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# Effect of co-applied corncob biochar with farmyard manure and NPK fertilizer on tropical soil

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ABSTRACT

Biochar has shown a positive impact on degraded soils. However, the effect of co-applied biochar with farmyard manure and inorganic fertilizer on soil chemical characteristics, yield, nutrient constituent and economic analysis of cucumber did not receive adequate research attention in sub-Saharan Africa. A field experiment was conducted on sandy clay loam soil with biochar at 10 t/ha individually or combined with farmyard manure and NPK using cucumber as a test crop. The co-applied biochar with the 5t/ha farmyard manure and NPK significantly increased soil pH, total nitrogen, available phosphorus, total organic carbon and effective cation exchangeable capacity than the sole application of the NPK fertilizer and the farmyard manure. Cucumber yield, net income, nutrient content such as nitrogen, phosphorus and potassium were significantly higher in the co-applied biochar with farmyard manure and NPK than the sole application of the NPK and the manure. Co-applied biochar with inorganic NPK showed higher soil available phosphorus, nitrogen, cucumber yield and net income than the co-applied biochar with farmyard manure. Similarly, co-applied biochar with NPK plots observed higher macronutrient constituents than the co-applied biochar with farmyard manure. These findings revealed that combined biochar with NPK proved to be an effective reclamation strategy to improve low fertile soils in the tropics than the co-applied biochar with farmyard manure.

## 1. Introduction

The degradation of the soils has been considered the major constraint for feeding the world's ever-growing population (Gupta, 2019). Soil degradation results from the high use of intensive agriculture activities, land use changed and mismanagement of soil (Lucas-Borja et al., 2019). Intensive agriculture activities in tropical soils have led to severe soil degradation through soil organic carbon (SOC) loss, deteriorate soil structure, increase risk of erosion and decline in soil ecosystem services (Adelman and Barton, 2002; Tsiafouli et al., 2015; Rockström et al., 2017).

Inorganic fertilizers and farmyard manures are being used to restore the degraded soils in the tropics. However, the continuous use of the inorganic fertilizers to restore degraded soil may increase soil acidification, decline microbial abundance and population, affect both the soil biota and biogeochemical processes thus posing an environmental risk and decreasing crop yield (Seufert et al., 2012). Also, soil amendments such as manure or compost have proven to enhance the physical environment and supply the soil with macro and micronutrients. Still, the high rapid decomposition and mineralization of organic resources make it ineffective for the reclamation of highly weathered soils on a long-term basis (Mensah and Frimpong, 2018).

Given that healthy soils will help feed the ever-growing world population, innovative agriculture technologies and practices are needed to prevent healthy soil from degradation (Nikitin and Kuzicheva, 2019). Sustainable agricultural intensification (SAI) has been proposed as a climate-smart approach for remediation of degraded soil (Maertens et al., 2006; Tilman et al., 2011; Drechsel et al., 2015). One of the major aims of SAI practices is to enhance soil storage of black carbon on degraded soils, which can be derived by incorporating biochar into the degraded soil (Obiahu et al., 2020).

Biochar is a carbona organic by-product;resulting from the pyrolysis of biomass composed of recalcitrant organic carbon, which is not easily mineralized by soil microbes (Lehmann and Joseph, 2009). Biochar can also be defined as a solid by-product of biomass pyrolysis at 300 to 900 °C, is characterized by stable aromatic organic matter, high surface area, variable charges and functional groups (DeLuca et al., 2015; He et al., 2016). However, the availability of nutrients and their content in biochar are affected by the biomass type and processing conditions (Dieguez-Alonso et al., 2018).

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Many soil properties have been reported to improve after the application of biochar. These include soil bulk density, hydraulic conductivity, water holding capacity, soil structure, water retention, nutrient retention, soil pH, available phosphorus, potassium, total nitrogen, microbial biomass, calcium, soil porosity, hydraulic conductivity, total organic carbon, cation exchange capacity and soil aggregation (DeLuca et al., 2015; Abujabhah et al. 2016; Joseph et al., 2020; Nakhli et al., 2020; Rehman et al., 2020; Toková et al., 2020; Zhang et al., 2020).

