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RESEARCH ARTICLE

THE IMPLICATIONS OF BIOCHAR AMENDMENT AND PLANTING ON SANDY LOAM SOIL PROPERTIES UNDER HUMID LOWLAND TROPICAL AGROCLIMATIC CONDITIONS

Serah Temai[a], Aniyo Erain[a], Gim Shong[a], Gideon Wiap[a], Patrick S. Michael[a,b]*

[a]Department of Agriculture , Papua New Guinea University of Technology, PMB, LAE, MP 411, Papua New Guinea
[b]Environmental Research and Management Center, Papua New Guinea University of Technology, PMB, LAE, MP 411, Papua New Guinea
**Corresponding Author Email: patrick.michael@pnguot.ac.pg*

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ABSTRACT

Climate change affects agricultural productivity because it impacts agroclimatic factors such as soil physical, chemical, and biological properties, rainfall, temperature, irradiation, and carbon dioxide concentrations. Climate change's adverse impacts warrant studies showing how these factors influencing crop productivity can be sustainably managed in an altered climate. This study tested the effectiveness of biochar obtained from pyrolyzed sugarcane leaves collected from the field following mechanical harvesting. The biochar was applied in the soil alone or in combination with NPK fertilizer and planted with *Oryza longstaminata.* Farmyard manure was included as a common soil amendment to compare the results. Eight treatments were replicated four times and set up in a completely randomized design (CRD) under greenhouse conditions. Watering was done twice daily, and soil samples were taken after four months. During sampling, soil from only three replicates were removed, placed on a canvas and homogenized, and a 500 g each was taken for processing. The samples from the three replicates were mixed again and air-dried for two days, and triplicate (n=3) samples were taken again, placed in separate paper bags per replicate and sent to the laboratory for analysis and measurements using standard analytical procedures. The data from the replicates of the treatments were pooled, averages taken, and analyzed statistically. The results showed biochar application had no significant effect on soil pH, electrical conductivity, organic matter content, and carbon stock even when planted, compared to the effects on water holding capacity, bulk density, and total porosity. Consequently, there was no significant effect on soil nitrogen, phosphorous, potassium, magnesium, and the calcium contents. The results were the opposite when co-application with the chemical NPK fertilizer was made. To a large extent, our results showed biochar interaction is quite effective when co-application is made with another nutrient source, and the findings have implications for the management of sandy loam soil under humid lowland tropical climatic conditions.

KEYWORDS

Amendments, biochar, climate change, humid lowland, implications, PNG,

1. INTRODUCTION

Climate change is multifaceted (IPCC, 2007) and affects crop productivity due to its direct impact on various environmental and climatic factors (e.g., Michael, 2019a; 2020a). The roles of most of these factors in agricultural productivity are closely interrelated and directly influence the specific roles (Karmarkar et al., 2016). Broadly, these factors that affect crop productivity are the abiotic (the non-living) and biotic (the living) components of an environment (e.g., the farm). The biotic component is made up of all life forms (e.g., microorganisms, animals, and plants), and the abiotic component includes soil (e.g., organic matter, nutrients, water, and temperature), carbon dioxide, oxygen, and irradiation (energy from the sun) (Mills et al., 2014; Horel et al., 2015). The interaction of crops (the biotic component in general) with these factors influences productivity.

Nutrients and moisture, for instance, are obtained from the soil. The organic matter in leaf litter, root exudates, manure, and death carcass eventually become available to microbes (act as a substrate). It sustains the continuum of pedological processes (biological, chemical, and physical). These processes include regulating nutrient availability, organic matter content, moisture retention, pH, redox, electrical conductivity, temperature, and to some extent, the soil and atmospheric carbon dioxide composition (Hotchkiss et al., 2000). The soil pH and redox, regulated by organic matter from the biotic factors and moisture from precipitation and cellular respiration, control nutrient availability, absorption, and adsorption. The oxygen composition in the soil is affected by organic matter, bulk density, porosity, and biological activities, e.g., burrows of earthworms and roots (Moebius et al., 2007).

