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Effect of Biochar Application Rates on Soil Properties, Growth and Yield of Maize under Greenhouse Conditions

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Abstract

A greenhouse experiment was conducted two consecutive times to assess the effects of biochar from different sources on the growth of maize (*Zea mays*) with a view to determining the biochar rate that would give optimum growth performance of the test crop. The experiment consisted of six different biochar as treatments [cocoa pod husk (CPH), maize stovers (MAS) and maize cobs (MAC) applied singly and in equal combination ($CPH_{50}MAS_{50}$, $CPH_{50}MAC_{50}$ and $MAS_{50}MAC_{50}$)]. All the treatments were applied at different rates (0, 5, 10, 15, 20, 25 t ha^{-1}), each replicated thrice and arranged in completely randomized design. Highest stem girth of 4.2 ± 0.21 cm was obtained with 5 t ha^{-1} of MAS biochar application. Similar results were obtained with the plant height and number of leaves. However, highest grain yield of 21.37 g 10 kg^{-1} of soil (4.27 t ha^{-1}) at 15 t ha^{-1}, which was not significantly ($F_{70, 107} = 1.88$; $p > 0.05$) different from 16.16 g 10 kg^{-1} of soil (3.23 t ha^{-1}) at 10 t ha^{-1} of MAS application was obtained during the first cultivation. The repeat experiment without further biochar additions gave lower and comparable values. Soil pH, organic carbon, nitrogen and available phosphorus increased with biochar addition to soil. Also, except for Na^+, concentrations of Ca^{2+}, Mg^{2+} and K^+ increased with biochar addition, and with high concentrations of these cations at high levels of biochar application. It was concluded that addition of biochar to sandy loam soil increased soil chemical properties, growth and yield of maize.

Les effets des taux d'application de biochar sur les propriétés du sol, la croissance et le rendement du maïs sous conditions de 'greenhouse'

Abstrait

Une expérience en 'greenhouse' a été menée deux fois consécutives pour évaluer les effets du biochar de différentes sources sur la croissance du maïs (Zea mays) en vue de déterminer le taux de biochar qui donnerait des performances de croissance optimales de la culture d'essai. L'expérience consistait en six traitements différents au biochar [coque de cabosse de cacao (CPH), tiges de maïs (MAS) et épis de maïs (MAC) appliqués seuls et en combinaison égale ($CPH_{50}MAS_{50}$, $CPH_{50}MAC_{50}$ et $MAS_{50}MAC_{50}$)]. Tous les traitements ont été appliqués à des taux différents (0, 5, 10, 15, 20, 25 t ha^{-1}), chacun répliqué trois fois et disposé selon une conception complètement *aléatoire. La plus haute circonférence de tige de 4,2 ± 0,21 cm a été obtenue avec 5 t ha^{-1} d'application de biochar MAS. Des résultats similaires ont été obtenus avec la hauteur de la plante et le nombre de feuilles. Cependant, le rendement en grains le plus élevé de 21,37 g 10 kg^{-1} de sol (4,27 t ha^{-1}) à 15 t ha^{-1}, ce qui n'était pas significativement différent ($F_{70, 107}$ = 1,88; p> 0,05) de 16,16 g 10 kg^{-1} de sol (3,23 t ha^{-1}) à 10 t ha^{-1} d'application de MAS a été obtenu lors de la première culture. L'expérience répétée sans autres ajouts de biochar a donné des valeurs inférieures et comparables. Le pH du sol, le carbone organique, l'azote et le phosphore disponible ont augmenté en ajoutant de biochar au sol. De plus, à l'exception de Na^+, les concentrations de $Ca2^+$, $Mg2^+$ et K^+ ont augmenté avec l'ajout de biochar et avec des concentrations élevées de ces cations à des niveaux élevés d'application de biochar. Nous avons conclu que ajouter de biochar au sol limoneux sableux augmentait les propriétés chimiques du sol, la croissance et le rendement du maïs.*

Introduction

Maize (*Zea mays* L.), a member of the Poaceae family, was introduced into Nigeria in the 16th Century by the Portuguese (Osagie and Eka, 1998). It is a plant which is grown on variety of soils ranging from fairly coarse sand to the heaviest of clay (Kochhar, 1986), and it is grown in most parts of Nigeria. Maize is the most preferred energy source among other cereals due to the palatability conferred by its energy density and low fibre content (Panda *et al*., 2011). In Nigeria, maize is known and called by different vernacular names depending on locality like 'agbado', 'igbado' or 'yangan' (Yoruba); 'masara' or 'dawar masara' (Hausa); 'ogbado' or 'oka' (Ibo); 'apaapa' (Ibira); 'oka' (Bini and Isha); 'ibokpot' or 'ibokpot union' (Efik) and 'igumapa' (Yala) (Abdulrahaman and Kolawole, 2006).

Nitrogen requirement for maize crop production is high (Awe *et al*., 2014), whereas most cultivable Nigerian soils are mostly sandy with low-activity clay that are low in nitrogen (Akinrinde and Obigbesan, 2006). Presently in Nigeria, most farmers are resource-poor and hence, they practice subsistence agriculture. Therefore, the demand for organic-based fertilizers is on the increase because they are generally in abundance and cheap as against the conventional scarce and expensive synthetic ones (Adewole and Aboyeji, 2013).

