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Effect of biochar on soil physical properties, growth parameters and yield of soybeans on a five-year fallow

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The potential of biochar as a soil amendment in agricultural fields is a recently recognized and yet underutilized technology. The objective of this study was to investigate the mid/long-term effects of a single biochar application on soil physical properties, growth parameters and the yield of soybeans in a sandy clay loam. Biochar was added to a highly weathered tropical soil at rates of 40 tons ha-^{1} five years prior to this study (2017 to 2022). Soybeans were grown in the biochar-amended soils and the control in the 2021/2022 season. Biochar amendment significantly increased porosity, biological activity, improved soil structure type and grade, increased the initial and basic infiltration rates, and lowered the bulk density. Soybean growth characteristics, such as shoot length, weight, and diameter at the base; root weight, pod number, and grain yield, were significantly improved by biochar. The improved agronomic performance of the crop was attributed to improved rooting conditions, soil water-holding capacity, and nutrient use efficiency promoted by biochar amendment. Thus, biochar is a promising practical approach to improve soil agronomic properties, nutrient acquisition, and the yield of soybeans in a sustainable way on sandy clay loam soils.

Key words: Biochar, crop yield, soybeans, growth parameters, soil properties, Zambia.

INTRODUCTION

There are various soil amendment technologies, including chemical fertilizers, organic fertilizers and lime, aimed at improving soil properties. The potential of biochar as a soil amendment in agricultural fields has recently been recognized as a promising yet underutilized technology (Jemal and Yakob, 2021). Biochar, a product of slow and incomplete combustion of organic materials, can enhance the physical, chemical and biological properties of soil when used in agriculture (Prendergast-Miller et al., 2014; Hossain et al., 2020). Unlike organic fertilizers, which mineralize rapidly in tropical conditions, the stability of biochar allows for long-term carbon storage, soil amelioration and reduced soil acidity, leading to improved crop production (Major, 2010).

The long-term effects of biochar on nutrient availability are attributed to increased surface oxidation and cation

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exchange capacity (CEC), intensifying over time and resulting in greater nutrient retention in "aged" biochar compared to "fresh" biochar (Liang et al., 2006; Cheng et al., 2008; Major, 2010). Biochar's high affinity for sorbing nutrients helps prevent nutrient leaching, keeping them available for plant uptake and enhancing crop yields. Additionally, biochar application improves crop productivity by enhancing water-holding capacity, creating suitable conditions for soil microorganisms, and positively influencing soil content of N, P, K and Mg, ultimately leading to higher grain yields (Jemal and Yakob, 2021). Notably, the most significant improvements in crop yields from added biochars have been observed in tropical and sub-tropical soils characterized by low carbon content and CEC, high acidity and coarse texture (Jeffery et al., 2017; Liu et al., 2019).

As biochars can persist in soils for thousands of years, a single application has the potential to achieve long-term nutrient management goals (Kuzyakov et al., 2014; Kalu et al., 2021). The objective of this study was to investigate the long-term effects of biochar on soil physical properties, growth parameters, and soybean yield in a highly weathered tropical sandy clay loam. The hypothesis was that biochar-amended soil would lead to better soil structure, reduced soil bulk density for improved root growth, enhanced soil infiltration and water-holding capacity, and increased sites for the retention of base cations, ultimately resulting in greater nutrient uptake and crop yields.

METHODS

The experiment was conducted at Mulungushi University located 26 km away from Kabwe town. It is located at a longitude of 28°33′36″E, latitude14°17′42″S and an altitude of 1,182 m above sea level. It lies in Agro-Ecological zone II which receives rainfall of between 800 and 1000 mm. The experimental field plots of 6 m × 4 m were set up side by side, one was amended with biochar at the rate of 40 t/ha in October 2017 while the other was not. The two plots were cultivated with maize in the year 2017/2018 season and were left farrow until 2021/2022. The soils were highly weathered tropical sandy clay loam.

Soil chemical characteristics

The composite end of experiment soil samples was analysed using the Bray-1 method for determination of phosphorus content in soils as described by Murphy and Riley (1962). Exchangeable K, Ca and Mg will be extracted with 1 N ammonium acetate buffered at pH 7.0. Concentrations of K, Ca and Mg in solution were determined by Atomic Absorption Spectrometry. The CEC was determined by summation of exchangeable cations. pH and EC were determined electrochemically using pH/EC meter (Combo pH/EC waterproof HI 98130, Hanna Instruments, Woonsocket, RI USA) in suspension with 0.01 M $CaCl_2$ using a 1:2.5 soil to solution ratio. Available phosphorus was extracted using the Bray-1 method (Olsen and Dean, 1965) and determined using the standard procedures of the Association of Official Analytical Chemists (AOAC, 1998).

Soil infiltration rate

Infiltration rate was measured using the single-ring infiltrometer. The polythene rings were pushed or pounded into the soil surface. The water was applied to the soil surface inside the rings recording the depth of the *falling head*, over time as water infiltrated, for a continuous period of 1 h. The infiltration rate was calculated as an average of three measurements from each plot. Cumulative infiltration was calculated as the total amount of water infiltrated during a given period.

Measurement of the bulk density, soil porosity and other soil physical parameters

For bulk density (BD), the samples were collected at four random positions in each of the two plots using a soil core ring of 70 mm height and 42 mm radius. The soils samples were oven dried for 48 h at 105°C and weighed using a mass balance. The volume was determined using the formula $V=\pi r^2 h$. BD was calculated (mass/volume) after removal of stones (>2 mm in diameter) as an average of the four samples in each plot. Soil porosity was calculated by using the following formular.

$$\text{Soil porosity (\%)} = 100 - \left(\frac{Bulk\ Density}{Partical\ density\ (2.65)}\right) \times 100$$

Other soil physical parameters were determined from the top 15 cm soil depth from a 50 × 50 × 50 cm mini pit dug in each plot. The following parameters were measured using the FAO guideline for soil profile description (Jahn et al., 2006). Soil structure grade, size and type, field porosity, pores abundance, pores type, pores size, root abundance and root size. Soil colour was measured using the Mansell colour chart.

