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ORIGINAL ARTICLE - Silviculture

Filter Cake Biochar as a Soil Conditioner Cultivated with Native Cerrado Species: Effect on Soil Chemical and Microbiological Properties

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Abstract

The objective of this study was to evaluate the effect of filter cake biochar on the chemical and microbiological attributes of a dystrophic red-yellow latosol cultivated with macaúba (*Acrocomia aculeata*), araçá (*Psidium firmum*) and cajuzinho do cerrado (*Anacardium humile*), species native to the Cerrado. Thus, the responses of soil attributes were evaluated 120 days after transplanting the seedlings using four doses of biochar (1%, 2%, 4% and 8% v/v) and two control treatments (one with soil correction and fertilization and the other with no fertilization). The attributes evaluated were pH, contents of calcium, magnesium, phosphorus, potassium, CTC, total and microbial organic carbon and nitrogen, and C:N ratio. For the soils cultivated with the three Cerrado species, the 1% dose of biochar and mineral fertilization were the treatments that best conditioned the soil during the cultivation period and promoted a better response of the chemical and microbiological attributes of the soil.

Keywords: Biochar, microbial carbon, total organic carbon, soil fertility, nitrogen.

1. INTRODUCTION

The Cerrado biome has a great diversity of tree species, many of which have high commercial value (Soares et al., 2017). Among the many species that provide non-timber products are the macaúba (*Acrocomia aculeata* (Jacq.) Lodd. ex Martius), the araçá (*Psidium firmum* O. Berg), and the Brazilian cashew tree (*Anacardium humile* A. St.-Hil.). Apart from their economic value, they are also important for plantations for reforestation. Nevertheless, little is known about the nutrient requirements for establishing plantations in the field.The survival of seedlings planted as part of a reforestation project depends on several factors, with edaphic conditions of the degraded soil among the most important (Carnevali et al., 2016).

Despite all the advances in research on fertility management of soils with low fertility, such as those prevalent in degraded areas in the Cerrado, the search for alternative sustainable technologies to improve these soils has been stimulated (Falcão et al., 2013; Boecha et al., 2014; Lima et al., 2015). Thus, the use of agroindustrial residues is an alternative to achieve environmental sustainability with higher crop productivity and survivability, mainly due to the increase of soil organic matter (Berilli et al., 2019). Among these residues, it is worth highlighting the filter cake from the sugarcane industry, which is a mixture of ground bagasse and decanter sludge and is an excellent organic product for improving soils with low natural fertility (Silva et al., 2021).

The application of these residues has a limited effect on soil carbon over time. Studies show that much of the applied carbon is lost through decomposition (Scala et al., 2006). One strategy to reduce this loss is the use of biochar, a solid, porous, carbon-rich material obtained through the thermal decomposition of organic wastes in an oxygen-deficient environment (Sánchez-Reinoso; Ávila and Restrepo, 2020). The availability and high content of organic matter in the filter cake shows the potential for obtaining biochar and its various application possibilities (Bernardino et al., 2018). Biochar, compared to natural waste, has the advantage of reducing the final volume of waste and adding nutrients and carbon to the soil in a more stable form (Gwenzi et al., 2016; Sheng et al., 2016).

Biochar helps to retain, make available, and increase nutrients and promotes better nutritional performance of plants cultivated in nurseries or in the field (Enders et al., 2012; Novotny, 2014), and the supply of nutrients depends on its parent material (Enders et al., 2012; Novotny, 2014). Akhtar et al., 2015). Biochar application promotes stability and increase in carbon stocks, improves soil quality, reduces nutrient leaching, and helps reduce irrigation and fertilization (Li et al., 2017). The interactions with soil microorganisms lead to changes in pH, rate of organic matter decomposition, and availability of energy and nitrogen to plants (Du et al., 2014).

In this way, biochar presents itself as an efficient soil conditioner in forest restoration projects, as it promotes the improvement of physical and chemical properties and can restore degraded soils and create a more favorable environment for root system development and plant biological activity (Achete et al., 2013).