The pedological processes are affected by temperature, which is entirely dependent on the biological, chemical, and physical processes and the energy generated, the principal energy source being the irradiation from the sun (Rey, 2015; Bard et al., 2017). The insolation and availability depend on the atmospheric compositions (e.g., relative humidity, cloud cover, and carbon dioxide concentration), altitude, and distance from the equator. More energy is available along the equator than at the poles because of divergence in biodiversity coupled with insolation being high in the lower altitudes and arid climates. Carbon dioxide concentration is directly dependent on the microbial activities, cellular respiration of living things, and anthropogenic and natural activities and has a direct bearing

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on the productivity through photosynthetic activities of crops, including the release of oxygen which is important to the whole process (Haynes, 2008; Saha and Mandal, 2009). Under most soil use conditions, the release of carbon dioxide from the decomposition of organic matter as a substrate depends on the type of microbial ecology established, soil moisture, and ambient temperature (Gottschalk et al., 2012; Walter et al., 2013). Decomposition and release of carbon dioxide are further limited by oxygen, whose availability is influenced by soil organic matter, bulk density, and porosity.

Climate change is affecting all the environmental and climatic factors that support crop productivity and provide important ecological services such as the nutrient, water, carbon dioxide and the oxygen cycles. Vegetation is already highly affected because of change (compared to the usual) in precipitation, temperature and atmospheric air composition. The changes in turn are affecting the soil biological, chemical and physical properties (Sing et al., 2011; Horel et al., 2014). Mills et al. (2014) pointed out the impacts of moisture and temperature stresses soil functions, with too much water leading to inundation and displacement of oxygen, lesser decomposition and nutrient cycling. Similarly, high temperature leads to loss of soil moisture and lesser microbial activity, which again, leads to poor soil biological, chemical and physical conditions (Michael, 2019b; 2020b). Prolonged period of lesser rain and high temperature followed by heavy rain leads to erosion, runoff, and desertification (Varallyay, 2010) and has negative impact of aggregate stability, soil texture, pH, bulk density, porosity, organic matter content and water retention (Singh et al., 2011; Singh et al., 2019).

As pointed out earlier, the atmospheric carbon dioxide concentration contributed by microbial decomposition of organic matter is affected, and that alone is a detriment to the survival of other living things because of the impacts on oxygen and food (carbohydrate) production (e.g., Michael, 2020c). An altered climate affects all important cycles that are important to crop productivity and survival of any life form and need tailored approaches to manage the negative impacts (Michael, 2020d).

2. MATERIALS AND METHODS

2.1 Description of Study and Soil Collection Sites

The study was conducted at the Papua New Guinea University of Technology (PNGUoT) located in Lae, Morobe Province, PNG (6°42′55.89″S; 146°59′59.66″E). The farm (6°41‟S, 146°98‟E) from which the soil samples were collected is located 65 m above sea level. The mean annual rainfall is up to 3,800 mm; the average daily temperature is 26.3 °C, the average daily minimum is 22.9 °C, and the maximum is 29.7 °C. Annual evaporation (US Class A pan) is 2,139 mm, and rainfall exceeds evaporation each month. The climate is classified as Af (Koppen), i.e., a tropical rainy climate that exceeds 60 mm of rain in the driest month. The soil is well drained, derived from alluvial deposits, and is classified as a sandy, mixed isohyperthermic, Typic Tropofluents (US Soil Taxonomy) or Eutric Fluvisol (World Reference Base) (Aipa and Michael, 2018).

2.2 Soil and Organic Matter Collection

A stripping method was used to collect soil samples from the farm from the 0 - 30 cm of the surface. Several buckets full of this soil were collected and taken to the greenhouse, where the experiments were conducted. Before setting the experiments, all the soils were spread on a canvas placed on a smooth concrete surface inside the greenhouse, homogenized by manual mixing, and air-dried for three days. The air-dried soils were sieved using a 0.5 mm sieve to remove coarse materials, including plant matter, and repeated until sufficient amounts of soil for the whole experiment were obtained.

Table 1: The chemical and physical properties of the soil used.

	Soil properties											
	1	2	3	4	5	6	7	8	9	10	11	12
Content	5.0	2.9	38	85	0.4	6.7	0.1	0.1	25	0.2	0.9	4.3

The numbers in the order 1 to 13 are SOM (%), SOC (%), C_{stock} (g ha^{-1}), WHC (%), BD (g cm^{-3}), pH, EC (mS cm^{-1}), total nitrogen (%) and available phosphorus, potassium, magnesium and calcium (mg kg^{-1}), respectively.

Organic matter (sugarcane leaf trash from mechanical harvesting) was collected from a local sugarcane farm. These plant materials were brought to the greenhouse and sun-dried on a metal bench for nearly three days, then chopped into small pieces of equal size (50 mm) and oven dried at 70 °C for four days. The brittle plant materials were pyrolyzed at 550 °C, allowed to cool down for two hours, and collected for soil amendment. The farm yard manure was collected from the Agriculture Farm, PNGUoT. The commercial NPK fertilizer (12-12-17) was sourced from a local supplier.

