequential cropping in Northern Uganda

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Abstract
Biochar is a nature-based solution for sustainable agriculture but its potential adoption in some parts of sub-Saharan Africa is still minimal. In this study, we evaluated the agronomic potential of maize stover biochar in cowpea-maize sequential cropping in Uganda under field conditions. The treatments included; the common farmer practice of no inorganic fertilizer and no biochar (CTR), inorganic fertilizer (F), 10 t ha^{-1} biochar (B10), 40 t ha^{-1} biochar (B40), 10 t ha^{-1} biochar + inorganic Fertilizer (FB10), and 40 t ha^{-1} biochar + inorganic Fertilizer (FB40), arranged in a randomized complete block design (RCBD) with three replications. The results showed that cowpea seed yield was not significantly affected by biochar and fertilizer application but the haulm yield was significantly improved only in FB40 treatment. Maize grain and stover yield was significantly improved only in the FB40 treatment but biochar showed a high potential to also improve yield even without inorganic fertilizer. The potential for biochar to improve maize yield either in the presence or absence of fertilizers could be attributed to the residual soil fertility from cowpeas. In both seasons, biochar significantly improved soil pH, EC, SOC, total N, available P, exchangeable K and Ca, irrespective of fertilizer application. However, exchangeable Mg did not significantly vary among the treatments. This study further revealed that in cowpea-maize rotation, optimum yield could also be possible with sole biochar application. Therefore, instead of burning the maize stovers after harvest, farmers should convert the residues into biochar and return it to the soil so as to achieve sustainable food systems.

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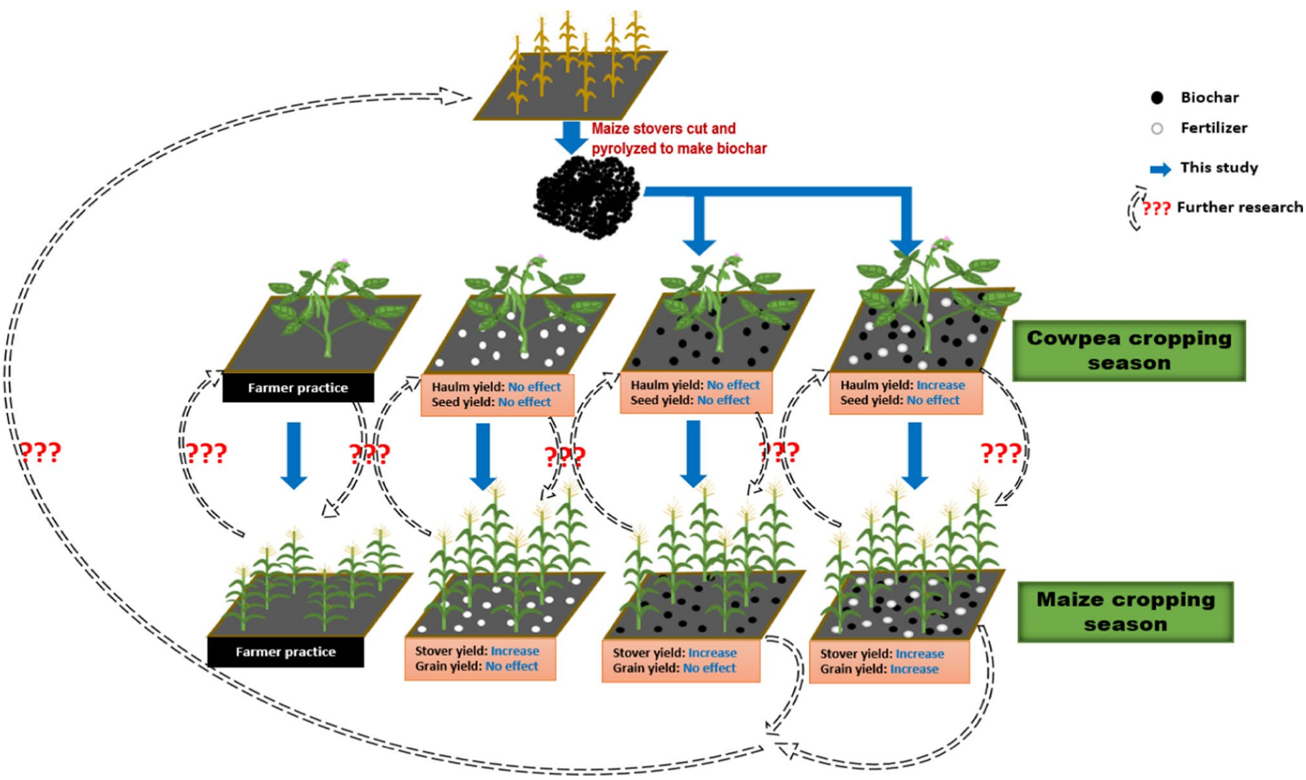
Graphical Abstract