In view of the above, the hypothesis was raised that the application of filter cake biochar can improve the chemical and biological characteristics of the soil. Therefore, the objective of this study was to evaluate the effect of filter cake biochar on the chemical and microbiological attributes of a dystrophic red-yellow latosol cultivated with three species native to the Cerrado.

2. MATERIAL AND METHODS

2.1. Biochar preparation and characterization

The biochar used in this study was prepared from the filter cake, a by-product of the sugar-alcohol industry obtained from the filtration of juice from the mills in the rotary filter and obtained from a mixture of ground bagasse and decanter sludge. After the material was collected in the yard of the factory, it was dried in an oven at 105 ºC for further pyrolysis. Then, the dried filter cake was packed in aluminum containers and transferred to the muffle, where pyrolysis was carried out at a temperature of 550 ºCand a residence time of 180 minutes. Then the biochar was crushed and sieved through a 1 mm sieve. Before the biochar was applied to the soil, it was characterized (Table 1). The ash content, pH and electrical conductivity were determined according to the method proposed by the International Biochar Initiative (IBI, 2012). And the content of macro- and micronutrients was determined according to the official method of the Ministry of Agriculture and Supply (MAPA, 2017) for organic fertilizers. The yield of biochar produced was 73.4% ± 0.73, calculated by the ratio between the mass of pyrolyzed biochar and the mass of raw material before the pyrolysis process.

Table 1. Characterization of the filter cake biochar used in the experiment.

Attribute	Value
Moisture (%)	1.8
pH (água)	8.50
CE (mS cm^{-1})	0.323
Ashes (%)	46.86
Total C (g kg $^{-1}$)	287.9
Total N (g kg $^{-1}$)	1.84
P (g kg $^{-1}$)	0.48
K (g kg $^{-1}$)	3.55
Ca (g kg $^{-1}$)	115.56
Mg (g kg $^{-1}$)	2.84
Zn (mg kg $^{-1}$)	0.017
Cu (mg kg $^{-1}$)	0.051
Mn (mg kg $^{-1}$)	0.055
Fe (g kg $^{-1}$)	12.68

2.2. Seedling production in the nursery and greenhouse experiment set-up

Seedlings of the three species used were produced at the Unimontes Plant Ecology Nursery in Montes Claros, Minas Gerais. The seedlings were transplanted into the pots at 180 days of age. The soil used for the experiment was collected in an area with native vegetation and classified as dystrophic red-yellow Latosol according to Embrapa (2018). The chemical and granulometric characterization is described in Table 2.

The three experiments were conducted in July 2020 in the medicinal plant nursery of the Institute of Agrarian Sciencesofthe Federal University of Minas Gerais (Universidade Federal de Minas Gerais – UFMG), one experiment per species. The native species of the Cerrado used were: macaúba (*Acrocomia aculeata* (Jacq.) Lodd. ex Martius), araçá (*Psidium firmum* O. Berg), and cajuzinho do cerrado (*Anacardium humile*A. St.-Hil.). Experiments were conducted in 12-liter pots in a greenhouse in a randomized block design with four replications, consisting of six treatments [four doses of biochar: 1 (B1); 2 (B2); 4 (B3) and 8% (B4) v/v and two control treatments: one with no fertilization (WNF) and the other with soil correction, 7.5 g GEOX and mineral fertilization, 380 g NPK 4:14:8 per plant (CA)]. The soil was sieved in a sieve with a mesh size <4 mm, mixed with biochar and placed in pots in which the seedlings were transplanted.

Table 2. Chemical and textural characterization of the soil used for the experiment.

Soil chemical analysis	
Soil attribute	Value
pH (água)	4.11
P (mg dm^{-3})	5.58
K (mg dm^{-3})	37.49
Ca (cmolc dm^{-3})	0.93
Mg (cmolc dm^{-3})	<0.1
Al (cmolc dm^{-3})	0.88
H+Al (cmolc dm^{-3})	5.28
SB (cmolc dm^{-3})	1.12
t (cmolc dm^{-3})	2.00
T (cmolc/dm^{3})	6.41
m (%)	44
V (%)	18
Soil granulometric analysis	
Areia (g kg^{-1})	387.4
Silte (g kg^{-1})	162.6
Argila (g kg^{-1})	450.0 Ar

2.3. *Evaluation of soil attributes*

At the end of the experiment, 120 days after transplanting the seedlings, the soil in the pots was sampled and the contents of Ca, Mg, P and K, pH, CTC, organic carbon (CO) and nitrogen (N) total and microbial (Cmic and Nmic), and C:N ratio were determined. For chemical analysis, the soil of each pot was completely mixed, passed through a 2-mm sieve, and characterized according to the methodology proposed by EMBRAPA (1997).