2.3 Planting Material

The root stocks of *Oryza longistaminata* (wild rice) were obtained from a local collection from the Department of Agriculture, PNGUoT, and used as the propagules. Excess leaves and older stalks were removed and kept in a bucket of water overnight prior to planting. Overnight incubation in water was to relive the rootstocks from stresses and rejuvenation.

2.4 Experimental Treatments

A total of eight treatments with four replicates (*n*=4) were prepared and setup:

(i) Control (Con)– no amendment or planting,

(ii) Manure (Man) – 2 tons ha^{-1} cattle manure (CM) only,

(iii) Biochar (Bio) – 2 tons ha^{-1} sugarcane trash (ST),

(iv) Fertilizer (Fert, recommended NPK) – 0.14:0.14:0.19 kg ha^{-1},

(v) Biochar + fertilizer (Bio+Fert) – 2 tons ha^{-1} ST +2 tons ha^{-1} CM amendment,

(vi) Planted (Pl) – No amendment,

(vii) Biochar + Planted (Bio+Pl) – 2 tons ha^{-1} ST amendment + planting, and

(viii) Manure + planted (Man+Pl) – 2 tons ha^{-1} CM amendment + planting.

Thirty-two polythene pots (30 cm in height and 40 cm in diameter) were filled with the air-dried soil (1300 g), and the required amendments were worked into it manually. In all the planted treatments, eight rootstocks were planted within the top 10 cm (two each at four spots in a pot) and replicated four times (i.e., 32 plants per treatment and 256 plants in total) and set in completely randomized design (CRD) under greenhouse conditions. Each treatment was carefully watered twice daily using tap water for four months. All the plants were fully grown but not mature enough to flower when harvested.

2.5 Soil Sampling and Laboratory Measurements

The plants were uprooted (and trashed) during harvesting, and soil samples were collected by manually pushing a metallic sampler with a 10 cm hollow diameter into the soil. Four samples were taken from a pot and mixed with those of the replicates. Triplicate samples from the mixed soil from each treatment were used to measure soil pH, soil organic carbon (SOC), water-holding capacity (WHC), and bulk density (BD) and analysis of selected macronutrients at the University Analytical Services Laboratory (USAL), PNGUoT. pH was measured in standard dilution (pH meter (1:5 soil: water w/v)) using a pH meter (potentiometry) (e.g., Michael et al., 2014), and electrical conductivity was measured using a Direct Soil EC meter (Spectrum Technologies Inc., 12360S Industrial Dr. East Plainfield, IL 60585) in a solution (1:5 soil: water w/v) (potentiometry).

The SOC content (%) was measured using the weight loss-on-ignition method (Schutle and Hopkins, 1996). As a standard procedure (Michael, 2019b), a 5 g of the soil samples were placed in a crucible by weighing and heated in a muffle furnace for 12 h at 105 °C to remove moisture (Wf) and combusted again at 375 °C for 17 h, cooled for 2 h. The soil residue in the crucibles was combusted in the muffle furnace at 800 °C for 12 h, cooled for 2 h (Fw). The SOC was calculated as follows:

$$\text{SOC (\%)} = [((W_f - F_w) \div W_f) \times 100] \div 1.724 \quad (1)$$

where the SOC content was determined using the weight loss-on ignition method, and 1.72 is a conversion factor. The conversion factor was used to convert the organic matter content to organic C, assuming there was 58% C in the organic matter. The organic matter contents of the soil (SOM) were estimated using the SOC content and the conversion factor (Cf, 1.72) as

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follows:

$$SOM = [(SOC) \times C_f)] \quad (2)$$

Bulk density (g soil cm^{-3}) was calculated by oven-drying of the cores at 105 °C for 48 h followed by re-weighing. The oven dry weights (ODW) were divided by the volume of the core (VOC) and kept as the bulk density (BD) of the 30 cm (Michael, 2021) as per Eqn. 3.

$$BD\ (g\ soil\ cm^{-3}) = [(ODW\ (g) \div VOC\ (cm^{-3}))] \quad (3)$$

Total porosity (TP) was determined as pointed out by Landon (1999):

$$TP = \left(1 - \frac{BD}{d}\right) 100 \quad (4)$$

TP (%) and BD were as described and *d* is particle density equal to 2.65 g cm^{-3}.