Keywords Biochar · Crop rotation · Biological Nitrogen fixation · Low fertilized soils · Residual soil fertility · Sustainable food production

Abbreviations

ANOVA	Analysis of variance
BNF	Biological Nitrogen Fixation
RCBD	Randomized Complete Block Design
SOC	Soil Organic Carbon
DAP	Diammonium Phosphate
EC	Electrical Conductivity

1 Introduction

The Agriculture sector is an important source of rural livelihoods for many communities in sub-Saharan Africa but it is still under-performing when compared to other regions of the world [1, 2]. The challenges facing the agricultural systems in sub-Saharan Africa include the reliance on rain-fed agriculture, low levels of mechanization, low use of farm inputs such as fertilizers, low yielding crop varieties and limited public funding [3]. These have increased the susceptibility to climate change shocks which negatively impact on food security, exposing the sub-Saharan population to hunger and malnutrition. Recently, the adoption of affordable and innovative climate smart agricultural practices involves the increased use of biochar as a soil fertility management strategy [4].

Biochar is a nature-based solution for sustainable agriculture which is obtained from pyrolysis of biomass under oxygen limited conditions with the purpose of improving crop productivity, environmental management and soil carbon sequestration [5, 6]. The effects of biochar may vary with the feedstock, pyrolysis conditions, application rate, environmental conditions and soil type. Biochar addition to tropical soils with lower initial soil pH prior to biochar application has been reported to increase yields by 25% compared to temperate soils where the responses are negligible [7]. This implies that the tropical regions including sub-Saharan Africa need to adopt biochar in their cropping systems so as to benefit from its untapped potential in soil. Increments in maize yield following biochar application especially in combination with chemical fertilizer in acidic soils (pH 4.0–5.0) have been reported on smallholder farms in Kenya and Tanzania [8–10]. This increase in yield results in proportionately high maize stover biomass which is left unused or burnt in the field or utilized as fuel for cooking which implies that this biomass is indeed available for biochar production [11]. The conversion of these residues to biochar can result in a significant increase in soil fertility which promotes crop growth and yield of the proceeding crops [7, 12, 13].

Legume-cereal rotations are commonly adopted in sub-Saharan Africa to maintain soil fertility so as to compensate for the limited access to inorganic fertilizers. However, a limited number of studies have focused on addressing the effects of biochar in legume-cereal production systems in this region. Moreover, a significant variation in nitrogen (N) supplying ability exists among legume species such as groundnuts and cowpeas which potentially contribute large quantities of N to other associated crops when grown in soils of low N status [14]. The 24–240 kg N ha^{-1} fixed by cowpea could benefit the associated crops especially the cereals [15]. Crop rotation of maize and cowpea is an effective strategy for sustainable soil fertility management which results in improved nutrient use efficiency and higher maize yield [16]. A recent study in Nigeria that evaluated the effects of growing legumes and maize in the same year in rotation revealed that cowpea-maize rotation resulted in generally higher dry matter yield of maize than in the soybean-maize and maize-maize rotation system due to the increased soil total N, available P, exchangeable K, Mg, and effective cation exchange capacity [17]. Another study by Jalal et al. [18] also reported higher maize yield in plots where cowpea was grown as the preceding crop compared to fallow plots, and this was more pronounced in the biochar amended soils. Therefore the substantial contribution of N_2 fixation from cowpeas to farmers in Africa should not be ignored [19] especially with biochar application.

