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Biochar in different topsoil type as alternative for increase the cassava development and soil quality

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RESUMO

O biochar aplicado ao solo cria interações complexas que impactam positivamente o desenvolvimento da planta e a qualidade do solo. No entanto, essas interações podem variar entre diferentes fontes para produzir o biochar, o tipo de solo e planta cultivada. Aqui, levantamos a hipótese de que o biocarvão de diferentes fontes exibe comportamentos diferentes em diferentes tipos de *topsoils* superficiais e impacta no crescimento da mandioca. Para testar esta hipótese, um experimento de campo foi implementado em delineamento inteiramente casualizado e esquema fatorial duplo (2 x 4), combinando dois tipos de *topsoils* (Argissolo e Luvisolo), e quatro fontes de biochar: casca de feijão (BHB), resíduo de graviola (SRB), borra de café (CGB) e testemunha (CONT: solo sem biochar), com quatro repetições. Nossa análise revelou que o biochar aplicado aos dois *topsoils* afetou positivamente o crescimento da mandioca, como número de folhas e altura da planta. Promoveu aumentos do K⁺ na camada superficial do *topsoil*. BHB adicionado ao Luvisolo foi consideravelmente eficaz em promover o crescimento da mandioca e aumentar a qualidade do solo por aumentar sua fertilidade, melhorando o condicionamento do solo pelo aumento dos níveis de K⁺. No geral, nossas descobertas expandem nosso conhecimento sobre biochar aplicado ao *topsoil* e adicionam informações importantes que podem ser adequadas para exploração futura e desenvolvimento de alternativas para reutilização de resíduos, aumento da produção vegetal e promoção da saúde do solo.

Palavras-chave: biocarbono, fertilidade do solo; enzima do solo, práticas de manejo, análise de componentes principais.

Biochar in different topsoil type as alternative for increase the cassava development and soil quality

ABSTRACT

The biochar applied to the soil create complex interactions that impact the plant development and soil quality. However, these interactions may vary among different sources to produce the biochar, the soil type, and plant cultivated. Here, we hypothesized that biochar from different sources exhibit different behaviors on different types of *topsoil* and impact on cassava growth. To test this hypothesis, one field experiment was implemented in a completely randomized design and double factorial scheme (2 x 4), combining two kinds of *topsoils* (Acrisol or Luvisol), and four sources of biochar: bean husk (BHB), soursop residue (SRB), coffee grounds (CGB) and control (CONT: soil without biochar), with four repetitions. Our analysis revealed that biochar applied to the two *topsoil* positively affected the cassava growth, such as

number of leaves, plant height and fresh mass. The *topsoil* promoted increases in K^+ . BBH biochar added to Luvisol topsoil was considerably effective in promote the cassava growth and increase soil quality by increases the soil fertility, improving soil conditioning by increasing K^+ levels. Overall, our findings expand our knowledge about biochar applied to *topsoil* and add important information that can be suitable for future exploration and the development of alternative strategies to waste reuse, increase plant production, and promote soil health.

Keywords: biocarbon, soil fertility; soil enzyme, management practices, main component analysis.

Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most important crops in the world and was selected as the food of the 21st century by the United Nations (UN) due to its importance as a food source and industrial applications. Its main harvested product is the tuberous roots which are the starch reserve organs; its production increases by more than 3% per year, which accounts for 7% of the starch produced globally (Wang et al., 2022) and is one of the five commodities used in the production of bioethanol, biodiesel and biogas (EMBRAPA, 2021).

Considered a good source of energy, it is present in the diet of millions of people around the world (Nunes et al., 2021) and Brazil occupies the fifth position in the ranking of the world's largest producers (FAOSTAT, 2021), in addition to being the country with the greatest genetic diversity of the crop (Nunes et al., 2021). Cassava has good drought tolerance (Caldana et al., 2022), is rich in water and nutrients, moderate incidence of pests and diseases, as well as low input requirements and is cultivated in more than 100 countries (Silva et al., 2022). However, cassava productivity is still low and requires sustainable and low-cost techniques to improve its production.

