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Residual effects of corncob biochar on tropical degraded soil in central Uganda

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Abstract

Background: The residual effects of biochar are yet to receive adequate research attention in Sub-Saharan Africa despite the assumption that the positive effect of biochar may last longer on degraded tropical soil. Hence a field experiment was conducted to assess the residual effects of biochar, farmyard compost and NPK fertilizer applications on a Ferralsol in central Uganda. The field used for the study was previously used to conduct experiments for two seasons to assess the contribution of corncob biochar to the chemical properties of this highly degraded tropical soil.

Result: The co-applied biochar with compost and NPK fertilizer significantly ($p < 0.05$) increased some soil chemical properties such as soil pH, available phosphorus, soil organic carbon, and potassium than the control. The co-applied biochar with compost also significantly ($p < 0.05$) increased the soil pH and effective cation exchange capacity compared to the solely applied compost and NPK fertilizer. Collard plant height, canopy, stem girth, number of leaves, leaf length, and total biomass were significantly ($p < 0.05$) higher in the biochar amended soil than the unamended soil.

Conclusion: It was concluded that the addition of biochar with compost and NPK fertilizer had a significant residual effect on degraded tropical soils than solely applied NPK and compost.

Keywords: Biochar, Residual effects, Soil quality, Nutrient constituents

Introduction

The long-term cultivation of most tropical soils has resulted in severe depletion of organic carbon, the disintegration of soil aggregate stability, serious soil erosion and deterioration of soil fertility (Ding et al. 2016). As a measure to sustainably restore and manage these degraded tropical soils, biochar has been used to improve their physico-chemical properties (El-Naggar et al. 2019). Biochar is a carbonaceous material produced from the by-product of feedstock pyrolysis in a limited or no oxygen condition (Verheijen et al. 2010; Sohi et al. 2010). The nutrients content of biochar is dependent on the pyrolysis time, feedstock type and pyrolysis temperature (Ronsse et al. 2013; Al-Wabel et al. 2018). Some of the physical properties of the soil that have been reported to improve after the application of biochar are bulk density, porosity, soil aggregation, soil structure, infiltration rate and water retention (Blanco-Canqui, 2017). Laird et al. (2010), concluded that applying biochar to the soil can lead to retention of 15% more soil moisture compared to soils without biochar. Chemical and biological characteristics of the soil that have been reported to improve after biochar application are microbial activities and enzyme, nitrogen and phosphorus recycling, soil acidity reduction, cation exchange capacity and electrical conductivity (Xu et al. 2014; Lehman et al. 2011; Nguyen et al. 2018).

However, the sole application of biochar cannot provide adequate amounts of nutrients for proper plant growth nor can the sole application of convectional fertilizer or the sole application of organic resources (Glaser and Birk 2012). Hence many studies have concluded that combining biochar with organic or inorganic resources is very effective for reclamation of degraded soil (Sánchez-Monedero et al. 2019; Liu et al. 2012; Tang et al. 2020). Co-applying biochar with organic resources causes the

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slow release of nutrient to the soil environment, resulting in the decrease of nutrient leaching (Mensah and Frimpong 2018) while co-applying biochar with conventional fertilizer decreased the amount of biochar needed to improve the degraded soil, decreased soil acidity, enhanced the soil physical environment to boost the inorganic fertilizer retention resulting in high nutrients use efficiency (Nielsen et al. 2018).

Many studies have focused on the direct effect of co-applying biochar with organic resources and conventional fertilizers although there is an assumption that the positive effect of co-applied biochar with organic and inorganic resources may last longer (Wisnubroto et al. 2017). As a result of high nutrient absorption capacity of the biochar, there is a potential that applying biochar with inorganic and organic resources will cause a slow release of nutrient to the soil environment on a long-term basis. Hence the main objective of this study was to assess the residual potential of co-applied biochar with organic resources and convectional fertilizer for the restoration of tropical degraded soil. The study is underpinned by the hypotheses that the residual effects of co-applied biochar with compost and/NPK will improve degraded soil more than the residual effect of the compost and the NPK.

Table 1 Physico-chemical properties of the field soil, corn cob biochar and farmyard compost used in the previous experiment

Parameters	Corn cob biochar	Farmyard manure compost	Experimental soil
pH-H_2O	6. 9	6.12	5.1
Total organic carbon (%)	73	68.2	0.33
Total nitrogen (%)	0.75	1.50	0.29
Available phosphophorus (mg/kg)	6.57	7.13	5.21
Potassium (cmol/kg)	7.9	4.36	0.43
Calcium (cmol/kg)	1.1	0.71	0.4
Sodium (cmol/kg)	0.9	1.32	0.9
Magnesium (cmol/kg)	1.4	3.41	2.1
Cation exchange capacity (cmol/kg)	1.7	0.98	4.32
Percent sand	NA	NA	64
Percent clay	NA	NA	30
Percent silt	NA	NA	6

NA not applicable

Materials and methods

Study setup

The study was conducted on a field that was previously used to examine the direct contribution of applied corncob biochar in combination with compost and NPK fertilizer on highly degraded soil at Uganda Martyrs University Research Farm in Central Uganda in 2020. Uganda Martyrs University Research Farm lies alongside the equator line at Latitude 0°00′17′N and Longitude 32°00′57′E. The site receives a bimodal rainfall with a mean annual rainfall of 1100 mm and with minimum annual temperature ranging between 20–23 °C and the maximum between 23–36 °C, respectively. The soil in the experimental field is a haplic Ferralsol with a sandy clay loam texture. Detailed physicochemical properties of the soil used are presented in Table 1.

Table 1 shows the results of the laboratory analysis of the experimental site soil, corncob biochar and farmyard manure compost used in the previous field study. These results show that the experimental site soil is sandy clay loam, quite acidic (pH: 5.1) and generally very poor in most plant nutrients when compared to the corncob biochar and farmyard manure compost.