Positive effects of biochar on the growth and yield of cowpeas have been documented [20–22]. This is mainly attributed to the increase in Biological Nitrogen Fixation (BNF), soil aeration, water holding capacity, and higher plant nutrient uptake [21, 23, 24]. However, since the effects of biochar could change with the soil types, environmental conditions, application rates and the type of biochar [25], there is a need to further assess the effects of biochar under legume-cereal dominated cropping systems in Sub-Saharan Africa especially in soils with limited synthetic N fertilizer input. Therefore, the objective of this study was to evaluate the agronomic potential of maize stover biochar with or without fertilizer application on; (i) the growth and yield of cowpea and maize crops in particular, when grown in a sequence (ii) Soil chemical properties at the end of each cropping season. It was hypothesized that the biochar would increase the growth and yield of both cowpea and maize and also improve on the soil chemical properties.

2 Materials and methods

2.1 Experimental site

The field experiment was carried out during the 2022 seasons A and B at the University farm of Uganda Martyrs University, Ngetta Campus, Lira district, Uganda (2.3130° N, 32.9288° E). The land at this farm was at least three years under fallow prior to the experiment. The soil at the experimental site had a sandy clay loam texture. Table 1 shows the chemical

Table 1 Selected characteristics of the soil and biochar used in this experiment

Properties	Soil	Properties	Biochar
pH (H_2O) $_{1:2.5\ (w/v)}$	5.40	pH (H_2O) $_{1:2.5\ (w/v)}$	9.2
EC (dS m^{-1})	0.07	EC (dS m^{-1})	3.6
Organic C (%)	1.40	Organic C (%)	15.7
Total N (%)	0.13	Total N (%)	0.97
Available P (mg kg^{-1})	6.50	Available P (%)	3.1
Exchangeable K (cmol(+) kg^{-1})	0.36	Exchangeable K (%)	4.6
Exchangeable Ca (cmol(+) kg^{-1})	4.40	Exchangeable Ca (%)	1.6
Exchangeable Mg (cmol(+) kg^{-1})	2.11	Exchangeable Mg (%)	0.1

characteristics of the soil before the start of the experiment. Lira district generally experiences a bimodal rainfall pattern with one peak during April–May and the other in August–October but these weather patterns have changed over the years due to climate change. The first season which begins in March and ends in May is characterized by short rains while the long rains occur between July and November. The average annual rainfall in this area varies between 1000–1400 mm with average minimum and maximum temperatures of 22.5 °C and 25.5 °C, respectively. The total monthly rainfall and daily temperatures at the experimental site in 2022 were described by Wacal et al. [26].

2.2 Establishment of the field experiment

The experiment was conducted using biochar from maize stovers (Fig. 1), selected because of its high abundance on farms after maize harvest in this area. In order to promote adoption by smallholder farmers, the biochar was made using a small-scale traditional open pit method and its chemical characteristics are shown in Table 1. The details of the biochar preparation, and its other properties were described by Wacal et al. [26]. The agronomic performance of the biochar was evaluated by growing cowpeas in the first season, followed by a residual trial of maize grown in the same treatment plots. These plots were arranged in a randomized complete block design (RCBD) with three replications. The six treatments comprised the farmer practice of no inorganic fertilizer and no biochar (CTR), inorganic fertilizer (F), 10 t ha^{-1} biochar (B10), 40 t ha^{-1} biochar (B40), 10 t ha^{-1} biochar + inorganic Fertilizer (FB10), and 40 t ha^{-1} biochar + inorganic Fertilizer (FB40). The biochar and fertilizer were uniformly spread on a 2 × 2 m plot and then manually mixed to 15 cm depth using a hand hoe, with a 1 m buffer distance between the plots.

