Vol. 13(28), pp. 1443-1452, 12 July, 2018
DOI: 10.5897/AJAR2018.13280
Article Number: DB44C2B57765
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Cultivation of common bean with the application of biochar of ouricuri (*Syagrus coronata* (Mart) Becc.) endocarp

Felipe Alexandre Tenório[1*], Abel Washington De Albuquerque[1], Tania Marta Carvalho Dos Santos[1], João Inácio Soletti[2], Ferdnando Mariano Brito Silva[3] and Karoline De Melo Padilha[1]

[1]Center of Agricultural Sciences, Federal University of Alagoas, Rio Largo, AL, Brazil.
[2]Technology Center, Federal University of Alagoas, Maceió, AL, Brazil.
[3]Department of Earth Sciences and Environment, State University of Feira de Santana, BA, Brazil.

Received 30 May, 2018; Accepted 18 June, 2018

Biochar has attracted the attention of the scientific community due to its promising applicability and contribution to the elevation of soil chemical and biological aspects, directly influencing the microbiota, fertility levels and yield of agricultural crops. The objective of this study is to determine the chemical and biological attributes of an acrisol cultivated with beans and submitted to the application of ouricuri biochar. The design was completely randomized in a 4 × 4 factorial scheme, with 4 replications. The factors were the combination of four granulometric bands: G1 (0.42 mm), G2 (0.84 mm), G3 (1.19 mm), G4 (1.68 mm) and four biochar doses (8, 16, 24 and 32 Mg ha^{-1}). Then, a control treatment without biochar was added. Morphophysiological aspects of bean culture, and chemical and biological soil indicators were evaluated. Ouricuri biochar promoted improvements in some soil quality indicators. The dose of 32 Mg ha^{-1} of biochar positively influenced the vegetative development of the plants. The results of this study showed that there is a direct relationship between the particle size and the amount of biochar in the soil. This had a direct effect on the carbon stock of the soil and the microbial population.

Key words: Biocarbon, pyrogenic carbon, soil quality, *Phaseolus vulgaris,* productivity.

INTRODUCTION

In searching for new solutions to minimize environmental impacts such as degradation of agricultural soils, the use of biochar as a soil conditioner has been one of the most frequent management practices for improving the chemical, physical and biological properties of the soil. Biochar has been evidenced after the discovery of soils called Terra Preta de Índio (TPI) in the Amazon, referring to the soils associated with the former indigenous occupations, in which the natives deposited coal, animal bones and ceramics, among other residues of human activity (Van Zwieten et al., 2010; Mangrich et al., 2011).

Biochar has attracted the attention of the scientific community because of its promising applicability in different areas, both at environmental and economic

---

*Corresponding author. E-mail: felipetenorio2012@gmail.com.

Table 1. Chemical and physical analysis of a dystrophic Red-Yellow Oxisol, with a medium/clay texture in depth of 0 to 20 cm, collected in a rural area in the municipality of Anadia – AL.

	Chemical attributes										Physical attributes		
pH (H_20)	P	K	Na	Ca	Mg	Al	H + Al	CEC	V	MO	Sand	Silte	Clay
	mg dm^{-3}		cmol$_c$ dm^{-3}						%	g kg^{-1}	g kg^{-1}		
5.7	5.0	56.0	24	1.40	1.0	0.68	6.80	8.30	28	18.60	310	100	410

levels (Qian et al., 2015). The addition of biochar can affect the physical properties of soil via indirect and direct means (Burrell et al., 2016). It can contribute to increase of the pH levels, by correcting the acid soils. It promotes an increase in the cation exchange capacity (CEC) and availability of nutrients to the soil, resulting in improvements in soil fertility (Lima et al., 2015). In the soil biological conditions, biochar acts by influencing the composition, diversity and microbial activity of the soil (Doan et al., 2014; Purakayastha et al., 2015; Wang et al., 2015; Pan et al., 2016).

In the soil, oxidation of the biochar can produce carboxylic groups, which increase its reactivity and its cation exchange capacity, making the biochar more efficient in improving soil quality conditions. Its high porosity and high specific surface area gives favorable conditions for the absorption of soluble organic compounds, which can contribute to increase in the availability of nutrients. When the partial oxidation of the edges of the aromatic structures of the biochar occurs, new electrochemical sites emerge, an effect that may aid in the retention and availability of nutrients for plants (Petter and Madari, 2006).

The mixture of substrates with biochar, aiming to improve soil physicochemical properties, has been studied as a valuable resource that can improve crop yield in tropical infertile and acid soils, and can be used by farmers to increase the productivity of crops of agricultural importance and promote the carbon stock in the soil (Arruda et al., 2007; Maia et al., 2011).

The bean culture has a significant economic and social importance in Brazil, since it is cultivated largely by small farmers. Its importance goes beyond the economic aspect, due to its relevance as a food security factor, and nutritional and cultural relevance in the cuisine of different countries and cultures. Brazil obtained a national average of bean production, in the 2016/2017 harvest, estimated at 3.029.3 thousand tons (CONAB, 2017). Productivity varies by region, as it depends on factors such as the climate, the planting season and the level of technology used.

In this way, it is necessary for the crop to manifest its productive potential, that the fertility of the cultivated soils is in chemical equilibrium, and that the essential elements are available in the soil to be absorbed. The use of alternative inputs in agriculture to raise crop productivity levels, such as biochar as a soil conditioner, appears as an ally to improve the conditions of low fertility soils, such as the Brazilian soils. The objective of the present work was to determine the chemical and biological attributes of an acrisol cultivated with beans, subjected to ouricuri biochar application.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Center of Agricultural Sciences, Federal University of Alagoas (CECA/UFAL), Delza Gitaí Campus, km 85, Rio Largo - AL, located at 9° and 29'45" south latitude, 35° and 49'54" longitude west and 165 m of altitude. The soil was classified as a dystrophic Red - Yellow Oxisol, with a medium/clay texture in depth of 0 to 20 cm, collected in a rural area in the municipality of Anadia - AL.

Before implementation of the experiment, the chemical and physical characteristics of the soil were determined (Table 1), following the methodology of Embrapa (2009). Based on this, a base mineral fertilization with NPK was carried out at the dosages of 20, 80 and 40 kg ha^{-1}, respectively, according to the recommendation for bean cultivation, consistent with the Recommendation Bulletin of Corrective and Fertilizer for State of Pernambuco (IPA, 2008). After its fertilization, the soil under study had the following characteristics described in Table 1.

The experiment was installed in a completely randomized design, in a 4 x 4 factorial scheme, with 4 replicates. The factors were composed of the combination of four granulometric bands: G1, G2, G3 and G4 (0.42, 0.84, 1.19 and 1.68 mm, respectively) and four biochar doses equivalent to 8, 16, 24 and 32 Mg ha^{-1}. At the time, a control treatment without biochar was added.