For the determination of total CO and soil N content, the samples were air dried, sieved through 2 mm sieves, homogenized, ground, and sieved again through 0.150 mm sieves. For the determination of CO, the method of wet oxidation over potassium dichromate was used (Yeomans &Bremner, 1988), while for total N content in the soil, the sulfur digestion method was used according to the Kjeldhal method (Bremner& Mulvaney, 1982); Tedesco et al., 1995). The C:N ratio was then calculated.

For the analysis of carbon and nitrogen in soil microbial biomass, small plant fragments were manually collected from the samples. The initial moisture content of the samples was determined and then water was added until 60% of the field capacity was reached, the ideal moisture for the proliferation of soil organisms. Cmicand Nmic were determined using the fumigation-extraction method of Vance et al. (1987), andadapted from Silva et al. (2007).

2.4. *Statistical analysis*

The data obtained were subjected to multivariate analysis of variance (MANOVA) to determine the grouping of the different soil characteristics and the difference between treatments. For this purpose, the MANOVA function of the Stats package was used, applying the Pillai test at 5% significance. After verifying that there was no multicollinearity, the data were subjected to canonical variable (CV) analysis using the Multivariate Analysis package. Statistical procedures were performed using R software (R Development Core Team, 2021).

3. RESULTS

In the soil cultivated with macaúba, the first two canonical variables (CV1, CV2) explained 94.8% of the total variation observed and canonical variable 1 (CV1) explained 90.0% of the total variation, the variables with the highest contribution being Cmic, Nmic, C:N ratio, CTC, and K content (Table 3). Considering the negative correlation of these variables with CV1, the graphic dispersion shows that treatment B1 (1% biochar) provided higher values of these variables (Figure 1).

The second canonical variable (CV2) explained 4.7% of the variation between treatments and the main variables were CO, N, pH and P, Ca and Mg contents (Table 3), with negative correlation with Mg content and positive correlation with the others. Thus, the graphic dispersion shows that the treatments WF and B1 promoted higher values of CO, N, pH and P and Ca contents, while the treatment B2 had the highest Mg content (Figure 1).

For the soil cultivated with araçá species, the first two canonical variables (CV1, CV2) explained 89.9% of the total variation observed, and canonical variable 1 (CV1) explained 76.9% of the total variation, while canonical variable 2 (CV2) explained 12.9% (Figure 2). For CV1, Cmic, Nmic, N, pH, CTC, and the contents of P, K, and Ca were the attributes with the largest contribution (Table 4). The negative correlations of CV1 with Cmic, N and pH show in the graph that treatment B1 promoted the highest values of these variables. On the other hand, the positive correlations show that the highest Nmic, CTC, and P, K, and Ca levels were obtained in the WF treatment (Figure 2).

For the second canonical variable (CV2), the most important attributes were CO, C:N ratio, and Mg content (Table 4), with negative correlation with Mg content and positive correlation with CO and C:N ratio. The graphic dispersion shows that treatments WNF and B1 contributed with higher values for CO and C:N ratio, and treatment B4 was the one with the highest Mg content (Figure 2).

Table 3. Canonical correlations referring to the canonical scores for the 11 attributes of the soil cultivated with macaúba, in the treatments with the addition of biochar at doses of 1, 2, 4, and 8%, with fertilization - WF (7.5 g of GEOX corrective and 380 g of mineral fertilizer NPK 4:14:8 per plant) and with no fertilization (WNF).

