Effect of Biochar on Growth, Nodulation, Yield and Soil Properties of Cowpea

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Summary

It is necessary to search for an inexpensive soil additive capable of raising soil pH comparable to conventional agricultural lime. In 2020 and 2021 cropping seasons at the Teaching and Research Farm, Landmark University, Omu-Aran, Kwara State Nigeria, field experiments were conducted to evaluate the effects of various levels of wood biochar on soil chemical properties and bulk density, growth, nodulation and yield of cowpea (*Vigna unguiculata* (L.) Walp.). The soil of the experimental sites is an Alfisol classified as Oxic Haplustalf or Luvisol. The treatments were made up of five levels (0, 2.5, 5.0, 7.5, and 10 t ha^{-1}) of wood biochar arranged in a Randomized Complete Block Design and each treatment was replicated three times. The application of biochar improved soil chemical characteristics (pH, N, P, K, Ca, Na, Mg and CEC), growth (vine length per plant, number of leaves per plant, leaf area/plant and tap root length), nodulation and yield parameters of cowpea (pod weight per plant and number of pods per plant) related to the control. Biochar application reduced exchangeable acidity relative to the control. The yield of cowpea was increased from 0 to 10 t ha^{-1} biochar rate. Using the means of the two years, relative to the control, application of biochar at 10, 7.5, 5, and 2.5 t ha^{-1} increased the pod weight of cowpea by 217, 118, 73 and 33%, respectively. This was adduced to a rise in soil pH and exchangeable cation and CEC and reductions in exchangeable acidity and soil bulk density which resulted in P solubility and availability, increased N fixation, enhanced root growth, increased nodulation leading to improved growth and yield of cowpea. Therefore, biochar can be used as an approach to improving the productivity of acidic tropical soil and hence improving crop productivity. Nevertheless, additional investigations are needed to show the rate of biochar that will result in optimum pH for cowpea production in the ecological zone.

Key words

biochar, cowpea, soil chemical properties, bulk density, pH, nodulation

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Introduction

Soil acidity is one of the major reasons for low soil and crop productivity in many parts of the world. It is projected that nearly 50% of the world's cultivated soils are acidic and the tropics and subtropics account for 60% of the acidic soils in the world (Sumner and Noble, 2003). The major causes of soil acidity might be due to high rainfall and leaching (Deressa et al., 2007; Taye, 2008), parent materials that are acidic, crop removal especially high-yield crops and incessant use of acidic forming straight fertilizers. The adverse effect of soil acidity allows for a decrease in the availability of major plant nutrients, such as phosphorus and molybdenum, and increases the availability of some toxic elements to harmful levels, particularly aluminum and manganese (Menzies, 2003). Acidity can degrade the soil ecosystem, making it more difficult for bacteria, earthworms and other soil microbes to survive. Extremely acidic soils can make it difficult for helpful bacteria, such as the rhizobia bacteria that aid legume nitrogen fixation to survive (Sylvia et al., 2005). Also, greater proton (H^+) action in the soil rises the protonation and adsorption of soil organic matter, thereby reducing its microbial availability (Kleber et al., 2015) and leaching mobility (Oulehle et al., 2018). When the soil is acidic, the yield of most crops is lowered (Ano 2006).

Soil acidity is commonly corrected through the application of agricultural lime (Anetor and Akinrinde, 2007). It involves the use of calcium- and magnesium-rich minerals, such as marl, chalk, limestone, or hydrated oxide, to the soil in a variety of forms. Nevertheless, in a tropical country like Nigeria, a good number of farmers cannot afford agricultural lime due to its cost and scarcity. It is thus necessary to search for an inexpensive soil additive capable of raising soil pH comparable to conventional agricultural lime.

Biochar is a solid and stable carbon-rich material made by heating organic materials in the absence of oxygen (Lehmann and Joseph, 2015). It was foremost used by pre-Columbian native peoples of the Amazon area between 500 and 9000 years ago (Solomon et al., 2007) as among a lot of soil amendments that produced 'terra preta', a more nutrient-rich and high pH agricultural soil than the region's existing acidic and infertile soils (Lehmann et al., 2007). The application of biochar to the soil has been revealed to enhance soil properties and health by raising soil pH, improving water-retention ability, enhancing CEC and improving the activities of useful soil microorganisms (Gul et al., 2015; Mensah and Frimpong, 2018) and retaining nutrients (Minhas et al., 2020). Due to the fact that biochar research is still at the infant stage in Nigeria, data on the effects of biochar in improving soil pH and cowpea performance is not common.

Cowpea (*Vigna unguiculata* (L.) Walp.) is a major grain legume food crop in Nigeria. The dry grains, immature pods and young leaves are the main sources of plant proteins (cowpea dry beans supply about 22 - 25% protein (Goenaga et al., 2010) food for man (Sheahan, 2012) complementing the low protein content of carbohydrate food derived from cereal and tuber crops consumed in Nigeria. It is projected that cowpea supplies about 40% of the daily protein needs of most of people in Nigeria (Muleba et al., 1997). After harvesting, the leftover pods and leaves of cowpea can be used to feed farm animals (Ghady and Alkoaiki, 2010). However, Adekiya (2022) has reported that cowpea like other legumes responds well to pH change; reduced pH may result in lower yields, poor legume nodulation and stunted root growth. Soil acidity limits symbiotic N_2-fixation, reduces nodulation and causes nutrient imbalance (Fageria et al., 2013; Abera and Abebe, 2018). In order to improve the productivity of the soil and cowpea performance, the pH of such soil should be raised to a level that becomes suitable for the optimum growth of the plants.

There has not been much research carried out on the effect of biochar on soil chemical properties and cowpea growth, nodulation and yield in the tropics. Few studies existing are where biochar is co-applied with other amendments to cowpea or where methods of biochar application are the authors' priority (Yeboah et al., 2020; Rafael et al., 2017). To the best of our knowledge, no field study has been undertaken in Nigeria on the impact of biochar on soil properties, growth, nodulation and yield of cowpea. Therefore, the objectives of this study were to determine the effects of different rates of biochar on soil chemical properties, bulk density, growth, nodulation and yield of cowpea on a derive savanna Alfisol.

Materials and Methods

In 2020 and 2021 cropping seasons at the Teaching and Research Farm, Landmark University, Omu-Aran, Kwara State field experiments were conducted to evaluate the effects of various levels of wood biochar on soil chemical properties and bulk density, growth, nodulation and yield of cowpea. Landmark University lies within latitude 8° 7' 26.21388" and 5° 5' 0.1788". The total annual rainfall in the area is about 1300 mm while the mean annual temperature is 32 °C. The biochar used for the experiment had EC, pH, ash, organic carbon (OC), N and C: N of 3.93 dS m^{-1}, 7.31, 8.41%, 61.5%, 0.81% and 75.9, respectively. P, K, Ca, Mg, and Na were; 0.69%, 1.39%, 4.20%, 3.4% and 0.41%, respectively. The values of bulk density and porosity were 0.62 g cm^{-3} and 76.6%, respectively.

