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Biochar as a soil conditioner for common bean plants

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ABSTRACT. Biochar is a carbon-rich material produced during organic waste pyrolysis. In this context, two experiments were performed to evaluate the effect of biochar produced from rice husks and cattle manure on soil fertility and common bean production, as well as to identify the optimal dose of cattle manure biochar to be applied. The first experiment (Experiment I) was conducted according to a completely randomized design (factorial scheme 2 × 2 × 2 + 1) with six replicates: two types of biochar (cattle manure biochar and rice husk biochar), with and without acidity correction [addition of calcium carbonate and magnesium carbonate (PA) in a proportion of 4:1 (Ca:Mg) to raise the soil base saturation to 60%], with or without the addition of 120 mg dm^{-3} of phosphorus (P) as ammonium phosphate, and a control treatment (without biochar, acidity correction, and P). Based on the results of Experiment I, a second experiment was conducted according to a completely randomized design, with five treatments (doses of biochar from cattle manure) and four replications. Rice husk biochar, as a conditioner of soil chemical properties, had less prominent effects than cattle manure biochar. Cattle manure biochar functioned as a corrective for soil acidity and a source of nutrients (mainly phosphorus). The dose corresponding to 5.46% of the soil volume led to the maximum grain production by common bean plants.

Keywords: liming; biocarbon; common bean; waste management; organic residue.

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Introduction

Brazil is one of the world's largest food producers one of the largest importers of mineral fertilizer on the planet, as the national production of these mineral inputs has been insufficient to meet increasing demands. It is estimated that more than 50% of fertilizer used in the country are imported (ANDA, 2021).

The expansion of agricultural activities leads to the generation of large amounts of waste, which, when not treated or managed correctly, can contribute to global warming through the emission of greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4) - this effect is especially salient in case of cattle and rice production (Nayal, Mammadov, & Ciliz, 2016). Agricultural activities may be responsible for 90.6% of N_2O emissions in Brazil, mainly because of the contribution of nitrogen loss from fertilizers and animal waste (Fachinetto & Brisola, 2018).

Increasing agricultural production sustainably through alternative sources of nutrients would reduce international dependence on external inputs, and the proper disposal of waste arising from these activities would help preserve natural resources (Kovacs & Szemmelveisz, 2017). The conversion of residues into biochar is an attractive option for the management of agricultural soil, as it can sequester carbon over a long period and improve soil fertility and crop productivity (Abbasi & Anwar, 2015).

Various studies have shown the potential of biochar to neutralize soil acidity and increase soil phosphorus (P) content (Almeida et al., 2020; Alves et al., 2021). However, there are few studies on the effects of the interaction between biochar, liming, and phosphate fertilization on soil fertility and plant productivity.

We hypothesized that biochar (i) is a source of phosphorus capable of influencing the availability of this element in the soil, (ii) acts as a soil acidity corrective, improving its chemical properties, and (iii) contributes to increasing the leaf nutrient content and common bean production. Thus, the objectives of this study were to evaluate the effects of biochar produced from cattle manure and rice husks on soil fertility and common bean production, as well as to identify the optimal dose.

Material and methods

Two experiments were conducted in a greenhouse at the Institute of Agricultural Sciences (ICA) of the Federal University of Minas Gerais (UFMG). The first experiment (Experiment I) was conducted in a completely randomized design with a factorial scheme of 2 × 2 × 2 + 1, with six replications (54 experimental plots and two plants per plot). From the results of Experiment I, a second experiment was conducted (Experiment II) in a completely randomized design, with five treatments (doses of biochar from cattle manure) and four replications (20 experimental plots and two plants per plot).

In Experiment I, the treatments consisted of two types of biochar (rice husk biochar and cattle manure biochar), with and without acidity correctives (addition of calcium carbonate and magnesium carbonate (PA) in a proportion of 4:1 (Ca:Mg), in order to raise the soil base saturation to 60%), without and with P (addition of 120 mg dm^{-3} of phosphorus as ammonium phosphate), and a control treatment (without addition of biochar, acidity correctives, and P). In treatments in which ammonium phosphate was not applied, 162 mg dm^{-3} of nitrogen (N) was added as urea.