In recent years, biochar has aroused interest due to its agricultural and environmental utility, being a by-product of pyrolytic transformation at high temperatures and limited oxygen conditions (Bolan et al., 2023). versatile, used mainly as a soil conditioner, as it has a series of physicochemical properties, such as an increase in the cation exchange capacity (CEC), which provides a reduction in soil acidity, and a reduction in available Al, promoting greater absorption of nutrients by plant roots (Lu et al., 2023). Biochar can also be used to improve the attributes of sandy soils with low fertility in dry regions under controlled and field conditions, in addition to being used as a vehicle for inoculation of microorganisms (França et al., 2022) and in the management of diseases of plants (Medeiros et al., 2021), attesting

to the advantages of their use in agricultural production systems.

Considering the importance of searching for new sustainable strategies to increase plant production and improve soil quality, studies have focused on the interaction of biochar in different *topsoil* types in field condition (Vijay et al., 2021; Yadav et al., 2023). These studies are important to disentangle variables that can help producers. The results of this study can help producers understand the variables that affect cassava production and improve soil quality.

Here, we hypothesized that different sources of biochar applied to different *topsoil* type would respond of different ways on cassava growth and soil quality due to their different attribute's combinations. In order to test this hypothesis, we grew cassava under different combinations of biochar from different sources and two *topsoil* type. This approach allowed us to investigate the effect of different biochar and *topsoil* gathering information that can contribute for future studies on cassava breeding, helping to improve plant growth and health.

Material and methods

Soil sample and attributes

The field experiment was carried out in the municipality of Garanhuns, PE, Brazil (08° 53' 25" S, 36° 29' 34" W), with a Mesothermal Tropical Altitude climate (Cs'a according to Köppen) with annual temperature average and precipitation of 20 °C and 1.300 mm.

The experiment was realized in double factorial design (2 x 4) was conducted, combining two types of topsoils (Acrisol or Luvisol), and four sources of biochar (bean husk biochar (BH), soursop residue biochar (SR), coffee grounds biochar (CG), and soil without biochar), with four replicates.

The topsoil technique (Ferreira, 2015, Rezende et al., 2021) was used, which consists of removing the surface layers of a soil from a given location and depositing it in another, following the

order of removal of the layers, that are 0-05 cm and 05-25 cm.

The soil used were classified as Acrisol and Luvisol by the classification system of the Food and Agriculture Organization (IUSS Working Group WRB 2015). The chemical characteristics of the two soil classes were analyzed: Acrisol [pH 6.6, P 23.7 mg dm⁻³, K 8.6 cmolc kg⁻¹, and Na 93.7 cmolc kg⁻¹] and Luvisol [pH 6.0, P 6.2 mg dm⁻³, K 11.2 cmolc kg⁻¹, and Na 97.2 cmolc kg⁻¹].

Biochars production and characterization

Bean husks, coffee grounds and soursop wastes were subjected to slow pyrolysis at 530 °C for 10 – 12 h under limited oxygen conditions. The determination of pH in water and C were also obtained according to Silva (2009). The K, P, N, Ca, and Mg contents were submitted to nitroperchloric digestion according to the methodology recommended by Tedesco et al. (1995). According to previous analyses, these materials presented the following chemical characteristics: bean husks - BH (pH 8.2, C 42.6%, N 1.68%, P 1.04 g kg⁻¹, K 0.85 g kg⁻¹, Ca 0.02 g kg⁻¹, and Mg 0.13 g kg⁻¹); coffee grounds - CG (pH 10.3, C 68.81%, N 0.44%, P 0.03 g kg⁻¹, K 0.15 g kg⁻¹, Ca 0.02 g kg⁻¹, and Mg 0.08 g kg⁻¹); soursop residue - SR (pH 10.0, C 58.72%, N 1.74%, P 1.35 g kg⁻¹, K 0.72 g kg⁻¹, Ca 0.06 g kg⁻¹, and Mg 0.06 g kg⁻¹).