The biochar used was produced by carbonization at 500°C, with a heating rate of 20°C min^{-1}, from the endocarp samples of the fruit of ouricuri *Syagrus coronata* (Mart) Becc.), in the Laboratory of Separation and Optimization Systems of Processes, LASSOP, from the Technology Center- CETEC, Federal University of Alagoas, UFAL. The samples composed of the endocarp with the rest of the fruit (almonds) were initially ground in a roller mill, prior to pyrolysis, for cleaning leaving only the endocarp.

The experimental system used to perform the pyrolysis consists of a Jung tubular furnace model LT6 2010, with a time and temperature controller J200. The furnace reaches a maximum temperature of 1000°C, heating the cylindrical reactor that is connected to the condensation system for the collection of bio-oil. The last condenser is connected to a FANEM model 089-Cal compressor/aspirator with a maximum volumetric flow rate of 0.024 m^3/min and a power of 550 W. For cooling of the condensers, a TECNAL thermostatic bath model TE-184 was used. Uncondensable gases resulting from the pyrolysis were released into a vessel containing water, thereby preventing its direct release into the atmosphere and allowing part to be trapped.

The soil and biochar mixtures were placed in polyethylene pots with a diameter of 26 cm and a capacity of 10 dm^{-3}, which had a drainage hole in the bottom covered with polypropylene fabric. The weighing was done with a balance for 20 kg with a resolution of 5 g.

Table 2. Chemical analysis of ouricuri biochar produced at 500°C.

pH (H_2O)	P	Ca	Mg	K	S	Fe	Zn	Cu	Al
	(%)								
7.6	10.01	8.22	-	61.21	3.84	3.89	1.66	2.11	-

[a]Percentage in mass.

The pots were filled with the soil mix with each corresponding treatment of the biochar and kept in a greenhouse for subsequent planting.

Biochar chemical analysis was performed by x-ray dispersive energy (EDX) spectrometry analysis shown in Table 2. The analysis was performed on a *Shimdzu* model EDX 800HS equipment at the electron microscopy scanning laboratory (SEM) of the group of optics and nanoscopy of the Federal University of Alagoas.

At the time of the study, four seeds per pot of common bean (*P. vulgaris* L.) cv. *BRS Agreste* were seeded, and at 10 days after sowing (DAS), the thinning of the less vigorous seedlings was performed, leaving only one plant per pot. Preventive phytosanitary control of pests was carried out using 2% (v/v) neem extract (*Azadirachta indica*) in three applications before flowering (R6) with a 7-day interval.

During the development of the bean crop, soil moisture was maintained at around 70% of the field capacity (FC), irrigating daily according to the water requirement of the crop. The soil field capacity was determined using a graduated beaker, a glass funnel with previously moistened filter paper, and 100 g of soil. The soil sample was initially weighed (dried at 60°C to constant weight) and transferred to the glass funnel. Then, 200 mL of distilled water was added to the soil contained in the funnel until saturation, noting the volume of percolated water. The FC was given by the difference between the added water and the percolated water.

At eighty DAS, in full harvest maturation (R9), all portions of the experiment were collected for further analysis. After that, the soil samples were collected and sieved, passing through a 2.0 mm mesh sieve, removing the visible roots and residues of plants and soil organisms. The soil samples were conditioned in paper bags and kept in a forced circulation hothouse at 105°C for 48 h until their total drying.

Soil chemical analyzes were carried out in the soil fertility and plant nutrition laboratory (CECA/UFAL), where the pH in 0.01M $CaCl_2$ solution was determined by potentiometry (pH meter) determined in the soil suspension after agitation and decantation. After reading, 5 mL of the SMP solution were added to determine the SMP pH in potentiometry (pHmeter) determined in the soil suspension after agitation and decanting. With the pH SMP readings, the value of the potential acidity (H + Al) was obtained. To obtain P content in the soil, the method of Mehlich^{-1} HCl 0.05 mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}, was used by spectrophotometry, and the K by flame photometry. The extraction of Ca^{2+}, Ca^{2+}+ Mg^{2+} and Al^{3+} was carried out with the extracting solution of KCl 1 N, titling with EDTA solution 0.0125 Mol L^{-1}. Finally, for Al^{3+}, 5 drops of the Blue Bromothymol indicator were added and titrated with the standard NaOH 0.025 N solution.

The number of leaves per plant (NL), the stem diameter (SD), expressed in mm, was determined. The plants were cut close to the soil and the dry weight of the aerial part (DWA) and dry weight of roots (DWR), expressed in grams, were obtained in air hothouse with forced circulation, at a temperature of 60°C up to constant weight, and total dry matter (TDM), expressed in grams. The seeds provided the final yield after manual threshing (correcting their humidity to 13% and transforming the data to kg ha^{-1}). The average number of pods per plant (NPP), obtained by the ratio between the total number of pods and the number of plants in the plot, were determined; the weight of pods per plant (WPP), and weight of grains per plant (WGP) expressed in grams; mass ratio of 100 plant grains (r100), were determined taking the seed samples randomly.

The soil samples were conditioned in plastic bags and kept under refrigeration at 4°C for the determination of total organic carbon (TOC), carbon of microbial biomass (Cmic) and soil basal respiration (SBR), determined in the laboratory of general microbiology of CECA/UFAL. For the determination of TOC, the modified Walkley-Black method was used (Embrapa, 2009). Microbial carbon (Cmic) was determined by the irradiation-extraction process, described by Mendonça and Matos (2005) and quantified according to Bartlett and Ross (1988). The Cmic contents were expressed based on the mass of oven dried soil at 105°C for 24 h.

The results of the evaluations were subjected to analysis of variance with application of the F test ($p < 0.05$), and the means were compared by the Tukey test ($p < 0.05$). For the quantitative variables, regression equations were adjusted using ASSISTAT software version 7.7.

RESULTS AND DISCUSSION

The results of the soil chemical analysis for the obtained data, showed that there was statistical difference for pH, phosphorus, potassium, hydrogen and aluminum (H + Al), calcium, cation exchange capacity and basal saturation (V%), with the addition of ouricuri biochar in the soil at 80 days after application (DAA). However, for the levels of Al, base sum (SB), calcium and magnesium (Ca + Mg) and Mg, no statistical difference was observed with the use of biochar.

For SB and Mg values, non-significant results probably occurred due to the absence of this element in the chemical composition of ouricuri biochar (Table 2), which influenced the non-significant SB values observed in this study. In other works, authors such as Van Zwieten et al. (2010), using biochar from other raw materials such as sewage sludge and paper mill residue, observed an increase in the levels of elements such as Ca and Mg, in Ferralsol in Australia with the addition of the equivalent of 10 Mg ha^{-1}.