The cattle manure biochar was produced from fresh manure spheres approximately 4 cm in diameter (handmade). The spheres were dried in ovens at 103 ± 2°C for a period of 48h to achieve complete dehydration. To produce biochar, the dried spheres were placed in a hermetically sealed steel container in an industrial muffle. The pyrolysis temperature was 450°C, with a residence time of 30 min. and heating rate of 5°C min.$^{-1}$.

To obtain rice husk biochar, the same procedure was used for dried cattle manure spheres. Both the cattle manure and rice husk biochar were mechanically crushed and passed through a 0.25 mm mesh sieve for chemical characterization and application to the soil.

Cattle manure and rice husk biochars were characterized (Table 1): pH, density, and electrical conductivity, according to Rajkovich et al. (2012); ashes were determined according to the procedure described in ASTM D1762-84; C and N were determined using an elemental analyzer; and nutrients and trace elements were determined by ICP-MS/MS, according to the United States Environmental Protection Agency [USEPA] (1996) 3051 method.

Table 1. Characterization of rice husk (RHB) and cattle manure biochars (CMB) and the amounts of nutrients and trace elements added to the soil (mean = 4).

Characteristics	Results from characterization		Amounts of nutrients and trace elements	
	RHB	CMB	RHB	CMB
pH	7.3	9.8	-	-
Electrical conductivity (µS cm^{-1})	178	411	-	-
Density (g cm^{-3})	0.56	0.54	-	
Ash (%)	24.5	36.2		-
Biochar (g dm^{-3})	-	-	40	40
Total carbon (g kg^{-1})	91.84	167.9	6.56	12.44
Total nitrogen (g kg^{-1})	1.96	6.43	0.14	0.48
P (g kg^{-1})	14.17	32.67	1.01	2.42
K (g kg^{-1})	1.90	5.40	0.14	0.40
Ca (g kg^{-1})	12.10	19.33	0.86	1.43
Mg (g kg^{-1})	18.14	23.22	1.30	1.72
Na (g kg^{-1})	<0.01	1.08	<0.01	0.08
S (g kg^{-1})	0.32	0.70	0.02	0.05
Fe (mg kg^{-1})	7.22	375.3	0.52	27.8
Zn (mg kg^{-1})	21.50	100.4	1.54	7.44
Mn (mg kg^{-1})	44.91	82.08	3.21	6.08
Cu (mg kg^{-1})	9.63	15.28	0.69	1.13
B (mg kg^{-1})	2.24	6.64	0.16	0.49

For both experiments, a surface layer (depth: 0–20 cm) of a Red Yellow Latosol (Oxisol) under Cerrado *sensu stricto* vegetation was used. The physical and chemical properties of the soil were determined according to Teixeira, Donagemma, Fontana, and Teixeira (2017): pH (H_2O) = 5.0; Available P (Resin method) = 1.8 mg dm^{-3}; K = 17 mg dm^{-3}; Ca = 2.5 mmol$_c$ dm^{-3}; Mg = 1.2 mmol$_c$ dm^{-3}; Al = 4.2 mmol$_c$ dm^{-3}; base saturation = 12.7%; cation exchange capacity = 32.5 mmol$_c$ dm^{-3}; total C = 10.6 g kg^{-1}; sand =780 g kg^{-1}; silt = 100 g kg^{-1}; clay = 120 g kg^{-1}. The remaining P, 28 mg L^{-1}, was determined according to Alvarez, Novais, Dias, and Oliveira (2000).

The soil and respective treatments were placed in three-liter pots (3 dm^{-3}) and incubated for 30 days with humidity close to field capacity. The amount of biochar was 120 g per pot (4% m/v). After the incubation period, the soil from each pot was homogenized, and a sample was taken for chemical analysis. All treatments were fertilized with 100 mg dm^{-3} of K and 36 mg dm^{-3} of N as potassium nitrate. The soil was returned to the pots, and four seeds of the common bean (*Phaseolus vulgaris* L.) were sown. Seven days after sowing, thinning occurred, leaving only two plants per pot. Common bean plants were cultivated until grain production (80 days), keeping the soil humidity close to field capacity during the cultivation process.