Field experiment

Cassava seedlings of the “*Manteiga*” variety, measuring 8-10 cm, were obtained by selecting the middle third of the stem of vigorous plants between 10 and 14 months of age, and previously disinfected. Two cuttings were planted in each hole, and were thinned after 15 days, retaining the most vigorous plant. For planting, holes of 20 cm³ were dug and foundation fertilization was carried out (based on IPA 2008), using monoammonium phosphate (MAP), applying 3.1 kg ha⁻¹ of N, 62.5 kg ha⁻¹ of P₂O₅, and 75 kg ha⁻¹ of K₂O (as KCl). Afterwards, the holes were filled according to the soil corresponding to the experiment. At 30 days after planting (DAP), topdressing fertilization with N was performed using ammonium sulfate, applying 31.5 kg ha⁻¹ 40 DAP. At 60 DAP the second topdressing fertilization was carried out, using 33.6 kg ha⁻¹ of ammonium sulfate.

The biochars were applied after fifteen days in the holes at 10 cm of depth in the soil, in an amount corresponding to 200 kg ha⁻¹. Fifteen days later, seedlings measuring from 15 to 20 cm long were planted, horizontally, 5 cm deep. The spacing adopted was 1.0 m between rows and 0.5 m between plants, resulting in a stand corresponding to 20,000 plants ha⁻¹.

After 10 months of growth, plants were harvested. Plant height was measured up to the first sympodial branch (FSB), and total height (TH) from the ground to the apex of the plant, and the leaves counted. Roots were divided into commercial (presenting more than 2 cm diameter and 10 cm in length) and non-commercial, were counted and weighed.

Soil samples were collected at 0-20 cm layer in the middle of each plot, stored in sealed plastic bags and transported in an icebox to the laboratory. A portion of the soil samples was stored in bags and kept at 4 °C for enzyme analysis and another portion was air-dried, sieved through a 2-mm screen, and homogenized for chemical analyses.

Chemical and microbiological soil attributes

Soil chemical attributes were determined and measured using standard laboratory protocols by Silva (2009). Briefly, the soil pH was determined in water 1:2.5. The contents of P, Na⁺ and K⁺ were obtained through the Mehlich-1 extractor (HCl 0.05 mol L⁻¹ + H₂SO₄ 0.0125 mol L⁻¹), where the determination of P was performed by colorimetry with metavanadate and ascorbic acid in the libra 522 UV spectrophotometer – Biocrom® according to Braga and Defelipo (1974). N and K were quantified by flame photometry 910M Analyser®. Soil basal respiration (SBR) was quantified by CO₂ evolved from 30 g of soil, incubated for 72 hours, extracted with 0.5 mol L⁻¹ NaOH solution and titrated with 0.05 mol L⁻¹ HCl (Isermeyer 1952). The acid phosphatase (EC 3.1.3), and urease (EC 3.5.1.5) were determined according to the methods described by Eivazi and Tabatabai (1977), and Kandeler and Gerber (1988).

Statistical analysis

All statistical analyzes were performed using the R software version 3.6.3 (R Core Team, 2021) in conjunction with RStudio 1.4.1717 (RStudio Team 2021). Data were submitted to analysis of variance (ANOVA) followed by linear

regression analysis and Fisher's least significant difference (LSD) post-hoc test with Bonferroni correction using the R libraries "stats" (R Core Team 2021) and "agricolae" version 1.3-5 (Mendiburu, 2021) at a significance level of 5% ($\alpha = 0.05$). Soil chemical and biochemical variables were subjected to multivariate analysis by principal coordinate analysis (PCA) and using the "vegan" R package version 2.5-7 (Oksanen et al., 2020). All figures were drawn using the graphic resources of the R "ggplot2" library" version 3.4.1 (Wickham, 2016).

Results and discussion

Cassava growth

Biochar application to the different soil conditions has been shown to increase cassava growth (Figure 1). For example, the height of the first branch (HB) of cassava varied according to the source of biochar and soil class. The SR biochar applied to Acrisol allowed the highest HB, which was significantly larger than on Luvisol (0.42 m). The HB for plants treated with CG biochar in both soils was also high (0.42 m).