In 2020 and 2021 the treatments were made up of five levels (0, 2.5, 5.0, 7.5, and 10 t ha^{-1}) of wood biochar. The treatments were arranged in a Randomized Complete Block Design (RCBD) and each treatment was replicated three times. Each block comprised 5 plots and each plot measured 2 × 2 m. The spacing between blocks was 1 m apart while the spacing between plots was 1 m apart.

Biochar Incorporation and Sowing of Cowpea Seeds

Biochar used in the experiment was produced from hardwood (*Prosopis africana*), a common tree in Landmark University. The experimental site was prepared in the years 2020 and 2021 by the conventional method of ploughing and harrowing, after which the site was laid out to the required plot size of 2 × 2 m. Immediately after land preparation, biochar was weighed at the specified rates of 0, 2.5, 5.0, 7.5 and 10 t ha^{-1} which was respectively equivalent to 0, 0.5, 1.0, 1.5, and 2.0 kg $plot^{-1}$ and were spread evenly on the plots. The biochar was incorporated using a hoe to a depth of about 10 cm. This was done 2 weeks before the sowing of cowpea seeds.

Sowing of cowpea seeds (Variety Paiyur 1Cowpea) was done on August 20th each year. Two seeds were sown using inter-row spacing of 20 cm and intra -row spacing of 75 cm apart. Thinning to one plant per stand was done two weeks after sowing to give a plant a population of 21 plants per plot and 53,333 plants ha^{-1} for the erect variety. Two manual weedings were done during the course of the experiment. Insect pests were controlled by spraying cypermethrin weekly at the rate of 30 mL per 10 L of water from 2 weeks after sowing.

Determination of Soil and BiocharProperties

Before the application of biochar in 2020 and 2021, five undisturbed samples were collected at 0–15 cm from ten positions using a core steel sampler (4 cm diameter, 15 cm high). The samples were used to evaluate bulk density after oven-drying at 100 °C for 24 h. Also, soil samples from 0 to 15 cm depth were randomly collected from 10 points from the study area each year, these samples were bulked together, air-dried, and sieved with a 2 mm sieve for soil physical and chemical analysis. The hydrometer method was used for the determination of particle size (Gee and Or 2002), while the chemical analysis of the soil and biochar was made as described by Carter (1993). The pH and the EC of the biochar were determined in a 1% (w/v) suspension in deionized water made by shaking at 100 rpm for 2 h (Cantrell et al., 2012). The ash content on a dry weight basis of samples of biochar was determined by combusting the sample in a muffle furnace at 750 °C for 6 hours (ASTM D1762-84, 2021).

One month after the application of biochar, bulk density in all plots was determined and the process was continual at 1 ½, 2, 2 ½ and 3 months after biochar application. The samples were collected from the center of each plot at random and 15 cm away from each cowpea crop using a core steel sampler. The samples were used to evaluate bulk density.

Three plants were excavated with their rhizosphere soils intact. This was done when the cowpea plants had attained 50% flowering on a plot basis (65 days after sowing). The nodules in the roots of the excavated plants were counted with the aid of a magnifying glass. At the end of the experiment, soil samples were also collected on a per-plot basis. The collected soil samples were air-dried and sieved using a 2-mm sieve and analyzed for soil chemical properties as described by Carter (1993).

Determination of Growth and Yield Parameters

Growth parameters. Growth parameters were determined at mid-flowering of the cowpea plant (65 days after sowing). The number of leaves (leaves count) was determined by counting the number of fully expanded leaves, the vine length was measured by the use of a measuring tape and the number of branches per plant was determined by counting the number of branches on the plant. Leaf area was estimated by using the model of Osei-Yeboah et al. (1983); $A = L \times W \times 2.325$, where A = leaf area, L = leaf length and W = leaf width. The cowpea plant was carefully removed by digging around with a garden fork to prevent damage to the roots. Taproot length was thereafter determined using a meter rule.

Yield Parameters. The cowpea pods were harvested at maturity and the number of harvested pods was counted and recorded per plot and per treatment. Harvested matured cowpea pods were weighed using a sensitive weighing balance and the value recorded on a plot basis.

Statistical Analysis

Data collected were subjected to statistical analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS, Institute Inc. 2009). The treatment means were compared using the Duncan Multiple Range Test (DMRT) at 0.05 level of probability.

Results and Discussion

Initial Soil Properties and Response of Soil Chemical Properties and Bulk Density to Different Biochar Levels

The results of soil properties of the sites in 2020 and 2021 before cropping are presented in Table 1. The soils of the sites in both years are sandy loam in texture, fairly high in bulk density and strongly acidic (FFD 2011), with low levels of soil organic carbon (SOC), N, P, K and Ca. Acidity was high, Mg was adequate (FFD, 2011).

Table 1. Soil physical and chemical properties of the experimental sites prior to planting

Property	2020	2021
Sand (%)	68.2	68.1
Silt (%)	16.1	16.1
Clay (%)	15.7	15.8
Textural class	Sandy loam	Sandy loam
Bulk density (g cm^{-3})	1.58	1.59
Total porosity (%)	40.4	40.0
Organic C (%)	1.13	1.14
pH (water)	5.33	5.30
pH (KCL)	5.28	5.28
N (%)	0.11	0.15
P (mg kg^{-1})	9.2	9.6
K (cmol kg^{-1})	0.14	0.14
Ca(cmol kg^{-1})	0.99	0.99
Mg (cmol kg^{-1})	0.81	0.82
Na (cmol kg^{-1})	0.11	0.11
(H + AL) (cmol kg^{-1})	1.80	1.82
CEC (cmol kg^{-1})	3.85	3.88

Before the start of the experiment, the initial soil was low in nutrients, strongly acidic and high in bulk density. This was so because of the sandy nature of the soils and incessant cultivation of crops on the soil without application of organic amendment.

Also, over the years the method of land preparation on the soil had been conventional which could have resulted in soil compaction and degradation of quality, leading to high soil bulk density and low soil fertility coupled with characteristically intense rainfall under tropical condition which could cause rapid mineralization of organic material of the soil and consequently lead to the loss of some nutrients, especially the cations, which lowers the soil pH and causes soil acidity problems.

The result of the response of soil chemical properties and bulk density to different biochar levels are presented in Fig. 1 - 4 and Fig. 6 respectively. The addition of biochar to the soil improved pH, SOC, N and P (Fig. 1 and 2) relative to the control.