Measurement of growth parameters and yields of soybeans

In 2018/19 season the two plots were demarcated. One was treated with biochar at the rate of ≈ 40 t ha^{-1} (2%) while the second plot was without biochar (the control). The two plots were planted with maize in the first year and left fallow for four years. In 2021/2022 season, the land was weeded and tilled to the depth of 10 cm using a hand hoe. A Zambian soybean variety, *Lukanga* was planted - a determinate non-self-modulating variety developed by ZARI, obtained from Zambia Seed Company Ltd. The seeds were inoculated with rhizobia (*Rhizobium leguminosarum*) at the time of seeding. The seed was planted at the recommended rate of 400,000 plants ha^{-1} with the optimum inter row spacing of 50 cm and 5 cm intra-row spacing. Two weeks after gemination, each plot was applied with a stimulative dose of 33kg ha^{-1} of D-Compound (NPK 10:20:10+6S) fertilizer as recommended (Miti, 1995).

Weeding, pests and disease control were done as the need arose. Supplemental irrigation was done only when the rains were inadequate and soil moisture was deemed to be below field capacity. Biomass weight was determined using destructive sampling method. In each of the measurements, ten plants were randomly selected and carefully uprooted from the rows of the subplot (each plot was divided into three subplots across the slope). The biomass was segmented into the shoot and root biomass weights. These were oven dried at 105°C for 72 h and weighed.

The grain harvesting was done by hand, approximately 130 days after sowing when the crop started drying (passed physiological

Table 1. The chemical characteristics of the soil in biochar and in the control.

Parameter	Units	Biochar	Non biochar	Critical values
pH	-	5.22	5.46	<4.5
EC	mS/cm	0.07	0.08	-
P	Ppm	22.89	13.29	<20
K	Ppm	152.1	105.3	<40
Ca	Ppm	970	1100	>200
Mg	Ppm	150	186	<50
CEC	cmol/kg	6.47	5.82	-

These were determined on bulk samples from each plots.

maturity). The grain weight was determined after air-drying for two weeks followed by a 48 h of oven drying at 40°C. The harvest index (HI) was calculated as a ratio of grain weight to total shoot dry matter weight: - a measure of reproductive efficiency (HI=grain/shoot weight).

Plant growth characteristics of shoot length, tap root length and shoot diameter at the base was measured using a tape rule; the shoot length was taken from the plant base to the upper most shoot tip; the diameter was calculated from the circumference measured at the base using a string and a tape rule (diameter= C/π). Number of pods and nodules per plant, were determined by counting pods and the nodules from each plant; root weight and shoot weight were weighed using a mass balance.

RESULTS

Chemical characteristics of the soil

The chemical characteristics of the soil measured on the soils in the biochar and the control plots are presented in Table 1. All the elements were above the critical minimum values except for phosphorus (P) (P<20 ppm) in the control while calcium was above the critical maximum (P>200 ppm) in both treatments. Biochar improved the CEC, K and P while it decreased Mg and Ca, and showed very little differences in pH, EC. However, all the characteristics were not below the critical minimum.

Comparison of the soil bulk density, porosity and other qualitative physical soil parameters between the soils with and without biochar amendment

The effect of biochar treatment on soil physical parameters and biological activity are shown in Table 2. The calculated bulk density was 25.5% lower in biochar plot than in non-biochar plot while porosity was 16.2% higher in biochar than in non-biochar plot. Both dry and moist soil colour was darker (by at least one value unit) in biochar treatment (greyish brown (10YR5/2) vs dark greyish brown (10YR4/2)) and brown (10YR4/3) vs black (10YR2/1)) respectively. While the soil structure was the same, the structure grade was weak to moderately strong in biochar plots and moderately strong in the non-biochar plots and the type was subangular blocky in biochar vs subangular blocky to angular blocky in non-biochar plot. Soil consistency when dry was slightly hard in biochar compared to hard in non-biochar. Biochar plot showed more biological activity with three (3) grubs of beetle larvae (*Arthropoda Incecta*) and many ants while in non-biochar there were only many ants. The root abundance of >2 mm root size was more in the biochar plots described as “few” (2 to 5 roots per square inch) than in non-biochar with “very few” (1 to 2 roots per square inch). All other parameters of soil texture, soil consistency when moist, stickiness, plasticity, pore types, sizes and abundancy were similar in both plots.

The effect of biochar on soil infiltration rate

The infiltration measurements showed that the biochar plot had higher infiltration rates both the instantaneous and cumulative infiltrations as compared to the non-biochar plot (Figure 1). The initial infiltration in biochar was 3 cm/min compared to 1.9 cm/min in non-biochar accounting for 57.9% higher intake rates in biochar plot than in non-biochar plot. Similarly, the basic infiltration rate in biochar plot after 60 min was 0.7cm/min compared to 0.35 cm/min in non-biochar control. The time required to infiltrate 30 cm of water was 25 min for biochar compared to 60 min for the non-biochar plot.

Effect of biochar on plant growth parameters and yield

The differences in means among the growth parameters of soybeans grown in soils amended with biochar and the control is shown in Table 3. Apart from tap root length, nodule number, grain weight, HI and 100 seed weight, all other parameters: Shoot length, shoot diameter, number

Table 2. The effect of biochar on soil physical parameters and biological activity.