There was influence of the biochar doses on the increase of P level on the soil, ranging from 18.81 mg dm^{-3} at the dose of 8 Mg ha^{-1}, to 40.5 mg dm^{-3} with the application of 32 Mg ha^{-1} of ouricuri biochar. Results were significantly higher ($p<0.05$) than that of the control treatment (18.10 mg dm^{-3}) (Figure 1A). Another researcher (Castro et al., 2018) showed the application of biochar of branches and pruned logs of *Gliricidia sepium* resulted in an increase of the content of macronutrients such as phosphorus and potassium.

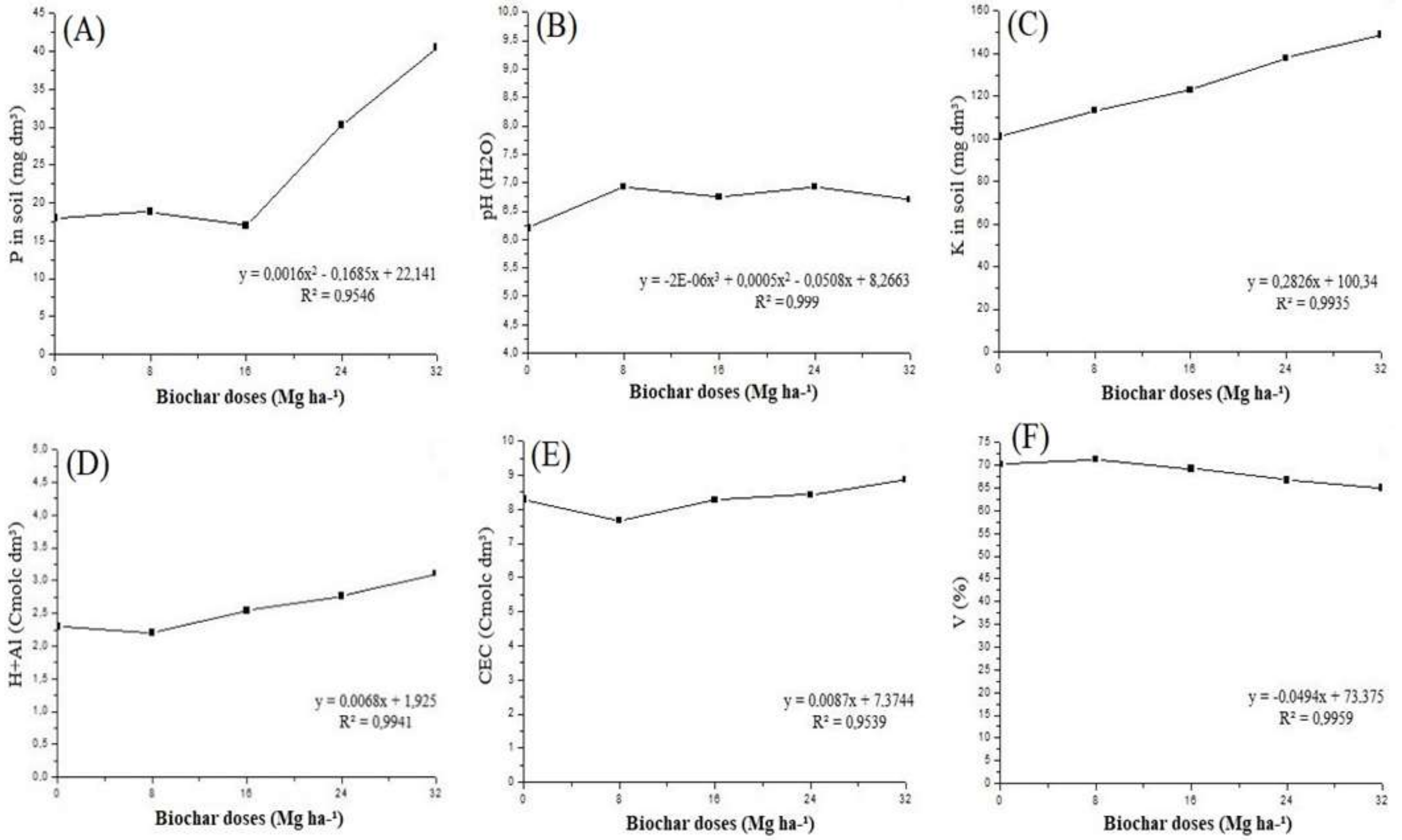

Figure 1. Chemical characteristics of soil after application of different doses of biochar. A- Phosphorus (P); B- Hydrogen ion potential (pH); C- potassium (K); D - hydrogen and aluminum - (H + Al); E - cation exchange capacity (CEC); F - base saturation - (V%)

Phosphorus can be connected to the biochar by means of physical adsorption (Van Der Waals), being a force of low magnitude, allows the easy exchange of P with the solution of the soil and for this reason, the adsorption on the biochar does not cause fixation process, differently from the kaolinites and oxides (Deluca et al., 2009; Gatiboni et al., 2013). The biochar has the capacity to strongly adsorb the orthophosphate ions (Lehmann, 2007), corroborating with the levels of P found in the soil of this study. Cui et al. (2011) also observed that the presence of the biochar reduced the adsorption of P in the Fe and Al oxides, increasing their residual power. In the plant, the P plays the role of storing and transferring energy through the phosphate molecules (ADP and ATP). In addition, it plays a key role in photosynthesis, respiration and cell division and is also a component of several proteins and nucleic acids (Dechen and Nachtigall, 2007).

The alkalinity of the biochar increased the pH values in the soil, with a significant interaction ($p<0.01$) between the factors, that remained above 6.5 and the control that presented 6.25 in its pH value, demonstrating that the addition of biochar, regardless of the dose applied, makes it possible to raise soil pH levels (Figure 1B), which probably maintained influence on Al adsorption, and absence of toxicity in the soil. After the pyrolysis, the biochar may have the potential to neutralize the soil acidity, as it presents high levels of calcium carbonate and magnesium (Van Zwieten et al., 2010).

Soil pH influences the rate of nutrient release, the solubility of all soil materials and the amount of ions stored at the exchange sites. The high reactivity of biochar caused by the dissociation of the functional groups present in the peripheries of its structures, can adsorb H^+ ions of the soil raising the pH (Madari et al., 2009). Smebye et al. (2016) showed that the application of a carbon dose at 10% (m/m) was able to alter the soil pH from 4.9 to 8.7. According to Si et al. (2018), soil pH was significantly increased by approximately 0.1 unit on average when the rice straw-derived biochar was applied.