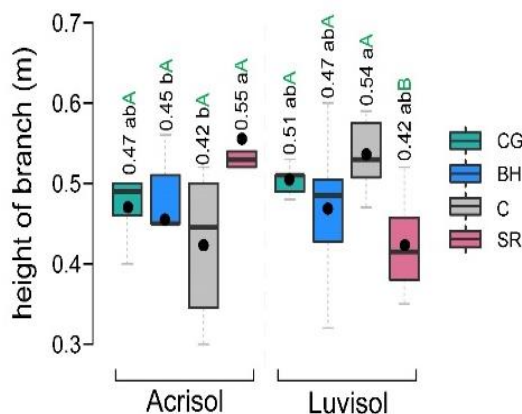


Figure 1. Scatter analysis of height of the first branch (m) of cassava plants growth in Acrisol and Luvisol treated with bean husk biochar (BH), coffee grounds biochar (GC), soursop residue biochar (SR), and negative control (C). Averages (black dots) followed by uppercase letters compare the soil classes and lowercase letters compare the Biochar treatments, according to the least significant difference (LSD) at a 5% significance level.

Treatments with biochar increase cassava growth, highlighting the number of leaves (L), height of plants (HP), and fresh weight of non-commercial roots (FWR) (Figure 2). Plants that

received BH-biochar had the highest number of leaves (Figure 2.A), height of plants (Figure 2.B), and fresh weight of non-commercial roots (Figure 2.C). Plants with BH-biochar had significantly higher mean FWR than all other three treatments ($p < 0.05$, LSD test) that contrasted with plants that received the control treatment, which showed the lowest FWR.

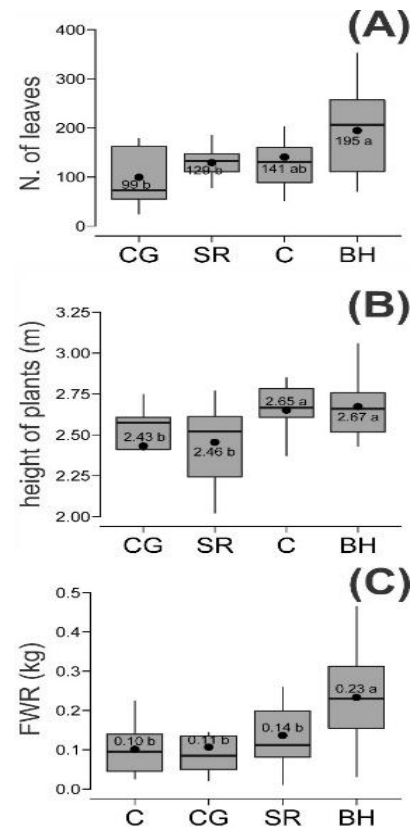


Figure 2. Scatter analysis of number of leaves (A), height (B), and fresh weight of non-commercial roots (C) of cassava plants growth in soil treated with bean husk biochar (BH), coffee grounds biochar (GC), soursop residue biochar (SR), and negative control (C). Averages (black dots) followed by different lowercase letters are different from each other by least significant difference (LSD) at a 5% significance level.

Effect on soil chemical and microbial attributes

Soil chemical properties responded differently depending on the soil type, showing a significant simple effect on available P, K^+ , and Na^+ contents (Figure 3). The available P content in Acrisol (17.9 mg gm^{-3}) was significantly higher than in Luvisol (8.2 mg gm^{-3}) (Figure 3B). In contrast, the K^+ content in Luvisol ($11.7 \text{ cmol}_c \text{ kg}^{-1}$)

¹) was significantly higher than in Acrisol (8.8 $\text{cmol}_c \text{kg}^{-1}$) (Figure 3C). The same was observed for Na^+ , measuring 108 $\text{cmol}_c \text{kg}^{-1}$ and 92 $\text{cmol}_c \text{kg}^{-1}$ for Luvisol and Acrisol, respectively (Figure 3D).