Cowpea (SECOW 2W) was planted during the first rains (March to June, 2022A) in 2022 at a spacing of 50 × 20 cm. SECOW 2W is a spreading variety, that matures in 80 – 90 days and has a yield potential of 2.5 t ha^{-1}. The recommended inorganic fertilizer rate of 22.5 kg N ha^{-1} and 57.5 kg P_2O_5 ha^{-1}, an equivalent to 50 kg of Diammonium Phosphate (DAP) per acre for beans production [27] was applied to the respective plots. There was no potassium fertilizer applied to the treatment plots. To promote nodulation, the cowpea seeds were first inoculated with MAK-BIO-FIXER, a N_2 Fixing bacteria Inoculum formulated by Makerere University, Kampala, Uganda. Three inoculated seeds were planted per hill and two weeks later, they were thinned to one plant per hill. To manage pests, the cowpea plants were sprayed using dimethoate (40% EC at a rate of 1.0 L/ha) at flower initiation, flowering and podding. All plots were kept weed free by hand hoeing before flowering. At harvest, all the cowpea biomass (above ground) were removed and the plots were left undisturbed.

In the second season (2022B), maize was planted on the same undisturbed plots during the second rains (July to December, 2022B) of the same year. Two seeds of maize variety "LONGE 10H" were sown in the plots at a spacing of 75 × 60 cm resulting in 12 hills per plot (24 plants per plot). However, at this plant spacing in these plots, it was inevitable to sample some maize plants from the border rows during yield determination and we acknowledge this as a limitation in this study. Regarding the maize variety, LONGE 10H is a hybrid maize variety, maturing in about 120 days, with a yield potential of 7.5 t ha^{-1}. No additional biochar was applied during this season. However, a micro dosing of DAP was applied at a recommended rate of 50 kg $acre^{-1}$ (22.5 kg N ha^{-1} and 57.5 kg P_2O_5 ha^{-1}) before planting, and urea applied at ten leaf stage at a rate of 50 kg $acre^{-1}$ using micro dosing (57.5 kg N ha^{-1} as top dressing) only in the fertilizer plots.

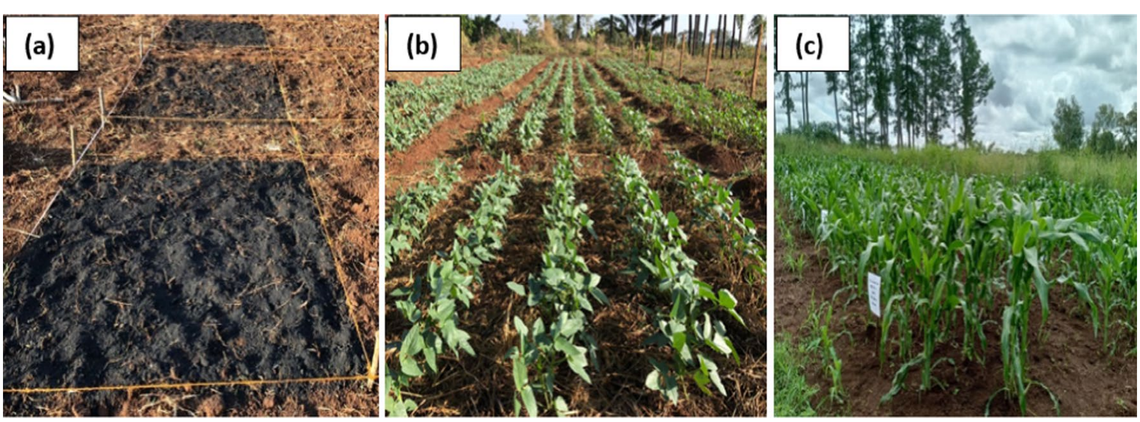


Fig. 1 Establishment of the field experiment. Biochar spread evenly on the plots before mixing in soil (**a**); cowpea at vegetative stage (**b**); maize at vegetative stage (**c**)

Weeding was done at two and eight weeks after planting. To manage fall armyworms, maize plants were sprayed with Rocket (Profenofos 40% + Cypermethrin 4% Emulsifiable Concentrate (20–50 ml per 20 L of water).