Promoting a 15-fold increase in pH with the addition of ouricuri Biochar, Dai et al. (2014) have inferred that the application of biochar to the soil in addition to altering the pH value, is able to increase the soil buffering range. Castro et al. (2018) in his studies, using the biochar of *Gliricidium sepium* managed to raise the soil pH to 5.9, being statistically superior as compared to the pH control of 4.8. Castellini et al. (2015) pointed out that obtaining these benefits is dependent on soil and biochar type, as well as its rate of application.

Biochar also contributed to the increase in available K levels in the soil, ranging from 101 (control) to 148.75 mg dm^{-3} at the maximum dose of 32 Mg ha^{-1} (Figure 1C). Yao et al. (2010), Madari et al. (2006) and Oguntunde et al. (2004) also observed increases in K levels in the soil with the application of biochar. Steiner et al. (2004) stated that much of the biochar ashes is rich in potassium in its constitution, depending on which part of the plant material was charred. The treatments with biochar were characterized by larger K content, supporting the data by Martinsen et al. (2014) that biochar is rich in K.

According to Petter and Madari (2012), biochar contributes to a higher absorption of nutrients, mainly as a function of the reactive surfaces at the edges of the aromatic structures of the biochar pores. This characteristic of the biochar raises the concentrations of bases and consequently reduces the acidity in the substrate. However, it is believed that this increase of K levels in the soil is due to the presence of this nutrient in the biochar (Table 2), which shows that this increase occurred in doses equal to or greater than 8 Mg ha^{-1}.

However, an increase in potential acidity (H + Al) was observed as the dosage of biochar in the soil increased (Figure 1D). This increase in the potential acidity values possibly occurred due to a nutrient dissolution effect in the soil solution, where greater nutrient retention by coal surface structures would lead to an increase in nutrient uptake and greater availability of reactive sites in the surface of the clays to bind to H and Al (Rondon et al., 2006). According to Gao et al. (2016), over time, the leaching of the alkaline components of the biochar takes place as the water percolates the soil, therefore the pH can decrease and the acidity increase.

The application of increasing doses of biochar, allowed an increase in CEC values in the soil, presenting levels of 8.3 cmolc dm^3 for the control, up to 9.0 at the dose of 32 Mg ha^{-1} (Figure 1E). This could be attributed to a combination of high availability of cations in exchangeable form in this treatment, possibly related to the presence of biochar (Novotny et al., 2015). Liang et al. (2006) quoted two reasons for a high biochar efficiency in retaining nutrients. The first one is attributed to the pyrogenic coal presenting higher density of negative charge per unit of surface area and consequently a higher charge density. The second one is that in which the nutrients are trapped through physical forces in the fine pores of the carbonized material or that the slow biological oxidation of the aromatic structures at the edges contribute to the elevation of the cation exchange capacity (CEC) (Glaser et al., 2002).

In the case of biochar, reactive sites are formed over the years, whereas the particles are attacked by microorganisms in the soil, changing the chemical and physical characteristics of the surface (Cohen-Ofri et al., 2006). This also corroborates the statistically significant increase in effective CEC of the soil in the biochar, inoculant and fertilizer plots over the duration of the study by Castro et al. (2018).

In adding doses of biochar to the soil, one of the fertility indicators represented by the base saturation index (V%), increased from 62.25 (control) to 71.25% at the dose of 8 Mg ha^{-1} (Figure 1F), showing significant improvements in soil chemical aspects. However, as an increase from the 8 Mg ha^{-1} dose of bio-carbon was provided, base saturation values below 70% were obtained, still, providing conditions that allow the development of most plants in acidic soils such as the Brazilian Cerrado.

The addition of biochar also contributed to the increase of Ca in the soil. It was verified in the study that, with the increase of the biochar granulometry, there was a significant increase ($p<0.05$) from 2.32 (G1) to 2.73 cmolc dm^{-3} (G4) in the contents of Ca in soil. The results of the application of ouricuri biochar were superior to the control (2.23 cmolc dm^{-3}) (Figure 2), demonstrating positive results in the increase of Ca in the soil, with the application of ouricuri biochar. There were no significant differences between the doses × granulometry factors used. The increase of Ca in the soil is due to the high content of the element in the ouricuri biochar (Table 2). Van Zwieten et al. (2010) also evaluated two biochar obtained from paper mill residue in an experiment during two months in a greenhouse and reported that the use in acid soil raised the level of available Ca in the soil from 1.23 to 8.87 cmolc kg^{-1}, as compared to the control soil.

For the biological results of the soil, with the increase in the biochar dosages, there was a significant increase ($p<0.05$) from 175.72 (control) to 256.35 mg kg^{-1} (32 Mg ha^{-1}) on microbial biomass carbon (Cmic) (Figure 3B). Nevertheless, it was found that when the dose 0 was compared with the 8 Mg ha^{-1} dose, the Cmic kept the level of 107.2 mg kg^{-1}, which shows that after the application of the biochar in the soil, there was immediate consumption of readily available C as compared to the Cmic values obtained with the addition of biochar. The biochar granulometries used did not influence the Cmic levels in the soil, with the reaction period equivalent to 80 days. However, during the pyrolysis process, there is also the formation of more labile forms of carbon, which is readily available to the microorganisms in the soil, causing a part of C labile and another part of C stable in the material, where the labile part presents an aliphatic fraction that is more rapidly mineralizable and exists in less abundance in the biochar produced at high temperatures. The stable part presents an aromatic portion that is more slowly oxidized, creating functional groups, such as the carboxylic acid (Lehmann and Stephen, 2009).

For the total organic carbon (TOC), the contents presented a significant increase ($p<0.01$) of 11.35 (dose 0) to 15.40 g kg^{-1} (8 Mg ha^{-1}), about 27% increase in soil