The previous experiment adopted a Complete Randomized Block (CRB) design with nine (9) treatments, namely control, two rates of biochar, one level of compost, one level of NPK, and four levels of mixtures of biochar, compost and NPK. Four blocks of the nine plots were made with 0.5 m and 1.0 m gaps between plots and blocks, respectively. The rate of the farmyard manure compost used was adopted and modified from Van der Wurff AW et al. (2016) who concluded that the application rate of compost ranging from 6 t/ha to 10 t/ha adequate to provide soil nutrient to horticulture crops when applied to the soil. The recommendation rate of NPK (200 kg/ha) was adopted and modified from Mclaurin and Reeves (2009) whiles the treatment combination used the integrated plant nutrition system strategy (IPNS) i.e. combining half of the sole application of the biochar with half of the sole application of the farmyard compost and NPK (Choudhary et al. 2013). IPNS promotes the minimum effective rate of adequate and balanced quantities of applying inorganic and organic resources to results in high soil nutrients availability and crop productivity (Selim 2020). The biochar used was produced from a modified oil barrel having a similar function as the Elsa stove. Corncob feedstock was selected for biochar production and pyrolysis at a temperature between 450 °C. A detailed description of the treatments used in the previous experiment is presented in Table 2 while the characteristics of the biochar and the compost are presented in Table 1.

In this current study, the previously studied plots and the treatments were maintained to evaluate the residual effect of biochar, farmyard yard compost and/ NPK on tropical degraded soil conducted in September 2020 using *Brassica oleracea var. viridis* (Collard plant) as a test crop. The selection of the collard plant was based on its high consumption in Eastern Africa (Neugart et al.

2017) and their low nutrient composition in their leaves as a result of the poor fertility of the degraded soil (Antonious et al. 2014). Hence we aim to improve the nutrient composition of the collard plant by improving the degraded soil through biochar technology. The collard plant seed was purchase from the seed shop in Kampala, Uganda. A thirty days old seedling of the collard plants was transplanted per plot using a planting distance of 0.5 m × 0.5 m. In all, sixteen seedlings were transplanted per plot. Weeding was done every three weeks using a hoe and Supplementary irrigation was supplied every 2 days using watering cans in the event of no rainfall.

From Table 3, the carbonization time for the production of the corncob using the Elsa barrel was 49 min. A weight of 15.5 kg of the corncob feedstock gave a biochar output of 6.75 kg and a lower efficiency of 30.67%. The volatile matter recorded was 9.24% whiles Ash and the fixed carbon recorded a value of 37.96% and 40.41%, respectively. The low efficiency recorded by the Elsa barrel was due to the uncontrolled burning of biochar with open air. Volatile matter recorded was low for the carbonization methods compare with the Ash and fixed carbon content of the biochar. According to Yuan et al. (2011), volatile matter of biochar decreases with regard to high temperature. The ash content recorded was very high due to the increased exposure to oxygen supply because whenever the amount of smoke increased, the cover was opened to allow more airflow into the barrel. Biochar with high ash content will have lower fixed carbon less than 50%, contributing to the inhibition of aromatic carbon structures (Enders et al. 2012).

Soil sampling and physicochemical analysis of the soil

The soil samples were collected from each plot at a depth of 0–30 cm using the auger after harvest. The samples were air-dried at room temperature in the drying room before sending it to the laboratory. The samples were crushed with the help of the pestle and mortar, then sieved with a 2 mm sieve net for the physicochemical analysis of the soil. The determination of the soil pH was done using a pH meter in 1:2.5 soil: water (w/v) suspension (Anderson and Ingram 1993). Available phosphorus (Av. P) content in the soil was analyzed following the Bray-1 acid method (Sahrawat et al. 1997) whiles the flame photometer was used to determine the potassium content. The tot. N was determined by the Kjeldahl method (Sáez-Plaza et al. 2013). Exchangeable bases were extracted with 1.0 M ammonium acetate solution. Sodium and potassium contents in the extract were determined using a flame photometer while calcium and magnesium were determined by Atomic Absorption Spectrophotometer (AAS) (Rhoades et al. 1982). Effective cation exchange capacity (ECEC) was estimated by summation of total exchangeable bases and exchangeable acidity (Al + H) determined by 1 M KCl extract and titrated with dilute sodium hydroxide solution (Anderson and Ingram 1993).

Physical characteristics, yield and macro-nutritional composition of collard plant

Two weeks after transplanting (14 DAT), eight collard plants in each plot were randomly selected and tagged for data collection. Data was collected at 15, 30 and 60

Table 2 Treatment rate of biochar, farmyard manure compost and NPK used in the previous experiment

Treatment	Biochar (t/ha)	Farmyard manure compost (t/ha)	NPK (kg/ha)
Control	0	0	0
Compost only (C)	0	10	0
NPK	0	0	200
Biochar only (B1)	10	0	0
Biochar only (B2)	20	0	0
Biochar + compost (BC1 + CM)	5	5	0
Biochar + compost (BC2 + CM)	10	5	0
Biochar + NPK (BC1 + NPK)	5	0	100
Biochar + NPK (BC2 + NPK)	10	0	100

Table 3 Carbonization characteristics of the ELSA barrel and proximate analysis of the corncob biochar used for the previous experiment

Feedstock	N	Time (Min)	Weight FSt (kg)	Weight BC (kg)	Eff.ww (%)	Yield (kg/ha)	M (%)	VM (%)	ASH (%)	FC (%)
Corncob	9	49	15.5	6.75	30.67	9.13	12.40	9.24	37.96	40.41

FSt feedstock, *BC* biochar, *Eff* efficiency, *ww* per weight, *VM* volatile matter, *FC* fixed carbon, *EC* electrical conductivity, *M* moisture content

DAT on plant height (cm), number of leaves per plant, stem girth (cm), leaf length (cm); plant canopy (cm), total fresh biomass (g) and total dry biomass (g). The stainless steel Vernier caliper was used for the measurement of the stem girth while the tap measure was used to measure the leaf length from the axil to the leaf tip. Collard leaves were harvested and weighed (g) for only one cutting period at 65 days after transplanting (DAT) for the determination of the yield. Collard plant tissue (root, stems and leaves) was immediately weighed to determine the fresh total biomass. For the determination of the nutrient constituents of the collard leaf, freshly harvested collard leaves were weighed separately for each plant per plot for determination of calcium, nitrogen, available phosphorus and potassium compositions of the collard leaf. The harvested leaves were oven-dried for 72 h and ground into a fine powder using pestle and mortar. A known weight of 0.5 g of the dried and ground leaves' sample was used for the determination of the N, P, K and Ca. The colorimetric method was used for the determination of phosphorus (Regalado and Cruz 2016). Total potassium and calcium were determined using the flame photometer (Barros et al. 2012) and the nitrogen content was determined by the Kjeldahl method (Sáez-Plaza et al. 2013).