Biochar, an organic-based soil amendment has the potential to increase soil nutrients (Masulili *et al*., 2010) and to retain the inherent soil nutrients from leaching (Sombroek *et al*., 2003; Steiner *et al*., 2008 and Uzoma *et al*., 2011). Increase in water holding capacity of soil had also been reported by Chan *et al*., (2007) when biochar is used as soil amendment. Biochar addition to soil provided increased levels of refuge for soil microorganisms (Kolb *et al*., 2009) and reduced soil bulk density (Gundale and DeLuca, 2007).

Globally, approximately 140 billion metric tons of crop residues are produced yearly with 141 million metric tons in India (Bimbraw, 2019) and 150 metric tons in Nigeria (Olanrewaju *et al*., 2019). These crop residues are generated from agricultural practices and they pose both disposal and environmental pollution problems. Crop residues, when left on the soil surface eventually decompose releasing CO_2 back into the atmosphere, an addition to greenhouse gases. The conversion of crop residues into biochar and their application to soils is thus an eco-friendly way of returning plant nutrients to the soil. Despite the abundance of farm wastes and numerous uses of biochar in crop husbandry, there is dearth of information on its use in Nigeria. This study therefore determined the effects of different sources and rates of biochar applications to soil on the growth pattern and yield of a maize variety. It also determined the residual effect of these biochar uses on soil properties.

Materials and Methods

Experimental location, design used and agronomic practices employed

The study was conducted in the greenhouse of the Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Nigeria. The experiment consisted of slowly pyrolysed biochar from different sources, namely; cocoa pod husk (CPH), maize stovers (MAS) and maize cob (MAC) applied singly and in equal combinations (CPH_{50} MAS_{50}, CPH_{50} MAC_{50}, $MAS_{50,}$ MAC_{50}) to give a total of six treatments. All the treatments were applied at the rates of 0, 5, 10, 15, 20, 25 t ha^{-1}; each was replicated thrice to give a total of 108 experimental units and arranged in a completely randomized design.

Surface soil sample was collected from an exhaustively cropped farmland; air-dried for 7 days and then sieved through a 2 mm mesh. The surface soil sample was analysed using standard methods (Page *et al*., 1982) to determine their properties. The soil pH was determined in 1:1 soil-1M KCl suspension using a glass electrode pH meter. Total nitrogen of the soil was determined by the macro-Kjeldahl method.

Available phosphorus in the soil was extracted using Bray P1 method and P in the extractants was determined by colorimetry. The organic carbon in soil was determined using the Walkley-Black wet oxidation method.

Ten kilograms each of the air-dried and sieved soil was filled into the plastic pots with space at the top to make allowance for watering, and the pots perforated at the bottom to enhance soil aeration during the greenhouse experimentation. Biochar of known properties (Table 1) were thoroughly incorporated in the soil and 2.37 L of distilled water per pot was added to attain field moisture capacity. The set-up was allowed to incubate for 14 days to ease soil equilibration.

Two weeks after biochar incubation, seeds of maize (ART/98/SW6) purchased from the Institute of Agricultural Research and Training (IAR&T), Ibadan, Nigeria were planted at three seeds per pot and thinned to two stands two weeks after sowing. Water was supplied to the maize plants regularly throughout the duration of the experiment. Data on growth parameters (number of leaves, plant height and stem girth) commenced at 2 weeks after sowing (WAS) and continued fortnightly till 12 WAS. Plant height and stem girth were measured, while the leaves were counted. At full physiological maturity, maize ears were harvested, dried, manually shelled and maize grains weighed.

Statistical Analyses

Data on yield of maize and post-cropping soil properties were subjected to analysis of variance and their treatment means separated using the Duncan's Multiple Range Test (SAS version 9.1 at 95% level), and data on growth parameters were plotted using GraphPad prism 5.0 statistical software at 95% level.

Table 1: Physical and chemical properties of biochar used

Property	Value		
	CPH	MAC	MAS
pH (1:2 biochar-water)	11.98	10.77	11.10
Ash (%)	15.69	17.59	16.75
Organic carbon (g kg^{-1})	436.10	483.50	511.00
Total nitrogen (g kg^{-1})	7.40	10.90	12.10
C/N ratio	58.93	44.35	42.23
Total phosphorus (mg kg^{-1})	1150.00	700.00	620.00
P/N ratio	155.41	64.22	51.24

Legend: CPH = Cocoa pod husks, MAC = Maize cobs, MAS = Maize stovers
Adapted from Ilesanmi et al. (2016)

Results and Discussion

Properties of soil for the greenhouse experiment

The pre-cropped physical and chemical properties of soil for the greenhouse experiment are presented in Table 2. Particle size distribution of the soil was: sand 712 g kg^{-1}, silt 194 g kg^{-1} and clay 94 g kg^{-1} to give a soil texture of sandy loam. The soil was slightly alkaline with soil pH of 7.34 in 1:1 soil-1M KCl ratio. Organic carbon and total N were 17.05 and 1.60 g kg^{-1} respectively, while available P was 5.18 mg kg^{-1}. The cation exchange capacity, CEC (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}) was 6.58 cmol kg^{-1}, but dominated by 78.9% of Ca^{2+}.