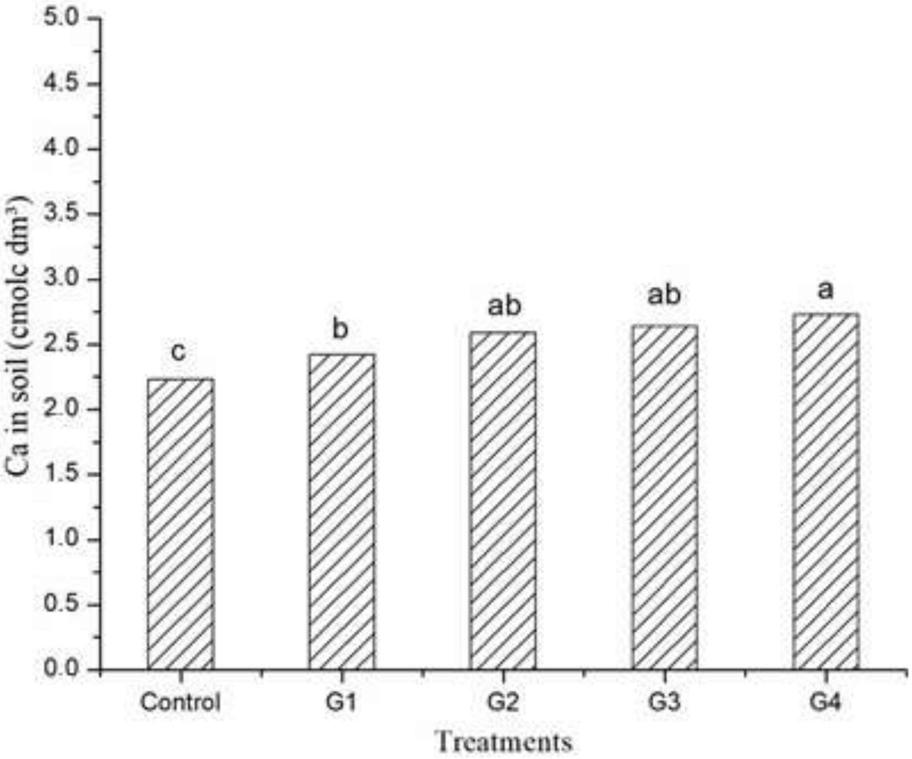

Figure 2. Availability of calcium in the soil after application of different biochar granulometric ranges. Means followed by the same letter do not differ from each other by the Tukey test at 5% probability level.

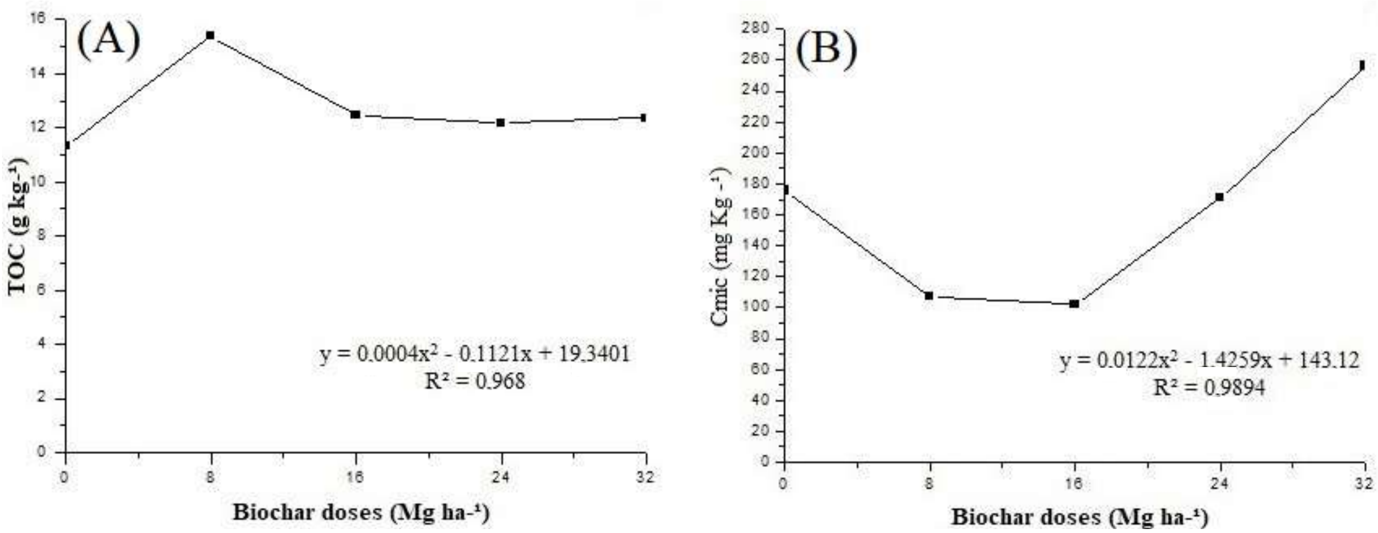

Figure 3. (A) Total organic carbon and (B) availability of microbial carbon of soil subjected to different doses of biochar

TOC stock. However, as doses were increased to a maximum of 32 Mg ha^{-1}, the TOC content was reduced to 12.36 g kg^{-1} (Figure 3A). For the granulometries used, the highest TOC value was obtained with the G1 treatment in the particle size, obtaining an average of 14.35 g kg^{-1}, as compared to the control treatment (11.35 g kg^{-1}) (Figure 4).

Increases in organic carbon additions improved the

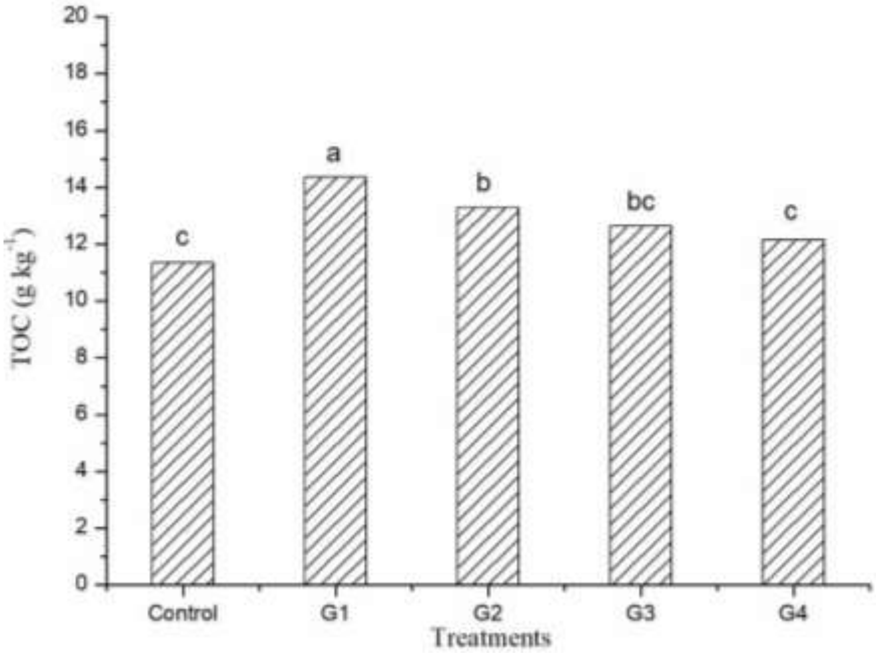

Figure 4. Total organic carbon (TOC) of soil after application of different granulometric bands of biochar

retention of nutrients that become accessible to microorganisms on the particle surface (Lehmann et al., 2011). Chen et al. (2013), in a long-term field experiment in sandy soil with 0, 20 and 40 Mg ha^{-1} of wheat straw biochar, verified that communities of bacteria increased by 28 and 64% in soils conditioned with 20 and 40 Mg ha^{-1} of biochar.