Parameter	Units	Treatment	
		Biochar field	Control field
Density	g cm^{-3}	0.94 ±0.10[a]	1.18 ±0.10[a]
Porosity (calculated)	%	64.6 ±3.6[a]	55.5 ± 3.9[a]
Color moist	HVC	Black (10YR2/1)	Brown (10YR 4/3)
Color dry	HVC	dark greyish brown (10YR 4/2)	greyish brown (10YR 5/2)
Structure grade		Moderate	Weak to Moderate
Structure size	mm	Fine (5-10); medium (10-20)	Fine (5-10); medium (10-20)
Structure type		Subangular blocky	Subangular and angular blocky
Textural class		Sandy clay loam	Sandy clay loam
Consistency dry		Slightly hard	Hard
Consistence moist		Very firm	Very firm
Stickiness		Slightly sticky	Slightly sticky
Plasticity		Plastic	Plastic
Pores type		Interstitials and channels	Interstitials and channels
pore size	mm	Very fine (< 0.5 mm); fine (0.5-2 mm); medium (2-5 mm)	Very fine to fine
Pores abundance	No.	Common (50-200) very fine to fine); very few (1-2) medium	Common -very fine to fine; very few -medium
Porosity	%	>40 porous (high)	>40 porous (high)
Root abundance	No.	Common (50-200) (<2 mm); few (2-5) (>2 mm)	Common (50-200) (<2 mm); very few (1-2) (>2 mm)
Root size	mm	Coarse (> 5); fine (0.5-2); very fine (<0.5)	Course, fine and very fine
Biological activity	count	3 Grubs: beetle larvae (arthropoda incecta) and many ants	Many ants

HVC= hue, value, chroma-; Mansell colour chart; YR = Yellow Red; Values for BD and Calculated Porosity represent the mean ± SEM of three determinations (n=3), the differences were NS (same superscript means not significantly different), P=0.169 for both parameters.

of pods per plant, root weight and shoot weight of soybeans planted in biochar amended soils were significantly (P<0.01) higher than those in the control (Table 3). Even though the difference between treatments (biochar vs control) in nodule number (14.8±2.7 vs 11.5±1.6; 28% increase), grain yield (6.29±0.58 vs 4.15±0.72; 51.6% increase) and harvest Index (0.381±0.037 vs 0.461±0.056; 17.4% decrease) were not statistically significant at P>0.05, but they were reasonably large (Figure 2 III, VIII, IX). The grain weight was significantly greater in biochar than in non-biochar at P=0.08. Similarly, the shoot length, shoot weight shoot diameter at base, root weight, and pod number, were significantly higher (P<0.05) in biochar amended plots than the control by 35.5, 117.2, 34.6, 114.5 and 62.5%, respectively (Figure 2 I, II, V, VI and VII). There was no significant difference in tap root length (25.9±1.1 vs 25.0±1.5) and 100 seed weight (15.13±0.35 vs 15.21±0.05) between treatments (Figure 2X and XI).

DISCUSSION

Chemical characteristics of the soil

All the elements were above the critical minimum values except for P (P<20 ppm) in the control while calcium was above the critical maximum (P>200 ppm) in both treatments.

Biochar improved the CEC, K and P due to induced soil biological activity and mineralization (Hassana et al., 2019; Iijima et al., 2015) of

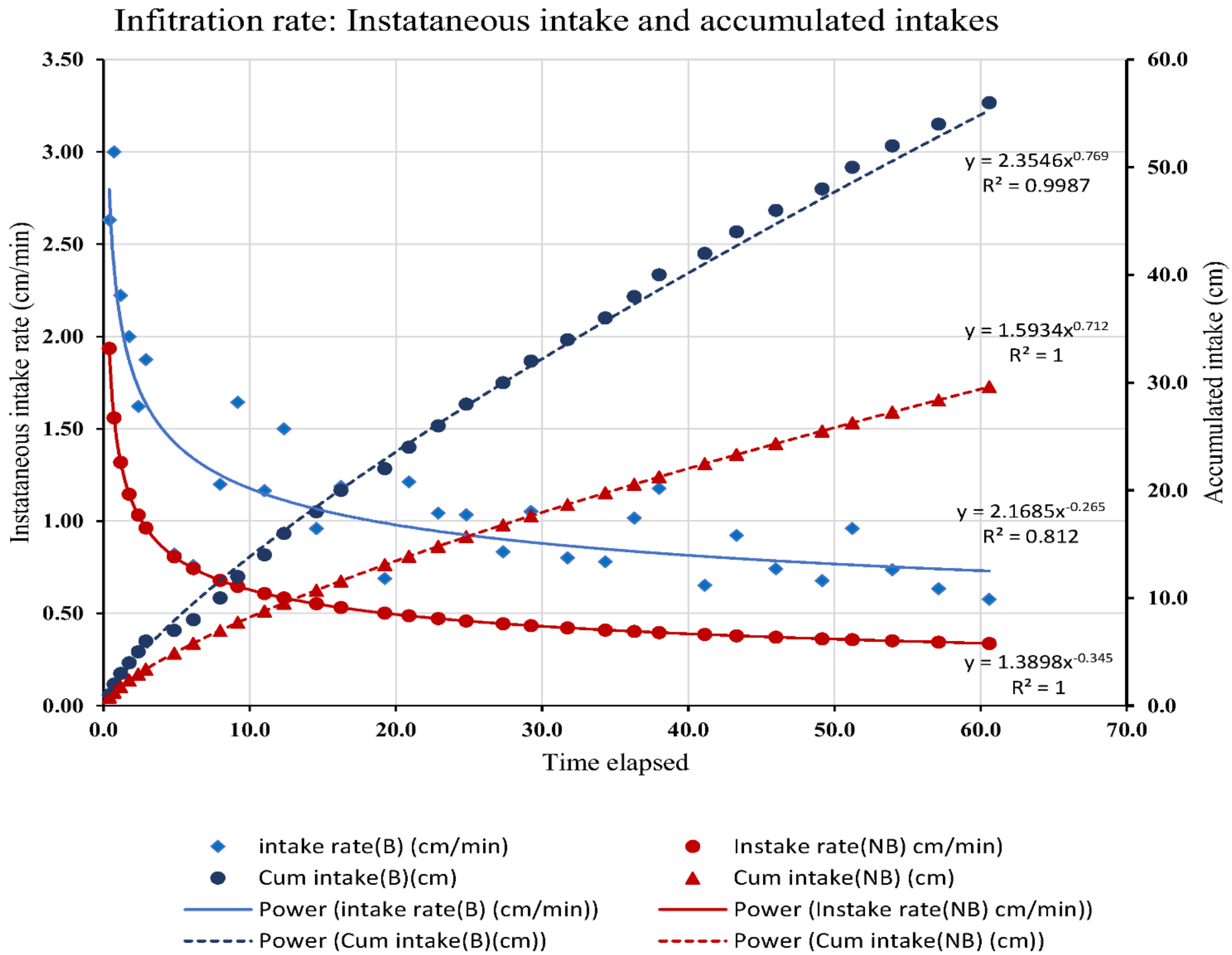

Figure 1. The instantaneous rate and accumulated intake infiltration for a biochar (B) and non-biochar (NB) field.