The size of the C stock in each 30 cm profile was calculated as the sum of the individual C fractions (%) × BD (g soil cm^{-3}) × sampling profile (SP, m) and expressed as g C ha^{-1}.

$$C_{stock}\ (g\ C\ ha^{-1}) = [(SOC \times BD \times SP)]10\ 000 \quad (5)$$

The water-holding capacity (WHC) was estimated by setting soil samples at 100% WHC by soaking them in water and draining them through a filter overnight. These were weighed for the wet weight (Ww) and dried in an oven at 105 °C overnight, and reweighed for the oven-dry weight (ODw) (Bob and Michael, 2022). WHC was determined as follows:

$$WHC\ (\%) = [((Ww-ODw) \div ODw) \times 100\% \quad (6)$$

All the soil nutrients were measured using standard analytical procedures: Kjeldhal (Buchi K436 speed digester and Buchi K-350 Kjeldahl distillation unit) for nitrogen, and OLSEN (Shimadzu 1800 UV/VIS spectrophotometer, Mettler Toledo, Model UV5Bio) for available phosphorus, and ICP-OES (Spectro ARCOS brand) following 1 M NH_4Cl extraction for exchangeable potassium, magnesium, and calcium.

2.6 Statistical Analysis

The data from only three replicates were analyzed, as reported in various studies (Michael, 2020e). The treatment averages of all the parameters (e.g., pH) were obtained by taking the mean of the three replicates. Significant differences ($p \leq 0.05$) between treatment means were determined by two-way ANOVA using statistical software JMPIN, AS Institute Inc., SAS Campus Drive, Cary, NC, USA 27513 to compare the treatment means. In all the data figures, the values are mean ± standard error of three replicates (n=3). An asterisk (*) indicates a significant difference ($p \leq 0.05$) between the control and the treatments.

3. RESULTS AND DISCUSSION

3.1 Effects on Soil Organic Matter, Water Holding Capacity, Bulk Density And Total Porosity

The SOM, WHC, BD, and TP were estimated using the relevant equations previously given. The highest SOM content was measured in soil co-amended with biochar and fertilizer, followed by lone manure and fertilizer (Table 2). Planting alone or following biochar and manure amendment resulted in a decrease in the SOM. The SOC stock estimated based on the SOC, BD, and sampling profile decreased the carbon stock. The decreases being higher in the Bio+Fert>Fert>Man>Bio+Fert>Bio>Man+Pl>Pl>Control (Table 2). These results showed all the amendments enhanced the microbial interaction of the SOC as a substrate for energy. The loss in the planted soil indicated plants used carbon as an energy source. The results showed that biochar amendment and planting contributed to the SOC stock but were insignificant. There was also no clear relationship between the SOM and the SOC stock. There was lesser carbon in the soil when organic matter content was high, e.g., in the manure and fertilizer-amended soils (Table 2).

Table 2: The SOM, WHC, BD and TP in soils planted with or without amendments

Effects	Treatments							
	Con.	Man.	Bio.	Fert.	Bio+Fert	Pl	Bio+Pl	Man+Pl
SOM (%)	6.0	7.4	5.9	7.1	8.8	4.8	4.0	6.2
C_{stock} (g ha^{-1})	63.0	38.7	51.0	36.9	30.6	58.8	41.4	54.0
WHC (%)	45	60	39	56	75	30	33	40
BD (g cm^{-3})	0.6	0.3	0.5	0.3	0.2	0.7	0.6	0.5
TP (%)	30	40	35	37	45	26	27	33

The SOM influenced the WHC, and there was a clear relationship. As SOM increased, so was the WHC, the highest measured in the Bio+Fert amended soil with 8.8% (Table 1). As expected, where SOM was higher, BD was smaller, reflected in the TP. The TP was high when SOM was high, and BD was lesser (Table 1).

The changes in pH measured are shown in Figure.1. Compared to the initial soil pH (broken line), the changes measured in all the treatments were small except in the manure-amended soil without and with plants. Cattle manure amendment significantly lowered the pH to a range of 5.5 – 5.8 units (Figure. 1). The changes measured in the fertilizer and biochar amended were higher than the control, but the differences were insignificant. Biochar amended and planting alone significantly increased the pH by 1.0 unit (Figure. 1).

The literature shows the role of cow manure on soil pH is variable. One study showed cow manure increased soil pH, and others the opposite. Citak and Sonmez (2011) added cow manure to soil with initial pH of 8.6 that decreased it to 7.7 units, supporting our findings where the pH was decreased to a range of 5.6 to 5.9 from an initial pH of 6.7 (Figure. 1). Chemical fertilizer addition also decreased the pH (Citak and Sonmez, 2011). Many other studies (Ticman Jr., 2022; Kameyama et al., 2017) have shown biochar amendment increases soil pH and more so in acidic soils (Jemal and Yakob, 2021).