Graber et al. (2010), studying the use of biochar in the soil, suggest that the changes observed in the growth of the microbiological composition were stimulated by the organic tars that are residual of the biochar. In general, the specific soil surface influences all essential functions for soil fertility, including water, air and nutrient cycling and microbiological activity (Bailey et al., 2011).

The agronomic data from the obtained from common bean cultivation obtained were significantly ($p < 0.05$) influenced by the application of biochar, in relation to the number of pods per plant (NPP), weight of pods per plant (WPP), grain weight per plant (WGP), dry weight of roots (DWR), dry weight of the aerial part matter (DWA) and mass ratio of 100 grains (r100).

For the variable NPP, the values increased from 17 to 18 pods per plant, with the addition of the biochar in the dose of 32 Mg ha^{-1} as compared to the dose 0 (control), being also superior to the other dosages used (8, 16 and 24 Mg ha^{-1}) (Figure 5A). Avila et al. (2010), in their studies using common bean cultivation with and without irrigation for the same cultivar, obtained NPPs of 13 and 21, respectively. For WPP (Figure 5B), WGP (Figure 5C), TDM (Figure 5E) and r100 (Figure 5F) variables, increases in yield were respectively 22.76, 16.17, 12.18 and 3.70%, with the addition of biochar in the dose of 32 Mg ha^{-1} as compared to the control. Castro et al. (2018) also had the physiological parameters of the bean influenced by the application of biochar with fertilizer.

However, the highest agronomic development of bean plants was verified for dry weight of root (DWR), which reached a mean of 35.24% in weight gain with the addition of biochar at the dosage of 32 Mg ha^{-1}, as compared to the control treatment (Figure 5D). Smider and Singh (2014) showed that the dry mass of the maize crop increased in response to application of biochar, and Vaccari et al. (2011) verified a 30% increase in the biomass of wheat with application of 30 Mg ha^{-1} biomass of wood. Some authors such as Graber et al. (2010) and Jones et al. (2012), also highlighted indirect changes in microbial activity in soil with biochar and suggested that biochar stimulates plant growth by inducing effects on the rhizosphere, with effects on quality and quantity of root exudates, thus influencing good root development. Results from a field trail across multiple years and in multiple locations across the USA supported the hypothesis that crop yield in different locations responds differently to complicated interactions of soil, biochar and climate (Laird et al., 2017).

According to Ramos Junior et al. (2005), number of grains and r100 are considered the main components that influence productivity, which, in the same way, responded in a significant way. Mete et al. (2015) also tested the joint application of biochar with the addition of

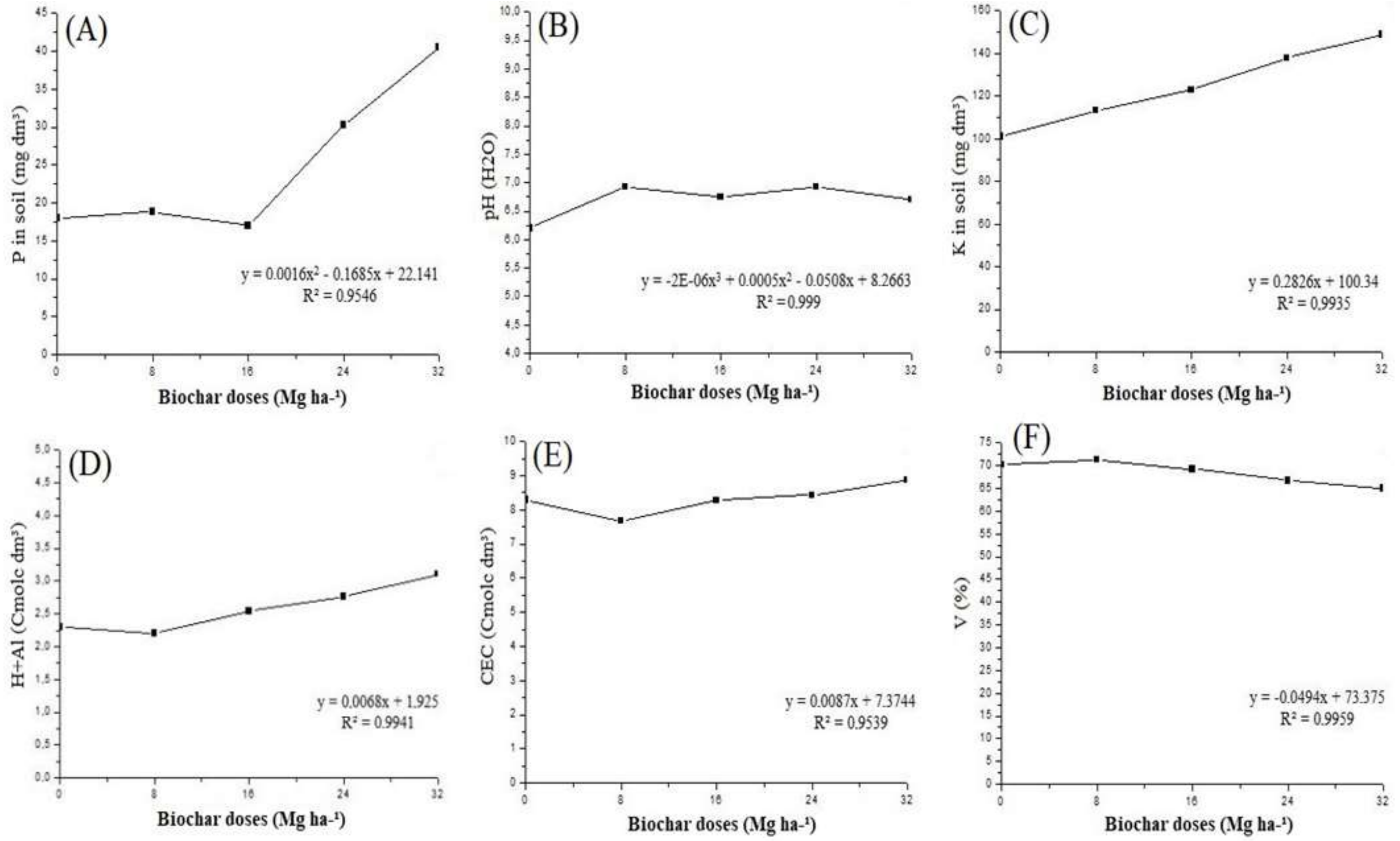

Figure 5. Number of pods per plant (A), weight of pods per plant (B), weight of grains per plant (C), weight of dry root matter (D), weight of total dry matter (E), mass ratio of 100 grains (F) of common bean "*Phaseolus vulgaris*" grown under different granulometries and doses of biochar

NPK fertilizer in an alkaline soil in soybean cultivation. Results showed that the simultaneous application of both products increased on average, the yield in the production of biomass and seeds by 361 and 391%, respectively.