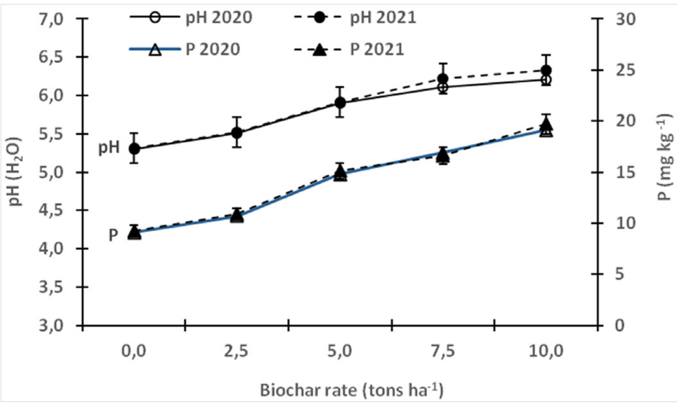

Figure 1. Effect of Biochar levels on soil pH and available P

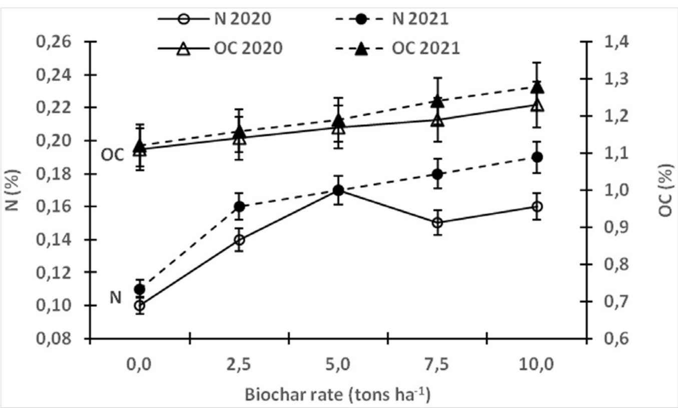

Figure 2. Effect of Biochar levels on soil total N and organic carbon (OC)

Although pH, N, SOC and P values increased from 0 -10 t ha^{-1} biochar level, there were no significant differences between pH values of 5 and 7.5 t ha^{-1} biochar level and also, there were no significant differences between the N values of 5 and 7.5 t ha^{-1} biochar level and also between N values of 7.5 and 10 t ha^{-1} biochar levels. Likewise, the addition of biochar increased K, Ca, Na, Mg and CEC relative to the control (Figures 3 and 4). These soil chemical properties were also increased from 0 - 10 t ha^{-1} biochar level. There were no significant differences between the K values for 2.5, 5 and 7.5 t ha^{-1} biochar levels. Exchangeable acidity was reduced relative to the control (Figure 3). The reduction was from 0 - 10 t ha^{-1} biochar level. Using the means of the two years, relative to the control, the application of biochar at 10, 7.5, 5, and 2.5 t ha^{-1} reduced acidity by 27.3, 18.6, 12.3 and 6.1%, respectively.

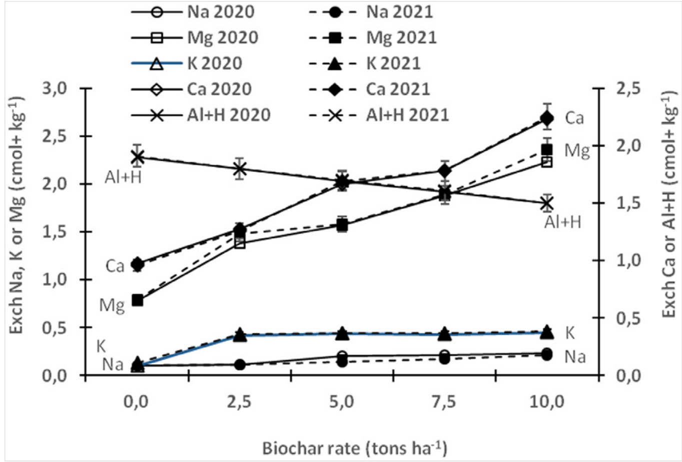

Figure 3. Effect of Biochar levels on soil exchangeable cation (Na, K, Mg and Ca) and acidity

In the same vein, relative to the control, pH was increased by 18.1, 16.2, 11.3 and 3.9% for biochar applied at 10, 7.5, 5, 2.5 t ha^{-1}. The application of biochar 10, 7.5, 5, 2.5 t ha^{-1} enhanced P availability in the soil by 110.8, 82.6, 61.9 and 17.4% respectively, relative to the control. Biochar addition to the soil significantly increased the soil pH, N, P, K, Ca, Mg, Na and SOC contents relative to the control. The increase in pH of biochar applied soils over the control soil confirmed biochar as a liming material in soils that are acidic (Adekiya et al., 2019; El-Naggar et al., 2019). The improved pH of biochar-applied soils was a result of the high pH (7.31) and EC (3.93 dS m^{-1}) of biochar which showed its higher soluble salts and greater calcium carbonate equivalent and Ca content (Alburquerque et al., 2014; Berek et al., 2018). According to Shetty and Prakash (2020), the rise in pH due to biochar could have led to the neutralization of soil acidity by a sequence of proton-dependent reactions. During the preparation of wood biochar used, some of the acid functional groups and cations in the wood may have changed to alkaline substances, such as –COO–, –O–, carbonates, and oxides, and these alkaline substances now neutralized H ions in the soil, hence there was a rise in pH of biochar-applied soils (Dai et al., 2017).

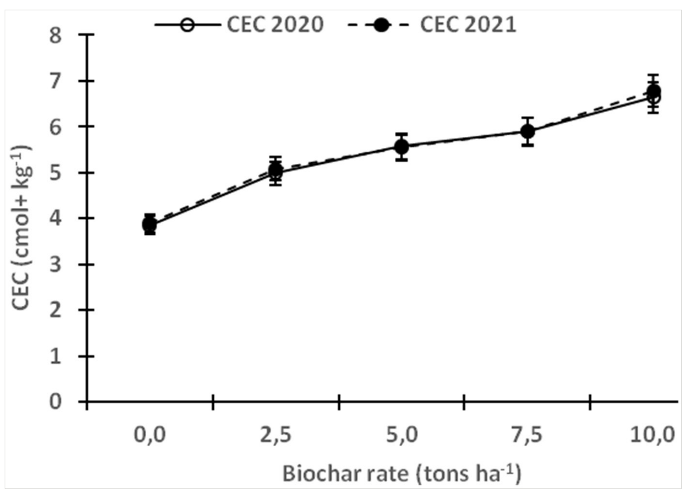

Figure 4. Effect of Biochar levels on soil CEC

In an experiment where nine types of biochar made from three biomasses (fruit tree branch, peanut shell and cow dung) and three pyrolysis temperatures were used to amend acidified brown soil, results showed that biochar increased soil pH by 8.48–79.25% (Geng et al., 2022). Also, Major et al. (2010) reported a change in soil pH from 3.89 to 4.05 due to biochar addition. Biochar-applied soil has higher organic C relative to the control, this is so because wood feedstock is known to contain high carbon content. Biochar in soils can also engross soil organic molecules and encourage organic molecule polymerization and produce organic matter by surface catalytic action (Liang et al., 2010; Van Zwieten et al., 2010). Biochar-applied soils enhanced soil N compared with the control due to greater availability of soil N as a result of retention in the biochar treatments relative to the control (where N might be prone to losses by leaching). Because biochar adsorbed cations and anions, the leaching of applied and regular soil nutrients was reduced (Major et al., 2009) or could be a result of better fixation of N due to increased nodules in biochar applied soils relative to the control.

Biochar addition to soil also has the tendency to reduce the leaching of P and therefore keep a sensible level of P in the soil (Miller et al., 2012), thus biochar-amended soil has significantly higher P content relative to no biochar treatments in this experiment. Furthermore, biochar addition can also increase the available phosphorus in the soil indirectly, which could be due to the fact that the ash content of biochar has some amount of phosphorus that may add to an increase in soil available phosphorus content (Steiner et al., 2007). Also, due to the increase in pH of the biochar-applied soils, some fixed soil P could now be made available (Bhattarai et al., 2015).