Table 2: Selected pre-cropped soil properties of the experiment

Property	Value
pH (1: 1 soil:1M KCl)	7.34
Organic carbon (g kg^{-1})	17.05
Total nitrogen (g kg^{-1})	1.60
Available phosphorus (mg kg^{-1})	5.18
Exchangeable cations (cmol kg^{-1})	
Ca^{2+}	5.19
Mg^{2+}	0.38
Na^{+}	0.43
K^{+}	0.58
Sand (g kg^{-1})	712.00
Silt (g kg^{-1})	194.00
Clay (g kg^{-1})	94.00
Soil texture	Sandy loam

Effects of biochar used on soil properties

The pH of the three biochar in 1:2 biochar - water ratio was: cocoa pod husks 11.98; maize cobs 10.77; and maize stovers 11.10 indicating their highly alkaline nature. The biochar OC contents were: cocoa pod husks 436.1 g kg^{-1}; maize cobs 483.5 g kg^{-1}; and maize stovers 511.0 g kg^{-1}. Cocoa pod husks, maize cobs and maize stovers biochar had total N contents of 7.4, 10.9 and 12.1 g kg^{-1}, respectively. The C/N ratio was 58.93, 44.35 and 42.23 for cocoa pod husks, maize cobs and maize stovers, respectively. Biochar from cocoa pod husks, maize cobs and maize stovers had total P contents of 1150, 700 and 620 mg kg^{-1}; and 155.41, 64.22 and 51.24 P/N ratios, respectively.

Biochar as a soil amendment has been reported to boost soil fertility and improve soil quality, thus resulting to increased crop yields (Prabha *et al.*, 2013). Soil pH is an important variable that influences many soil chemical and biological properties (Brady and Weil, 2008). Soil benefits as a result of biochar application include: raising soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving CEC and retaining nutrients (Lehmann *et al.*, 2006). Significant increase in pH was found in biochar amended soils with higher pH values at higher levels of biochar application and the lowest pH value in the control (Lehmann, 2007). Prabha *et al.* (2013) observed similar results (pH value from 4.5 to 4.8, 5.4 and 5.5 with the addition of 15 g, 25 g and 35 g of biochar to soils respectively) with biochar produced from rubber tree. In this study, soil pH increased from 7.34 to 8.32, 8.33, 8.38, 8.74, 8.78 and 8.87 when biochar from MAC/MAS, MAS, MAC, CPH/MAC, CPH/MAS and CPH respectively were applied to soil at 15 t ha^{-1}. Highest soil pH value (9.21) was observed in soils amended with cocoa pod husk biochar at 25 t ha^{-1}.

Other authors such as Chan *et al.*, (2008); Laird *et al.*, (2010); Van Zwieten *et al.*, (2010); Peng *et al.*, (2011); and Vaccari *et al.*, (2015) observed similar rise in soil pH when biochar was applied to soil. Increase of soil pH following biochar application may be related to the alkaline nature of biochar (Sukartono *et al.*, 2011). An increase in soil pH was also reported by Major *et al.*, (2010) who also reported further that exchangeable acidity showed a decreasing trend with biochar application. The three biochar used increased the SOC and nitrogen contents above the pre-cropped level. Highest values of OC and nitrogen were obtained in soils amended with maize stover biochar at the highest level of application. This might be as a result of the high C content of the maize stover biochar used. Demisie and Zhang (2015) observed similar increase in total OC with increasing biochar application. Addition of biochar to soil significantly increased the SOC content (Shenbagavalli and Mahimairaja, 2012), and will probably add to the decadal soil carbon pool (Steinbeiss *et al.*, 2009).

The high values of OC in biochar treated soils indicate the recalcitrant organic-C in biochar (Nigussie *et al*., 2012). The CEC measures the total sum of exchangeable cations that a soil can hold (Brady and Weil, 2008). A higher CEC indicates a higher capacity of the soil to adsorb and hold nutrients, and therefore higher nutrient availability. Except for Na^+, concentrations of Ca^{2+}, Mg^{2+} and K^+ increased by biochar addition in the greenhouse and with high concentrations of these cations at high levels of biochar application (Table 3). Vaccari *et al*., (2015) observed that biochar treatments increased significantly the concentrations of K^+ and Na^+ but not the concentrations of Ca^{2+} and Mg^{2+}. Contrarily, Major *et al*., (2010) observed that availability of nutrients such as Ca and Mg was greater with biochar addition. Prabha *et al*., (2013) reported an increase in CEC, N, P and K contents of soils treated with biochar with the highest values at high amounts of application. This variability in soil properties after biochar addition may not be unconnected with variations in biochar properties brought about by different organic materials used for biochar production.

Effect of biochars on agronomic growth and yield of maize

Plant growth was reduced in the second trial compared with the first, a trend that might be due to the fact that biochar was only applied once for both trials (Figures 1 to 3; features for 20 and 25 t ha^{-1} were excluded from the figures as these followed gradual increasing pattern). Schulz and Glaser (2012) also grew oat twice and found relatively higher yield from the biochar-amended soils regarding plant growth during the first than second period. Prabha *et al*., (2013) obtained maximum height, highest total biomass and grain yield of rice plants at the highest level of biochar application and stated that the applications of biochar considerably influenced the growth profile and grain yield of the rice plants comparedwith other amendments. Chan *et al.* (2008), Steiner *et al*. (2008), and Asai *et al.* (2009), were of the opinion that increased nutrient retention with increased rate of biochar application may be the most important factor for increased agronomic parameters.