During the growth period, three rounds of topdressing fertilization were conducted 15, 25, and 35 days after sowing, with 45 mg dm^{-3} of N as urea. At the end of the experimental period, the plants were harvested, and the grains were dried in a forced air circulation oven at 65-70°C until dry matter grains were obtained.

The soil properties of samples from each pot, collected after 30 days of incubation, were determined according to Teixeira et al. (2017): total C (TC) and total N by incineration, pH in water, P using Mehlich 1 solution, Al (exchangeable acidity), and exchangeable Ca, Mg, and K. From the results, the soil cation exchange capacity and base saturation were calculated.

At the end of Experiment I, the data were subjected to an analysis of variance. When significant, the control treatment was compared individually with each of the other treatments using the Dunnett's test ($p < 0.05$). The other treatments were compared using an F-test ($p < 0.05$). R Studio statistical software was used.

In Experiment II, the treatments consisted of five doses of cattle manure biochar (0, 2, 4, 6, and 8% mass/volume), with four replications. In pots filled with 3 dm^3 of soil, both in Experiment I and II, the respective doses of biochar were added. The soil with biochar was incubated for 90 d, keeping the soil humidity close to the field capacity. After the incubation period, soil samples were collected from each pot (experimental unit) for chemical analysis, and six seeds of the common bean (*Phaseolus vulgaris* L.) were sown. Ten days after sowing, thinning occurred, leaving only two plants per pot.

At the end of Experiment II, the dry mass production of the bean grains was determined. Data were subjected to an analysis of variance, and when significant, regression equations were used for the variables studied as a function of biochar dose. R Studio statistical software was used.

Results and discussion

In Experiment I, the soil total carbon (TC) and total nitrogen (TN) contents were lower in the control treatment, 10.3 and 2.3 g kg^{-1}, respectively, compared to the other treatments, mainly in those with the addition of cattle manure biochar (CMB) (Table 2). For CT and NT, there was no significant effect of adding soil acidity correctives and phosphorus fertilizer (Table 2). Biochars are materials rich in more stable forms of carbon that allow greater accumulation of this element in the soil over time (Gwenzi, Muzava, Mapanda, & Tauro, 2016). In addition to being sources of nitrogen, the incorporation of biochar into the soil can reduce losses of this element through volatilization and leaching (Liu et al., 2019).

Table 2. Total carbon (TC), total nitrogen (TN), pH, and exchangeable acidity (Al) in the treatment controls, rice husk (RHB), and cattle manure (CMB) biochars, without (NC) and with liming (WC) and without (NP) and with phosphorus (WP).

Treatments			TC	TN	pH	Al
			------------g kg^{-1}--------------		-	$mmol_c\ dm^{-3}$
Control			10.3	2.3	5.4	4.01
RHB	NC	NP	17.40a*	3.5a*	5.8a	1.02a*
		WP	17.28a*	3.2a*	5.8a	1.04a*
		Mean	17.3A	3.4A	5.8B	1.03
	WC	NP	16.8a*	3.3a*	8.7a*	0
		WP	16.9a*	3.2a*	8.9a*	0
		Mean	16.9A	3.3A	8.8A	0
	Mean		17.1C	3.3D	7.3D	0.52
CMB	NC	NP	17.3a*	7.1a*	8.9a*	0
		WP	16.5a*	7.5a*	8.9a*	0
		Mean	16.9A	7.3A	8.9A	0
	WC	NP	16.5a*	7.3a*	9.3a*	0
		WP	16.3a*	7.2a*	8.7a*	0
		Mean	16.6A	7.3A	9.0A	0
	Mean		16.8C	7.3C	9.0C	0

Means with an asterisk (*) differ from the control treatment according to Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without phosphorus, and within treatments without and with liming by the F test. Capital letters "A" and "B" compare treatments without and with liming and capital letters "C" and "D" compare RHB and CMB biochars.