The enhanced K, Ca, Mg and CEC of biochar-applied soils could be due to the fact that the pyrolyzed wood feedstock used for this experiment contains a large amount of K, Ca, and Mg, hence high K, Ca, Mg and CEC in their soils. The increase could also be adduced to the intrinsic features of the biochar since biochar has a high surface area that possesses unprotected negative charges. Biochar is very porous, possesses variable charges and therefore increases surface sorption capacity when added to the soil (Glaser et al., 2002). Glaser et al (2002) have also reported that in biochar oxidation takes place after weathering which brings about the development of carboxylic groups on the edges of the aromatic carbon, resulting in greater CEC. Biochar as reported by Jia et al (2015) can absorb leachate which can help to absorb organic matter, total soluble N, plant available P and K, thereby increasing the nutrient retention capacity of the soil. Biochar particles are colloidal with large specific surface areas and negative surface charges from deprotonated functional groups. Consequently, nutrients dissolved in the soil solution are attracted to the colloidal surfaces. It was reported (Jones et al., 2013; Wang et al., 2014) that biochar increased total C from 2.27 up to 2.78%, total N from 0.24 up to 0.25%, P from 15.7 up to 15.8 mg kg^{-1}, pH 3.33 up to 3.63.

The reduction in exchangeable acidity with biochar addition is adduced to the movement of H^+, Fe^{2+}, and Al^{3+} ions from soil adsorption sites (Onwonga et al., 2008) and release of organic acids, which may later suppress Al content in the soil through chelation (Onwonga et al., 2008).

Also, the bulk density (Figure 6) of the soil was reduced relative to the control. There was a reduction in soil bulk density as the level of the biochar increased from 0 to 10 t ha^{-1}. Biochar addition significantly reduced bulk density relative to the control, which is expected because of the relatively lower bulk density and porosity of biochar in this experiment relative to that of the experimental soil. The application of such porous materials like biochar reduces bulk densities and increases porosities of the soil perhaps by mixing or dilution effect (Alburquerque et al., 2014; Lehmann et al., 2011), or biochar can reduce bulk density by intermingling with soil particles and enhancing aggregation and porosity (Blanco-Canqui, 2017). Githinji (2014) and Agbede et al. (2022) also reported a reduction in the bulk density of the soil in response to the addition of biochar.

There were improved soil chemical properties and bulk density with an increase in the level of biochar, as a possible result of greater effects of biochar from each level of biochar application.

Biochar addition significantly improves the nodulation of biochar-applied soils when compared with the control. The addition of biochar causes an elevation in the pH of the soil, which in turn facilitates an increase in the rate at which phosphate ions are released into the soil solution (Kisinyo, 2016). Thus, the application of lime in form of biochar aids in hydrolyzing Al and Fe ions precipitated by P. Hence, the precipitated phosphate ion is released into the soil solution, making it available for plant absorption. Phosphorus is critical to cowpea yield because it is reported to stimulate growth, initiate nodule formation as well as influence the efficiency of rhizobium-legume symbiosis (Haruna, 2011). Biochar has been reported to raise soil pH (Adekiya et al., 2022), which makes fixed soil P more readily available for crop uptake and hence better nodulation, whereas P is an important nutrient element for cowpea production. Also, under low pH, rhizobia nodulation genes are not common (Richardson et al., 1988) and the making of Nod factor also decreases under low-pH settings (McKay and Djordjevic, 1993; Morón et al., 2005). This interrupts the signal conversation between the plant and bacterial companions (Hungria and Stacey, 1997), resulting in a decrease in root hair deformation and root hair curling (Miransari et al., 2006). Lin et al (2012) also report that low pH acts systemically by the action of autoregulation-of-nodule receptor kinase, GmNARK in the shoot to inhibit nodule development in the roots.

Response of Growth, Yield and Nodulation of Cowpea to Different Biochar Levels

The results of the response of growth (vine length, number of leaves (leaves count)/plant and leaf area/plant) and yield (number of pods (pods count)/plant and pod weight $plant^{-1}$) of cowpea to different biochar levels are presented in Figures 5 and 7 respectively. However, results for tap- root length and nodules count are presented in Figure 6. The applications of biochar increased the growth (vine length, number of leaves $plant^{-1}$, leaf area $plant^{-1}$ and tap root length) relative to the control (Fig. 5). The growth of cowpea was increased as the level of Biochar increased from 0 to10 t ha^{-1}. As the taproot length increases so does the number of leaves and vine length of the cowpea.

The improved root growth of cowpea on biochar-applied soils relative to the control could be due to: (1). reduced soil bulk density of biochar applied soils, (2). reduction in Al toxicity in the biochar-applied soils due to improved pH. The root system suffers immediate harm as a result of Al toxicity (Silva et al., 2010).

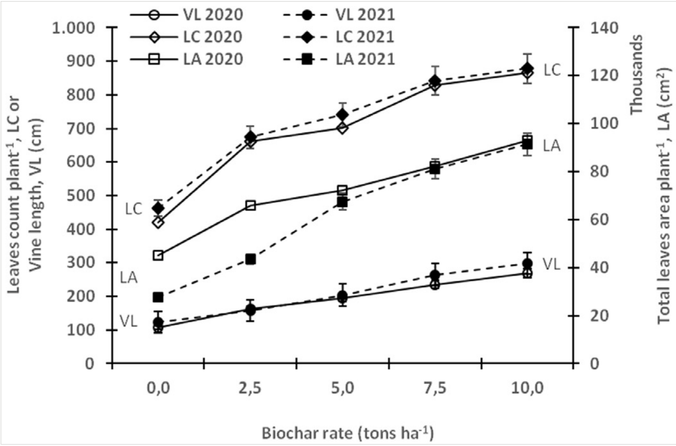

Figure 5. Effect of Biochar levels on growth parameters of cowpea (leaves count, vine length and total leaves area)

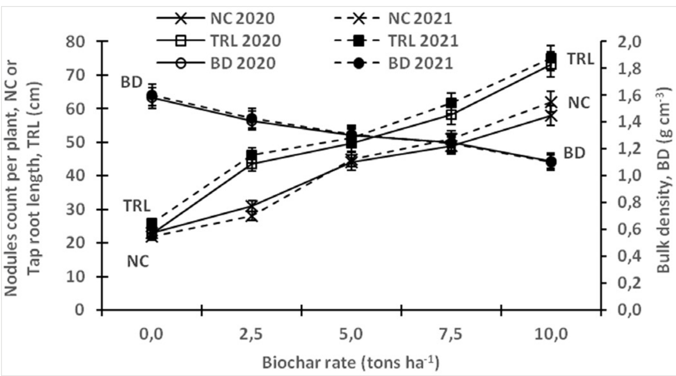

Figure 6. Effect of Biochar levels on nodules count, tap root length, and soil bulk density

The presence of aluminum in the soil close to the roots will obstruct the meristem cell division section, which will result in the cessation of root extension and a reduction in root penetration strength (Pavlovkin et al., 2009) and therefore poor root growth in the control plots, and (3). the possibility of P (which is more enhanced in biochar soils relative to the control) in helping in N uptake which may increase root growth (Wen et al., 2016).