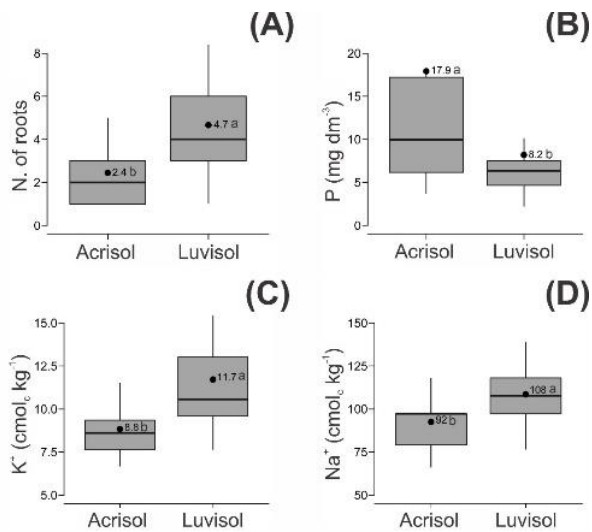


Figure 3. Scatter analysis of number of non-commercial roots (A), available content of phosphorus (B), potassium (C), and sodium (D) in Acrisol and Luvisol cultivated with cassava plants treated with bean husk biochar (BH), coffee grounds biochar (GC), soursop residue biochar (SR), and negative control (C). All compared means (black dots followed by different lowercase letters) indicated a least significant difference (LSD) at a 5% significance level.

Plant response to soil variables

Significant interactions between plant parameters and soil variables were found based on the Spearman's correlation (ρ) analysis. Positive and significant correlations were observed between P and NL, Ure and NL, and K^+ and NR. Additionally, a negative and significant correlation was found between pH and HB. The variables pH, Ure, P, Resp, and P.acid were more correlated with each other, forming a separate cluster of K^+ and Na^+ variables.

Regressions were performed to infer the linear dependence within the pairs, comparing the regression fit with each other (Figure 4). The ρ -correlations weights were greater than the adjustments of the linear models: pH and HB ($R^2 = 0.15$, $\rho = 0.47$, $p < 0.05$; Figure 4A), P and NL ($R^2 = 0.43$, $\rho = 0.45$, $p < 0.05$; Figure 4B), K^+ and NR ($R^2 = 0.32$, $\rho = 0.55$, $p < 0.01$; Figure 4C), and Ure and NL ($R^2 = 0.26$, $\rho = 0.55$, $p < 0.01$; Figure 4D).

Global interactions

The principal component analysis (PCA) explained 45% of the variation in the first two axes of the plot, clustering the samples according to the soil type and source of biochar (Figure 5). Only the variables and samples that contributed more than 1% of the total explanation in two main axes were shown. The CG biochar interacted with Luvisol soil and contributed for increases in K, Na, R, Resp, and FWR.

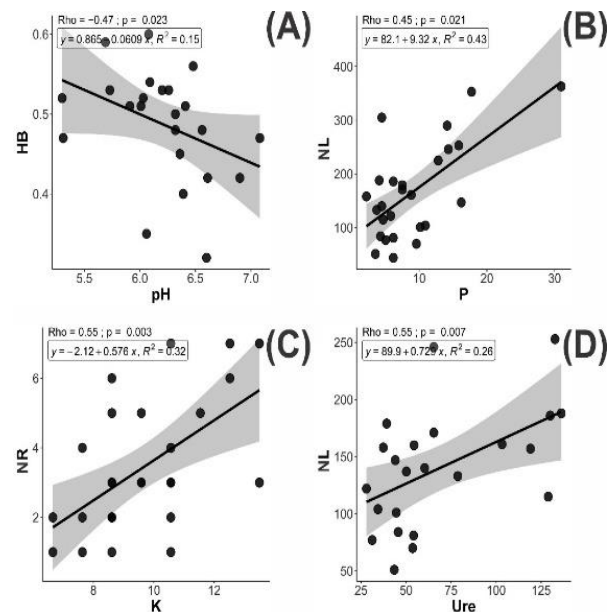


Figure 4. Relationships between parameters of cassava plants with highlighted variables in the soil. The lines represent the linear models calculated for significant Spearman's ρ -correlation (Rho) between the response variables (plant attributes) and the independent variables (soil attributes). Variables: Number of leaves (NL), number of non-commercial roots (NR), height of the first branch (HB - m), P availability (P - mg dm^{-3}), K^+ availability (K - $\text{cmol}_c \text{kg}^{-1}$), and urease activity (Ure - $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 2\text{h}^{-1}$).