Low grain yields of maize were obtained with cocoa pod husk biochar when applied singly or in combination with other biochar. This might be as a result of its highly alkaline pH as Kishimoto and Sugiura (1985) stated that applying a biochar with a liming effect to a soil whose pH is already high can aggravate micronutrient deficiencies and reduce crop yields. Essential plant nutrients such as K, N, Ca and P as suggested by Major *et al*. (2009), that improved crop yields as a result of added biochar was not so with cocoa pod husk biochar despite

Table 3: Selected post-cropped soil properties of the experimental units for 15 t ha-1 of biochar application

Property	Treatment					
	CPH	MAC	MAS	CPH/MAC	CPH/MAS	MAC/MAS
pH (1: 1 soil:1M KCl)	8.87	8.38	8.33	8.74	8.78	8.32
Organic carbon (g kg^{-1})	22.79	24.24	29.05	27.61	26.80	24.60
Total nitrogen (g kg^{-1})	2.17	2.32	2.80	2.66	2.57	2.35
Available phosphorus (mg kg^{-1})	7.75	3.54	5.26	9.23	11.55	4.71
Exchangeable cations (cmol kg^{-1})						
Ca^{2+}	20.05	14.89	7.15	17.28	19.31	11.93
Mg^{2+}	2.95	2.78	0.39	2.03	3.07	3.14
Na^+	0.43	0.42	0.38	0.43	0.40	0.39
K^+	2.48	1.42	0.67	1.81	2.33	0.65
Sand (g kg^{-1})	762.00	736.00	725.00	746.00	740.00	760.00
Silt (g kg^{-1})	144.00	169.00	179.00	154.00	169.00	154.00
Clay (g kg^{-1})	94.00	95.00	96.00	100.00	91.00	86.00
Soil texture	SL	SL	SL	SL	SL	SL

Legend: CPH = Cocoa pod husks, MAC = Maize cobs, MAS = Maize stovers, SL = Sandy loam high values of these nutrients. The C/N and P/N ratios were not considered by Major *et al*. (2009), as significant in plant nutrient release for enhanced crop yield. These ratios, particularly C/N was considered significant by Olayinka (2009) as a good indicator for mineralisation and nutrient release rate of organic-based fertilizers. The lower the C/N and/or P/N ratio, the faster is