Soil pH values in the control treatment (5.4) were similar to those in treatments with RHB without liming (5.8) and lower than those obtained in the other treatments (Table 2). In general, the higher pH values in treatments with biochar are due to the presence of basic compounds (calcium and potassium carbonate, for example) present in the ash, resulting from the pyrolysis process and feedstock (Alves et al., 2021). Thus, the higher pH values in the CMB treatments were due to their higher ash content (Table 1). However, due to the lower ash content, the application of RHB alone did not significantly alter the soil pH. In addition, CMB had higher calcium, magnesium, and potassium contents than RHB (Table 1). Some of these elements were likely in the form of bases, such as oxides (e.g., CaO, MgO, and K_2O) and hydroxides (e.g. $Ca(OH)_2$, $Mg(OH)_2$, and KOH) (Steenari, Karlsson, & Lindqvist, 1999), which increased the soil pH.

The control treatment had a higher exchangeable acidity (Al) value (4.01 $mmol_c\ dm^{-3}$) than the other treatments (Table 2). With the addition of RHB the soil acidity was corrected, and AI values were zero with the addition of CMB (Table 2). These results indicate the positive effects of liming and biochar on correcting soil acidity factors. As soil pH increases, exchangeable forms of Al are precipitated into $Al(OH)_3$ and can later be adsorbed by functional groups present on the surface of the biochar during its gradual oxidation. As the soil pH increases due to biochar, Al^{3+} is converted to $Al(OH)^{2+}$, $Al(OH)_2^{+}$, and $Al(OH)_3$, reducing the toxicity of aluminum to plants (Qian, Chen, & Hu, 2013; Tang et al., 2013). In addition to increasing soil pH, biochar can strongly adsorb the monomers $Al(OH)^{2+}$ and $Al(OH)_2^{+}$ (Almeida et al., 2020), because of its high aromaticity and specific surface area (Qian et al., 2013).

The soil available P content, extracted using Mehlich 1 solution, obtained in the control treatment (1.89 mg dm^{-3}), was lower than that in the other treatments (Table 3). For CMB, regardless of acidity correction, the highest P content was obtained with the addition of this element to the soil as fertilizer (Table 3). For CMB with liming, there were no differences between soil P content with or without the addition of this element as a fertilizer (Table 3).

Table 3. Phosphorus (P), calcium (Ca), magnesium (Mg), cation exchange capacity (CEC), and base saturation (V) in the control, cattle manure (CMB), and rice husk biochar (RHB) treatments, without and with liming, and with and without phosphorus.

Treatments			P	Ca	Mg	K	CEC	V
			mg dm^{-3}	--------------	-------------- $mmol_c\ dm^{-3}$	--------------	--------------	%
Control			1.89	4.4	2.0	0.38	28.8	23.6
RHB	NC	NP	3.89b*	5.2a	2.6a	0.41a	24.8a	33.1a*
		WP	19.5a*	5.0a	2.0a	0.51a	26.1a	28.8a*
		Mean	11.69A	5.1B	2.3B	0.46A	25.5B	30.9B
	WC	NP	3.72b*	15.0a*	8.0a*	0.41a	33.8a*	69.2a*
		WP	18.5a*	16.0a*	10.0a*	0.41a	37.1a*	71.2a*
		Mean	11.11A	15.5A	9.0A	0.41A	35.5A	70.2A
	Mean		11.40D	10.3D	5.7D	0.44D	30.5D	53.8D
CMB	NC	NP	78.0b*	20.0a*	9.0a*	1.33a*	36.4a*	83.3a*
		WP	90.0a*	20.0a*	11.0a*	1.46a*	39.0a*	83.3a*
		Mean	84.0A	20.0A	10.0B	1.40A	37.7A	83.3A
	WC	NP	86.0a*	22.0a*	12.6b*	1.33a*	41.5a*	86.5a*
		WP	92.0a*	25.0a*	16.6a*	1.23a*	49.3a*	86.8a*
		Mean	89.0A	23.5A	14.6A	1.28A	45.4A	86.7A
	Mean		86.5C	21.8C	12.3C	1.34A	41.6C	85.1C

Means with an asterisk (*) differ from the control treatment according to Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without phosphorus, and within treatments without and with liming by the F test. Capital letters "A" and "B" compare treatments without and with liming and capital letters "C" and "D" compare RHB and CMB biochars.