Also, yield (number of pods plant^{-1} and pod weight plant^{-1}) (Figure 7) and number of nodules (Figure 6) of cowpea significantly increased relative to the control.

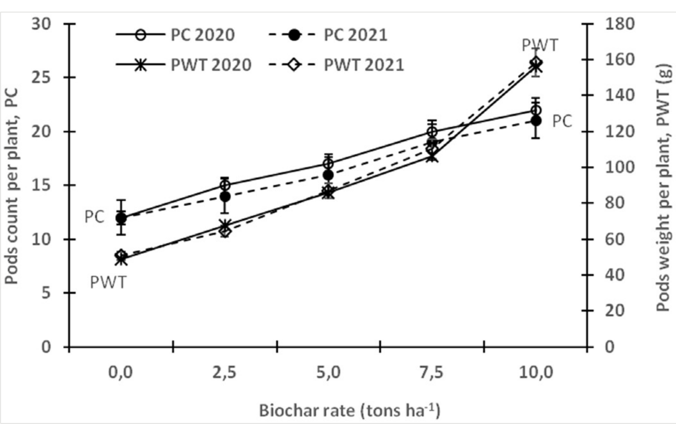

Figure 7. Effect of Biochar levels on yield parameters (pods count and pods weight) of cowpea

The yield and nodulation of cowpea were increased from 0 – 10 t ha^{-1} biochar level. The number of nodules significantly increased the yield parameters of the cowpea, as the yield parameters increased with number of nodules. Using the means of the two years, relative to the control, application of biochar at 10, 7.5, 5, and 2.5 t ha^{-1} increased the pod weight of cowpea by 217, 118, 73 and 33%, respectively.

Biochar-applied soils improve the growth and yield of cowpea relative to the control and up to 10 t ha^{-1} levels. The improved performance may be a result of improvement in soil chemical properties and bulk density by biochar. In this experiment, biochar has raised soil pH and reduced acidity, thus making fixed P to be available for cowpea uptake. Yamato et al. (2006) found that biochar application decreased the exchangeable Al^{3+} content of the soil by increasing the pH of the soil. It also increased the available P contents, exchangeable cations and the total plant N content (Yamato et al., 2006). Biochar also enhanced cowpea performance by reducing bulk density thereby creating rapid root penetration and nutrient absorption which enhance cowpea growth and yield.

Table 2 proves that the yield of cowpea in this experiment was dependent among other factors on: soil bulk density, root length, number of nodules, soil pH, OC, P, Na, N, Ca, Mg, acidity, and CEC. So for this study, the addition of biochar caused a rise in soil pH and exchangeable cation and CEC and a reduction in exchangeable acidity and soil bulk density. This resulted in P solubility and availability, increased N fixation, enhanced root growth and increased nodulation leading to improved growth and yield of cowpea. Therefore, biochar can be used as an approach for improving the productivity of acidic tropical soil and hence improve crop productivity. Under a greenhouse condition, Rafael et al (2017) found that baby corn peel biochar, branches of tree biochar, and rice husk biochar influenced soil properties and therefore cowpea yield. Shetty and Prakash (2020) also found that the application of wood biochar proved successful in improving soil pH and reducing soluble and exchangeable Al and therefore improved rice productivity.

Numerous studies have documented the beneficial impact of biochar usage on crop yields. However, a specific investigation carried out by Rondon et al. (2007) revealed a decrease in crop yield in a pot experiment using nutrient-deficient soil treated with 165 tonnes per hectare of biochar. Similarly, an experiment conducted in the United States indicated that applying peanut hull and pine chip biochar at rates of 11 and 22 tonnes per hectare, respectively, could result in lower corn yields compared to the control plots managed with standard fertilizers (Gaskin et al., 2010). Consequently, it becomes imperative to regulate the application rate of biochar to prevent any adverse effects it may have.

Finally, despite the potentially high initial cost of preparation, biochar production has emerged as an economical and sustainable technology with numerous benefits. It has been recognized as a means to enhance soil pH, stabilize soil organic carbon (SOC), and mitigate greenhouse gas emissions (Agegnehu et al., 2016; Oni et al., 2019). Furthermore, biochar can improve the physical and chemical properties of soil, leading to increased crop yield, productivity and farm revenue (Jeffery et al., 2011; Adekiya et al., 2019).

Table 2. Correlation coefficient between soil properties and cowpea yield parameters

	pH	N	OC	P	Na	Ca	Mg	K	Acidity	CEC	NC	TRL	BD	PC	PW
pH	1														
N	0.89*	1													
OC	0.96**	0.77	1												
P	0.99**	0.77	0.98**	1											
Na	0.98**	0.81	0.93*	0.97**	1										
Ca	0.96**	0.80	0.99**	0.98**	0.94*	1									
Mg	0.95**	0.81	0.98**	0.96**	0.90*	0.97**	1								
K	0.76	0.93*	0.74	0.71	0.694	0.75	0.83	1							
Acidity	-0.98**	-0.77	-0.99**	-0.99**	-0.95*	-0.99**	-0.98**	-0.75	1						
CEC	0.96**	0.85	0.98**	0.96**	0.92*	0.98**	0.99**	0.85	-0.98**	1					
NC	0.99**	0.81	0.99**	0.99**	0.97**	0.99**	0.97**	0.76	-0.99**	0.98**	1				
TRL	0.94*	0.81	0.98**	0.95*	0.89*	0.97**	0.99**	0.83	-0.98**	0.99**	0.97**	1			
BD	-0.96**	-0.84	-0.99**	-0.97**	-0.92*	-0.99**	-0.99**	-0.83	0.98**	-0.99**	-0.98**	-0.99**	1		
PC	0.98**	0.89*	0.98**	0.98**	0.92*	0.97**	0.99**	0.76	-0.99**	0.98**	0.98**	0.98**	-0.98**	1	
PW	0.91*	0.86*	0.98**	0.94*	0.87	0.97**	0.94*	0.64	-0.96**	0.94*	0.95*	0.95*	-0.95*	0.95*	1

Note: *Significant difference at $P < 0.05$; ** Significant difference at $P < 0.01$; NC= nodules count; TRL = tap root length; BD = soil bulk density; PC = pods count; PW = pods weight

One of the remarkable characteristics of biochar is its slow decomposition in the soil, thanks to its high concentration of recalcitrant carbon. This longevity distinguishes biochar from compost, which rapidly breaks down in humid tropical soils, necessitating repeated applications each year. For instance, wood biochar can persist in the soil for a range of 100 to 1000 years, which is approximately 10–1000 times longer than most soil organic matter (Duku et al., 2011).

By enhancing nutrient retention and sorption capacity, the addition of biochar to soils presents an opportunity to sequester carbon and simultaneously enhance soil nutrient availability for crop utilization. This dual role makes biochar a potential carbon sink while supporting agricultural productivity.