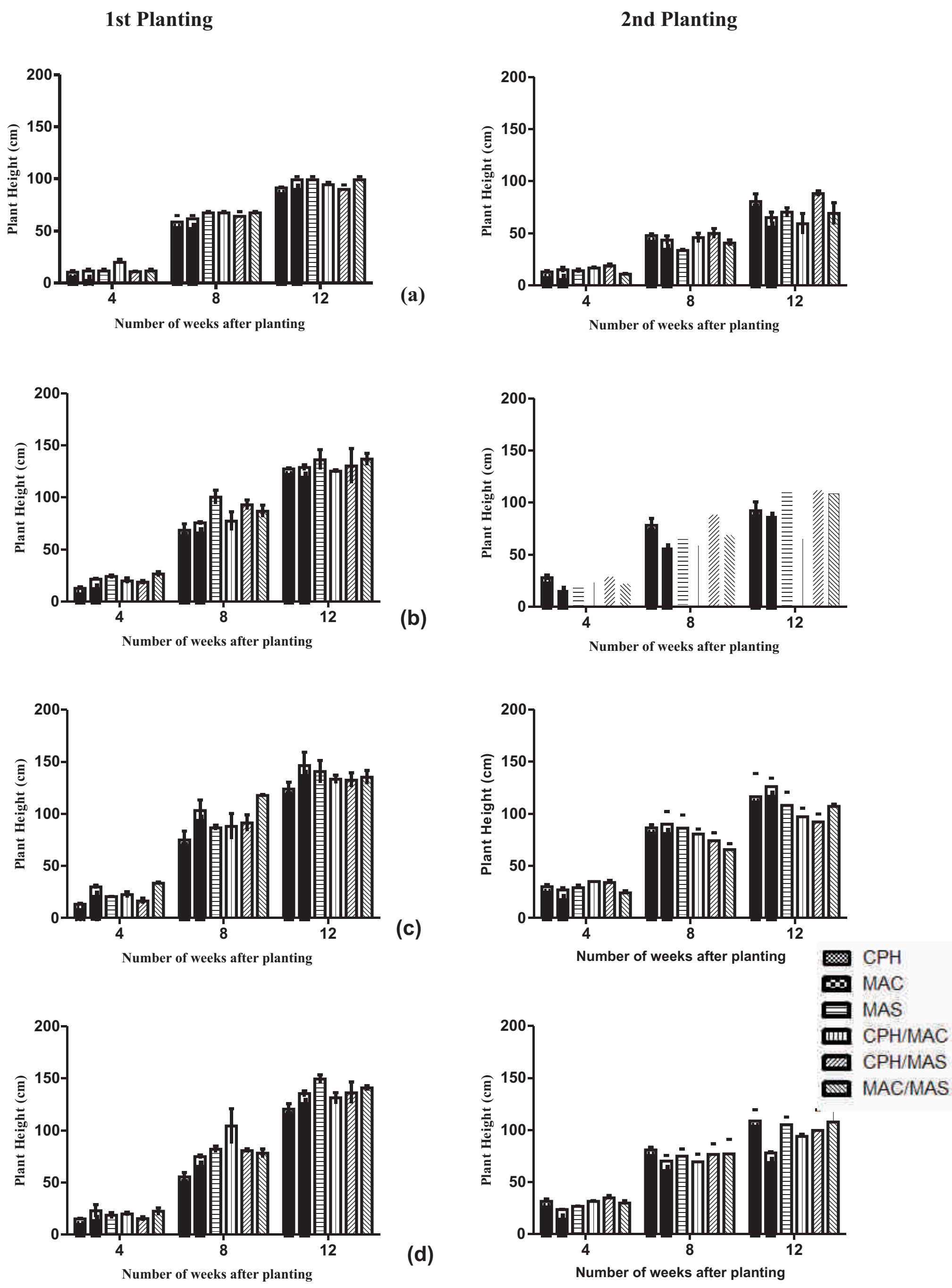

Figure 1: Mean plant height of maize under different rates (a) 0 (b) 5 (c) 10 (d) 15 t ha-1 of biochar applications. Vertical bars represent SE.

Legend: Cocoa pod husk = CPH, Maize stovers = MAS, and Maize cobs = MAC

the nutrient release for enhanced physiological growth and yield of crops as was observed in this experiment. For instance, stem girth was highest (4.2 ± 0.21 cm) for maize stover (MAS) biochar and lowest (3.4 ± 0.22 cm) for cocoa pod husk (CPH) and maize stover (MAS) biochar in equal proportion at 10 t ha^{-1}, 8 WAS.

In this study, grain yields were relatively and comparatively lower during the second cultivation compared with the first (Tables 4 and 5). The

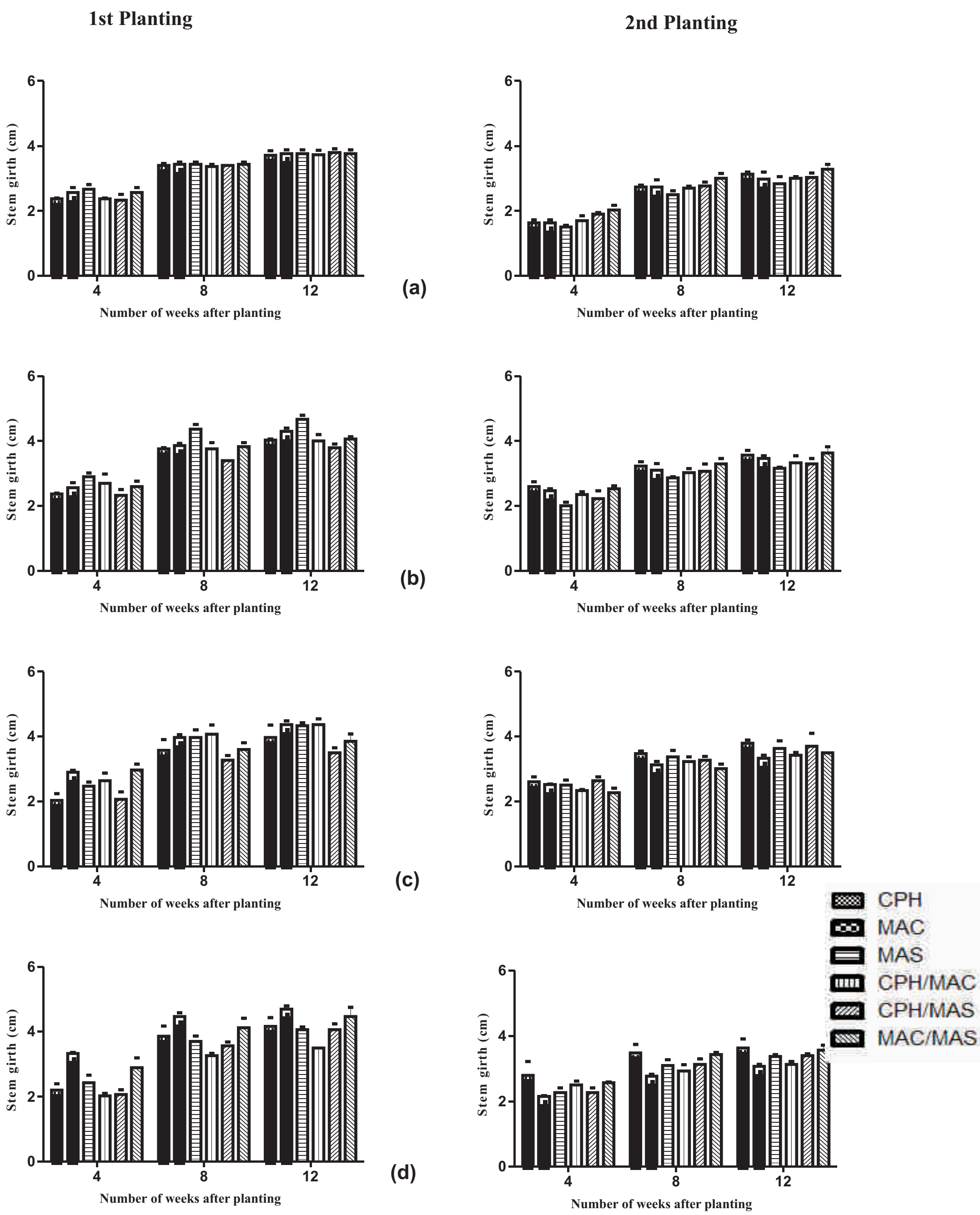

Figure 2: Mean stem girth of maize under different rates (a) 0 (b) 5 (c) 10 (d) 15 t ha-1 of biochar applications. Vertical bars represent SE.