2.3 Growth and yield analysis

At the end of the 2022A season, the number of branches per cowpea plant were recorded from 10 selected plants in each plot. All the pods were plucked off the plants, and then packed in paper bags for further natural drying under the sun. The biomass remaining in each plot were cut, weighed and recorded as haulm yield on a fresh weight basis. The dried pods were later threshed and the 100-grain weight and seed yield were determined.

Harvesting of maize was done when all the stalks and cobs had dried (turned brown). 10 plants were randomly selected per plot for determination of growth and yield parameters. The plant height (cm), length of cobs (cm), 1000-grain weight (g), stover yield (t ha^{-1}), and grain yield (t ha^{-1}) were considered for maize. The grain yield was determined after natural drying (sun drying) while the stover biomass yield was determined after weighing the dry maize stovers at harvest.

2.4 Soil sampling and analysis

Soil samples were collected at the end of each crop harvest using an auger to a depth of 15 cm. The soil samples were air-dried, ground, and passed through a 2 mm sieve before analysis following standard methods described by Okalebo et al. [28]. Briefly, soil pH and EC were measured in a 1:2.5 (w/v) soil: water ratio using a pH meter (Model pH 700 Meter, Eutech Instruments, Singapore) and EC meter (Model Meter HQ40d, Hach Co., UK) respectively. The soil organic carbon (SOC) was determined by the potassium dichromate wet acid oxidation method while Total N was determined by the micro-Kjeldahl digestion method. The exchangeable K, Ca, and Mg were extracted in 1 N ammonium acetate (pH 7.1) solution. Exchangeable K was analyzed by using a flame photometer (Model; Jenway PFP7, Cole-Parmer Co., USA) while Ca and Mg were analyzed using an atomic absorption spectrophotometer (Model BK-AA320N, Biobase. Co. Ltd, China). Available P was determined using the Bray 1 method, and P in filtrates was measured by the ammonium molybdate–ascorbic acid method using a spectrophotometer (Model UV-6300 PC, VWR International Co., USA).

2.5 Statistical analysis

Data were analyzed using IBM SPSS statistics (version 20.0). One-way analysis of variance (ANOVA) was used to examine the effects of biochar on crop growth, yield and in soil chemical properties at the end of each season, followed by Tukey's HSD test at $p < 0.05$ for means comparison.

3 Results

3.1 Cowpea growth and yield

The number of branches, 100-seed weight and seed yield were not significantly influenced by biochar and fertilizer combinations as compared to the control (Table 2). The haulm yield of cowpeas was significantly increased by 48.8% in the FB40 treatment compared to the control. However, there were no significant differences in haulm yield among control, F, B10, B40 and FB10 treatments.

3.2 Maize growth and yield

There were significant differences in plant height and stover yield among treatments but not for cob length and 1000-grain weight (Table 3). The plant height was significantly highest in the FB10 and FB40 treatments with no significant differences observed between these two treatments. Biochar application with or without fertilizers significantly increased the stover yield compared to the control but this was most significant in the FB40 treatment. The results further indicated

Table 2 Biochar effect on growth and yield parameters of cowpeas

Treatment	Number of branches per plant	100-seed weight (g)	Haulm yield (t ha^{-1})	Seed yield (t ha^{-1})
CTR	5.8a	10.3a	21.3b	2.3a
F	5.0a	10.1a	21.3b	2.7a
B10	4.8a	10.0a	24.6ab	2.8a
B40	5.3a	9.5a	28.3ab	2.5a
FB10	5.0a	9.9a	27.1ab	2.4a
FB40	5.7a	10.3a	31.7a	2.8a
p-values	*ns*	*ns*	*< 0.01*	*ns*

Means followed by the same letters are not significantly different according to Tukey's HSD test at p < 0.05. *ns* non- significant at p < 0.05

Table 3 Biochar effect on growth and yield parameters of maize

Treatment	Plant height (cm)	Cob length (cm)	1000-grain weight (g)	Stover yield (t ha^{-1})
CTR	232.2b	17.4a	388.9a	7.9c
F	253.6ab	18.7a	398.1a	15.7ab
B10	252.3ab	17.5a	404.5a	11.7bc
B40	254.3ab	17.2a	402.3a	14.5ab
FB10	267.2a	18.3a	419.0a	16.8ab
FB40	259.3a	19.4a	418.9a	19.0a
p-values	*< 0.05*	*ns*	*ns*	*< 0.01*