Conclusion

Findings from this study indicated that the application of biochar improved soil chemical characteristics (pH, N, P, K, Ca, Na, Mg, and CEC), growth (vine length per plant, number of leaves per plant, leaf area/plant and tap root length), nodulation and yield parameters of cowpea (pod weight per plant and number of pods per plant) related to the control. Biochar application reduced exchangeable acidity relative to the control. The yield of cowpea was increased from 0 to 10 t ha^{-1} biochar rate. This was adduced to a rise in soil pH and exchangeable cation and CEC and reductions in exchangeable acidity and soil bulk density which resulted in P solubility and availability, increased N fixation, enhanced root growth, increased nodulation leading to improved growth and yield of cowpea. Therefore, biochar can be used as an approach for improving the productivity of acidic tropical soil and hence improve crop productivity. Nevertheless, additional investigations are needed to show the rate of biochar that will result in optimum pH for cowpea production in the ecological zone.

CRediT authorship contribution statement

Aruna Olasekan Adekiya: Conceived the project and supervised the work. **Bolajoko Bisola Ayorinde:** Conceptualization, Investigation, performed most of the experiments, Dana analysis, Original draft preparation. **Elizabeth Temitope Alori, Ojo Timothy Adebiyi:** Performed some of the experiments. **Wutem Sunny Ejue:** Manuscript editing.

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.

References

Abera T., Abebe Z. (2018). Effects of Fertilizer, Rhizobium Inoculation and Lime Rate on Growth and Yields of Field Pea in Horro and Gedo Highlands. Adv Crop Sci Tech. 6: 397. DOI: 10.4172/2329-8863.1000397

Adekiya A.O. (2022). Improving Tropical Soil Productivity and Cowpea (*Vigna unguiculata* (L.) Walp) Performance Using Biochar and Phosphorus Fertilizer, Communications in Soil Science and Plant Analysis 53 (21): 2797-2811. doi: 10.1080/00103624.2022.2094392

Adekiya A.O., Agbede T.M., Aboyeji C.M., Dunsin O., Simeon V.T. (2019). Effects of Biochar and Poultry Manure on Soil characteristics and the Yield of Radish. Sci Hortic. 243: 457–463. doi: 10.1016/j.scienta.2018.08.048

Agbede T. M., Oyewumi A., Adekiya A. O., Adebiyi O.T. V., Abisuwa T. A., Ijigbade J. O., Ogundipe C. T., Oladele S. O., Olaogun O., Eifediyi E. K. (2022). Assessing the Synergistic impacts of Poultry manure and Biochar on Nutrient-Depleted Sand and Sandy Loam Soil Properties and Sweet Potato Growth and Yield. Exp. Agric. 58: e54. doi: 10.1017/S0014479722000497

Agegnehu G., Nelson P.N., Bird M.I. (2016). The Effects of Biochar, Compost and Their Mixture and Nitrogen Fertilizer on Yield and Nitrogen Use Efficiency of Barley Grown on a Nitisol in the Highlands of Ethiopia. Sci Total Environ. 569–570: 869–879. doi: 10.1016/j.scitotenv.2016.05.033

Alburquerque J.A., Calero J.M., Barrón V., Torrent J., del Campillo M.C., Gallardo A., Villar R. (2014). Effects of Biochars Produced from Different Feedstocks on Soil Properties and Sunflower growth. J Plant Nutr Soil Sci. 177: 16–25. https://doi.org/10.1002/jpln.201200652

Anetor M.O., Akinrinde E.A. (2007). Lime eEfectiveness of Some Fertilizers in a Tropical Acid Alfisol. J Cent Eur Agric. 8 (1): 17-24

Ano A.O. (2006). Effect of Vegetable Cowpea Population on Component Crop Yields and Productivity of Yam, Minisett Based System. Niger J Agric. 37:81-84.

ASTM D1762-84. (2021). Standard Test Method for Chemical Analysis of Wood Charcoal. Conshohocken, PA: American Society for Testing and Materials.

Berek A.K., Hue N.V., Radovich T.J.K., Ahmad A.A. (2018). Biochars Improve Nutrient Phyto- Availability of Hawai'i's Highly Weathered Soils. Agronomy 8(10) 203. doi:10.3390/agronomy8100203

Bhattarai B., Neupane J., Dhakal S.P., Nepal J., Gnyawali B., Timalsina R., Poudel A. (2015): Effect of Biochar from Different Origin on Physio-Chemical Properties of Soil and Yield of Garden Pea (*Pisum sativum* L.) at Paklihawa, Rupandehi. Nepal. World J Agric Res. 3, 129–138. doi: 10.12691/wjar-3-4-3

Blanco-Canqui H. (2017). Biochar and Soil Physical Properties. Soil Sci Soc Am J. 81: 687–711. doi: 10.2136/sssaj2017.01.0017

Cantrell K.B., Hunt P.G., Uchimiya M., Novak J.M., Ro S.K. (2012). Impact of Pyrolysis Temperature and Manure Source on Physicochemical Characteristics of Biochar. Bioresour Technol. 107: 419–428. doi: 10.1016/j.biortech.2011.11.084

Carter M.R. (1993) Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Boca Raton, FL: Lewis Publishers, p. 823.

Dai Z., Zhang X., Tang C., Muhammad N., Wu J., Brookes P.C., Xu J. (2017). Potential Role of Biochars in Decreasing Soil Acidification - A Critical Review. Sci Total Environ. 581–582: 601–611. doi: 10.1016/j.scitotenv.2016.12.169

Deressa A., Wakene N. C., Geleto T. (2007). Inventory of Soil Acidity Status in Crop Lands of Central and Western Ethiopia. Proceedings from: Utilization of Diversity in Land Use Systems: Sustainable and Organic Approaches to Meet Human Needs, Witzenhausen, Germany

Duku H.M., Gu S., Hagan E.B. (2011). Biochar Production Potentials in Ghana – A Review. Renewable and Sustainable Energ. Rev. 15: 3539–3551. doi: 10.1016/j.rser.2011.05.010

El-Naggar A., Lee S.S., Rinklebe J., Farooq M., Song H., Sarmah A.K., Zimmerman A.R., Ahmad M., Shaheen, S.M., Ok Y.S. (2019). Biochar Application to Low Fertility Soils: A Review of Current Status and Future Prospects. Geoderma 337: 536–554. doi: 10.1016/j.geoderma.2018.09.034

Fageria N. K., Moreira A., Castro C., Moraes M. F. (2013). Optimal Acidity Indices for Soybean Production in Brazilian Oxisols. Commun Soil Sci Plant Anal. 44 (20): 2941–2951. doi: 10.1080/00103624.2013.829484

FFD (Federal Fertilizer Department) (2011). Fertilizer Use and Management Practices for Crop Production in Nigeria. 4th ed. Abuja, Nigeria: Federal Ministry of Agriculture and Rural Development 2011.

Gaskin J.W., Speir R.A., Harris K., Das K.C., Lee R.D., Morris L.A., Fisher D.S. (2010) Effect of Peanut Hull and Pine Chip biochar on Soil Nutrients, Corn Nutrient Status and Yield. Agronomy J. 102: 623-633. doi: 10.2134/agronj2009.0083

Gee G.W., Or D. (2002). Particle-Size Analysis. In: Dane J.H., Topp G.C. (eds), Methods of Soil Analysis. Part 4. Physical Methods. Soil Science Society of America Book Series No. 5, Madison, Wisconsin, USA, pp. 255–293.