Our results showed biochar amendment did not increase the soil pH, just like manure, except when planted. The probable reason for this is the leaching of the alkalinity from the amendments due to the sandy nature of the soil (Michael, 2020d). Under the planted soil condition, the carbon need for the plants prevented the leaching behaviour, hence a high pH, compared to the planted soil where the presence of plants enhanced leaching and lowering of the pH (Figure. 1).

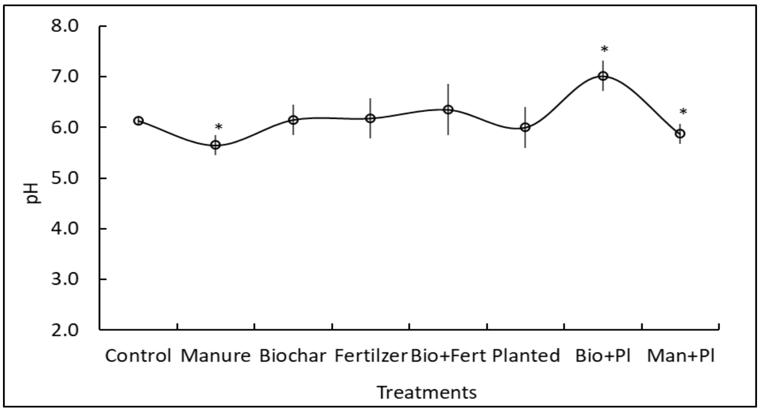

Figure 1: The changes in pH measured following amendments and planting.

The changes in electrical conductivity measured are shown in Figure. 2. The changes measured following manure amendment with or without plants had not much effect and were similar to the control soil. Such variable results were reported by Citak and Sonmex (2011). Electrical conductivity was significantly lower in the biochar-amended soil with or without plants, agreeing with the suggestion that biochar could be used to lower electrical conductivity and effects of biochar on electrical conductivity are insignificant (Tsai and Chang, 2020; Nawaz et al., 2018). Compared to all the treatments, fertilizer amendment alone or with biochar significantly increased the electrical conductivity to 0.34 and 0.45 mS cm^{-1}, respectively. This effect was as expected since manure carries charged ions, and their presence increases the electrical conductivity. In other words, manure is a high nutrient source containing many nutrients released into the soil, e.g., those shown in Figures. 4, 5, and 6.

3.2 Effects on Primary and Secondary Macronutrients

There was not much organic carbon addition by biochar amendment. Manure application increased it by 0.7% in the lone amendment and by 0.01% in the amended and planted soil (Figure. 3). Co-application of biochar and fertilizer increased the organic carbon content by nearly 2% and decreased in the soil planted without an amendment or biochar was applied and planted. The impact on soil organic matter was Bio+Fert(45.6%)>Bio(28.6%)>Fert(18.3%)>Man (5.7%)>Bio+Pl(1.4%). These results showed biochar significantly increased the soil organic matter content, agreeing with findings of other studies, (Cooper et al., 2020).

In almost all cases, planting decreased the soil organic carbon content, indicating plants need carbon as an energy source for growth and development, supporting recent findings (Michael, 2020c). Michael (2020e) added cogon biochar in sandy loam soil from the same site used in this study and reported that planting of *Panicum coloratum* decreased the SOC content. Similar results were reported when sweet potato was planted in the same sandy loam soil amended with organic matter.

Manure, fertilizer, and co-application of biochar and fertilizer significantly increased the soil nitrogen content, the highest being 0.56% from the co-application. In the soils amended with biochar, planted without amendment, and amended with biochar or manure and planted, the nitrogen content was around 0.2% (Figure. 4). The overall results showed only manure and the mineral fertilizer had a significant effect on the soil nitrogen content. In the planted soils, the nitrogen content was much smaller, a strong indication that the plants used this nutrient (Michael, 2020e). The lowest content of 0.18% being measured in the biochar amended and planted soil showed the concurrent availability of a carbon source is important for the acquisition of nitrogen by plants (Michael, 2020e).