Means followed by the same letters are not significantly different according to Tukey's HSD test at p < 0.05. *ns* non- significant at p < 0.05

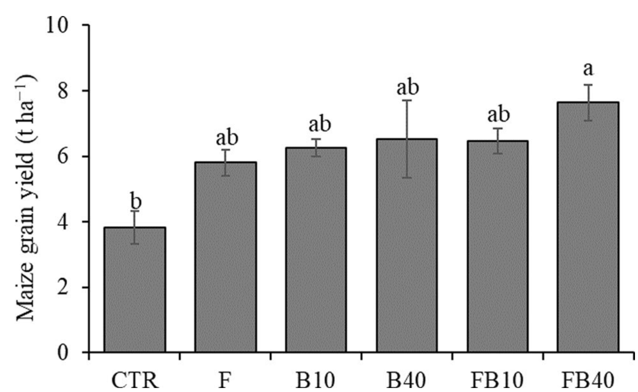


Fig. 2 Maize grain yield in the different treatments. Means followed by the same letters are not significantly different according to Tukey's HSD test at p < 0.05

that maize grain yield was significantly increased in the FB40 treatment compared to the control (Fig. 2). However, grain yield in the F, B10, B40 and FB10 were not significantly different from that in the FB40 treatment.

3.3 Soil chemical properties

The results showed the potential of biochar to improve some soil chemical properties in the presence or absence of fertilizer (Table 4). Soil pH significantly varied among treatments at the end of each cropping season. The pH was highest in the B40 and FB40 treatments, and lowest in the F treatment. After cowpea cropping, the soil EC was significantly higher in the FB40 treatment compared to the control but the soil EC did not vary significantly among the Control, F, B10, B40 and FB10 treatments. There was no significant difference in soil EC among the treatments after maize harvest. Biochar

Table 4 Soil chemical properties at the end of each season

Cropping	Treatment	pH (H_2O)	EC (dS m^{-1})	SOC (%)	Total N (%)	Avail.P (mg kg^{-1})	Cmol(+) kg^{-1}		
							Exch.K	Exch.Ca	Exch.Mg
Cowpea	CTR	5.7ab	0.26b	1.5b	0.15b	13.8bc	0.66c	7.35b	2.09a
	F	5.3b	0.26b	1.9ab	0.19ab	15.0bc	0.77bc	3.65c	1.72a
	B10	5.5b	0.26b	1.6b	0.14b	12.1c	0.69bc	5.70bc	1.56a
	B40	6.1a	0.27b	1.7ab	0.16b	21.9b	1.33a	7.30b	2.31a
	FB10	5.4b	0.25b	1.6b	0.17b	12.8c	0.75bc	6.60bc	1.54a
	FB40	6.2a	0.34a	2.2a	0.24a	34.1a	1.04ab	14.85a	3.11a
	p-values	*< 0.001*	*< 0.001*	*< 0.01*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*ns*
Maize	CTR	5.9ab	0.19a	1.7bc	0.17bc	11.5c	0.58 cd	8.20b	1.84a
	F	5.3b	0.12a	1.9abc	0.21ab	27.6abc	0.51d	5.20b	1.62a
	B10	6.0ab	0.13a	2.0ab	0.23a	29.3ab	0.83bc	6.85b	2.00a
	B40	6.4a	0.15a	1.6c	0.17c	31.1a	1.29a	6.60b	1.68a
	FB10	5.9ab	0.12a	1.6c	0.17bc	12.7bc	0.84b	7.20b	2.17a
	FB40	6.2a	0.17a	2.1a	0.24a	31.2a	1.13a	16.40a	2.57a
	p-values	*< 0.01*	*ns*	*< 0.001*	*< 0.001*	*< 0.01*	*< 0.001*	*< 0.01*	*ns*