Data analysis

The data was analyzed using Statistix Edition 8.1 software. One-way ANOVA was used to compare soil physicochemical properties, collard plant biomass and nutritional constituents. Analysis of variance was performed to test the treatment effect for significance and means were separated using Tukey HSD at the 0.05 significance level.

Results

Residual effects of biochar, farmyard compost and/or NPK applications on soil properties

Soil pH

The residual effects of biochar with farmyard compost and NPK applications did not influence the soil pH. The soil pH varied from 5.35 control to 6.23 at 10 t/ha biochar and 5 t/ha compost addition plot. The high rate (20 t/ha) of the biochar did not differ in the soil pH obtained compared to the low rate (10 t/ha) of the biochar plot. The biochar and compost addition elevated the soil pH by 0.17 units greater than the solely applied compost. However, the 10 t/ha biochar and 5 t/ha compost addition increased the soil pH by 0.5 units greater than the 5 t/ha biochar and 5 t/ha compost addition. The biochar (5 t/ha) and NPK (100 kg/ha) addition plot increased the soil pH by 0.17 units more than the residual plots of the solely applied NPK (Table 4).

Soil available phosphorus

The soil available phosphorus ranged from 5.48 mg/kg at control plot to 7.48 mg/kg at biochar (10 t/ha) and compost (5 t/ha) addition plot. The high rate of the biochar plot (20 t/ha) elevated the available phosphorus by 2.03% more than the low rate of the biochar (10 t/ha). The biochar (10 t/ha) amended soil increased the available phosphorus by 8.98% greater than the control. The residual effect of biochar and compost addition plot elevated the available phosphorus by 5.32% greater than the compost plot. The treatment BC1 + NPK obtained available phosphorus higher than the residual NPK plot by 9.26%. As expected, the 10 t/ha biochar with NPK and/ compost addition increased the available phosphorus more than the 5 t/ha biochar with NPK and/ compost addition (Table 4).

Total organic carbon (TOC)

The total organic carbon varied from 1.36% at control to 2.78% at 10 t/ha biochar and 5 t/ha compost addition. The 10 t/ha biochar elevated the TOC by 9.04% more than the control. Biochar improved the TOC with a high rate of biochar application, such that the 10 t/ha biochar obtained 1.63% TOC whiles the 20 t/ha biochar plot gained 1. 88% TOC. The 5 t/ha biochar and 100 kg/ha NPK plot showed a higher influence on the TOC than the solely applied NPK, such that the 5 t/ha biochar and 100 kg/ha NPK addition plot increased the TOC by 19.3% greater than the NPK plot. The plot of the combined application of the biochar and farmyard manure compost increased the TOC with an increasing rate of the biochar such that, the 10 t/ha biochar and 5 t/ha farmyard

Table 4 Residual effects of biochar farmyard, compost and/ or NPK applications on the soil pH, total soil organic carbon, nitrogen and available phosphorus

Treatment	pH (H_20)	Av.P (mg/kg)	TOC (%)	N (%)
CTRL	5.35b	5.48f	1.36e	0.07c
CM	5.56ab	6.32e	1.60de	0.10ab
NPK	5.41b	5.54f	1.40e	0.09bc
BC1	5.66ab	6.30e	1.63de	0.11bc
BC2	5.74ab	6.56d	1.88cd	0.12bc
BC1 + CM	5.73ab	7.03b	2.43ab	0.13abc
BC2 + CM	6.23a	7.48a	2.78a	0.18a
BC1 + NPK	5.58ab	6.68c	2.07bc	0.11bc
BC2 + NPK	5.55ab	7.28b	2.39b	0.13abc
Significant^X	NS	***	***	**
SED^Y	0.14	0.15	0.06	0.01

SED^Y and Significant^X effects were obtained from one-way analysis of variance: *, **, ***Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. See Table 2 for a description of the treatments; Means followed by the same letter in each column are not significantly different at $p \leq 0.05$ using Tukey HSD compost addition plot obtained a higher TOC of 2.78% compared with a TOC of 2.43% recorded by the 5 t/ha biochar and 5 t/ha farmyard compost plot (Table 4).

Total nitrogen (N)

There was a significant ($p < 0.05$) increased in soil total nitrogen among the treatments. The nitrogen ranged from 0.08 at control to 0.18% at 10 t/ha biochar and 5 t/ha compost addition plot. The 10 t/ha biochar plot increased the nitrogen by 15.78% more than the control. The combined biochar (5 t/ha) and compost (5 t/ha) addition plot increased the nitrogen by 13.04% more than the solely applied compost plot. However, the 5 t/ha biochar and the NPK addition plot did not significantly influence the nitrogen obtained compared to the solely applied NPK plot (Table 4).

Exchangeable bases (K^{+}, Mg^{2+} Ca^{2+} Na^{+})

Statistically, the differences among means were significant in the potassium, calcium, sodium and magnesium content as the result of the residual effect of the biochar, farmyard compost and NPK applications. The potassium content varied from 0.16 cmol/kg at control to 0.46 cmol/kg at biochar and NPK addition plot. The co-applied biochar with NPK and/ compost obtained a higher potassium content more than the solely applied compost and the NPK. The calcium content varied from 1.57 cmol/kg to 3.38 cmol/kg with the highest obtained by the 10 t/ha biochar and 5 t/ha compost addition. There was no significant difference between the solely applied 10 t/ha biochar and the 20 t/ha biochar. However, the 5 t/ha biochar and 5 t/ha compost increased the calcium content by 10.76% more than the solely applied compost. Similarly, the combined 5 t/ha biochar and 100 kg/ha NPK increased the calcium content by 15.44% greater than the solely applied NPK. The combined application of biochar and farmyard manure compost increased the calcium content with an increasing rate of the biochar such that, the 10 t/ha biochar and 5 t/ha farmyard compost addition plot obtained higher calcium content of 3.38 cmol/kg compared with the calcium content of 2.47 cmol/kg recorded by the 5 t/ha biochar and 5 t/ha farmyard compost plot. Varying sodium content was observed, ranging from 0.16 cmol/kg at 20 t/ha biochar to 0.38 cmol/kg at 10 t/ha biochar and 100 kg/ha NPK plots. The sodium content decreased as biochar increased such that, 20 t/ha biochar obtained a sodium content of 0.16 cmol/kg compared to 0.21 cmol/kg obtained by 10 t/ha biochar plot. As usual, the combined biochar with NPK and/ compost increased the sodium content greater than the solely applied NPK and compost. The magnesium content differ from 0.45 cmol/kg at control to 0.74 cmol/kg at 10 t/ha biochar and 5 t/ha compost addition plot. The sole application of the 10 t/ha biochar increased the magnesium content by 13.46% more than the control. The combined 5 t/ha biochar and 5 t/ha compost increased the magnesium content by 7.44% more than the solely applied compost. Also, the combined application of biochar and NPK increased the magnesium content with an increasing rate of the biochar such that, the 10 t/ha biochar and 100 kg/ha addition plots obtained a higher magnesium content of 0.65 cmol/kg compared with the magnesium content of 0.55 cmol/kg being recorded by the 5 t/ha biochar and 100 kg/ha plot (Table 5).