To compare the effect of different sources of biochar between Acrisol and Luvisol, a principal component analysis (PCA) was used (Figure 5). The PCA showed a cluster between the biochar SR and the control treatment. Both treatments are in opposite quadrants to the vectors of the main variables, showing little or non-positive effect. This was already expected for the control treatment. In contrast, BH biochar allowed for higher levels of P and higher activities of acid phosphatase in the soil. Additionally, BH allowed for a higher number of commercial roots of cassava

and larger FWCR, which is the part of the plant with greater commercial interest.

This study assessed the impact of adding different sources of biochar in two different topsoils cultivated with cassava and confirmed the hypothesis that different sources of biochar, combined with different soil types, increase cassava growth and change soil attributes. In general, the addition of biochar to Chromic Luvisol topsoil had a positive effect on the development of the cassava plant. This study observed that the development of the crop was favored in treatments with larger volumes of topsoil, characterized by greater richness of nutrients available for root exploration, as well as higher contents of organic matter.

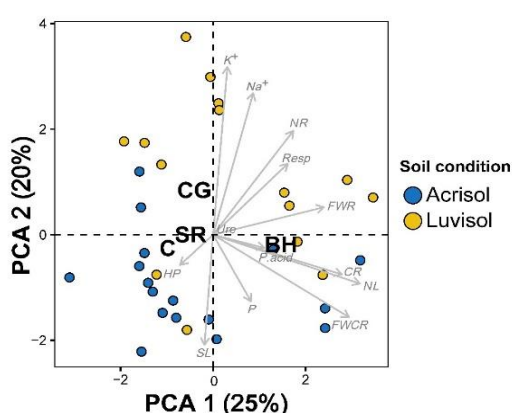


Figure 5. Biplot from Principal Component Analysis (PCA) done through the correlation matrix of the standardized variables showing greater separation as a function of the soil condition (Acrisol or Luvisol). Only the variables and samples that contributed more than 1% of the total explanation in two main axes were shown. The dots and acronyms in italics indicate the scores of the samples and vectors of variables, respectively, and the larger codes in bold indicate the centroids of the samples grouped by treatments with biochar (control - C, coffee grounds biochar - CG, soursop residue biochar - SR, and bean husk biochar - BH). Variables: Number of leaves (NL), number of non-commercial roots (NR), height of the first branch (HB - m), P availability (P - mg dm^{-3}), K^+ availability (K - $\text{cmol}_c \text{ kg}^{-1}$), and urease activity (Ure - $\mu\text{g NH}_4\text{-N g}^{-1} \text{ soil } 2\text{h}^{-1}$).

In our study, we also reported that Luvisol stood out by increasing the number of cassava roots and by containing more K^+ cations. However, Luvisol showed lower available P content. The study by Omondi et al. (2019) may partly explain

this response of cassava, as it demonstrated that in some cases, at P concentrations above 10 mg dm^{-3} , the number of storage roots per plant can decrease. This finding is in line with recent research, such as the studies by Yuniwati et al. (2020) and Wang et al. (2022), who also observed a decrease in the number of roots of cassava plants, highlighting the relationship between phosphorus concentrations in the soil and root development.

On the other hand, the addition of biochar to the soil has shown positive results in cassava root development. Studies like those by Frimpong et al. (2021) report that the presence of biochar promotes an increase in the number and size of cassava roots, even in soils with low phosphorus availability. These results indicate the importance of proper phosphorus management in cassava cultivation, as well as the positive influence of biochar on the root development of this crop.