Table 3. Effect of biochar on growth parameters and grain yield of soybeans grown.

Parameter	Treatment		Statistics
	B	NB	Sig.
Tap root length (RL_T) (cm)	25.9±1.1	25.0±1.5	0.645
Nodule No. (NN) (no)	14.8±2.7	11.5±1.6	0.287
Shoot length (SL) (cm)	53.0±1.5	39.1±2.0	0
Shoot diameter (SD) (mm)	7.0±0.3	5.2±0.2	0
Pod No. (PN) (no.)	36.4±3.0	22.4±2.5	0.001
Root weight (RW) (t/ha)	1.03±0.10	0.48±0.04	0.008
Shoot weight (SW) (t/ha)	16.50±0.77	8.87±0.56	0.001
Plant weight (PW) (t/ha)	17.53±0.17	9.34±0.54	0.001
Grain yield (GW) (t/ha)	6.29±0.58	4.15±0.72	0.083
Harvest index (HI)	0.381±0.037	0.461±0.056	0.269
100 seed weight (SW_{100}) (g)	15.13±0.35	15.21±0.05	0.837

Values represent the mean ± SEM of eight determinations (n=8) except RW, SW, PW, GW, HI and SW_{100} (n=4).

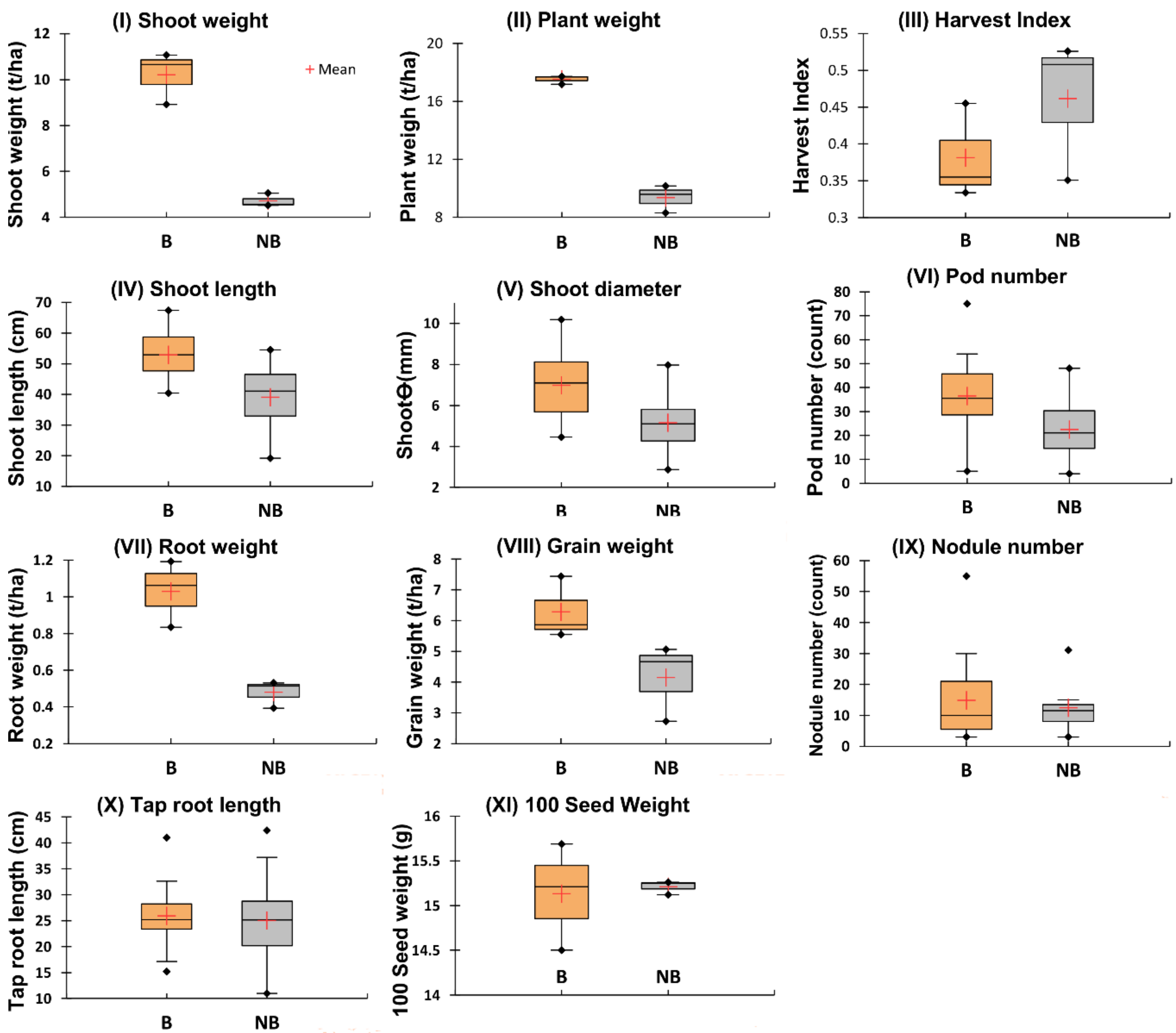

Figure 2. The growth parameters in the soybean between biochar and the control.

organic matter promoted by biochar. The decrease in pH, EC Mg and Ca were small and the values were all above the critical minimum and did not affect the growth of the plant.