Soil variable	Canonical variables(VC)	
	VC1	VC2
Microbial carbon	-0.92	0.33
Microbial nitrogen	-0.38	0.17
Total organic carbon	-0.36	0.69
Total nitrogen	0.31	0.34
C/Nrelationship	-0.57	0.47
Content of P	0.16	0.41
Contentof K	-0.45	-0.20
Contentof Ca	-0.20	0.37
Contentof Mg	0.05	-0.46
pH	-0.09	0.51
Cation exchange capacity (CTC)	-0.56	-0.23

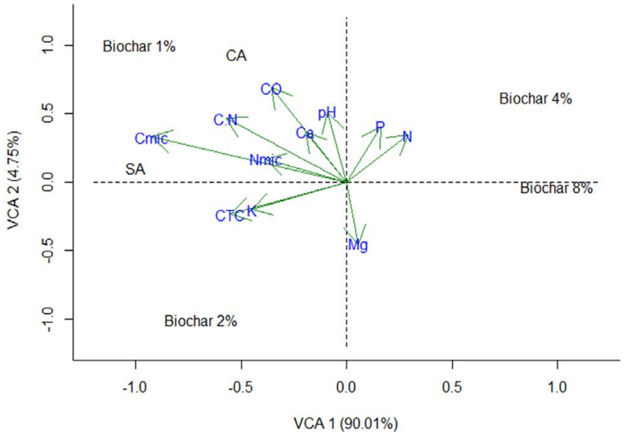

Figure 1. Graphic dispersion of canonical variables CV1 and CV2 in the study of soil attributes, cultivated with macaúba, in treatments with addition of biochar at doses of 1, 2, 4, and 8%, with fertilization - WF (7.5 g GEOX corrective and 380 g mineral fertilizer NPK 4:14:8 per plant) and with no fertilization (WNF).Cmic - microbial Nmic - microbial nitrogen, CO - total organic carbon, N - total nitrogen, P – phosphor, K – potassium, Ca – calcium, Mg – magnesium, CTC - cation exchange capacity.

Table 4. Canonical correlations referring to the canonical scores for the 11 attributes of the soil cultivated with araçá, in the treatments with the addition of biochar at doses of 1, 2, 4, and 8%, with fertilization - WF (7.5 g of GEOX corrective and 380 g of mineral fertilizer NPK 4:14:8 per plant) and with no fertilization (WNF).

Soilvariable	Canonical variables (VC)	
	VC1	VC2
Microbial carbon	-0.55	0.34
Microbial nitrogen	0.80	0.44
Total organic carbon	-0.44	0.80
Total nitrogen	-0.65	-0.59
C/N relationship	-0.11	0.86
Content of P	0.91	0.13
Content of K	0.84	-0.14
Content of Ca	0.96	-0.22
Content of Mg	0.19	-0.68
pH	-0.27	0.12
Cation exchange capacity (CTC)	0.89	0.02

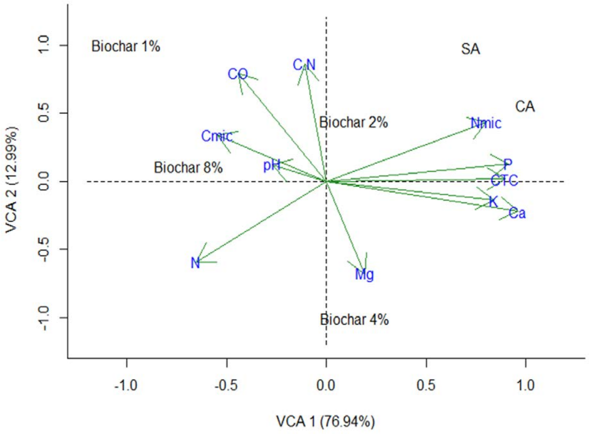

Figure 2. Graphic dispersion of canonical variables CV1 and CV2 in the study of soil attributes, cultivated with araçá, in the treatments with the addition of biochar at doses of 1, 2, 4, and 8%, with fertilization - WF (7.5 g GEOX corrective and 380 g mineral fertilizer NPK 4:14:8 per plant) and with no fertilization (WNF).Cmic - microbial Nmic - microbial nitrogen, CO - total organic carbon, N - total nitrogen, P – phosphor, K – potassium, Ca – calcium, Mg – magnesium, CTC - cation exchange capacity.