The combined application of biochar with organic resources decreases the decomposition and mineralization of the organic resources, causing the slow release of nutrients to the soil environment, resulting in decreased nutrient leaching (Mensah and Frimpong, 2018). Moreover co-applying biochar with conventional fertilizer decreases the amount of biochar needed to improve the degraded soil, reduce soil acidity, and enhance the soil physical environment to boost the inorganic fertilizer retention resulting in high nutrients use efficiency (Nielsen et al., 2018). On the contrary, other studies indicated an antagonistic effect of co-application of biochar with organic or inorganic resources than the sole application of the organic or inorganic resources on plant productivity (Domene et al., 2015; Seehausen et al., 2017). This is because the high sorption ability of the biochar can reduce the nutrient availability, especially for mineralized N or available P (DeLuca et al., 2015). However, ' acidic surface biochar's sorption capacity of nutrients may be significantly affected by biochar's properties, including pH, acidic surface groups, ion exchange capacity, biochar application rates, feedstock source and pyrolytic temperature (Morales et al., 2013; Yao et al., 2013).

Notwithstanding the positive impacts of biochar on soil health, reduction of greenhouse gas emission, and crop productivity on degraded soils, most of the updated work on biochar amendment has focused on temperate soils. Whiles the mechanism explaining its impact on degraded soil in sub-Saharan Africa is still not adequately examined (Frimpong et al., 2016). Also, the nutrient constituents in biochar are insufficient to provide a substantial amount of nutrients needed to support plant growth when solely applied (Siedt et al., 2020). Therefore the motive of this research was to evaluate the impacts of applied biochar with NPK and/farmyard manure on chemical properties of selected soil in central Uganda. The hypothesis tested is that the combination of biochar with farmyard manure and the NPK will improve the low fertile tropical soil than the sole application of the biochar, manure and NPK.

## 2. Materials and methods

### *2.1. Site description and experiment*

A field of about 100 $m^2$ was selected for the experiment at Uganda Martyrs University Research Farm in Central Uganda with latitude and longitude of 0.0100 and 32.00, respectively. The climate in the study area is characterized by mean annual precipitation of 1100 mm and the minimum annual temperature ranging between 20–23 °C and the maximum between 23–36 °C, respectively. The soil was classified as sandy clay loam (64% sand, 6% silt and 30% clay) according to the U.S. textural classification triangle or ferralsol based on the World Reference Base for soil resources (2006). The topsoil (0–30 cm layer) had an adequate Effective cation exchange capacity (ECEC) of 4.32 cmol/kg, soil pH of 5.8, Total Organic Carbon (TOC) of 0.93%, 0.31% of nitrogen, available phosphorus of 6.21 mg/kg and 0.43 cmol/kg of the potassium content. The study soil pH had a low pH, ECEC, which affects nutrient availability for plant growth. Parikh and James (2012) stated that soil pH ranging from 6 to 7.5 is optimal for plant growth, but some plant species can tolerate more basic or acidic conditions. Analytical procedures used to measure soil properties are in Section 2.3.

A seedbed of 2 m × 2 m was raised and leveled using hand-hoe. Four blocks with six plots each were made with 0.5 m and 1.0 m gaps between plots and blocks, respectively. The study adopted the Complete Randomized Block (CRB) experimental design involving six (6) treatments. The treatments were (i). Untreated soil as the control (ii) biochar (iii) 15-15-15 NPK inorganic fertilizer (iv) Farmyard manure (v) Biochar and farmyard manure addition (vi) Biochar and NPK addition. The biochar rate used for this study was adopted from Agegnehu et al. (2019), 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 manure and the NPK. The treatment details are presented in Table 1.

**Table 1**
Treatment rate of biochar, farmyard manure and NPK.

| Treatment | Biochar (t/ha) | Farmyard manure (t/ha) | NPK (kg/ha) |
|---|---|---|---|
| Control | 0 | 0 | 0 |
| Farmyard manure | 0 | 10 | 0 |
| NPK | 0 | 0 | 150 |
| Biochar | 10 | 0 | 0 |
| Biochar – farmyard manure | 5 | 5 | 0 |
| Biochar -NPK | 5 | 0 | 75 |