Comparison of the soil bulk density, porosity, and other qualitative physical soil parameters between the soils with and without biochar amendment

Biochar application reduced bulk density from 1.18±0.10 to 0.94±0.10 cm^{-3} while it increased the calculated porosity from 55.5±3.95 to 64.5±3.65% compared to the non-biochar control. Biochar application accounted for a 25.5% decrease in bulk density and a 16.2% increase in soil porosity (Table 2) since porosity and bulk density are inversely related. Blanco-Canqui (2017) highlights two mechanisms by which biochar may reduce bulk density and increase porosity. Firstly, biochar is highly porous and has a lower bulk density (<0.6 g cm-^{3}) than mineral soil (~1.25 g cm^{-3}). Thus, adding porous materials like biochar reduces bulk densities probably through the mixing or dilution effect and increases porosities of soils through its highly porous nature (Singh et al., 2022;

Prakongkep et al., 2020). Biochar contains numerous longitudinal pores of sizes that range from micro- to macro-pores (Tomczyk et al., 2020). Secondly, biochar could also reduce bulk density in the long term by interacting with soil particles and improving aggregation and porosity. When biochar is added to soil, it becomes a binding agent that connect the soil micro aggregates to form macro-aggregates leading to an increase in the diameter of the soil aggregates (Sharma et al., 2021; Cheng et al., 2006), thereby changing the pore size distribution and the aggregate stability of a soil. The latter mechanism is especially true when monitoring bulk density changes through extended periods of time (>5 years) as it is an artifact of long-term biochar effect. Similarly, Lu et al. (2014) observed that rice husk biochar increased soil porosity by 20% and aggregation by 8 to 36%. The 25.5% decrease in bulk density was significant since the experiment was only five years long which time may not fully reflect the long-term effects of biochar on this soil. However, the large magnitude of the decrease in density may be explained by the large difference in densities between the soil (sand clay loam with ~1.2 g cm^{-3}) and biochar (maize biochar with ~0.220 g/cm^{-3}) (Ogunjobi and Lajide, 2013; Blanco-Canqui, 2017). According to Blanco-Canqui (2017) the magnitude of change tends to be larger if the difference is large and smaller if the difference is small.

Soil colour

High concentrations of biochar darken soil colour. Application of biochar darkened both dry and moist soil colour by at least one value unit than in soils without biochar. The application of biochar darkened the dry soil from greyish brown (10YR 5/2) to dark greyish brown (10YR 4/2) while the moist soils changed from Brown (10YR 4/3) to dark greyish brown (10YR 4/2). This darkening was probably due to the combined effect of the colour of biochar (with Munsell value 0-2), the biochar concentration in the soil, which was 20 g kg^{-1} and the degree of mixing (related to particle size of both the biochar and the soil) (Verheijen et al., 2009)

Soil structure type, grade, consistency and biological activity

Soil structure refers to the grouping of soil particles (sand, silt, clay, organic matter and fertilizers) into porous compounds also called aggregates. Soil structure also refers to the arrangement of these aggregates separated by pores and cracks. The application of biochar improved the soil structure grade from weak-moderate structure to moderate structure, the structure type from subangular-angular blocky to subangular blocky and the consistency when dry from hard to slightly hard. Application of biochar enhances soil aggregation by providing organic binding agents (Sharma et al., 2021) and stimulates growth of fungi that produce abundant hyphae that bind to other soil particles (Blanco-Canqui, 2017). Furthermore, biochar provides refuge to microorganisms and protects them from predators and desiccation, and these microorganisms secrete polysaccharides which increase soil aggregation (Aslam et al., 2014). Thus, biochar application improves aggregation processes and increase aggregate stability. Soil aggregation is responsible for soil structure, and it is fundamental for soil to function as well as for agricultural productivity (Juriga and Šimanský, 2018).

The biological activity was more in the biochar amended soil. In addition to the many ants in both plots, the biochar amended soils had few (2-5 per square decimeter) roots (>2 mm in size) and few grubs (3 grubs: beetle larvae (arthropoda incecta) while there were "very few" (1-2 per square decimeter) roots (>2 mm in size) and no grubs in the control plot within the mini pits. The results of many experiments have shown that application of biochar can be a sustainable way of improving physical (Pietikainen et al., 2000; Zhang et al., 2020; Nguyen et al., 2022), chemical (Chintala et al., 2013) and biological (Egamberdieva, 2016, Zhang et al., 2019; Shaaban, et al., 2018; Egamberdieva, 2022) properties of the soil. Therefore, the enhanced biological activity in biochar amended soils was not a random occurrence but was attributable to the application of biochar.

Other qualitative soil parameters of structure size, textural class, soil consistence when moist, stickiness, plasticity, pore type, pore size, pores, abundance, porosity (qualitatively determined) and root sizes showed no difference between biochar application and the control (Table 2). The difference was not noticeable using the qualitative criteria applied in the measurement of these parameters because some of the ranges applied in the categories are too large to capture differences attributable to biochar application to the soils.