Güereña et al. (2015) showed promising results on the use of biochar in common bean cultivation. Thus, when compared with the control, the application of biochar changed on average, 262% biomass of the aerial part, 164% radicular biomass and 357% biomass of nodules. Other researchers (Schmidt et al., 2015; Glaser et al., 2015) showed that the effect of biochar on crop productivity is a function of a range of factors such as the type of biochar and the amount of biochar added to the soil, where biochar is being applied and how much additional nutrient is added.

Conclusion

Ouricuri biochar caused improvements in the major chemical indicators of soil quality (pH, Ca, P, K and CEC) even reacting to a short time (80 DAA). The development of plant roots, total organic carbon (TOC) and Cmic were positively influenced by ouricuri biochar, mainly at the dose of 32 Mg ha^{-1}. However, it is believed that its effect on plants cannot be explained as a factor dependent on soil fertility results.

The results of this study demonstrate a direct relationship between the particle size and the amount of biochar in the soil, which influences the effect on the carbon stock of the soil and the microbial population.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Arruda MR, Pereira JCR, Moreira A, Teixeira WD (2007). Enraizamento de estacas herbáceas de guaranazeiro em diferentes substratos. Ciência e Agrotecnologia 31(1):236-224.

Ávila MR, Barizão DAO, Gomes EP, Fedri G, Albrecht LP (2010). Cultivo do feijoeiro no outono/inverno associado à aplicação de bioestimulante e adubo foliar na presença e ausência de irrigação. Scientia Agrária 11(3):221-230.

Bailey VL, Fansler SJ, Smith JL, Bolton Jr H (2011). Reconciling apparent variability in effects of biochar amendment on soil enzyme activities by assay optimization, Soil Biology and Biochemistry 43:296-301.

Bartlett RJ, Ross DS (1988). Colorimetric determination of oxidizable carbon in acid soil solutions. Soil Science Society America Journal 52:191-1192.

Burrell LD, Zehetner F, Rampazzo N, Wimmer B, Soja G (2016). Long-term effects of biochar on soil physical properties. Geoderma 282:96-102.

Castellini M, Giglio L, Niedda M, Palumbo AD, Ventrella D (2015). Impact of biochar addition on the physical and hydraulic properties of a clay soil. Soil and Tillage Research 154:1-13.

Castro A, da Silva Batista N, Latawiec AE, Rodrigues A, Strassburg B, Silva D, Araujo E, de Moraes LFD, Guerra JG, Galvão G, Alves-Pinto H, Mendes M, dos Santos JS, Rangel MC, Figueredo M, Cornelissen G, Hale S (2018). The Effects of *Gliricidia*-Derived Biochar on Sequential Maize and Bean Farming. Sustainability 10:578.

Chen J, Liu X, Zheng J, Zhang B, Lu H, Chi Z, Pan G, Li L, Zheng J, Zhang X, Wang J, Yu X (2013). Biochar soil amendment increased bacterial but decreased fungal gene abundance with shifts in community structure in a slightly acid rice paddy from Southwest China. Applied Soil Ecology 71:33-44.

Cohen-Ofri I, Weiner L, Boaretto E, Mintz G, Weiner S (2006). Modern and fossil charcoal: aspects of structure and diagenesis. Journal of Archaeological Science 33(3):428-439.

Companhia Nacional de Abastecimento [CONAB]: Safra 2016/2017. (2017). Sexto levantamento/intenção de plantio. Acompanhamento safra brasileira de grãos 4:6.

Cui HJ, Wang MK, Fu ML (2011). Enhancing phosphorus availability in phosphorus-fertilized zones by reducing phosphate adsorbed on ferrihydrite using rice straw-derived biochar. Soils and Sediments 11(7):1135-1141.

Dai Z, Wang Y, Muhammad N, Yu X, Xiao K, Meng J, Liu X, Xu J, Brookes PC (2014). The Effects and Mechanisms of Soil Acidity Changes, following Incorporation of Biochars in Three Soils Differing in Initial pH. Soil Science Society of America Journal 78(5):1606-1614.

Deluca TH, Mackenzie MD, Gundale MJ (2009). Biochar effects on soil nutrient transformation. In: Lehmann, J., Joseph, S. (Eds.) Biochar for environmental management science and technology pp. 251-280.

Dechen AR, Nachtigall GR (2007). Elementos requeridos à nutrição de plantas. In: Novais, R. F., Alvarez V., V.H., Barros, N.F., Fontes, R. L. F., Cantarutti, R. B., Neves, J. C. L. (Eds). Fertilidade do solo. Viçosa: Sociedade Brasileira de Ciência do Solo pp. 91-132.

Doan TT, Bouvier C, Bettarel Y, Bouvier T, Henry-des-Tureaux T, Janeau JL, Lamballe P, Nguyen BV, Jouquet P (2014). Influence of buffalo manure, compost vermicopost and biochar amendments on bacterial and viral communities in soil and adjacent aquatic systems. Applied Soil Ecology 73:78-86.

Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA]. Centro Nacional de Pesquisa de Solos. (2009). Manual de análises químicas de solos, plantas e fertilizantes. 2ed. rev. ampl. - Brasília, DF: Embrapa Informação Tecnológica 627 p.

Gao S, DeLuca TH (2016). Influence of Biochar on Soil Nutrient Transformations, Nutrient Leaching, and Crop Yield. Advances in Plants & Agriculture Research 4:1-16.

Gatiboni LC, Brunetto G, Rheinheimer DS, Kaminski J (2013). Fracionamento químico das formas de fósforo do solo: usos e limitações. Tópicos em Ciência do Solo 8:142-187.

Glaser B, Lehmann J, Steiner C, Nehls T, Yousaf M, Zech W (2002). Potential of pyrolyzed organic matter in soil amelioration. Beijing: People's Republic of China Ministry of Water Resources 426 p.

Glaser B, Wiedner K, Seelig S, Schmidt H-P, Gerber H (2015). Biochar organic fertilizers from natural resources as substitute for mineral fertilizers. Agronomy for Sustainable Development 35:667-678.

Graber ER, Harel YM, Kolton M, Cytryn E, Silber A, David DR, Tsechansky L, Borenshtein M, Elad Y (2010). Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. Plant Soil 337:481-496.

Güereña DT, Lehmann J, Thies JE, Enders A, Karanja N, Neufeldt H (2015). Partitioning the contributions of biochar properties to enhanced biological nitrogen fixation in common bean (*Phaseolus vulgaris*). Biology and Fertility of Soils 51:479-491.

Instituto Agronômico de Pernambuco [IPA] (2008). Recomendação de adubação para o Estado de Pernambuco: 2ª aproximação. 3.ed. Recife, PE 212 p.