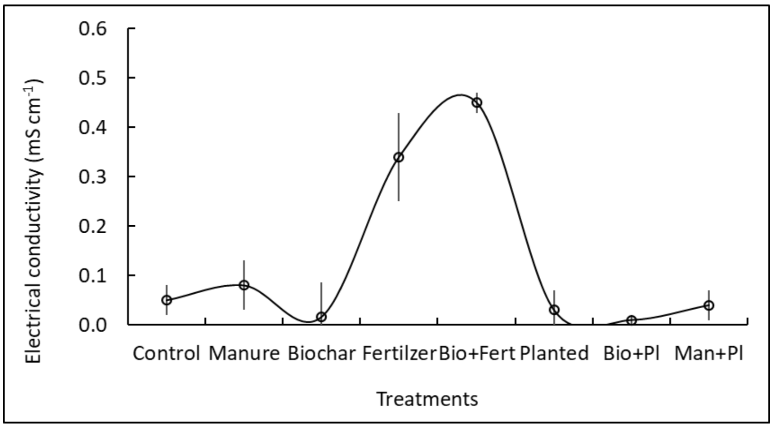

Figure 2: The changes in electrical conductivity measured following amendments and planting.

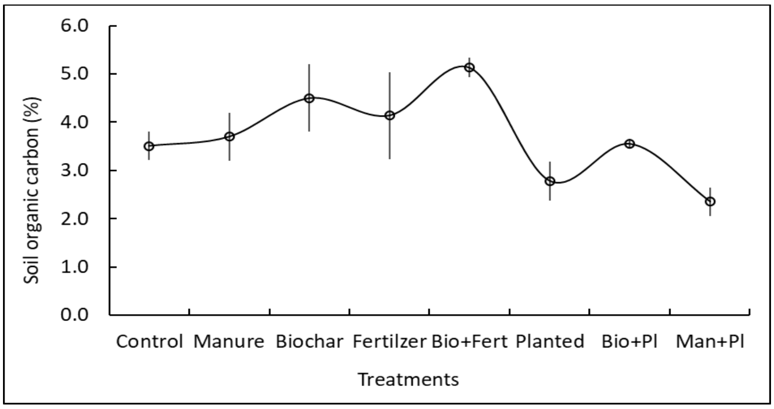

Figure 3: The changes in soil organic carbon measured following amendments and planting.

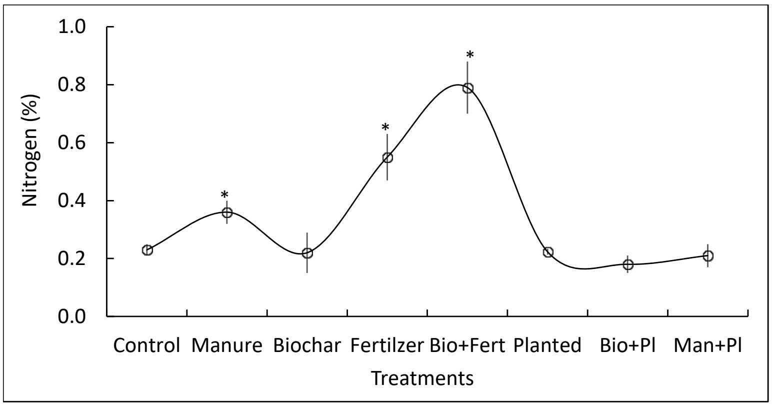

Figure 4: The changes in nitrogen measured following amendments and planting.

As shown in Figure. 5, the changes in the soil phosphorus content measured were Bio+Fert (355 mg kg^{-1})>Man (126 mg kg^{-1})>Fert (100 mg kg^{-1})>Man+Pl (88 mg kg^{-1})>Control (44 mg kg^{-1} mg kg^{-1})>Bio (25 mg kg^{-1}). Over 300 mg kg^{-1} of phosphorus was added to the soil by co-application of biochar, and fertilizer, showing these amendments are important for soil of low phosphorus content. The decreased phosphorus content measured probably resulted from adsorption (Ghodszard et al., 2021). In all the soils, plants decreased the phosphorus content irrespective of manure or in the biochar amended soil, pointing out the plant's need.

The changes in potassium (Figure. 6) measured were such that Bio+Fert (1.78 mg kg^{-1})>Fert (0.98 mg kg^{-1})>Man (0.45 mg kg^{-1})>Control (0.26 mg kg^{-1})>Pl (0.21 mg kg-1)>Bio (0.11 mg kg-1)>Man+Pl (0.09 mg kg^{-1})>Bio+Pl (0.04 mg kg^{-1}). These data showed that biochar amendment significantly decreased the potassium content, indicating that the increase in soil co-amended with biochar and fertilizer resulted from the interaction between the nutrient sources. The other plausible observation is that the co-existence of biochar with fertilizer was important for the release of potassium. The result meant that the availability of an energy source is important for biochar and fertilizer interaction (Fig. 5).