Effective cation exchange capacity (ECEC)

The residual effect of biochar, farmyard manure compost and/NPK applications significantly ($p < 0.05$) increased the effective cation exchange capacity (ECEC). The ECEC ranged from 2.37 cmol/kg at control to 4.75 cmol/kg at 10 t/ha biochar and 5 t/ha compost addition. The biochar and compost addition increased the ECEC by 10.36% more than the solely applied compost while the combined 5 t/ha biochar and 100 kg/ha NPK addition elevated the ECEC by 10.32% more than the NPK plot. Doubling the biochar rate elevated the ECEC by 21.92% more than the control (Fig. 1).

Residual effects of biochar, farmyard compost and/NPK applications on collard growth development and yield

Collard plant canopy, plant height, plant stem and number of leaves at 15 DAT

The residual effects of co-applied Biochar with Farmyard compost and NPK applications significantly ($p < 0.05$) increased plant canopy and plant height at 15 DAT. The plant canopy ranged from 34.10 cm at control to 42.10 cm at 10 t/ha biochar and 100 kg/ha NPK addition plot. The 10 t/ha biochar and 5 t/ha compost addition increased the plant canopy by 3.14% more than the 5 t/ha biochar and 5 t/ha compost addition plot. The plant height varied from 23.58 cm at control to 32.88 cm at 10 t/ha biochar and 100 kg/ha NPK addition. The 10 t/ha biochar plot increased the plant height by 6.1% more than the control. The 20 t/ha of the biochar addition plot increased the plant height by 6.98% more than the sole application of the 10 t/ha biochar. The 5 t/ha biochar and 5 t/ha compost addition plot increased the plant height by 0.64% compared to the sole application of the 10 t/ha compost plot while 5 t/ha biochar and 100 kg/ha NPK addition plot increased the plant height by 10.58% more than the sole application of the NPK. The collard plant stem and the number of leaves were not significantly influenced by the residual effects of co-applied biochar with farmyard compost and NPK. The plant stem varied from 0.38 cm at control to 0.70 cm at 10 t/ha biochar and 100 kg/ha NPK addition plot while the number of collard

Table 5 Residual effects of biochar farmyard, compost and/or NPK applications on the exchangeable bases (K^{+}, Mg^{2+} Ca^{2+} Na^{+})

Treatment	Potassium (cmol/kg)	Calcium (cmol/kg)	Sodium (cmol/kg)	Magnesium (cmol/kg)
CTRL	0.16c	1.57e	0.20cd	0.45e
CM	0.28bc	1.99cd	0.24c	0.56cd
NPK	0.36ab	1.67de	0.36a	0.51de
BC1	0.34ab	1.80de	0.21cd	0.59bc
BC2	0.39ab	2.51b	0.16d	0.65b
BC1 + CM	0.38ab	2.47b	0.20bc	0.67ab
BC2 + CM	0.43a	3.38a	0.26cd	0.74a
BC1 + NPK	0.44a	2.28bc	0.32ab	0.55cd
BC2 + NPK	0.46a	2.48b	0.38a	0.65b
Significant^{X}	***	***	***	***
SED^{Y}	0.03	0.06	0.01	0.01

Significant^{X} effects were obtained from one-way analysis of variance: *, **, ***Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. See Table 2 for a description of the treatments; Means followed by the same letter in each column are not significantly different at $p \leq 0.05$ using Tukey HSD

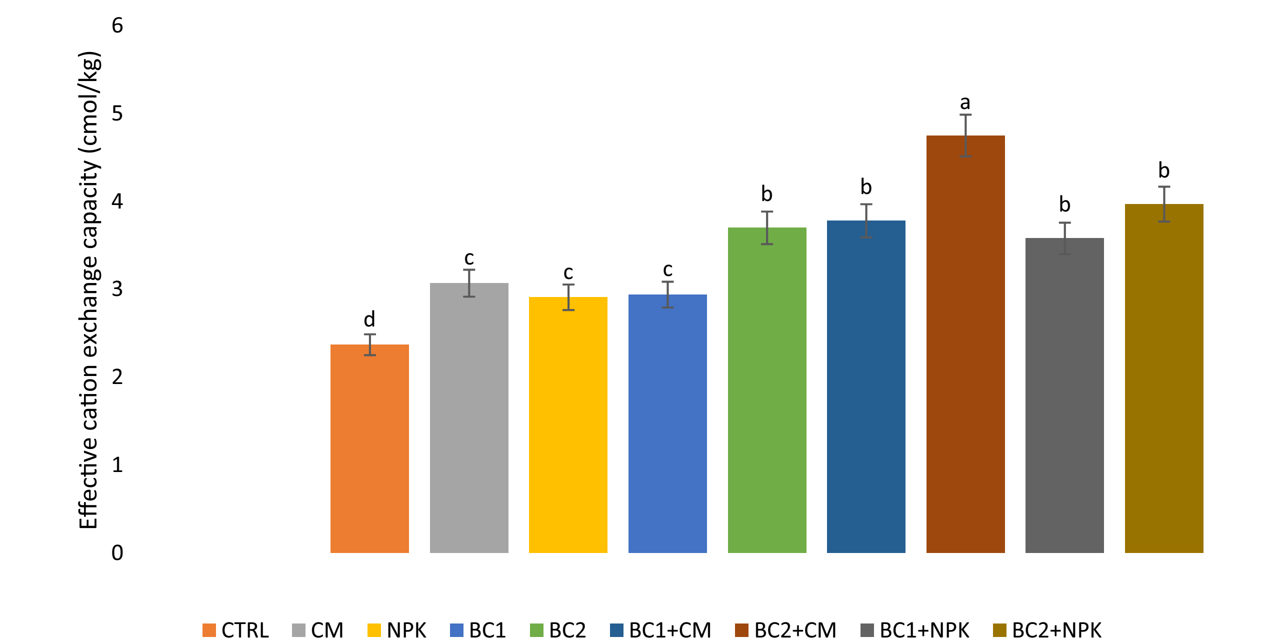

Fig. 1 Residual effect of biochar, farmyard manure compost and/NPK on the on the effective cation exchange capacity. The same letter on the bars are not significantly different at p ≤ 0.0 5 using Tukey HSD. Error bars represent standard deviation of the means

leaves ranged from 7.6 at control plot to 9.66 at 10 t/ha biochar and 100 kg/ha NPK addition plot (Table 6).