**Table 2**
The chemical properties of experimental soil, farmyard manure and biochar.

| Parameters | Experimental soil | Corn cob Biochar | Farmyard manure |
|---|---|---|---|
| pH-$H_2O$ | 5.8 | 7.5 | 6.12 |
| Total organic carbon (%) | 0.93 | 73 | 65.2 |
| Total nitrogen (%) | 0.31 | 0.75 | 1.50 |
| Available phosphorus (mg/kg) | 6.21 | 6.57 | 7.13 |
| Potassium (cmol/kg) | 0.43 | 7.3 | 4.36 |
| Effective Cation exchange capacity (cmol/kg) | 4.32 | 1.7 | 0.98 |
| Moisture content (%) | NA | 14.85 | ND |
| Volatile matter (%) | NA | 14.23 | ND |
| Ash content (%) | NA | 50.04 | ND |
| Fixed carbon (%) | NA | 20.59 | ND |

ND- not determined; NA-not determined.

Corn cob biochar was used for the production of the biochar. The corn cob feedstock was selected based on its accessibility and availability in the region. A modified oil barrel having the same functions as the Elsa stove as a gasifier was constructed using simple top-lit-updraft gasifiers for the biochar's production. Corn cob feedstock was selected for the biochar production and pyrolysis at a temperature between" 400 °C-500 °C. Farmyard manure was collected from a local poultry farm and Uganda Martyrs University dairy farm mainly consisted of discarded cattle feed, pig droppings, poultry litter, chopped fodder and animal excreta dumped in the boundary of it. The chemical properties of farmyard manure and biochar are presented in Table 2.

Amendments as per treatment details were incorporated into the soil for 14 days (incubation period) before transplanting to allow equilibration of the amendment in the soil and for mineralization to start. The application procedure involved evenly spreading amounts of the biochar and farmyard manure onto the soil surface and were thoroughly mixing with a hand rake and hoe to the required soil depth of 20 cm. The recommended rate of the NPK 15-15-15 fertilizer was applied 20 days after transplanting. Cucumber seedlings with two true leaves were transplanted into the field by hand, with double rows of 98 cm row spacing and 22 cm plant spacing on the seedbed after the 14 days of treatment amendments. The planting density of cucumber seedlings was 12 plants per plot (2 m* 2 m). Supplementary irrigation estimated at 4 mm of water was supplied every two days using watering cans in the event of no rainfall. The hoe-weeding of the field was done every three weeks.

### *2.2. Physicochemical properties and proximate analysis of biochar*

The sample of the biochar produced was taken to the laboratory for chemical and proximate analysis. Fifty (50) g of corncob biochar was put in an oven at 60 °C for dry matter determination. The produced biochar was analyzed for ash, volatile matter and fixed carbon content by proximate analysis following ASTM standards (D 1762–84) with modifications outlined by Mukherjee et al. (2011). Fixed carbon was determined by the difference between the volatile matter and the ash content. The corncob pH of biochar was estimated using the pH meter in 1:5 biochar: water (w/v) suspension. The Kjeldahl method was used for the determination of the total nitrogen (Allen et al., 1974), while the Bray-1 phosphomolybdate blue method was used to analyze the available phosphorus (AvP) content in biochar (Sahrawat et al., 1997). The potassium content of the biochar analyses was done using the $NH_4OAc$ method at pH 7. The characteristics of the biochar are presented in Table 2.

### 2.3. Soil sampling and physicochemical analysis of the soil

Composite samples were collected from each plot at 0 to 20 cm depth using the screw auger after harvest. In the laboratory, samples were air-dried at room temperature, crushed and sieved through a 2-mm sieve for physicochemical analysis. The soil pH was determined by a pH meter in 1:2.5 soil: water (w/v) suspension (Anderson and Ingram, 1993). Total Organic Carbon (TOC) was determined using the Colorimetric method (Schulte and Hoskins, 2009). The Kjeldahl method was used to determine total Nitrogen (Sáez-Plaza et al., 2013). Available phosphorus (Av. P) content in the soil was analyzed following the Bray-1 acid method (Sahrawat et al., 1997). Potassium content was determined using a flame photometer (Rhoades, 1983). 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).