Geng N., Kang X., Yan X., Yin N., Wang H., Pan H., Yang Q., Lou Y., Zhuge Y. (2022). Biochar Mitigation of Soil Acidification and Carbon Sequestration Is Influenced by Materials and Temperature. Ecotoxicol Environ Saf. 232 (2022): 113241. doi: 10.1016/j.ecoenv.2022.113241

Ghady, A.E., Alkoaiki, F.N. (2010). Examination of Protein from Common Plant Leaves for Use as Human Food. Am J Appl Sci. 7 (3):323-334. doi: 10.3844/ajassp.2010.323.330

Githinji L. (2014). Effect of Biochar Application Rate on Soil Physical and Hydraulic Properties of a Sandy Loam. Arch Agron Soil Sci. 60: 457–470. doi: 10.2136/vzj2018.05.0101

Glaser B., Lehmann J., Zech, W. (2002). Ameliorating Physical and Chemical Properties of Highly Weathered Soils in the Tropics with Charcoal—A Review. Biol Fert Soils 35: 219–230. doi: 10.1007/s00374-002-0466-4

Goenaga R., Gillaspie A.G., Quiles A. (2010). Field Screening of Cowpea Genotypes for Alkaline Soil Tolerance, Hortscience 45 (11): 1639–1642. doi: 10.21273/HORTSCI.45.11.1639

Gul S., Whalen J.K., Thomas B.W., Sachdeva V., Deng H. (2015). Physico-Chemical Properties and Microbial Responses in Biochar-Amended Soils: Mechanisms and Future Directions. Agric Ecosyst Environ. 206: 46–59. doi: 10.1016/j.agee.2015.03.015

Haruna I. M. (2011). Dry Matter Partitioning and Grain Yield Potential in Sesame (*Sesamum indicum* L.) as Influence by Poultry Manure, Nitrogen and Phosphorus at Samaru, Nigeria. Elixir Agric. 39: 4884–87.

Hungria M., Stacey G. (1997). Molecular Signals Exchanged between Host Plants and Rhizobia: Basic Aspects and Potential Application in Agriculture. Soil Biol Biochem 29: 819–830. doi: 10.1016/S0038-0717(96)00239-8

Jeffery S., Verheijen F.G.A., van der Velde M., Bastos A.C. (2011). A Quantitative Review of the Effects of Biochar Application to Soils on Crop Productivity Using Meta-Analysis. Agric Ecosyst Environ. 144: 175–187. doi: 10.1016/j.agee.2011.08.015

Jia, X., Yuan W., Ju X. (2015). Short Report: Effects of Biochar Addition on Manure Composting and Associated N_2O Emissions. Journal of Sustainable Bioenergy Systems 5 (2): 56–61. doi: 10.4236/jsbs.2015.52005

Jones D.L., Cross P., Withers P.J., DeLuca T.H., Robinson D.A., Quilliam R.S., Harris I.M., Chadwick D.R., EdwardsJones G. (2013). Nutrient Stripping: The Global Disparity between Food Security and Soil nutrient Stocks. J. Appl. Ecol. 50: 851–862. doi: 10.1111/1365-2664.12089

Kisinyo O. (2016). Long Term Effects of Lime and Phosphorus Application on Maize Productivity in an Acid Soil of Uasin Gishu County, Kenya. Sky Journal of Agricultural Research 5: 48 - 55.

Kleber M., Eusterhues K., Keiluweit M., Mikutta C., Mikutta R., Nico P.S. (2015). Mineral-Organic Associations: Formation, Properties and Relevance in Soil Environments. Adv.Agron. 130: 1–140. doi: 10.1016/bs.agron.2014.10.005

Lehmann J., Joseph S. (2015). Biochar for Environmental Management: Science, Technology and Implementation. London, UK: Earthscan.

Lehmann J., Kaempf N., Woods W.I., Sombroek W., Kern D.C., Cunha T.J.F. (2007). Classification of Amazonian Dark Earths and Other Ancient Anthropic Soils. In Lehmann J., Kern D.C., Glaser B. and Woods W.I. (eds), Amazonian Dark Earths: Origin, Properties, Management. New York: Springer, pp. 77–102.

Lehmann J., Rillig M.C., Thies J., Masiello C.A., Hockaday W.C., Crowley D. (2011). Biochar Effects on Soil Biota—A Review. Soil Biol Biochem. 43(9): 1812–1836. doi: 10.1016/j.soilbio.2011.04.022

Liang B., Lehmann J., Sohi S., Thies J. E., Oneill B., Trujillo L., Gaunt J., Solomon D., Grossman J., Neves E.G., Luizao F.J. (2010). Black Carbon Affects the Cycling of Non-Black Carbon in Soil. Org Geochem. 41 (2): 206–213. doi: 10.1016/j.orggeochem.2009.09.007

Lin M.H., Gresshoff P.M., Ferguson B.J. (2012). Systemic Regulation of Soybean Nodulation by Acidic Growth Conditions. Plant Physiol. 160: 2028–2039. doi: 10.1104/pp.112.204149

Major J., Rondon M., Molina D., Riha S.J., Lehmann J. (2010). Maize Yield and Nutrition during 4 Years after Biochar Application to a Colombian Savanna Oxisol. Plant Soil 333: 117–128. doi: 10.1007/s11104-010-0327-0

Major J., Steiner C., Downie A., Lehmann J. (2009). Biochar Effects on Nutrient Leaching. In Lehmann J. and Joseph S. (eds), Biochar for Environmental Management: Science and Technology. London, UK: Earthscan, 271–288. doi: 10.4324/9780203762264

McKay I.A., Djordjevic M.A., (1993). Production and Excretion of Nod Metabolites by *Rhizobium leguminosarum* bv. *trifolii* Are Disrupted by the Same Environmental Factors That Reduce Nodulation in the Field. Appl Environ Microbiol 59: 3385–3392. doi: 10.1128/aem.59.10.3385-3392.1993

Mensah A.K., Frimpong K.W. (2018). Biochar and/or Compost Applications Improve Soil Properties, Growth and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. International Journal of Agronomy 2018: 6837404. doi: 10.1155/2018/6837404

Menzies N. W. (2003). Toxic Elements in Acid Soils: Chemistry and Measurement. 267-296. In: Zdenko Rengel (ed.) Handbook of Soil Acidity. University of Western Australia, Perth, Western Australia, Australia

Miller J.S., Rhaodes A., Puno H.K., (2012). Plant Nutrient in Biochar. Advo. Agro, pp. 125

Minhas W.A., Hussain M., Mehboob N., Nawaz A., Ul-Allah S., Rizwan M.S., Hassan Z. (2020). Synergetic Use of Biochar and Synthetic Nitrogen and Phosphorus Fertilizers to Improve Maize Productivity and Nutrient Retention in Loamy Soil. J Plant Nutr. 43: 1356–1368. doi: 10.1080/01904167.2020.1729804

Miransari M., Balakrishnan P., Smith D., Mackenzie A., Bahrami H., Malakouti M., Rejali F. (2006). Overcoming the Stressful Effect of Low pHon Soybean Root Hair Curling Using Lipochitooligosacharides. CommunSoil Sci Plant Anal. 37: 1103–1110. doi: 10.1080/00103620600586391

Morón B., Soria-Díaz M.E., Ault J., Verroios G., Noreen S., RodríguezNavarro D.N., Gil-Serrano A., Thomas-Oates J., Megías M., Sousa C. (2005). Low pH Changes the Profile of Nodulation Factors Produced by *Rhizobium tropici* CIAT899. Chem Biol 12: 1029–1040. doi: 10.1016/j.chembiol.2005.06.014

Muleba N., Dabire C., Suh J.B., Drabo I., Ouedraogo J.T. (1997). Technologies for Cowpea Production Based on Genetic and Environmental Manipulations in the Semi-Arid Tropics. In: Technology options for sustainable agriculture in sub-Saharan Africa. In: Publication of the semi-arid food grain research and development agency (SAFGRAD) of the scientific, (Bezuneh T., Emechebe A.M, Sedgo J., Ouedraogo M., eds) Technical and Research Commission of OAU. Ouagadougou, Burkina Faso, pp. 195-206.