Plant canopy, plant height, plant stem and number of leaves at 30 DAT

The residual effect of biochar with farmyard manure compost and/or NPK showed a significantly ($p < 0.05$) increased plant canopy, plant height and plant stem at 30 DAT. The plant height ranged from 44.73 cm at control to 63.25 cm at 10 t/ha biochar and 100 kg/ha NPK addition plot. The 5 t/ha biochar and 5 t/ha compost addition plot increased the plant canopy by 3.58% compared to the sole application of the 10 t/ha compost plot while 5 t/ha biochar and 100 kg/ha NPK addition plot increased the plant height by 6.96% more than the NPK plot. The 10 t/ha biochar plot increased the collard plant canopy by 8.04% more than the control. The high rate (20 t/ha) of the biochar plot did not differ from the low rate (10 t/

ha) biochar plot of the plant canopy obtained. The plant height varied from 33.85 cm at control to 46.19 at 10 t/ha biochar and 100 kg/ha NPK addition plot. The biochar and compost addition plot showed higher plant height than the sole compost plot. The l5 t/ha compost and 100 kg/ha NPK addition plot increased plant height by 10. 64% more than the solely applied NPK. The collard plant stem girth varied from 0.63 cm at control to 0.94 cm at 10 t/ha biochar and 100 kg/ha NPK plot. The biochar and compost addition plot obtained a higher stem girth more than the sole application of the compost. The collard plant number of leaves was not significantly influenced by the residual effects of co-applied Biochar with Farmyard compost and/or NPK. The number of leaves varied from 10.28 at 5 t/ha biochar and 5 t/ha compost addition plot to 11.28 at solely 10 t/ha biochar plot (Table 7).

Plant canopy, plant height, plant stem and number of leaves at 60 DAT

Varying plant canopy, plant height and stem girth were observed as a result of the biochar with farmyard manure compost and NPK at 60 DAT. The plant canopy varied from 69.93 cm at the control plot to 90.14 cm at 10 t/ha biochar and 100 kg/ha plot. The biochar and compost addition plot obtained a higher plant canopy than the sole application of the compost. As expected, the l5 t/ha biochar and 100 kg/ha addition plot increased the plant canopy by 6.68% more than the NPK plot. The plant height ranged from 61.40 cm at control to 77.22 cm at 10 t/ha biochar and 100 kg/ha NPK addition. The plot of the low rate (10 t/ha) and high rate biochar (20 t/ha) did not differ regarding the plant height observed. However, the plot of the biochar and compost addition obtained higher plant height more than the sole application of the compost. The stem girth ranged from 1.92 cm at control to 3.62 cm at 10 t/ha biochar and 100 kg/ha NPK addition plot. The collard plant number of leaves was not significantly influenced by the residual effects of the co-applied biochar with farmyard compost and NPK (Table 8).

Collard plant leaf length

The leaf length did not differ significantly ($P > 0.05$) among the treatments in the 15 and 30 DAT but differ significantly ($P < 0.05$) at 45 and 60 DAT. During the 45 DAT, the 20 t/ha biochar plot obtained the higher leaf length but was not significant ($P > 0.05$) compared to the co-applied biochar with compost and/NPK application plot, however, 10 t/ha biochar and 100 kg/ha NPK obtained the higher leaf length at 45 DAT (Fig. 2).

Residual effects of biochar farmyard compost and/or NPK applications on collard plant yield and fresh total plant biomass at 60 DAT

Collard plant yield The yield differs significantly ($P > 0.05$) among the treatments. The yield ranged from 458.19 g/plant at control to 588.79 g/plant at treatment BC2 + CM. The combined 5 t/ha biochar and 5 t/ha compost increased the yield by 5.08% more than the solely applied compost. However, it did not differ as compared to the 10 t/ha biochar and 5 t/ha compost. The 5 t/ha biochar and 100 kg/ha NPK increased the yield by 4.16% more than the solely applied NPK (Fig. 3).

Table 6 Residual effects of co-applied biochar with compost and/or NPK collard plant canopy, plant height, plant stem and the number of leaves at 15 DAT

Treatment	Plant canopy (cm)	Plant height (cm)	Plant stem (cm)	Number of leaves
CTRL	34.10a	23.58c	0.38a	7.28a
CM	34.20a	30.62a	0.44a	7.86a
NPK	35.73a	24.64bc	0.40a	7.60a
BC1	38.65a	26.64a	0.45a	7.69a
BC2	33.36a	30.64ab	0.42a	7.84a
BC1 + CM	38.75a	31.01a	0.45a	8.38a
BC2 + CM	39.84a	32.42a	0.48a	7.68a
BC1 + NPK	39.53a	30.47a	0.47a	7.81a
BC2 + NPK	42.10b	32.88a	0.70a	9.66a
Significant^{X}	*	***	NS	NS
SED^{Y}	2.66	2.01	0.13	1.32

Significant^{X} and SED^{Y} effects were obtained from one-way analysis of variance: *, **, *** significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. See Table 2 for a description of the treatments; Means followed by the same letter in each column are not significantly different at $p \leq 0.05$ using Tukey HSD

Table 7 Residual effects of co-applied biochar with compost and/or NPK collard plant canopy, plant height, plant stem and number of leaves at 30 DAT