### 2.4. Crop yield and macronutrient composition of cucumber fruit

Nine plants were selected per plot based on visual evaluation and tagged. The data collected on the nine plants were the number of fruits per plant and per hectare, fruit fresh and dry weights, and fruit diameter and length. Harvesting of the cucumber fruits was regularly done weekly by hand plucking the matured fruits eight weeks after transplanting. The cumulative fruit numbers and their associated weight and the total plant yield were recorded. The harvested fruits in the first week of July (9 weeks after transplanting) were used to determine the nutrient constituents. For the determination of the nutrient constituents of the cucumber fruit, two fruits per plot were sampled. The harvested fruit was 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 ground leaves' sample was used for the determination of the N, P and K. Two digestion methods described by Malavolta et al. (1997) were used for the determination of the N, P and K content such that nitric-perchloric acid was used to determine P and K while sulfuric acid was used to analyze the N content.

### 2.5. Economic analysis of treatment application

The cost–benefit analysis of the treatment was estimated based on the agronomic results obtained. The nearby local market determined the estimated farm cost. The agronomic cost included the soil amendment input (farmyard manure and biochar) and labor to prepare the land. Since the farmers made the biochar, the biochar production cost includes the kiln construction and the operation, feedstock transportation to the field. The feedstock used for biochar production was excluded from the cost because it was available at the school farm. The details of all the agronomic input costs are provided in Table 3. The net profit of the treatment was calculated as Total income sales of cucumber yield per treatment - Total agronomic input cost per treatment. The local market was used to stipulate the price of the cucumber fruit. i.e. 1.13 US$ per kg cucumber fruit.

### 2.6. Data analysis

The data was analyzed using Statistix Edition 8.1 software. One-way ANOVA was used to compare soil physicochemical properties, cucumber yield, nutritional constituents and net income. 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.

## 3. Results and discussion

### 3.1. Effect of biochar, farmyard manure and/NPK on soil chemical properties

#### 3.1.1. Soil pH

Soil pH ranged from 5.09 to 6.12 units, with the higher end of the ranges being for biochar and manure additions. The sole application of the biochar increased the soil pH more than the unamended biochar plots. Biochar and NPK addition significantly ($p < 0.05$) increased the soil pH compared with the sole application of the NPK. The biochar and manure addition obtained higher pH than the biochar and NPK addition plots (Fig. 1a). The rise of the soil pH could be attributed to the high pH of the biochar (7.5) as alkaline substances were released from the biochar into the acidic soil during the remediation process (Antonangelo et al., 2020; Shetty et al., 2020). The increase of the soil pH during the liming process is attributed to the substitution of hydrogen and aluminum iron on the colloidal surface of the soil with the cation oxides, thereby decreasing the exchangeable acidity ($H^+ + Al^{3+}$) in the soil environment (Chintala et al., 2014). However, the possibility of biochar to increase the soil pH depends on the ash content, basic oxide cations and the absorbent nature of the biochar (Novak et al., 2009; Luo et al., 2011). The lower soil pH obtained by the biochar and NPK addition compared to the biochar and manure addition plots was because of the acidic nature of the NPK, which could probably contribute to the less pH (Adekiya et al., 2020). Besides increasing the soil pH by the biochar in the biochar and manure addition plot, manure contributes to raising the soil pH through the complexation of its organic anion released into the soil exchange site (Wong and Swift, 2011).

#### 3.1.2. Total Organic Carbon (TOC)

Total organic carbon varied from 0.63% to 1.82% with the higher end of the ranges being for biochar and manure addition. As expected, the addition of biochar increased the TOC by 43.33% compared to the control. The biochar amended plots showed higher TOC content than the sole application of manure and the NPK (Fig. 1b). The increased TOC observed in the biochar amended soil was because of the abundance of aromatic compounds in the biochar that are resistant to biological degradation (Phares et al., 2020). Biochar potentially contributes to the TOC through the increase of the soil labile organic carbon pool size when it undergoes mineralization and increases aromatic carbon with a decrease of the O-alkyl C contents, resulting in the lignin's increase content and the aromatic compound in the soil as reported by Singh and Cowie (2014). The increase of the TOC in the combined biochar and the manure plots was because of the C added by the biochar and the additional C from the organic matter through the manure addition (Grunwald et al., 2016), while the biochar and NPK addition solely depended on the C input from the biochar. The actual cause of the lower TOC recorded by biochar and NPK addition was because of the less contribution of the 15-15-15 NPK fertilizer to add C input into the soil environment as compared to the C input being added by the manure (Adekiya et al., 2020). The increase in the TOC observed after biochar and manure application agreed with the findings of Frimpong et al. (2016), as they concluded that C accumulation and sequestration are stimulated by biochar and manure application. According to Hu et al. (2019), an increase in soil organic carbon reflects soil organic carbon stabilization and sequestration potential.