In the canonical analysis of soil attributes cultivated with cajuzinho do cerrado, the first and second canonical variables corresponded to 44.8 and 27.1% of the total variation, respectively. This corresponds to 71.9% of the total variation. For canonical variable 1 (CV1), Cmic, Nmic, CO, N, C:N ratio, pH, Ca and Mg contents were the variables with the highest contribution (Table 5). When considering the positive correlations of N and Mg content with CV1, the graphic dispersion shows that the B4 treatment resulted in a greater increase in these soil characteristics. For Cmic, Nmic, CO, the C:N ratio, pH, and

Ca content, the correlations with CV1 were negative, so the graph shows that the WF treatment contributed to an increase in the values of these soil attributes (Figure 3).

In canonical variable 2 (CV2), the attributes with the highest contribution were CTC and P and K contents, with negative correlations (Table 5). Thus, the graphic dispersion shows that a dose of 2% biochar obtained the best results in these attributes (Figure 3).

Table 5. Canonical correlations referring to the canonical scores for the 11 attributes of the soil cultivated with cajuzinho do cerrado, in the treatments with the addition of biochar in doses of 1, 2, 4 and 8%, with fertilization - WF (7.5 g of corrective GEOX and 380 g of mineral fertilizer NPK 4:14:8 per plant) and with no fertilization (WNF).

Soilvariable	Canonical variables (VC)	
	VC1	VC2
Microbial carbon	-0.51	-0.19
Microbial nitrogen	-0.83	0.38
Total organic carbon	-0.62	-0.41
Total nitrogen	0.89	-0.03
C/N relationship	-0.80	-0.30
Content of P	-0.02	-0.62
Content of K	0.23	-0.80
Content of Ca	-0.39	-0.26
Content of Mg	0.85	0.01
pH	-0.82	0.21
Cation exchange capacity (CTC)	-0.19	-0.68

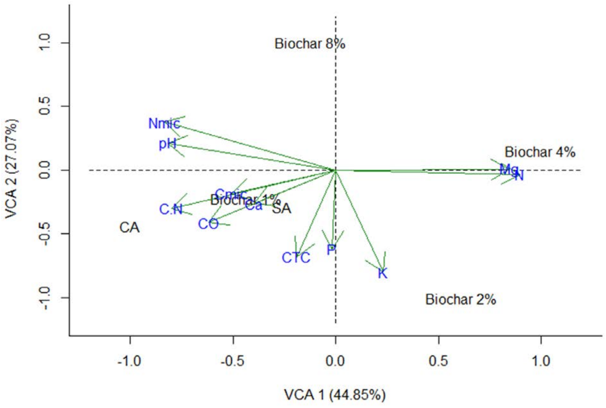

Figure 3. Graphic dispersion of the canonical variables CV1 and CV2 in the study of soil attributes, cultivated with cajuzinho do cerrado, in treatments with the addition of biochar at doses of 1, 2, 4 and 8%, with fertilization - WF (7.5 g of GEOX corrective and 380 g of mineral fertilizer NPK 4:14:8 per plant) and with no fertilization (WNF).Cmic - microbial Nmic - microbial nitrogen, CO - total organic carbon, N - total nitrogen, P – phosphor, K – potassium, Ca – calcium, Mg – magnesium, CTC - cation exchange capacity.

4. DISCUSSION

In the present study, the hypothesis that the application of filter cake biochar can improve the chemical and microbiological characteristics of the soil was confirmed, since the 1% dose of biochar contributed to increase the chemical and microbiological attributes of the soil.

The adjustment of soil pH not only improves the quality, but also triggers a series of biochemical processes in the soil (Shaaban et al., 2018; Liu et al., 2019) may result in physical (effect of polysaccharide excretion on soil aggregation) and chemical (enzymes, respiration and heat production) activity, thus promoting numerous soil processes (Balota et al., 1998). This could also explain the fact that the WF and B1 treatments promoted an increase in Cmic and Nmic contents in the soil.