Rasuli et al. (2022) reported that biochar produced from corn and wheat residue increased the potassium content in calcareous soil. A similar increase in potassium was reported by other studies (Chen *et al.,* 2023; Acharya *et al.,* 2022, Wang *et al.,* 2018; Jindo *et al.,* 2020). The potassium content measured in this study was lower than the control, and the probable cause is leaching (Widowati and Asnah, 2014) because of the sandy nature of the soil used. Our results of high potassium content measured from the soil co-amended with biochar and fertilizer are supported by the findings of (Adekiya et al., 2022; Yandong et al., 2022; Sing et al., 2019). The mechanism for these results is better interactions between biochar and fertilizer and the combined effects of the two amendments (Adekiya et al., 2022).

Only manure amendment increased the magnesium content by 0.3 mg kg^{-1} (Figure. 7). All the other treatments decreased it, the significance being observed in the biochar and fertilizer-amended soils. Among the treatments where the contents were decreased, co-application of biochar and fertilizer, planting without an amendment followed by biochar and manure amendment, and planting were high compared to the soils amended with biochar and manure. These results agree with that planting mobilizes and increases the magnesium content of the soil, but use is plant-specific and dependent on the growth stages of plants (Michael, 2020e). Michael (2020e) reported that the magnesium needed by sweet potato during the vegetative growth stage is high, similar to the findings of Calcan et al. (2022).

When biochar obtained from vine prune was added to the soil, the soluble magnesium content measured was lower than that of the control soil (Calcan et al., 2022). In a similar study, the magnesium content in the biochar-amended soil was small when biochar obtained from rice husk was added to the soil (Abdul and Abdul, 2017). Syuhada et al. (2016) used commercial biochar and planted corn and showed that the plant's available magnesium content was low. In disagreement, studies of showed increased magnesium when a range of biochar were used (Dang et al., 2022; Wu et al., 2020). These results, to a great extent, point out that the variability of the magnesium content depends on the type of soil (e.g., alkaline vs. acidic), biochar (e.g., commercial vs. lab-made), soil moisture (e.g., rainfed vs irrigation) and sites (e.g., control environment vs. field).

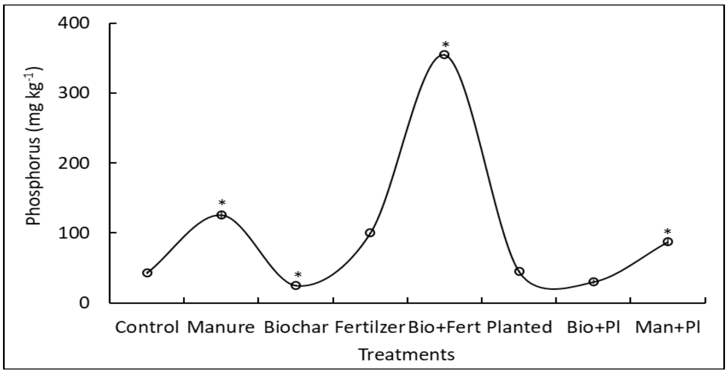

Figure 5: The changes in phosphorus measured following amendments and planting.