**Table 3**
Production costs of the treatment application in the agricultural system in US$ per ha per cucumber crop season.

| Description | Treatments | | | | | |
|---|---|---|---|---|---|---|
| | Control | Biochar | Manure | NPK | Biochar-manure | Biochar-NPK |
| Production Cost | Cost in US$ | | | | | |
| Labour[a] | 291.50 | 291.50 | 291.50 | 291.50 | 291.50 | 291.50 |
| Transportation of the corn cob | 0 | 26.99 | 0 | 0 | 26.99 | 26.99 |
| Seeds[b] | 45.8 | 45.8 | 45.8 | 45.8 | 45.8 | 45.8 |
| Farmyard manure[c] | 0 | 0 | 143.9 | 0 | 71.95 | 0 |
| Biochar[d] | 0 | 48.59 | 0 | 0 | 48.59 | 48.59 |
| NPK[e] | 0 | | | 102.63 | 0 | 51.52 |
| Total | 337.3 | 412.88 | 481.2 | 439.93 | 556.78 | 515.51 |

[a]Land clearing (215.93 US$/ha/season) and weeding/digging (48.58 US$/ha/season), seedling transplanting (48.58 US$/ha/season).
[b]20 kg cucumber seeds (2.29 US$ per kg) required for one season per hectare.
[c]10 tonnes farmyard manure (14.39 US$ per tonne).
[d]The biochar cost involves, the cost of the local kiln production (48.59 US$/ha/season) and labor for biochar production (26.99 US$).
[e]150 kg NPK (0.68 US$ per kg).

### *3.1.3. Effective Cation Exchange Capacity (ECEC)*

Biochar addition to the NPK and the manure showed a significantly higher ($p < 0.05$) ECEC content than the control and all other treatments. The ECEC varied from 4.03 cmol/kg to 5.97 cmol/kg, with the higher end of the ranges being for biochar and manure addition. The amount of the ECEC obtained in the applied biochar was higher than the sole application of the manure and the NPK (Fig. 1c). The increased ECEC in the biochar amended soil was because of the slow oxidation of biochar to oxygenate the functional groups of biochar surface and enhance the formation of organo-mineral (Chen et al., 2011). According to Lehmann et al. (2015), biochar in the soil can have larger negative charges on their surface, attributed to the formation of the phenolic group by abiotic oxidation, contributing to the increase of the ECEC in the soil environment. Therefore, biochar and manure addition differs significantly as compared with biochar and NPK addition. The combined biochar and manure plots obtained higher ECEC (5.97 cmol/kg) more than the biochar and NPK addition (5.73 cmol/kg) because of the organic matter derived from the farmyard manure. The organic matter entails large numbers of charged functional groups, which contribute significantly to the increase of ECEC (Mensah and Frimpong, 2018). Also, due to the high surface area of the biochar, it adsorbed the organic matter derived from the manure and the soil environment on its surface, causing the release of carboxylic and phenolic acid groups into the soil environment (Domingues et al., 2020). At the same time, the biochar and NPK addition depend much on the biochar to increase the ECEC (Gondek et al., 2019).

### *3.1.4. Phosphorus*

Biochar with farmyard manure and NPK showed a significant ($p < 0.05$) increased in available phosphorus. The available soil phosphorus ranged from 4.18 mg/kg to 7.54 mg/kg, with the highest being recorded by biochar and NPK addition. The addition of biochar increased the available phosphorus by 17.31% compared with the control (Fig. 1d). The biochar and manure increased the available soil phosphorus by 8.41% than the sole application of manure. In comparison, the combined application of biochar and NPK improved the available phosphorus by 16.17% compared to the sole application of the NPK. The biochar and NPK addition differs significantly as compared to biochar and manure addition. Biochar and NPK addition obtained available phosphorus of 9.92% higher than the biochar and manure addition. The addition of biochar to the weathered soil increased soil pH, leading to the alteration of P complexation with $Al^{3+}$ that occurs in highly weathered acidic soils, increasing soil P availability for plant uptake (Zhai et al., 2015; Arif et al., 2017). The high available phosphorus in the combined biochar and NPK plots was because of the high phosphorus concentration in the inorganic NPK fertilizer (Adekiya et al., 2020). Hence this could explain the higher available P in the combined biochar and NPK plot than the co-applied biochar with manure. The phosphorus availability could also be attributed to the P concentration in the biochar ash, manure and the inorganic fertilizer, which add up to the soil phosphorus pool, as reported by Apori and Byalebeka (2021).