Legend: Cocoa pod husk = CPH, Maize stovers = MAS, and Maize cobs = MAC

highest mean maize grain yield of 21.37 g 10 kg^{-1} soil (4.27 t ha^{-1}) with 15 t ha^{-1} of MAS biochar was not significantly ($p > 0.05$) different from 16.16 g 10 kg^{-1} soil (3.23 t ha^{-1}) with 10 t ha^{-1} of MAS biochar obtained during the first cropping. However, 13.05 g 10 kg^{-1} of soil (2.67 t ha^{-1}) with 25 t ha^{-1} of MAC and MAS biochar in equal proportion was the highest maize grain obtained during the repeat experiment. Results obtained from this study were in line with the works of Schulz and Glaser (2012) that observed low plant growth parameters and yield of *Avena sativa* during the second growth period when compared to the first with biochar addition to soil.

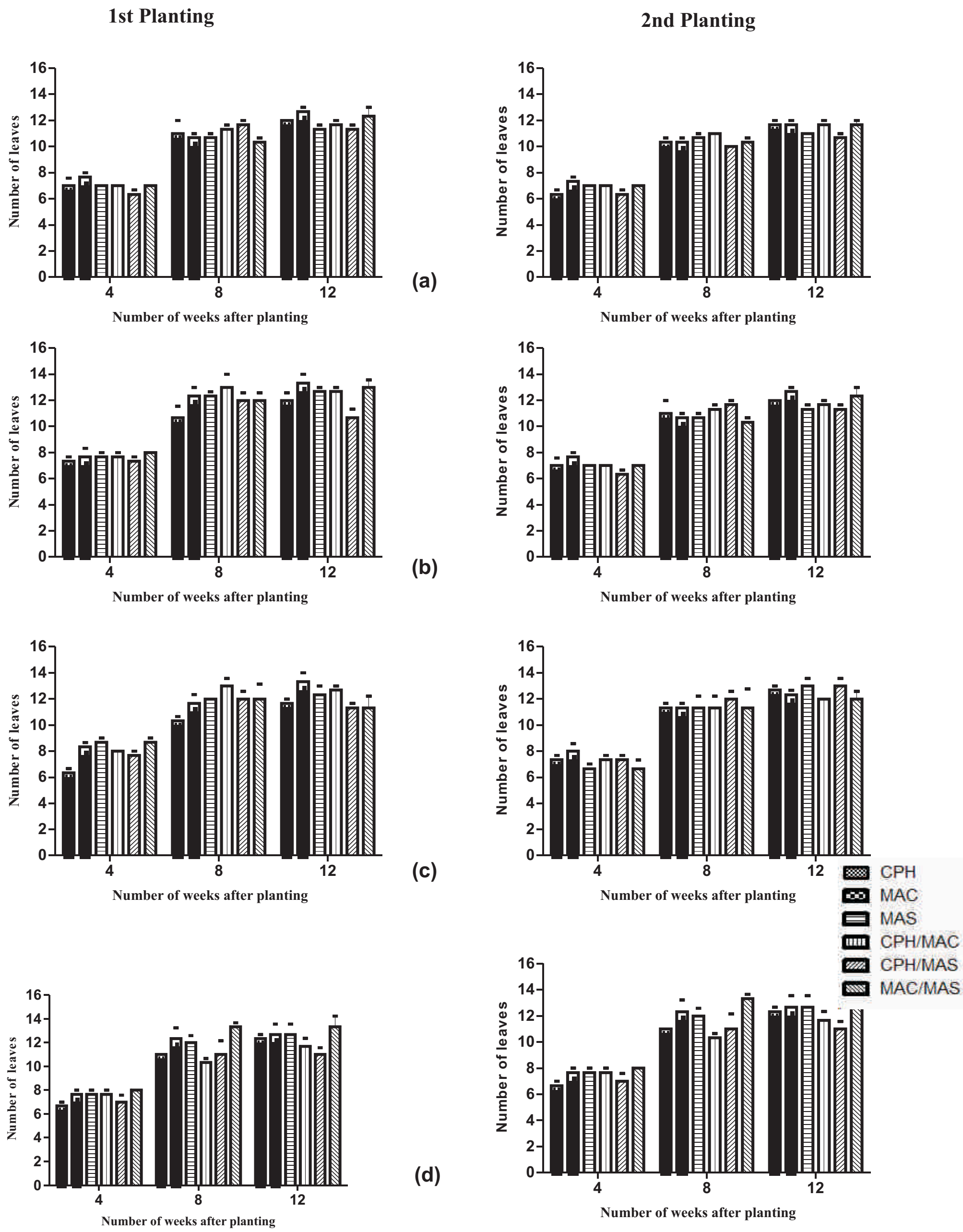

Figure 3: Mean number of leaves of maize under different rates (a) 0 (b) 5 (c) 10 (d) 15 t ha-1 of biochar applications. Vertical bars represent SE.