The effect of biochar on soil infiltration rate

Few studies have investigated the effect of biochar on infiltration and runoff formation. Studies have shown that biochar has varied effects on soil infiltration in soils depending soil type, texture, biochar amendment rate, biochar type and properties (Barnes et al., 2014; Brewer, 2012). In this experiment, application of biochar at the rate of 20 g kg^{-1} promoted the initial infiltration rate from 1.9 cm/min in non-biochar control to 3 cm/min in biochar accounting for 57.9% increase. Similarly, the basic infiltration rate at the infiltration time of 60 min was twice in biochar amended soil (0.7 cm/min) than in the control (0.35 cm/min). The time required to infiltrate (cumulative infiltration) 30 cm of water was 25 min in biochar amended soils compared to 60 min in the control (Figure 1). Thus, biochar amendment promoted soil water movement in this soil type. Itsukushima et al. (2016) also reported higher initial and final infiltration rates in amended soils with bamboo biochar and humus than in the control soils. Addition of porous substances like biochar to soil modifies water retention, bulk density, total porosity and pore structure, thereby enhancing physical and hydraulic soil properties (Villagra-Mendoza and Horn, 2018). Due to the physical characteristics of biochar, its addition to the soil changes the pore size distribution within the soil which alters the percolation patterns, residence time, and flow paths of the soil solution (Atkinson et al., 2010). The movement of water in the soil matrix depends on texture, structure and pore properties, that is configuration, size, shape and distribution (Hartge and Horn, 2016). Soil texture may be directly impacted at the macroscale by the addition of biochar because of its particle size distribution and macroporous nature. This would contribute to increased infiltration of the soil water through preferential flow though macropores. Soils with large pore diameters drain off first. At saturation, coarse textured soils conduct water more rapidly than finer textures (Jury and Horton, 2004). The same process occurs for aggregated soils compared with poorly aggregated ones. Biochar is particularly porous and once its hydrophobicity has been overcome, it has potential to oxidize and absorb and retain more water (Cheng et al., 2006). In addition, biochar by interacting with soil particles and improving aggregation and porosity can form macro-aggregates leading to an increase in diameter of the soil aggregates (Sharma et al., 2021; Cheng et al., 2006) thereby increasing the pore size distribution and the aggregate stability of a soil leading to enhancement of the soil infiltration rate (Verheijen et al., 2009).

Effect of plant growth parameters and yield

The results indicate that biochar amendment significantly increased various growth parameters in soybeans compared to the control. Specifically, shoot length, shoot diameter at the base, pod number, root dry weight, shoot dry weight, whole plant dry weight and grain weight showed increases of 35.5, 34.6, 62.5, 114.5, 117.2, 116.8 and 51.6%, respectively, in the biochar-amended plants (Figure 2). While some differences were statistically non-significant, there were substantial increases in nodule number (28%), grain weight (51.6% increase), and harvest index (39.9% decrease) for plants with biochar compared to the control.

Despite the lack of statistical significance in some cases, the large differences observed suggest that biochar significantly improved several physicochemical properties of the soil, including bulk density, porosity, soil structure (likely soil aggregation), biological activity, soil infiltration and water retention capacity, as well as levels of phosphorus (P), potassium (K) and cation exchange capacity (CEC). These positive changes in soil parameters contribute to the improved agronomic performance of the soybean crop (Warnock et al., 2007; Steinbeiss et al., 2009; Liang et al., 2007; Chan and Cu, 2009). The enhanced plant growth related to improvements in these physical parameters may be attributed to better rooting conditions, increased soil water-holding capacity, and improved nutrient use efficiency promoted by biochar amendment (Basso et al., 2013).

Biochar also increased the nodule number by 28%, likely due to increased porosity and the presence of biochar pores serving as habitats for bacteria and fungi colonization. These pores offer protection against predators of bacteria and mycorrhizal fungi, providing a conducive environment for nodule formation. Biochar amendment creates favorable conditions for microbial proliferation, including mycorrhizae, thereby enhancing the symbiotic benefits between plants and mycorrhizal fungi, which contribute to increased nutrient availability such as phosphorus, nitrogen and zinc to plants through induced soil biological activity and mineralization (Hassana et al., 2019; Iijima et al., 2015).

Interestingly, biochar application led to a decrease in the harvest index (HI) from 0.461 to 0.381 compared to the control. A higher HI indicates more dry matter partitioned to grain than to vegetative growth. The decreased HI with biochar suggests a delicate balance between vegetative and reproductive phases. Biochar may encourage excessive vegetative growth by providing better conditions for soil moisture and fertility than the control. Despite the lower HI, the grain yield per hectare in the biochar plot exceeded that of the control, indicating that the greater vegetative growth promoted by biochar resulted in more pod formation and grain production. In summary, the soils amended with biochar resulted in better crop establishment, improved crop development rates, and higher soybean production.

Conclusion

The results of this study offer compelling evidence supporting the judicious application of biochar, providing a valuable reference for soil improvement practices. Maize cob biochar, as demonstrated in this research, enhances various soil properties and influences related processes, including water storage and infiltration, and likely plays a role in controlling soil erosion under normal weather conditions. The implications of these findings are significant, suggesting that maize cob biochar stands as a promising and practical approach to enhance soil agronomic properties, promote growth, facilitate nutrient acquisition, and improve the yield of soybeans on sandy clay loam soils in a sustainable manner.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Association of Official Analytical Chemists (AOAC) (1998). Official methods of analysis. (9th Edn) Arlington, Virginia, USA.

Aslam Z, Khalid M, Aon M (2014). Impact of Biochar on Soil Physical Properties. Scholarly Journal of Agricultural Science 4(5):280-284.

Assefa T, Beebe S, Rao IM, Cuasquer J, Duque MC, Rivera M (2013). Pod harvest index as a selection criterion to improve drought resistance in white pea bean. Field Crop Research 148:24-33. Available at: https://doi.org/10.1016/j.fcr.2013.04.008

Atkinson CJ, Fitzgerald JD, Hipps NA (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant Soil 337:1-18.

Barnes RT, Gallagher ME, Masiello CA, Liu Z, Dugan B (2014). Biochar-Induced Changes in Soil Hydraulic Conductivity and Dissolved Nutrient Fluxes Constrained by Laboratory Experiments. PLoS One 9:e108340.

Basso AS, Miguez FE, Laird DA, Horton R, Westgate M (2013). Assessing potential of biochar for increasing water-holding capacity of sandy soils. Gcb Bioenergy 5(2):132-143.