### *3.1.5. Total nitrogen*

Varying nitrogen content was recorded after the treatment application. The total N content ranged from 0.09% to 0.41% with the highest obtained by biochar and manure addition. The sole application of the manure obtained a higher nitrogen content than the sole application of the applied NPK fertilizer (Fig. 1e). The high total nitrogen content in the manure could probably be attributed to manure functions to improve acidic soil, increase ECEC and supplement the soil with nutrients being released from their organic matter. The biochar and NPK addition recorded higher total nitrogen (0.41%) than the biochar and the manure addition (0.36%) since the 15-15-15 NPK fertilizer contains more nitrogen than the manure. The addition of the biochar to the NPK fertilizer and manure decreased the apparent ammonification and ammonium loss because of the temporary adsorption of $NH^{4+}$ onto the biochar surface. (Steiner et al., 2010; Widowati et al., 2011; Awasthi et al., 2016). Biochar can release a small amount of nitrogen add up to the total nitrogen pool, as reported by Cui et al. (2017).

### *3.2. Effect of biochar, farmyard manure and/NPK applications on cucumber yield*

The fruit weight varied from 106.15 to 189.85 g, with the higher end of the ranges being for the combined biochar and inorganic NPK fertilizer plots. However, the combined biochar and manure effect on the fruit weight did not differ significantly compared to the biochar and inorganic NPK addition. Application of biochar with farmyard manure and/NPK showed a significantly ($P < 0.05$) increased fruit yield. The fruit yield varied from 2.63 t/ha to 6.97 t/ha, with the higher end of the ranges obtained in the combined biochar and NPK plots (Table 4). The higher yield obtained in the biochar amended plots was because of the biochar's ability to improve the soil physicochemical properties of the soil, which result in better growth and yield than the unamended biochar plots.

Similarly, the biochar application increases the soil moisture to provide adequate water for plant metabolism activities, increasing plant productivity, as reported by Yu et al. (2019). According to Jaiswal et al. (2020), biochar increases plant physiological performance through its positive impact on the signaling pathway of plant hormones directly involved in plants' growth, development, and immunity. Similarly, Rab et al. (2016), concluded that the increase of crop yield in biochar amended plots is due to the enhancement of the reproductive efficiency