Treatment	Plant canopy (cm)	Plant height (cm)	Plant stem (cm)	Number of leaves
CTRL	44.73b	33.85a	0.63b	10.69a
CM	53.53ab	41.08a	0.79ab	10.78a
NPK	51.98ab	36.34a	0.70ab	10.56a
BC1	55.19ab	42.43ab	0.77ab	11.28a
BC2	56.19ab	43.581ab	0.81ab	10.75a
BC1 + CM	57.50ab	44.58ab	0.79ab	10.28a
BC2 + CM	59.05a	45.98b	0.82ab	10.56a
BC1 + NPK	59.75a	44.99ab	0.84ab	10.88a
BC2 + NPK	63.25a	46.19b	0.94a	10.63a
Significant^X	**	***	*	NS
SED^Y	3.83	2.17	0.08	0.47

Significant^X and SED^Y effects were obtained from one-way analysis of variance: *, **, ***significant at $P<0.05$, $P<0.01$, and $P<0.001$, respectively. See Table 2 for a description of the treatments; Means followed by the same letter in each column are not significantly different at $p \le 0.05$ using Tukey HSD

Table 8 Residual effects of co-applied biochar with compost and/or NPK collard plant canopy, plant height, plant stem and the number of leaves at 60 DAT

Treatment	Plant canopy (cm)	Plant height (cm)	Plant stem girth (cm)	Number of leaves
CTRL	69.93b	61.40e	1.92b	12.88a
CM	72.09b	65.04cde	2.08b	13.00a
NPK	70.84b	63.10de	1.97b	13.59a
BC1	78.25ab	67.52bcde	2.08b	13.13a
BC2	76.68b	67.82bcde	2.12b	13.06a
BC1 + CM	78.85ab	69.11bcd	2.08b	13.31a
BC2 + CM	82.10ab	70.73abc	2.39b	13.43a
BC1 + NPK	81.19ab	73.48ab	2.43b	13.13a
BC2 + NPK	90.14a	77.22a	3.62a	14.03a
Significant^X	***	***	**	NS
SED^Y	3.90	2.23	0.29	0.72

Significant^X and SED^Y effects were obtained from one-way analysis of variance: *, **, ***Significant at $P<0.05$, $P<0.01$, and $P<0.001$, respectively. See Table 2 for a description of the treatments; Means followed by the same letter in each column are not significantly different at $p \le 0.05$ using Tukey HSD

Fresh total plant biomass The residual effect of the co-applied biochar with farmyard manure compost and/or NPK observed a significant ($p<0.05$) increased in available phosphorus The fresh total plant biomass varied from 649.03 g at control to 925.27 g at 10 t/ha biochar and 5 t/ha compost addition plot. The 5 t/ha biochar and 5 t/ha compost addition plot increased the fresh total biomass by 7.44% more than the solely applied compost plot. As expected, the 5 t/ha biochar and 100 kg/ha NPK elevated the fresh total biomass by 0.46% more than the solely applied NPK (Fig. 4).

Residual effects of biochar, farmyard compost and NPK applications on nutrient constituents of collard leaf at 60 DAT

Macronutrient composition (N, P, K, Ca) of collard leaf

The residual effects of biochar with farmyard compost and/NPK applications significantly ($P<0.05$) increased the nitrogen, potassium, calcium and available phosphorus content of the dry matter biomass of the collard leaf. The nitrogen of the dry collard leaf ranged from 0.66% at control to 2.01% at 10 t/ha biochar and 5 t/ha compost addition plot. The combined application of the biochar and the compost and/NPK addition plot elevated the N content in the collard leaf more than the the sole application of the compost and the NPK. The potassium content of the collard leaf varied from 0.94% at control to 3.51%

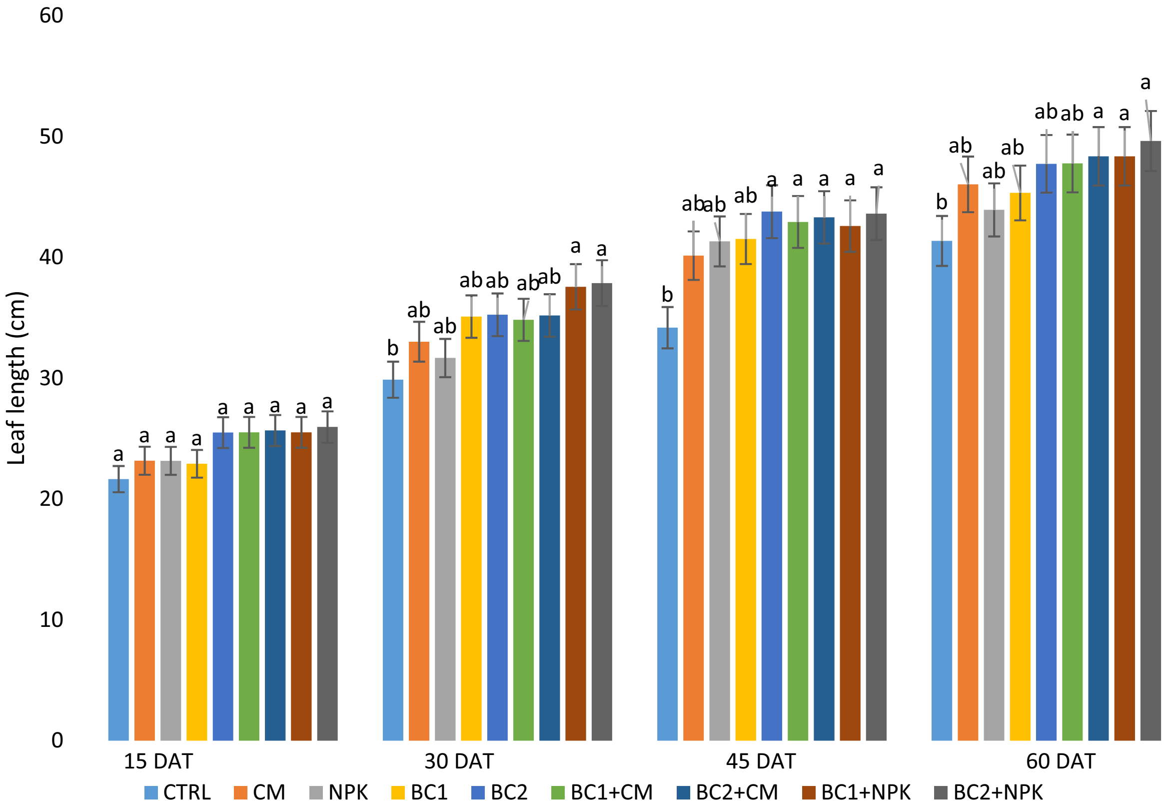

Fig. 2 Residual Effect of biochar, farmyard manure compost and/or NPK on the collard plant leaf length. The same letter on the bars are not significantly different at p ≤ 0.0 5 using Tukey HSD; Control (CTRL), 10 t/ha compost only (CM), 200 kg NPK (NPK), 10t/ha Biochar only (BC1), 20 t/ha Biochar only (BC2), 5 t/ha Biochar + 5 t/ha compost (BC1+CM), 10 t/ha Biochar + 5 t/ha compost (BC2+CM), 5t/ha Biochar + 100 kg/ha NPK (BC1+NPK), 10 t/ha Biochar + 100 kg/ha NPK (BC2+NPK); Error bars represent standard deviation of the means