Legend: Cocoa pod husk = CPH, Maize stovers = MAS, and Maize cobs = MAC

Table 4: Grain yield of maize (g /10 kg soil) at first harvest under greenhouse conditions

Biochar	Treatment					
rate (t/ha)	CPH	MAC	MAS	CPH/MAC	CPH/MAS	MAC/MAS
0	5.00b	4.40c	7.57c	7.30b	2.30c	7.30c
5	5.15b	8.30b	9.50b	10.80a	2.50c	7.23c
10	7.50a	12.90ab	16.16ab	8.27ab	4.30c	10.23b
15	7.50a	14.40ab	21.37a	7.40b	4.20c	9.03b
20	6.30ab	14.25ab	16.70ab	6.05b	5.40b	10.33b
25	5.90b	18.53a	15.73ab	8.83ab	8.70a	13.05a

Means followed by the same letter(s) within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test.
Legend: CPH = Cocoa pod husks, MAC = Maize cobs, MAS = Maize stovers, ns = not significant.

Table 5: Grain yield of maize (g /10 kg soil) at second harvest under greenhouse conditions

Biochar	Treatment					
rate (t/ha)	CPH	MAC	MAS	CPH/MAC	CPH/MAS	MAC/MAS
0	1.80d	1.80c	2.30ns	0.84d	1.50b	1.10b
5	2.15c	1.17c	2.76ns	1.10c	2.13a	1.90ab
10	2.45bc	1.40c	2.65ns	1.25c	2.07a	3.90a
15	2.60bc	2.65b	3.05ns	1.43c	3.35a	3.90a
20	3.90bc	3.23b	3.15ns	2.52b	4.00a	4.90a
25	7.05a	4.45a	3.47ns	7.40a	4.00a	4.17a

Means followed by the same letter(s) within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test.
Legend: CPH = Cocoa pod husks, MAC = Maize cobs, MAS = Maize stovers, ns = not significant.

Conclusion

The biochar obtained from different stocks impacted differently on the physiological growth and grain yield of maize when applied as enhancers to sandy loam soil. The grain yield of maize at 10 and 15 t ha^{-1} of maize stover biochar were not significantly ($p > 0.05$) different during the two consecutive cropping periods. Grain yield of maize obtained during the first cropping was higher than the repeat experiment. Therefore, for optimum yield of maize, 10 t ha^{-1} of maize stover biochar application to soil was considered adequate. We also concluded that the application of biochar to soil as amendment in maize production increased soil pH, organic carbon, nitrogen, and soil CEC, though dominated by Ca^{2+}.

References

Abdulrahaman AA, Kolawole OM (2006). Traditional preparations and uses of maize in Nigeria. *Ethnobotanical Leaflets* 10: 219 - 227.

Adewole MB, Aboyeji AO (2013). Yield and quality of maize from spent engine oil contaminated soils amended with compost under screenhouse conditions. *Journal of Agrobiology*. 30 (1): 9-19.

Akinrinde EA, Obigbesan GO (2006). Benefits of phosphate rocks in crop production: Experience in benchmark tropical soil areas in Nigeria. *Journal of Biological Sciences* 6(6): 999-1004.

Asai H, Samson BK, Stephan HM, Songyikhangsuthor K, Homma K, Kiyono Y, Inoue Y, Shiraiwa T, Horie T (2009). Biochar amendment techniques for upland rice production in Northern Laos: 1. Soil physical properties, leaf SPAD and grain yield. *Field Crops Research* 111: 81 - 84.

Awe AO, Okareh OT, Sridhar MKC (2014). Use of processed waste feathers as source of organic nutrients for maize production. *African Journal* *of Environmental Health Sciences* 1(1): 9 - 13.

Bimbraw AS (2019). Generation and impact of crop residue and its management. *Current Agriculture Research Journal* 7(3): 304 - 309.

Brady NC, Weil RR (2008). The nature and properties of soils, Pearson Education Prentice Hall, Upper Saddle River, New Jersey. 14th edition.

Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S (2007). Agronomic values of greenwaste biochar as a soil amendment. *Australian Journal of Soil Research* 45: 629 - 634.

Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S (2008). Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research* 46: 437 - 444.

Demisie W, Zhang M (2015). Effect of biochar application on microbial biomass and enzymatic activities in degraded red soil. *African Journal of Agricultural Research* 10 (8): 755 – 766.

Ilesanmi AO, Adewole MB, Odesola IF, Isichei AO (2016). Production and characterisation of biochar from different farm wastes. *African Journal of Sustainable Development*. 6(2): 239-250.

Gundale MJ, DeLuca TH (2007). Charcoal effects on soil solution chemistry and growth of *Koeleria macrantha* in the ponderosa pine/Douglas-fir ecosystem. *Biology and Fertility of Soils* 43: 303 – 311.

Kishimoto S, Sugiura G (1985). Charcoal as a soil conditioner, in: '*Symposium on forest products research international: achievements for the future*', Volume 5, CSIR, Pretoria, South Africa, pp. 1 – 15.

Kochhar SL (1986). Tropical Crops: A textbook of economic botany. Macmillan Publishers, Hong Kong, pp. 88 - 95.