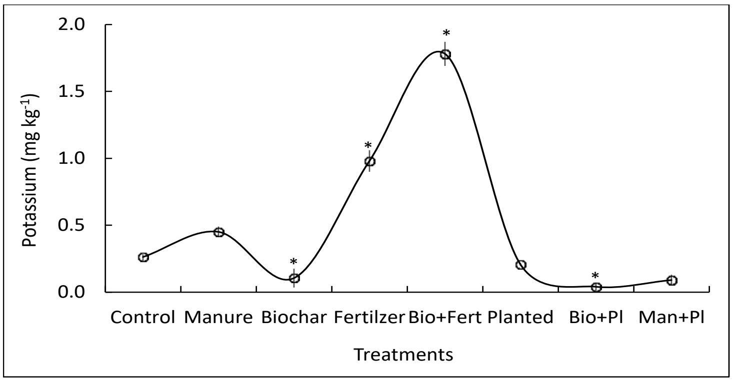

Figure 6: The changes in potassium measured following amendments and planting

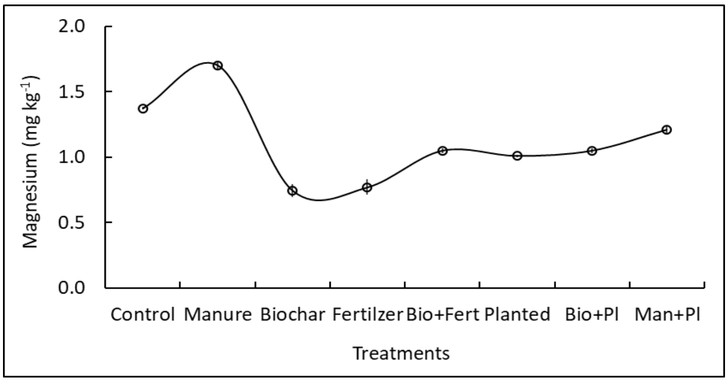

Figure 7: The changes in magnesium measured following amendments and planting.

When the changes in calcium contents (Figure. 8) were compared with magnesium (Figure. 7) as the second secondary macronutrient, the pattern of change observed was very similar. However, the calcium content was high, ranging from 6.5 to 8.0 mg kg^{-1} soil (Figure. 8). Manure amendment increased the calcium content by 1.3 mg kg^{-1}. The decrease in the rest of the treatments was Bio+Pl<Fert<Bio+Fert<Bio<Pl<Man+Pl (Figure. 8). Among these treatments, the calcium content was higher in the unamended planted soil and soil amended with manure and planted (Figure. 8). Th mechanism for this seems to be the same as that for magnesium discussed previously. Plants enhance the acquisition of secondary macronutrients, but their use depends on the plant types and developmental stages (Michael, 2020c).

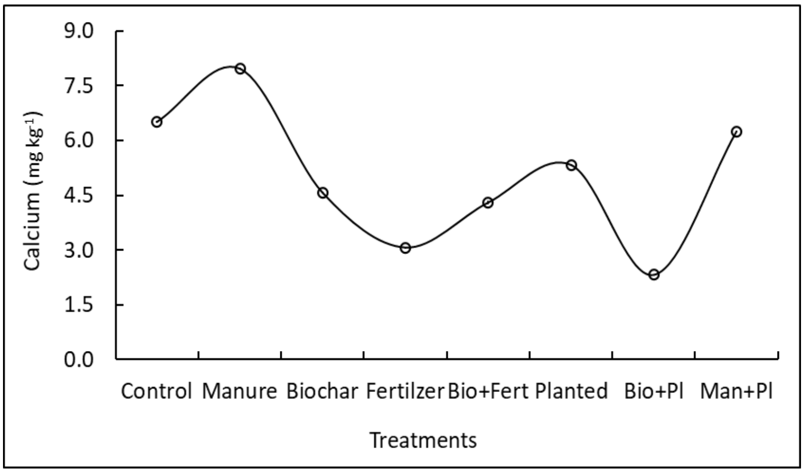

Figure 8: The changes in calcium measured following amendments and planting.

Wu *et al.* (2020) added corn straw biochar to the soil and reported that the calcium content measured was no different from the unamended soil. Prakongkep *et al.* (2020) amended a sandy loam soil using a range of biochar, and the difference in calcium content measured was the same as in the control soil. These varying results indicate that biochar's role in calcium availability depends on the rate of use and the duration of the studies (Novair et al., 2023). Availability to planted corn in sandy soil amended with commercial biochar showed that the calcium content was lower, similar to the findings of Wu *et al.* (2020; Syuhada et al., 2016). The results of the previous studies support our finding that biochar amendment and its effects on secondary macronutrient is variable. The underlying mechanisms responsible are the same as those pointed out for magnesium, the effectiveness depending on dosage, originating material, soil type, and soil moisture. Among these, the most significant effect is on acidic than alkaline soils (Premalatha et al., 2023).

4. CONCLUSIONS

The impacts of climate change are affecting the soil's physical, chemical, and biological properties, which in turn is affecting agricultural productivity. This study was conducted to understand the roles of biochar amendment in sandy loam soil compared to regular farm yard manure and commercial NPK fertilizer under humid lowland tropical agroclimatic conditions. When applied alone, the results showed insignificant effects on pH, electrical conductivity, soil organic matter, carbon stock, and water-holding capacity. The bulk density and total porosity were improved. Soil N, P, and K contents were higher when biochar and fertilizer co-existed than magnesium and calcium. Our findings indicated that soil interaction is significantly improved when another nutrient source co-exists with biochar, and the results have implications for managing sandy loam soils in the humid tropics.

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