Moreover, the responses to Cmic and Nmic were also positive in the treatment with no fertilization (WNF). These results may be attributed to the carbon recalcitrance in the filter cake biochar. According to Sato et al. (2017), the stabilized fraction of organic matter is more resistant to microbial attack due to its recalcitrance, in contrast to the labile fraction, which is more readily available to microorganisms. Considering the above, the fact that no positive effects on microbial stimulation were observed at the highest doses of biochar could be due to the difficulty for microorganisms to access the carbon source of the biochar used. Similar results were also reported by Zimmerman et al. (2011), who found lower than expected carbon mineralization in soils after application of biochar with pyrolysis temperatures ranging from 525 to 650 °C. The reduction in microbial activity following the application of high doses of biochar to soil was also reported by Chan et al. (2008), who attributed this unfavorable effect to the chemical components of the biochar. According to Deenik et al. (2010), the presence of volatile compounds in biochar can reduce soil microbial biomass.

As for the CEC value of the soil, the increase in this attribute was observed mainly in the treatments WF and B2. This is mainly due to the soil amendment applied in the treatment with fertilizer. Biochar showed variations in CEC mainly due to the biomass used as raw material (Cely et al., 2015) and the temperature used in pyrolysis (Song; Guo, 2012).

Under the conditions of the present work, the use of biochar did not increase CO. The lack of change in CO in soil might be related to the stability of pyrogenic carbon, which means that the addition of biochar hardly changes the oxidizable carbon content of soil determined by oxidation with potassium dichromate in acidic medium in the short term. According to Peter et al. (2012), the high molecular stability of the pyrogenic carbon of biochar is responsible for the fact that not all the material from pyrolysis can be oxidized by this method. Thus, biochar provides an increase in the long-term level and stocks of total carbon in the soil (Guimarães et al., 2017).

Total soil N content showed an increasing trend in treatments B3 and B4 with the highest biochar doses (4 and 8%, respectively), which is reflected in the low C:N ratio of the soils evaluated with these doses. There are reports of an increase in nitrogen after 1, 2, and 10 years of biochar application (Bai et al., 2015). Incorporating biochar into the soil is not only a source of nitrogen, but can also reduce losses of this element through volatilization and leaching (Liu et al., 2019).

For the soils cultivated with the three species, the correlations showed higher P and Ca levels in the WF treatment. This was due to the fertilizer used and the corrective NPK 4:14:8 and GEOX, which is 60% CaO. In addition, the filter cake biochar has low P content (Table 1). The K content in the soils cultivated with macaúba and cajuzinho do cerradotended to increase in treatment B2, and in the soil cultivated with araçá, this tendency was observed in the WF treatment. This was due to the higher content of exchangeable bases (K, Ca, and Mg) in these treatments. The highest Mg contents were near the doses of 2 and 4% (B2 and B3). Several studies have shown that soil fertility increases with the application of biochar from different raw materials and in different crops (Jeffery et al., 2011; Liu et al., 2014; Smider; Singh, 2014; Oram et al., 2014; Soinne et al., 2014; Tammeorg et al., 2014) and also the concentrations of some nutrients, such as P, Ca, Mg, K and micronutrients, decrease (Smider; Singh, 2014). These data show that several factors such as the type of raw material, pyrolysis time and temperature, management, and species cultivate may affect the feasibility of using this product in soil for various purposes such as production and cultivation of seedlings in soils with low natural fertility.

The species used in this study are typical of the Cerrado and may adapt to the environment, since the Cerrado vegetation normally occurs in dystrophic soils, poor in calcium and magnesium and with high availability of aluminum (Alves Júnior et al., 2015). Therefore, complementary studies are necessary to evaluate different types and forms of biochar application for these species.

5. CONCLUSIONS

The application of 1% biochar positively affected the responses of the attributes pH, CTC, CO, Cmic, Nmic, C:N ratio and Ca content in the soil cultivated with macaúba, pH, CO, Cmic and C:N ratio for the soil cultivated with araçá. In the soil cultivated with cajuzinho do cerrado, mineral fertilization increased pH and CEC and showed higher values of CO, Cmic, Nmic, and Ca.The dose of 4% biochar increased the N and Mg content of the soil, but the treatments with 1% biochar and mineral fertilization contributed the most to increase the chemical and microbiological attributes of the soil. Future work can be undertaken to address and advance this field of study.

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