Jones D, Rousk J, Edwards-Jones G, Deluca T, Murphy D (2012). Biochar-mediated changes in soil quality and plant growth in a three year field trial. Soil Biology and Biochemistry 45:113-124.

Laird DA, Novak JM, Collins HP, Ippolito JA, Karlen DL, Lentz RD, Sistani KR, Spokas K, Pelt RSV (2017). Multi-year and multi-location soil quality and crop biomass yield responses to hardwood fast pyrolysis biochar. Geoderma 289:46-53.

Lehmann J (2007). Bio-energy in the black. Frontiers in Ecology and the Environment, Washington 5(7):381-387.

Lehmann J, Stephen J (2009). Biochar for environmental management: Science and Technology pp. 1-12.

Lehmann J, Rillig MC, Thies J, Masiello CA, Hockaday WC, Crowley D (2011). Biochar effects on soil biota – A review. Soil Biology and Biochemistry 43(9):1812-1836.

Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O´neill B, Skjemstad JO, Thies J, Luizão FJ, Petersen J, Neves EG (2006). Black carbon increases cations exchange capacity in soils. Soil Science Society of America Journal 70:1719-1730.

Lima SL, Tamiozzo S, Palomino EC, Petter FA, Marimon-Junior BH (2015). Interactions of biochar and organic compound for seedlings production of Magonia pubescens A. St.-Hil. Revista Árvore 39:655-661.

Madari BE, Costa AR, Castro LM, Santos JLS, Benites VM, Rocha AO, Machado PLOA (2006). Carvão vegetal como condicionador de solo para arroz de terras altas (cultivar primavera): Um estudo prospectivo. Embrapa Arroz e Feijão. 125:2.

Madari BE, Cunha TJF, Novotny EH, Milori DMBP, Neto LM, Benites VM, Coelho MR, Santos GA (2009). Matéria orgânica de solos antrópicos da Amazonia (Terra Preta de Indio): Suas características e papel na sustentabilidade da fertilidade do solo. In: Teixeira, W. G., Kern, D. C., Madari, B. E., Lima, H. N., Woods, W. (Eds.). As terras pretas de indio da Amazonia: sua caracterização e uso deste conhecimento na criação de novas áreas. Manaus: Embrapa Amazônia Ocidental. Cap 2:172-188.

Maia CMBF, Madari BE, Novotny EH (2011). Advances in biochar research in Brazil. Dynamic soil, Dynamic plant 5:53-58.

Mangrich AS, Maia CMBF, Novotny EH (2011). Biorcarvão - as terras pretas de índios e o sequestro de carbono. Ciência Hoje 47:48-52.

Martinsen V, Mulder J, Shitumbanuma V, Sparrevik M, Borresen T, Cornelissen G (2014). Farmer-led maize biochar trials: effect on crop yield and soil nutrients under conservation farming. Journal of Plant Nutrition and Soil Science 177:681-695.

Mendonça ES, Matos ES (2005). Matéria orgânica do solo; métodos de análises. Viçosa, MG, Universidade Federal de Viçosa 107p.

Mete FZ, Mia S, Dijkstra FA, Abuyusuf M, Hossain ASMI (2015). Synergistic Effects of Biochar and NPK Fertilizer on Soybean Yield in an Alkaline Soil. Pedosphere 25:713-719.

Novotny EH, Maia CMBF, Carvalho MTM (2015). Madari, B.E. Biochar: Pyrogenic carbon for agricultural use-A critical review. Revista Brasileira de Ciência do Solo 39: 321–344.

Oguntunde PG, Fosu M, Ajayi AE, Giesen NV (2004). Effects of charcoal production on maize yield, chemical properties and texture of soil. Biology and Fertility of Soils 39:295-299.

Pan F, Li Y, Chapman SJ, Khan S, Yao H (2016). Microbial utilization of rice straw and its derived biochar in a paddy soil. Science of the Total Environment 559:15-23.

Petter FA, Madari BE (2012). Biochar: Agronomic and environmental potential in Brazilian 23 savannah soils. Revista brasileira de engenharia agrícola e ambiental 16(7):761-768.

Purakayastha TJ, Kumari S, Pathak H (2015). Characterization, stability, and microbial effects of four biochars produced from crop residues, Geoderma pp. 239-240, 293-303.

Qian M, Kumar A, Zhang H, Bellmer D, Huhnke R (2015). Recent advances in utilization of biochar. Renewable and Sustainable Energy Reviews 42:1055-1064.

Ramos Junior EU, Lemos LB, Silva TRB (2005). Componentes da produção, produtividade de grãos e características tecnológicas de cultivares de feijão. Bragantia 64:75-82.

Rondon MA, Lehmann J, Ramírez J, Hurtado M (2006). Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biology and Fertility of Soils 43(6):699-708.

Si L, Xie Y, Ma Q, Wu L (2018). The short-term effects of rice straw biochar, nitrogen and phosphorus fertilizer on rice yield and soil properties in a cold waterlogged paddy field. Sustainability 10:537.

Schmidt HP, Pandit BH, Martinsen V, Cornelissen G, Conte P, Kammann CI (2015). Fourfold increase in pumpkin yield in response to low-dosage root zone application of urine-enhanced biochar to a fertile tropical soil. Agriculture 5:723-741.

Smebye A, Alling V, Vogt RD, Gadmar TC, Mulder J, Cornelissen G, Hale SE (2016). Biochar amendment to soil changes dissolved organic matter content and composition. Chemosphere 142:100-105.

Smider B, Singh B (2014). Agronomic performance of a high ash biochar in two contrasting soils. Agriculture, Ecosystems and Environment 191:99-107.

Steiner C, Teixeira WG, Zech W (2004). Slash and char: An alternative to slash and burn practiced in the amazon basin. In: Glaser, B., Woods, W. I. (eds.). Amazonian Dark Earths: Explorations in Space and Time. Springer Verlag, Heidelberg. https://doi.org/10.1007/978-3-662-05683-7_14.

Vaccari FP, Baronti EL, Genesio L, Castaldi S, Fornasier F, Miglietta F (2011). Biochar as a strategy to sequester carbon and increase yield in durum wheat. European Journal of Agronomy 34:231-238.

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

Wang X, Song D, Liang G, Zhang Q, Ai C, Zhou W (2015). Maize biochar addition rate influences soil enzyme activity and microbial community composition in a fluvo-aquic soil. Applied Soil Ecology 96:265-272.

Yao FX, Arbestain MC, Virgel S, Blanco F, Arostegui J, Macia-Agullo JA, Macias F (2010). Simulated geochemical weathering of a mineral ash-rich biochar in a modified Soxhlet reactor. Chemosphere 80:724-732.