Beebe S (2012). Common bean breeding in the tropics. Plant Breeding Reviews 36(1):357-426. Available at: https://doi.org/10.1002/9781118358566.ch5

Beebe S, Rao IM, Blair MW, and Acosta-Gallegos JA (2013). Phenotyping common beans for adaptation to drought. Frontiers in Physiology 4:35. Available at: https://doi.org/10.3389/fphys.2013.00035

Beebe S, Rao IM, Devi M, Polania J (2014). Common beans, biodiversity, and multiple stress: challenges of drought resistance in tropical soils. Crop Pasture Science 65:667–675. Available at: https://doi.org/10.1071/CP13303

Blanco-Canqui H (2017). Biochar and soil physical properties. Soil Science Society of America Journal 81:687-711.

Brewer CE, Unger R, Schmidt-Rohr K, Brown RC (2011). Criteria to Select Biochars for Field Studies based on Biochar Chemical Properties. BioEnergy Research 4:312-323. Available at: https://doi.org/10.1007/s12155-011-9133-7

Chan KY, Cu Z (2009). Biochar: nutrient properties and their enhancement. In Lehmann J, Joseph S (eds.) Biochar for Environmental Management: Science and Technology. Earthscan, London P 6784.

Cheng CH, Lehmann J, Engelhard MH (2008). Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. Geochim. Cosmochim. Acta 72:1598-1610. Available at: https://doi.org/10.1016/j. gca.2008.01.010.

Cheng CH, Lehmann JJET, Burton SD (2006). Engelhard M.H. Oxidation of black carbon by biotic and abiotic processes. Org. Geo-Chem International Independent Inspection 37:1477-1488.

Chintala R, Mollinedo J, Schumacher TE, Malo DD, Julson LJ (2013). Effect of biochar on chemical properties of acidic soil. Archives of Agronomy and Soil Science 60(3):393-404.

Egamberdieva D, Alaylar B, Kistaubayeva A, Wirth S, Bellingrath-Kimura SD (2022). Biochar for Improving Soil Biological Properties and Mitigating Salt Stress in Plants on Salt-affected Soils, Communications in Soil Science and Plant Analysis. 53(2):140-152, Available at: https:// doi:10.1080/00103624.2021.1993884

Egamberdieva D, Wirth S, Behrendt U, Abd-Allah EF, Berg G (2016). Biochar treatment resulted in a combined effect on soybean growth promotion and a shift in plant growth promoting rhizobacteria. Frontiers in Microbiology 7:209. Available at: https://doi.org/10.3389/fmicb.2016.00209.

Hartge KH, Horn R (2016). Essential Soil Physics. Schweizerbart Science Publishers, Bagasse-Derived Biochar Application on Nitrate Leaching in Calcaric Dark Red Soil. Journal of Environmental Quality 41:1131-1137. Available at: https://doi.org/10.2134/jeq2010.0453

Hassana B, Mbawala A, Ngassoum M, Ibrahima A, Barka A (2019). Impact of Enriched Biochar on Bean Growth (Phaseolus vulgaris) in the Presence of Mycorrhizae on two Contrasting Soils of Ngaoundere (Cameroon), International Journal of Engineering Research and Technology 8:6.

Hossain MZ, Bahar MM, Sarkar B, Donne SW, Ok YS, Palansooriya KN, Kirkham MB, Chowdhury S, Bolan N (2020) Biochar and its importance on nutrient dynamics in soil and plant. Biochar 2(4):379-420. Available at: https://doi.org/10.1007/s42773-020-00065-z

Iijima M, Yamane K, Izumi Y, Daimon H, Motonaga T (2015). Continuous application of biochar inoculated with root nodule bacteria to subsoil enhances yield of soybean by the nodulation control using crack fertilization technique. Plant Production Science 18(2):197-208

Itsukushima R, Ideta K, Iwanaga Y, Sato T, Shimatani Y (2016). Evaluation of Infiltration Capacity and Water Retention Potential of Amended Soil using Bamboo Charcoal and Humus for Urban Flood Prevention, in: Proceedings of the 11th International Symposium on Ecohydraulics.

Jahn R, Blume HP, Asio VB, Spaargaren O, Schad P (2006). Guidelines for soil description, 4th edition. FAO, Rome. Available at: <http://www.fao.org/docrep/019/a0541e/a0541e.pdf>

Jeffery S, Abalos D, Prodana M, Bastos AC, Van Groenigen JW, Hungate BA, Verheijen F (2017). Biochar boosts tropical but not temperate crop yields. Environmental Research Letters 12(5):053001.

Jemal K, Yakob A (2021). Role of bio char on the amelioration of soil acidity. Agrotechnology 10:212.

Juriga M, Šimanský V (2018). Effect of biochar on soil structure—Review. Acta Fytotechnica et Zootechnica 21(1):11-19.

Jury WA, Horton R (2004). Soil Physics, 6th ed. John Wiley & Sons, USA.

Kalu S, Simojoki A, Karhu K, Tammeorg P (2021). Long-term effects of softwood biochar on soil physical properties, greenhouse gas emissions and crop nutrient uptake in two contrasting boreal soils. Agriculture, Ecosystems and Environment 316:107454. Available at: https://doi.org/10.1016/j.agee.2021.107454

Kuzyakov Y, Bogomolova I, Glaser B (2014). Biochar stability in soil: decomposition during eight years and transformation as assessed by compound-specific 14C analysis Soil Biology and Biochemistry 70:229-236. Available at: https://doi.org/10.1016/j.soilbio.2013.12.021

Liang B, Lehmann J, Kinyangi D, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luizao FJ, Peterson J, Neves EG (2007). Black carbon increases cation exchange capacity in soils. Soil Science Society of America Journal 70:17191730. Available at: https://doi.org/ 10.2136/sssaj2005.0383

Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luiz˜ao FJ, Petersen J, Neves EG (2006). Black carbon increases cation exchange capacity in soils. Soil Science Society of America Journal 70:1719-1730. Available at: https://doi. org/10.2136/sssaj2005.0383

Liu Q, Liu B, Zhang Y, Hu T, Lin Z, Liu G, Wang X, Ma J, Wang H, Jin H, Ambus P, Amonette JE, Xie Z (2019). Biochar application as a tool to decrease soil nitrogen losses (NH3 volatilization, N2O emissions, and N leaching) from croplands, options and mitigation strength in a global perspective. Global Change Biology 25:2077-2093. Available at: https://doi.org/10.1111/gcb.14613

Lu N, Liu XR, Du ZL, Wang YD, Zhang QZ (2014). Effect of biochar on soil respiration in the maize growing season after 5 years of consecutive application. Soil Research 52(5):505-512.