Oni B.A., Oziegbe O., Olawole O.O. (2019). Significance of Biochar Application to the Environment and Economy. Ann. Agric. Sci. 64: 222–236. doi: 10.1016/j.aoas.2019.12.006

Onwonga R.N., Lelei J.J., Freyer B., Friedel J.K., Mwonga S.M., Wandhawa P. (2008). Low Cost Technologies for Enhancing N and P Availability and Maize (*Zea mays* L.) performance on Acid Soils. World J. Agric. Sci. 4(S): 862-873.

Osei-Yeboah S., Lindsay J.I., Gumb S.F.A. (1983). Estimating Leaf Area of Cowpea (*Vigna ungiculata* (L.) Walp) from Linear Measurement of terminal Leaflets. Trop. Agr. 60 (2):149-150

Oulehle F., Tahovska K., Chuman T., Evans C.D., Hruška J., Růžek M., Bárta J. (2018). Comparison of the Impacts of Acid and Nitrogen Additions on Carbon Fluxes in European Conifer and Broadleaf Forests. Environ. Pollut. 238: 884–893. doi: 10.1016/j.envpol.2018.03.081

Pavlovkin J., Palóve-Balang, P., Kolarović, L., Zelinová, V. (2009). Growth and Functional Responses of Different Cultivars of *Lotus corniculatus* to Aluminum and low pH Stress. J. Plant Physiol. 166: 1479–1487. doi: 10.1016/j.jplph.2009.03.005

Rafae R.B.A., Fernandez-Marcos M.L., Cocco S., Ruello M.L., Fornasier F., Corti G. (2017). Benefits of Biochars for Soil Quality, Nutrient Use Efficiency and Cowpea (*Vigna unguiculata* L.) Growth in Acid Arenosol. Proceedings of the 1st World Conference on Soil and Water Conservation under Global Change-CONSOWA Lleida, Spain, pp. 18-22

Richardson A.E., Simpson R.J., Djordjevic M.A., Rolfe B.G. (1988). Expression of Nodulation Genes in *Rhizobium leguminosarum* biovar *trifolii* Is Affected by Low pH and by Ca and Al Ions. Appl Environ Microbiol 54: 2541–2548. doi: 10.1128/aem.54.10.2541-2548.1988

Rondon M, Lehmann J, Ramírez J, Hurtado M. (2007) Biological Nitrogen Fixation by Common Beans (*Phaseolus vulgaris* L.) Increases with Biochar Additions. Biology and Fertility of Soils. 43:699-708. doi: 10.1007/s00374-006-0152-z

Sheahan C.M. (2012). Plant Guide for Cowpea (*Vigna unguiculata* (L.) Walp). USDA- Natural Resources Conservation Services, Cape May, Plant Materials Center, Cape May, NJ

Shetty R., Prakash N.B. (2020). Effect of Different Biochars on Acid Soil and Growth Parameters of Rice Plants under Aluminium Toxicity. Sci Rep. (2020) 10: 12249. doi: 10.1038/s41598-020-69262-x

Silva A.J., Uchôa S.C.P., Alves J.M.A., Lima A.C.S., Santos C.S.V., Oliveira J.M.F., Melo V.F. (2010). Resposta do feijão-caupi à doses e formas de aplicação de fósforo em Latossolo Amarelo do Estado de Roraima. Acta Amazônica, 40: 31-36. doi: 10.1590/S0044-59672010000100004

Solomon D., Lehmann J., Thies J., Schafer T., Liang B., Kinyangi J., Neves E., Petersen J., Luizao F., Skjemstad J. (2007). Molecular Signature and Sources of Biochemical Recalcitrance of Organic C in Amazonian Dark Earths. Geochim. Cosmochim. Acta 71: 2285–2298. doi: 10.1016/j.gca.2007.02.014

Steiner C., Teixeira W.G., Lehmann J., Nehls T., de Macedo J.L.V., Blum W.E.H., Zech W. (2007). Long Term Effects of Manure, Charcoal and Mineral Fertilization on Crop production and Fertility on a Highly Weathered Central Amazonian Upland Soil. Plant Soil. 291(1):275-290. doi: 10.1007/s11104-007-9193-9

Sumner M.E., Noble A.D. (2003). Soil Acidification: The World Story. In: Handbook of soil acidity (Rengel. Z., ed.), Marcel Dekker, New York pp. 1–28.

Sylvia D.M., Fuhrmann J.J., Hartel P.G., Zuberer D.A. (2005). Principles and Applications of Soil Microbiology (No. QR111 S674 2005). Upper Saddle River, NJ, Pearson Prentice Hall.

Taye, B. (2008). Estimation of Lime Requirement. Training Manual for Regional Soil Testing Laboratory Heads and Technicians. National Soil Testing Center, Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia

Van Zwieten L., Kimber S., Morris S., Chan K.Y., Downie A., Rust J., Joseph S., Cowie A. (2010). Effects of Biochar from Slow Pyrolysis of Papermill Waste on Agronomic Performance and Soil Fertility. Plant and Soil 327(1–2): 235–246. https://doi.org/10.1007/s11104-009-0050-x

Wang L., Butterly C.R., Wang Y., Herath H.M.S.K., Xi Y.G., Xiao X. J. (2014). Effect of Crop Residue Biochar on Soil Acidity Amelioration in Strongly Acidic Tea Garden Soils. Soil Use and Management 30 (1):119–128. doi: 10.1111/sum.12096

Wen Z., Shen J., Blackwell M., Li H., Zhao B., Yuan H. (2016). Combined Applications of nitrogen and phosphorus Fertilizers with manure Increase Maize Yield and Nutrient Uptake via Stimulating Root Growth in a Long-Term Experiment. Pedosphere 26 (1):62- 73. doi: 10.1016/S1002-0160(15)60023-6

Yamato M., Okimori Y., Wibowo I. F., Anshori S., Ogawa M. (2006). Effects of the Application of Charred Bark of *Acacia mangium* on the Yield of Maize, Cowpea and Peanut, and Soil Chemical Properties in South Sumatra, Indonesia. J Soil Sci Plant Nutr. 52 (4): 489–495. doi: 10.1111/j.1747-0765.2006.00065.x

Yeboah E., Asamoah G., Ofori P., Amoah B., Agyeman K.O.A. (2020). Method of Biochar Application Affects Growth, Yield and Nutrient Uptake of Cowpea. Open Agriculture 2020 (5): 352–360.

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