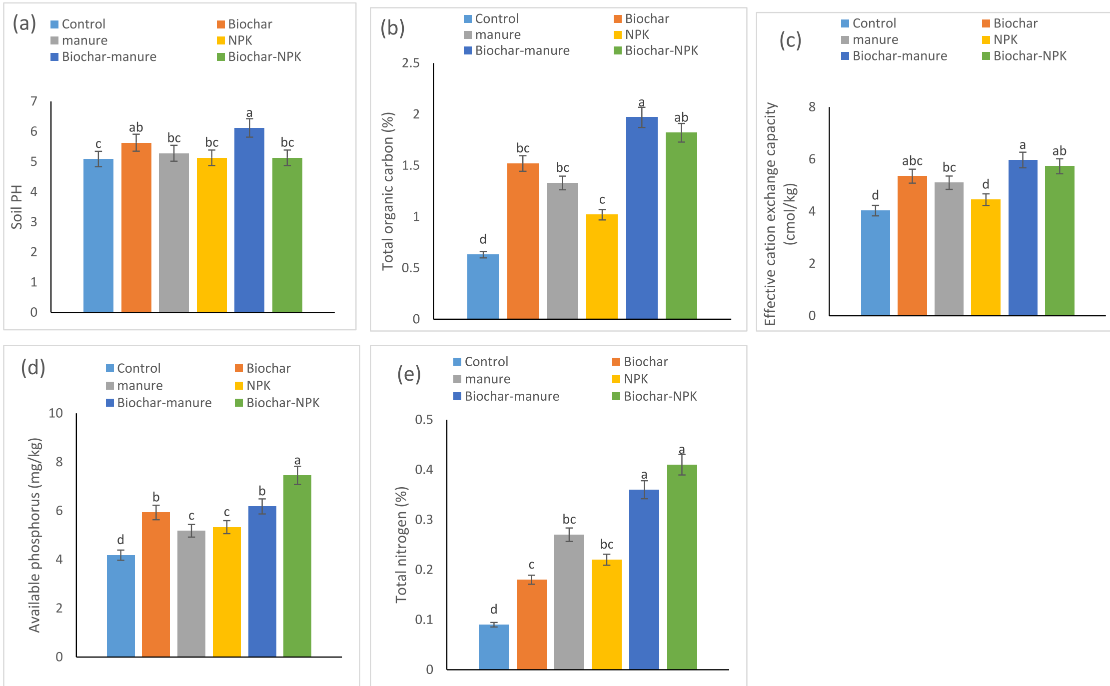


**Fig. 1.** Effect of biochar, farmyard manure and/NPK on soil pH (a), total organic carbon (b), effective cation exchange capacity (c), available phosphorus (d) and total nitrogen (e); The same letter on the bars are not significantly different at p ≤ 0.0 5 using Tukey HSD at the 0.05 significance level; Error bars represent standard deviation of the means.

**Table 4**
Combined effect of biochar with manure and NPK on cucumber yield.

| Treatment | Number of fruit per plant | Fruit length (cm) | Weight of fresh fruit (g) | Fruit yield (kg/plant) | Fruit yield (t/ha) |
|---|---|---|---|---|---|
| Control | 9.50c | 13.84a | 106.15d | 0.88d | 2.63f |
| Biochar | 10.75bc | 14.94a | 137.22cd | 1.62c | 4.87e |
| Manure | 9.50c | 14.78a | 145.50bcd | 1.73bc | 5.17d |
| NPK | 10.25bc | 15.215a | 157.73abc | 1.90abc | 5.73c |
| Biochar-manure | 11.50ab | 15.21a | 183.44ab | 2.21ab | 6.66b |
| Biochar-NPK | 12.75a | 15.52a | 189.85a | 2.31a | 6.97a |
| $Significant^X$ | ** | NS | ** | *** | *** |
| $SED^Y$ | 0.29 | 0.49 | 9.67 | 0.11 | 1.25 |

$SED^Y$ 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, NS = significant at P > 0.05. Means followed by the same letter in each column are not significantly different at p ≤ 0.0 5 using Tukey HSD.

by the biochar. The increased cucumber yield in the biochar and NPK addition than the combined biochar and manure plot was due to the higher nutrient concentration in the inorganic NPK fertilizer, which was adsorbed onto the surface biochar and restricted the nutrient from leaching. The interaction of the biochar and the NPK may lead to high fertilizer use efficiency and decreased plant nutrient loss, resulting in cell division and physiological performance (Agbede et al., 2019). A similar result was obtained by Adekiya et al. (2020), as they showed that co-applied biochar with NPK increased ginger yield than co-applied biochar with poultry manure. Increasing crop yield and performance due to biochar application has also been reported for crops including lettuce (Frimpong et al., 2016), maize (Mensah and Frimpong, 2018), soya bean (Lee et al., 2013), tomatoes (Usman et al., 2016), Mung bean (Rab et al., 2016) and radish (Nabavinia et al., 2015).