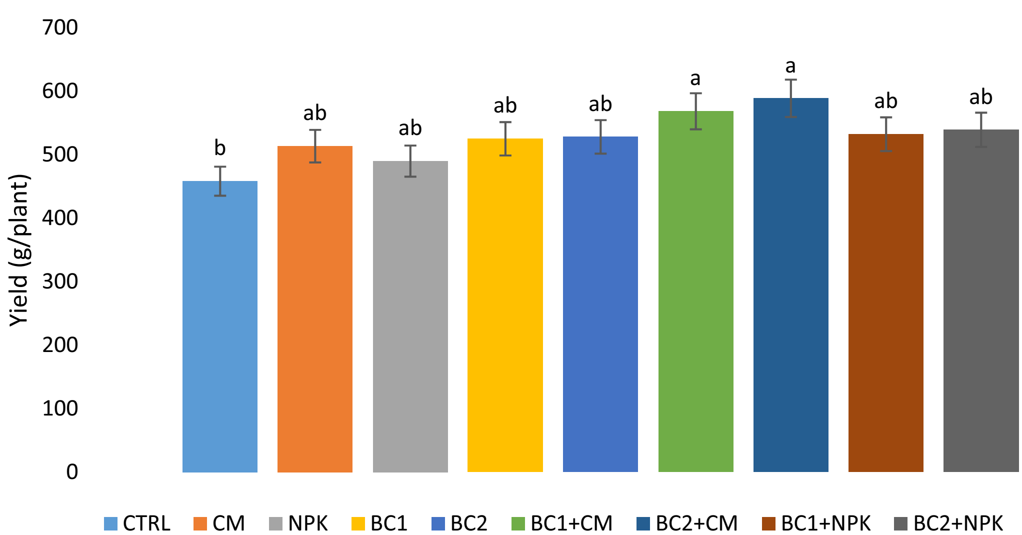

Fig. 3 Residual Effect of biochar, farmyard manure compost and/NPK on the collard plant yield. The same letter on the bars are not significantly different at p ≤ 0.0 5 using Tukey HSD; Control(CTRL), 10 t/ha compost only (CM), 200 kg NPK, 10t/ha Biochar only (BC1), 20 t/ha Biochar only (BC2), 5 t/ha Biochar + 5 t/ha compost (BC1+CM), 10 t/ha Biochar + 5 t/ha compost (BC2+CM), 5t/ha Biochar + 100 kg/ha NPK (BC1+NPK), 10 t/ha Biochar + 100 kg/ha NPK (BC2+NPK); Error bars represent standard deviation of the means

at 10 t/ha biochar and 5 t/ha compost addition plot. Treatment BC1 + CM increased the potassium content of the collard leaf by 10.55% more than the solely applied compost. The combined application of NPK and the biochar also increased the potassium content more than the solely applied NPK. The calcium content varied from 1.32 at control to 4.99 at 10 t/ha biochar and 5 t/ha compost addition plot. The co-applied biochar with the compost and/NPK increased the calcium content more than the solely applied compost and/NPK. The available phosphorus content varied from 0.38% at control to 1.41% at 10 t/ha biochar and 5 t/ha compost addition plot increasing the biochar content increased the phosphorus content, such that the 10 t/ha biochar obtained 0.74% of the phosphorus in the collard leaf while 1.17% was observed by the 20 t/ha biochar. Also, the combined application of the biochar with compost and/NPK showed a higher phosphorus content than the solely applied compost and the NPK (Table 9).

Discussion

In the present study, the residual effects of co-applied biochar with compost and NPK showed a positive impact on the reclamation of highly degraded soil. The increase in the soil pH in the residual biochar plots resulted from the functions of the biochar to released cation oxides for the replacement of the hydrogen and aluminum iron on the colloidal soil surface, resulting in the decrease of the exchangeable acidity as reported by Jien and Wang (2013). A similar result observation was made by Yuan et al. 2011, in which they concluded that biochar increased soil pH on a long-term basis. The results are in accordance with Frimpong et al. (2020) who reported a pH increased in a one-time application of biochar across three cropping cycles on highly weathered tropical soil. The higher soil pH in the residual biochar and compost addition plot than the residual biochar and NPK addition plot could be probably due to the greater liming potential of the biochar and compost in the long term than the biochar and NPK addition.

Increased CEC in the residual biochar and the compost addition plot could probably assign to the larger specific areas of the residual biochar particles in the soil environment which continue to increase the sorption capacity and base saturation of the soil environment (Chen et al. 2011). According to Lehmann Joseph (2015), biochar residues in the soil can have larger negative charges on their surface, which is attributed to the formation of the phenolic group by abiotic oxidation, hence contributing to the increase of the CEC in the soil environment. Also, as a result of the high surface area of the biochar, it adsorbed the organic matter derived from the compost and the soil environment on its surface, causing the slow release of carboxylic and phenolic acid groups into the soil environment (Novak et al. 2009). The carbon provided by the biochar in the previous amendment contributed to the TOC because C added from biochar is resistant to microbial attack or degradation and C added from biochar into the soil can be eliminated from the soil