Major J, Rondon M, Molina D, Riha SJ, Lehmann J (2010). Maize yield and nutrition during 4 years after biochar application to a Colombian Savanna Oxisol. Plant and Soil. 333(1):117-128.

Miti JM (1995). Soybean (*Glycine max* (L.) Merr). In: Zambian Seed Technology Handbook. Muliokela, SW (Ed.) Lusaka: Ministry of

Agriculture, Food and Fisheries pp. 195-199. ISBN 9982-08-000-8.
Murphy J, and Riley JP (1962). A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27:31-36. Available at: https://doi.org/10.1016/S0003-2670(00)88444-5.
Nguyen BT, Nguyen VN, Nguyen TX, Van Thai N, Tran HTT (2022). Biochar Enhanced Rice (*Oryza sativa* L.) Growth by Balancing Crop Growth-Related Characteristics of Two Paddy Soils of Contrasting Textures. Journal of Soil Science and Plant Nutrition 22(2):2013-2025. Available at: https://doi.org/10.1007/s42729-022-00790-3
Ogunjobi JK, Lajide L (2013). Characterisation of Bio-Oil and Bio-Char from Slow-Pyrolysed Nigerian Yellow and White Corn Cobs, Journal of Sustainable Energy and Environment 4:77-84.
Olsen SR, Dean LA (1965). Phosphorus in: Methods of soil analysis. Part 2:1035-1048.
Pietikainen JM, Hiukka R, Fritze H (2000). Does short-term heating of forest humus change its properties as a substrate for microbes? In Soil Biology and Biochemistry 32:277-288. Available at: https://doi.org/10.1016/S0038-0717(99)00164-9
Prakongkep N, Gilkes R., Wisawapipat W, Leksungnoen P, Kerdchana C (2020). Effects of Biochar on Properties of Tropical Sandy Soils Under Organic Agriculture. Journal of Agricultural Science Cambridge University Press (CUP) 13(1):1-17.
Prendergast-Miller MT, Duvall M, Sohi SP (2014). Biochar-root interactions are mediated by biochar nutrient content and impacts on soil nutrient availability. European Journal of Soil Science 65:173-185.
Rao IM (2014). "Advances in improving adaptation of common bean and Brachiaria forage grasses to abiotic stresses in the tropics," in Handbook of Plant and Crop Physiology, ed M. Pessarakli (Boca Raton, FL: CRC Press; Taylor and Francis Group) pp. 847-889.
Rao IM, Beebe S, Polania J, Ricaurte J, Cajiao C, Garcia R, Rivera M (2013). Can tepary bean be a model for improvement of drought resistance in common bean? African Crop Science Journal 21:265-281.
Shaaban M, Zwieten LV, Bashir S, Younas A, Núñez-Delgado A, Chhajro MA, Kubar KA, Ali U, Rana MS, Mehmood MA, Hu R (2018). A concise review of biochar application to agricultural soils to improve soil conditions and fight pollution. Journal of Environmental Management 228:429-440. Available at: https://doi.org/10.1016/j.jenvman.2018.09.006
Sharma P. Abrol V, Sharma V, Chaddha S, Rao CS, Ganie AQ, Hefft DI, El-Sheikh MA, Mansoor S (2021). Effectiveness of biochar and compost on improving soil hydro-physical properties, crop yield and monetary returns in inceptisol subtropics, Saudi Journal of Biological Sciences. 28:12. Available at: https://doi.org/10.1016/j.sjbs.2021.09.043.
Singh H, Northup BK, Rice CW, Prasad VVP (2022). Biochar applications influence soil physical and chemical properties, microbial diversity, and crop productivity: a meta-analysis. Biochar 4:8. Available at: https://doi.org/10.1007/s42773-022-00138-1
Steinbeiss S, Gleixner G, Antonietti M (2009). Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biology and Biochemistry 41:13011310.
Tomczyk A, Sokołowska Z, Boguta P (2020). Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. Reviews in Environmental Science and Bio/Technology 19(1):191-215. Available at: https://doi.org/10.1007/s11157-020-09523-3
Verheijen FGA, Jeffery S, Bastos AC, van der Velde M, Diafas I (2009). Biochar Application to Soils - A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. EUR 24099 EN, Office for the Official Publications of the European Communities, Luxembourg 149 p.
Villagra-Mendoza K, Horn R (2018). Effect of Biochar Addition on Hydraulic Functions of Two Textural Soils. Geoderma. 326:88-95.
Warnock DD, Lehmann J, Kuyper TW, Rillig MC (2007). Mycorrhizal responses to biochar in soil concepts and mechanisms. Plant Soil 300:920.
Zhang M, Riaz M, Zhang L, El-desouki Z, Jiang C (2019). Biochar Induces Changes to Basic Soil Properties and Bacterial Communities of Different Soils to Varying Degrees at 25 mm Rainfall: More Effective on Acidic Soils. Front. Microbiology 10:1321. Available at: http://doi.org/10.3389/fmicb.2019.01321
Zhang Q, Song Y, Wu Z, Yan X, Gunina A., Kuzyakov Y, Xiong Z (2020). Effects of six-year biochar amendment on soil aggregation, crop growth, and nitrogen and phosphorus use efficiencies in a rice-wheat rotation. Journal of Cleaner Production 242:118435.