Means followed by the same letters are not significantly different according to Tukey's HSD test at $p < 0.05$. *ns* non-significant at $p < 0.05$. SOC-Soil organic carbon. Avail. P represents available phosphorus; Exch. K represents exchangeable potassium; Exch.Ca represents exchangeable calcium; Exch. Mg represents exchangeable magnesium

significantly increased the soil organic carbon and total N but this effect was more pronounced in the FB40 treatment during the cowpea cropping season. Similarly, available P was significantly highest in the FB40 treatment and lowest in the B10 and FB10 treatments in the cowpea cropping. Interestingly, during the maize cropping season, available P was significantly highest in both the B40 and FB40 treatments compared to the control. In addition, exchangeable K was significantly increased in the B40 and FB40 treatments compared to the control in both seasons. Exchangeable Ca was also significantly highest in the FB40 treatment while there were less pronounced effects in the other treatments during the two seasons. Biochar application with or without fertilizer did not significantly affect the soil exchangeable Mg in both seasons.

4 Discussion

Biochar has been reported to improve crop productivity but its effects are still unclear since it can either improve, reduce or have no effect on crop growth, explained by the different soil types, biochar type, application rates and climatic conditions [25]. This has resulted in controversy as to whether biochar may actually improve crop productivity when applied solely or in combination with fertilizers especially in N limited acidic soils. The current study tested this hypothesis using cowpea-maize cropping based on the strong effects of Biological Nitrogen Fixation (BNF) which have been reported to increase N input especially with biochar addition in highly weathered acidic soils [29]. Biochar application significantly increased the biomass of cowpeas only in the presence of fertilizer and biochar at 40 t ha^{-1} which corroborates with other studies [20, 22] that reported biomass increase mainly when biochar is applied with fertilizer. This may be attributed to the increase in nutrient availability especially N, P and K made available directly or indirectly by biochar and taken up by the plant [21, 30].

Under the conditions of this study, farmers producing cowpeas for use as vegetables will likely benefit more from the biochar than those whose main aim is for seed production as evidenced by the non-significant effects of biochar and fertilizer application on seed yield (Table 2). For legumes to play an important role in maintaining soil fertility, they should have the tendency of releasing greater amounts of N from N_2 fixation in their plant parts but this may be possible only at lower grain yield [31]. Furthermore, the amount of residual N that remains after the legume cropping period depends on crop maturity and condition of legume crops among others [32]. Therefore, the non-significant effect of maize stover biochar on the seed yield of cowpea imply that most of the nutrients could be allocated to the other plant parts and it may be possible that an almost equal amount of N and other nutrients may be left at the end of the season to support maize growth. However, more research is needed to understand this phenomenon through studying the crop nutrient use efficiencies in cowpea-maize cropping systems following biochar application.

A number of studies conducted in sub-Saharan Africa have reported maize yield increment when biochar is applied with fertilizer [8–10, 33]. The authors attributed it to the positive interactions between biochar and fertilizer in soil that result in improvement in soil physical, chemical and biological properties. In some cases, biochar application may result in non-significant effect of biochar on maize yields possibly due to the low rate of biochar applied or the relatively high inherent fertility of the non-amended soil [34]. The present study revealed the potential of biochar to improve maize growth, irrespective of fertilizer application (Fig. 2) due to the increase in soil fertility resulting from the residual nutrients that remains in the soil after harvesting the cowpea. The residual nutrients from biochar into the soil, as well as the indirect effects from BNF, and cowpea residue decomposition after harvest explains the sustained maize yield in the absence of fertilizer. The variation in N supplying ability of a particular legume on a companion crop depends on the N_2 fixing ability, residue N content, N mineralization rate and the amount of N lost from the cropping system [14, 15]. Furthermore, the rapid decomposition of root nodules increase the total C and soil EC due to release of nutrients especially inorganic N [35] which could be made available during the maize cropping season. In addition, crop residue decomposition enhances moderate increase in soil pH due to the liming effect of basic cations released by root nodules and ligand exchange between the terminal OH^- at the soil surface and organic anions derived from the decomposing residues [36]. This increase in soil pH could increase nutrient availability in acidic soils resulting in higher crop yields. Furthermore, the maize stover biochar used in this study (Table 1) has a strongly alkaline pH, high ash content and nutrient composition [26] which also explains the significant increase in soil pH, SOC, total N, available P and exchangeable K and Ca that was observed in biochar treatments (Table 4).