### 3.3. Effect of biochar, farmyard manure and NPK applications on nutrient composition of cucumber fruit

Varying nitrogen, phosphorus and potassium contents in the cucumber fruit were observed after treatment application. Phosphorus content in the cucumber fruit ranged from 0.22% to 0.39%, with the higher end of the ranges being for the biochar and NPK addition plots. The nitrogen content in the cucumber fruit varied from 1.57% at control to 2.91% at biochar and NPK addition. The potassium content ranged from 1.12% at control to 2.15 at biochar and NPK addition. All the biochar amended plots showed higher potassium content compared to the control (Table 5). The combined biochar and NPK plots obtained a higher nutrients composition than the biochar and manure addition. The increased nutrients composition in the combined biochar and NPK plots was attributed to the synergistic relationship between the biochar and the 15-15-15 NPK fertilizer and the higher amount of nutrients in the NPK fertilizer, which could probably result in the higher nutrients uptake by the plant and fertilizer use efficiency. Also, the higher nutrients composition in the combined biochar and NPK fertilizer was due to the sorption of nutrients from the NPK fertilizer onto the biochar surface, causing a slow release of nutrient to the soil environment, stimulation of microbial colonization, enhancement of soil physical environment such as bulk density and porosity, etc. (Han et al., 2016; Nadeem et al., 2017). Hence, resulting in the nutrient's bioavailability for plant uptake via their root (Nigussie et al., 2012; Lusiba et al., 2020).

**Table 5**
Effects of biochar, farmyard manure and/NPK applications on the dry matter percentage of total N, P and K in the cucumber fruit after harvest.

| Treatment | Phosphorus | Nitrogen | Potassium |
|---|---|---|---|
| Control | 0.22e | 1.57d | 1.12d |
| Biochar | 0.32c | 1.91b | 1.55ab |
| Manure | 0.27d | 2.11c | 1.44cd |
| NPK | 0.28d | 2.23bc | 1.60bc |
| Biochar-manure | 0.36b | 2.51a | 1.91ab |
| Biochar-NPK | 0.39a | 2.91a | 2.15a |
| $Significant^X$ | *** | *** | *** |
| $SED^Y$ | 0.05 | 0.09 | 0.144 |

$SED^Y$ and $Significant^X$ effects were obtained from one-way analysis of variance: *** significant at P < 0.001. Means followed by the same letter in each column are not significantly different at p ≤ 0.0 5 using Tukey HSD.

**Table 6**
Costs and benefits under different fertilization treatments of cucumber.

| Treatment | Fruit sale (US$/ha) | Net income (US$/ha) |
|---|---|---|
| Control | 3005.8f | 2669.5f |
| Biochar | 5508.8e | 5097.1e |
| Manure | 5876.0d | 5394.45d |
| NPK | 6491.9c | 6054.3c |
| Biochar-manure | 7514.5b | 6959.8b |
| Biochar-NPK | 7870.5a | 7356.0a |
| $Significant^X$ | *** | *** |
| $SED^Y$ | 32.52 | 34.53 |

**= significant at P < 0.01, ***= significant at P < 0.001. Means followed by the same letter in each column are not significantly different at p ≤ 0.0 5 using Tukey HSD. The details of the production cost used for the calculation of the net income are presented in Table 2; 1UGX=0.00027 US$.

### *3.4. Economic benefit analysis of different fertilization treatments of cucumber production*

Each treatment's cost and financial benefit were estimated from the agronomic input cost/production cost (Table 3) and the fruit sales (Table 6). All the treatments observed higher net income compared to the control. The net income varied from 2669.5 US$/ha at control to 7356.0 US$/ha at biochar and NPK addition. The combined biochar and NPK plots obtained a higher net income (7356 US$/ha) than the sole application of NPK (6054.3 US$/ha) and the biochar and manure addition (6959) (Table 6). The higher cucumber yield owing to higher nutrient and water acquisition by the combined application of biochar with NPK could be the reason for the enhanced net income than the biochar and manure addition (Zheng et al., 2017). However, the high net income observed in the biochar amended plot was ascribable to the positive synergistic effect between the biochar and the cucumber plant, resulting in the cucumber's heavyweight fruit, which eventually leads to higher cucumber fruit sales.

## 4. Conclusion

Degraded tropical soils have low total organic carbon, available phosphorus nitrogen and soil pH; therefore, restoration of degraded tropical soil is needed to ensure crop productivity. This study showed that the combined application of biochar with farmyard manure and/NPK increased soil quality indicators such as soil pH, total organic carbon, soil available phosphorus, and total nitrogen than the solely applied manure and NPK. Furthermore, the Co-application of biochar with NPK increased available soil phosphorus, nitrogen, cucumber yield, nutrient constituents of cucumber fruit and net income than the co-applied biochar with manure. These findings showed that co-application of biochar and NPK fertilizer can restore degraded soil in the tropics than co-application of biochar with farmyard manure.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Availability of data and materials

All data generated or analyzed during this study are included in this manuscript.

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