The high plant development and increases in soil attributes in this study can confirm that cassava plants seem to benefit from biochar addition to different topsoil. Yuniwati et al. (2020), studying the effect of biochar on cassava growth cultivated in intercropping with maize in a monoculture system, found that regardless of whether cassava was intercropped or in monoculture, its development was favored by the addition of biochar. A similar effect was observed by Yuniwati et al. (2020), who, when investigating the impact of manure and biochar addition on the growth of cassava intercropped with corn and peanuts, found that the addition of manure resulted in increased cassava productivity within a year. In contrast, the addition of biochar not only enhanced productivity in intercropping for two consecutive years but also maintained high levels of organic matter in the soil even after the second harvest of the cassava crop, thus demonstrating a beneficial effect on soil quality (Li et al., 2022; Hardy et al., 2019). These findings emphasize the potential of biochar as a long-lasting soil amendment in promoting sustainable cassava production and intercropping systems.

This result has been reported since biochar has a higher capacity to promote the plant development and productivity (Ali et al., 2019), increasing the tolerance of plants to drought due the increase in water content of soils and to improvements in their physical-chemical soil attributes (Romdhane et al., 2019; Nguyen et al., 2020). The most significant changes of biochar application to the soil are the increase in soil pH,

reduction in Al content, and increase in cation exchange capacity - CEC (Xia et al., 2020), making it an ecological fertilizer for sustainable agriculture (Chen et al., 2018). In addition to enhancing soil microbial dynamics.

In soil microbiome, biochar can promote an increase in the density and diversity of beneficial microorganisms, such as N₂-fixing bacteria (Semida et al., 2019) and *Trichoderma* spp. (Silva et al., 2022), which act against plant diseases caused by pathogens inhabiting the soil (Medeiros et al., 2021). In addition, it brings several benefits to agriculture such as reducing nutrient leaching and the need for irrigation and fertilization of plants due to its ability to retain nutrients and water (Razzaghi et al., 2020). It is also a soil conditioner (Aamer et al., 2020; Ye et al., 2020), increases CEC as it has negatively charged functional groups on its surface and acts on soil aggregation (Amoah-Antwi et al., 2020). Biochar has been shown to enhance carbon stability and improve the adsorption and complexation of organic matter and toxic substances in the soil (Murtaza et al., 2023).

Icalla and Apostol (2020) used rice husk biochar as a soil remediator to ensure an increase in cassava productivity. They observed that biochar favored increases in the productivity of commercial roots; however, it did not interfere with the weight of non-commercial roots, which is different from what was observed in the present study. The type of biochar used may present physicochemical characteristics that allow better root development. In this case, bean husk biochar proved to be more efficient than the rice husk biochar.

The multivariate analysis revealed a strict separation of the biochar sources and soil type, with differences between BH and SR, and the soil type (Acrisol and Luvisol). The different clusters can suggest that the BH applied to Luvisol promotes cassava development and increases soil quality. This improvement with the use of BH biochar is mainly shown in relation to the increase in soil enzymatic activity, which has been used as the most sensitive indicator to demonstrate changes in soil quality (Medeiros et al., 2020). A vast literature uses enzyme activity as an indicator of changes caused by biochar addition to the soil (Martins Filho et al., 2021; Medeiros et al., 2020). Thus, increases in enzyme activities in these soils could respond more quickly to biochar addition.

Conclusion

In this study, we assessed the effect of different sources of biochar applied to different topsoil type on the cassava growth and soil quality. Our analysis revealed that biochar mainly from BH biochar added to Luvisol was considerably effective in promote the cassava growth and increase soil quality by increases the soil fertility, improving soil conditioning by increasing K⁺ levels. Treatments with biochar demonstrate the potential use as an ecologically viable input, mainly to replace high-value agricultural inputs. Collectively, our findings provide a better understanding of alternative methods to increase the cassava development and increase the soil quality. However, future field studies and long-term studies are needed in order to elucidate gaps that still exist.

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