Legumes in crop rotations stimulate soil microbial activity, soil organic carbon and enhance soil health [37], thereby increasing maize productivity. It is possible that there were available forms of N which interacted with biochar to result in higher crop growth and yield in biochar amended soils with no fertilizer. Similarly, Senaratne et al. [14] reported that greater N supplying ability was due to the higher N_2 fixation and greater residual N content in groundnuts in addition to the higher rate of residue mineralization. Therefore, the significant increase in maize grain yield in the FB40 treatment could be explained by the increase in nutrient supply resulting from the combination of fertilizer, BNF, residue decomposition and biochar. However, similar to fertilizers, legume residues have a high potential to elevate nitrous oxide (N_2O) emissions due to their low C/N ratios which increase nitrification, denitrification and rapid mineralization in soil [38]. Moreover, significant N_2O emissions have been reported during the first two weeks from the start of decomposition of legume crop residues such as root nodules [35]. Interestingly, biochar could mitigate these pre- and post-harvest N_2O emissions hence ensuring a sustainable cropping system [35, 39]. Our results revealed that it could be possible for smallholder farmers adopting cowpea-maize crop rotations to either use fertilizer or lower amounts of maize stover biochar to improve maize yield although the benefits are better for the latter option since it acts as a soil conditioner by improving soil physico-chemical properties as well as acting as an N_2O mitigation strategy from decomposing crop residues. Although fertilizer application with biochar may result in higher maize yields, the economic benefits of combining these two inputs need to be further assessed in cowpea-maize cropping systems. Glaser et al. [40] reported the potential of organic fertilizers as immediate substitutes to mineral fertilizers in temperate soils to improve maize yields. However, BNF from cowpeas could also be used as an alternative substitute to mineral N fertilizers in the presence of biochar to improve maize yield to similar levels equivalent to biochar-inorganic fertilizer combinations. More studies are needed to compare the feasibility and potential benefits of using BNF as an alternative to inorganic fertilizers to improve cereal yields under biochar application in various soil types. Furthermore, since the beneficial effects of biochar application in soil may decline with time [41], and also the fact that the application rates used in this study may be difficult for smallholder farmers to achieve, seasonal application could be feasible if farmers pyrolyzed the maize stovers after every maize harvest and return them to their fields as maize stover biochar. This study was conducted in a short-term and the results are promising although they may not be conclusive in the long run crop rotations. Nevertheless, they give us an insight to design long-term field trials to further assess the feasibility of cowpea-maize rotations under biochar application in the various agro ecological zones of Uganda.

5 Conclusion

This study revealed the agronomic potential of maize stover biochar to improve the growth and yield of cowpea and maize irrespective of inorganic fertilizer application in Northern Uganda. The increase was partly attributed to the improvement in soil chemical properties from biochar as well as the benefits of BNF, decomposition of cowpea residues such as the roots and the root nodules which benefited the maize crop. Therefore, applying biochar at a rate of 40 t ha^{-1} in the first season of cowpea followed by maize could have significant impacts on the maize productivity even without any fertilizer application during the maize cropping season. Future research on biochar adoption in Uganda should put much emphasis on its application with or without fertilizer to understand plant-soil-microbe interactions in intercrops and crop rotations as the most sustainable way of producing high yields at low production costs while quantifying the greenhouse gas emissions from these cropping systems which are characterized by low N input.

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Author contributions D.B, C.W, E.N, M.T conceived the idea; D.B and C.W performed the experiment; D.B and C.W collected, analyzed and interpreted the data; D.B, C.W and F.M.M wrote the manuscript and shared the first draft. All authors read and approved the final manuscript.

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Data availability The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The cowpea and maize plants/plant parts collected in this study complied with the national guidelines.

Competing interests The authors declare no competing interests.

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