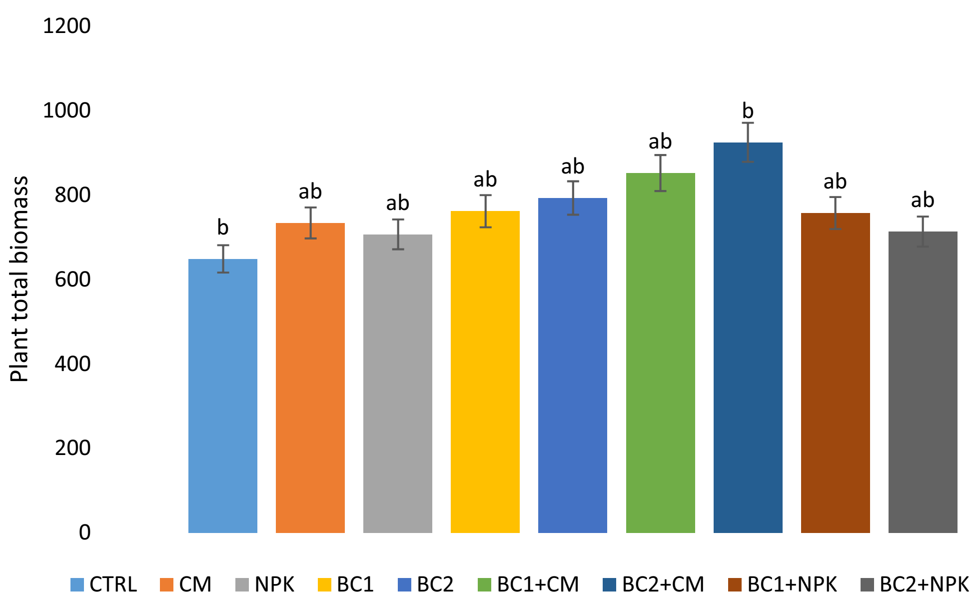

Fig. 4 Residual Effect of biochar, farmyard manure compost and/or NPK on the fresh total collard plant biomass. The same letter on the bars are not significantly different at p ≤ 0.0 5 using Tukey HSD; Control(CTRL), 10 t/ha compost only (CM), 200 kg NPK (NPK), 10t/ha Biochar only (BC1), 20 t/ha Biochar only (BC2), 5 t/ha Biochar + 5 t/ha compost (BC1+CM), 10 t/ha Biochar + 5 t/ha compost (BC2+CM), 5t/ha Biochar + 100 kg/ha NPK (BC1+NPK), 10 t/ha Biochar + 100 kg/ha NPK (BC2+NPK); Error bars represent standard deviation of the means

Table 9 Effect of biochar, farmyard manure compost and inorganic fertilizer on the dry matter percentage of total N, P, K and Ca in the collard leaf after harvest

Treatment	Nitrogen (%)	Potassium (%)	Calcium (%)	Phosphorus (%)
CTRL	0.66e	0.94e	1.32e	0.38d
CM	1.18bc	2.67bc	3.56cd	0.91
NPK	0.72e	1.83d	1.55e	0.64cd
BC1	0.82de	2.40cd	3.34d	0.74bcd
BC2	0.91de	2.87abc	4.10bc	1.17ab
BC1 + CM	1.88a	3.30ab	4.34b	1.27ab
BC2 + CM	2.01a	3.51a	4.99a	1.41a
BC1 + NPK	1.04cd	3.16abc	3.69cd	0.81abc
BC2 + NPK	1.35b	3.12abc	3.98bc	1.06bcd
Significant^X	***	**	***	**
SED^Y	0.97	0.19	0.15	0.13

Significant^X and SED^Y effects were obtained from one-way analysis of variance: **, ***Significant at $P < 0.01$, and $P < 0.001$, respectively. See Table 2 for a description of the treatments; Means followed by the same letter in each column are not significantly different at $p \leq 0.05$ using Tukey HSD

environment to the atmosphere for 1000 years and more (Lu et al. 2020; Hardy et al. 2017). The high available phosphorus and nitrogen in the combined biochar with compost and/NPK addition plots signified that there was a lot of excess nutrients which was not exhausted during the direct effects as compared to the solely residual compost and NPK plots as reported by Frimpong et al*.* (2020). The increase of the N content could probably assign to the residual $NH4^+$ absorbed on the biochar surface from the previously applied compost and the NPK, causing the slow release of N into the soil N pool (Zheng et al. 2013; Bai et al. 2015).

The biochar plots seem to improve the exchangeable cations exception for the surprising decrease of the sodium content. The increase of the potassium content was the result of the gradual leaching of the K^+ from the residual biochar into the soil environment. Immediately biochar is amended to the soil, there is a gradual increase of the potassium content in the soil due to the dissolution of potassium oxides from the biochar ash as reported by Hardy et al. (2017). The increase of the magnesium and the calcium content were ascribable to the gradual mineralization of the residual biochar, causing the release of the non-volatilized nutrients cations (Hailegnaw et al. 2019). Surprisingly, the residual biochar plot decreased the sodium content of the soil by increasing the sodium adsorption in the soil onto its biochar surface (Akhtar et al. 2015).

The residual effects of co-applied biochar with compost and NPK resulted in the enhancement of the soil physicochemical environment to elevate collard plant growth and biomass as the result of the excess nutrient which was not exhausted during the direct effects as reported by Frimpong et al. (2020) and Akhtar et al. (2015). Increasing crop yield and performance due to residual biochar effects have also been reported for crops including rice (Rizwan et al. 2018) and wheat (Akhtar et al. 2015). According to Akhtar et al. (2015), biochar increased wheat yield under salt stress and attributed it to the ability of the biochar to suppress the negative impact of salt on the vegetative growth and yield components whiles Frimpong et al*.* (2020), concluded that the increase of crop yield in biochar amended soil is due to the enhancement of the reproductive efficiency by the biochar. Also, the high nutrients composition of the collard leaves in the biochar amended soil could probably assigned to the excess nutrient which was not exhausted during the direct effects enhances the bioavailability of the soil nutrient for plant uptake (Nigussie et al. 2012; Agegnehu et al. 2016).

Conclusion

In this study, we demonstrated that the residual effect of combined application of biochar with compost and/ NPK enhanced the soil physicochemical properties such as soil pH, total organic carbon, soil available phosphorus, total nitrogen etc., collard plant biomass and a nutritional constituent as compared to the residual effect of NPK and compost.

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Authors' contributions
SOA and JB designed the research, perform the laboratory works, analyzed the data, wrote the manuscript and revised the drafted manuscript. GKM contributed to the collection of the field data and analyzed the data. All authors read and approved the final manuscript.

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Availability of data and materials
All data generated or analyzed during this study are included in this manuscript.

Declarations

Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Consent for publication
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