Kolb SE, Fermanich KJ, Dornbush ME (2009). Effect of charcoal quantity on microbial biomass and activity in temperate soils. *Soil Science Society of America Journal* 73: 1173 - 1181.

Laird D, Fleming P, Wang BQ, Horton R, Karlen D (2010). Biochar impact on nutrient leaching from a Midwestern agricultural soil. *Geoderma* 158: 436 - 442.

Lehmann J (2007). A handful of carbon. *Nature* 447: 143 – 144.

Lehmann J, Gaunt J, Rondon M (2006). Biochar sequestration in terrestrial ecosystems. A review. *Mitigation and Adaption Strategies for Global Change* 11: 403 - 427.

Major J, Rondon M, Molina D, Riha SJ, Lehmann J (2010). Maize yield and nutrition after 4 years of doing biochar application to a Colombian savanna oxisol. *Plant and Soil* 333: 117 – 128.

Major J, Steiner C, Downie A, Lehmann J (2009). Biochar effects on nutrient leaching (Chapter 15), in: J. Lehmann and S. Joseph (Eds.), *Biochar for Environmental Management*: Science and Technology, Earthscan, London, UK., pp. 271.

Masulili A, Utomo WH, Syekhfani Ms (2010). Rice husk biochar for rice based cropping system in acid soil 1. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. *Journal of Agricultural Sci*ence 2(1): 39 - 47.

Nigussie A, Kissi E, Misganaw M, Ambaw G (2012). Effect of biochar application on soil properties and nutrient uptake of lettuces (*Lactuca sativa*) grown in chromium polluted soils. *American-Eurasian Journal of Agriculture and Environmental Science* 12(3): 369 - 376.

Olanrewaju FO, Andrews GE, Li H, Phylaktou HN (2019). Bioenergy potential in Nigeria. *Chemical Engineering Transactions* 74: 61 – 66.

Olayinka A (2009). Soil microorganisms, wastes and national food security. Inagural lecture series 222. Obafemi Awolowo University, Ile-Ife, Nigeria. pp 40.

Osagie AU, Eka OU (1998). Nutritional quality of plant foods. Post Harvest Research Unit, University of Benin, Benin. pp. 34 -41.

Page AL, Miller RH, Keeney DR (1982). Methods of soil analysis, Part 2, Chemical and Microbiological properties. American Society of Agronomy, Inc., Madison, WI.

Panda AK, Raju MV, Rama Rao SV, Lavanya G, Pradeep KRE, Shyam SG (2011). Nutritional evaluation and utilisation of quality protein maize, Nityashree hybrid maize and normal maize in broiler chickens. *British Poultry Science* 52(5): 632 - 638.

Peng X, Ye LL, Wang CH, Zhou H, Sun B (2011). Temperature- and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China. *Soil and Tillage Research* 112: 159 - 166.

Prabha VS, Renuka R, Sreekanth NP, Padmakumar B, Thomas AP (2013). A study of the fertility and carbon sequestration potential of rice soil with respect to the application of biochar and selected amendments. *Annals of Environmental Science 7:* 17 - 30.

Schulz H, Glaser B (2012). Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment *Journal of Plant Nutrition and Soil Science 175:* 410 – 422.

Shenbagavalli S, Mahimairaja S (2012). Characterization and effect of biochar on nitrogen and carbon dynamics in soil. *International Journal for Advanced Biological Research 2*(2): 249 - 255.

Sombroek W, Ruivo ML, Fearnside PM (2003). Amazonian Dark Earths as carbon stores and sinks. In: Lehmann J, Kern DC, Glaser B, and Woods WI (Eds). Amazonian Dark Earths: origin, properties, management. Dordrecht, Netherlands: Kluwer Academic Publishers.

Steinbeiss S, Gleixner G, Antonietti M (2009). Effect of biochar amendment on soil carbon balance and soil microbial activity. *Soil Biology and Biochemistry* 41(6): 1301 - 1310.

Steiner C, Das KC, Garcia M, Forster B, Zech W (2008). Charcoal and smoke extract stimulate the soil microbial community in a highly weathered xanthic Ferralsol. *Pedobiologia* 51: 359 - 366.

Sukartono W, Utomo H, Kusuma Z, Nugroho WH (2011). Soil fertility status, nutrient uptake, and maize (*Zea mays* L.) yield following biochar and cattle manure application on sandy soils of Lombok, Indonesia. *Journal of Tropical Agriculture* 49 (1-2): 47 - 52.

Uzoma K, Inoue M, Andry H, Fujimaki H, Zahoor A, Nishihara E (2011). Effect of cow manure biochar on maize productivity under sandy soil condition. *Soil Use Management* 27: 205-212.

Vaccari FP, Maienza A, Miglietta F, Baronti S, Di Lonardo S, Giagnoni L, Lagomarsino A, Pozzi A, Pusceddu E, Ranieri R, Valboa G, Genesio L (2015). Biochar stimulates plant growth but not fruit yield of processing tomato in a fertile soil. *Agriculture, Ecosystems and Environment* 207: 163 - 170.

Van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S, Cowie A (2010). Effects of biochar from slow pyrolysis of paper mill waste on agronomic performance and soil fertility. *Plant and Soil* 327: 235 - 246.

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