The application of biochar, mainly CMB, significantly increased soil available P (Table 3). In addition to CMB having a higher P content than RHB (Table 1), it may have contributed more effectively to blocking clay P adsorption sites by adding organic binders and increasing soil pH. Alves et al. (2021) verified that sewage sludge biochar reduced the soil phosphorus adsorption capacity and, consequently, increased the phosphorus uptake by sugarcane plants. Another hypothesis for increasing soil P availability is the presence of soluble silica in biochar ash. Silica can block the P adsorption sites of clays, preventing the fixation of phosphate ions by the soil (Torres et al., 2020).

According to the results of this study, the use of biochar in highly weathered soils in tropical regions is a strategy used to increase phosphorus availability. This is done by either by adding this nutrient to the biochar itself, or by reducing phosphorus fixation, due to the neutralization of soil acidity and by the addition of organic binders and soluble silica.

The soil Ca and Mg contents in the control treatment were similar to those obtained in the RHB treatment without liming and were lower than those in the other treatments (Table 3). In treatments with biochar, regardless of liming, the addition of phosphate fertilizer did not affect the Ca and Mg content in the soil (Table 3). In relation to exchangeable K, only the contents obtained in the CMB treatments were higher than those in the control treatment (Table 3).

Cattle manure had higher calcium, magnesium, and potassium contents than rice husks (Table 1). With pyrolysis, biochar produced from cattle manure had 1.67 times more calcium, 1.32 times more magnesium, and 2.86 times more potassium than RHB. Thus, in the treatments with RHB, 103.2 mg of Ca, 156.0 mg of Mg, and 16.8 mg of K were added per pot (3 dm^{-3} of capacity), while in the treatments with CMB, 171.6 mg of Ca, 206.4 mg of Mg, and 48.0 mg of K were added per pot. The addition of Ca, Mg, and K to the soil by biochar contributed to the displacement of exchangeable Al adsorbed on clays to the soil solution, favoring the precipitation of this toxic element for plants.

The cation exchange capacity (CEC) in the control treatment was lower than that in the RHB treatments with liming and phosphate fertilizer and in the treatments with CMB (Table 3). The increase in CEC values was due to the increase in soil pH, the addition of Ca and Mg by liming, and the addition of organic binders Ca, Mg, and K by biochar. In addition, as discussed above, biochars incorporate aromatic forms of carbon that are more stable against degradation by soil microorganisms, favoring soil carbon stocks, reducing CO_2, CH_4, and N_2O emissions, and increasing soil CEC.

Interest in biochars arose precisely because of their effects on soil CEC and nutrient availability, as observed in the so-called "Terra Preta de Índio" (Amazonian Dark Earth) in the Amazon region. The "Terra Preta de Índio" were formed by exogenous inputs from alluvial deposition of carbon and mineral elements (Silva et al., 2021) and/or, in areas of prehistoric human occupation, by the accumulation of pyrogenic carbon in the soil (Kern et al., 2017). In addition to being a source of exchangeable bases (Ca, Mg, and K), biochars, which neutralize the acidity of the soil, change the density of pH-dependent negative charges, and the continuous oxidation of the surface of its particles continuously increases the CEC over time (Cheng, Lehmann, & Engelhard, 2008).

For base saturation (V), which expresses the percentage of exchangeable bases (Ca, Mg, and K) in the soil CEC, the value obtained in the control treatment was lower than that of the other treatments, and there was no effect of phosphate fertilizer addition (Table 3). The highest base saturation values were obtained for CMB treatments (Table 3). According to the results obtained in this study, biochar increases the pH, exchangeable bases, and CEC and can be considered corrective for soil acidity. Grain dry matter production (MSGR) was lower in the control treatment, and there were no significant differences among the other treatments (Figure 1). Although biochar is a source of nutrients, the increase in soil pH to values above seven, as observed with the addition of CMB (Table 2), may have harmed the bean plants. Soil pH values above seven can affect nutrient availability, mainly due to the precipitation of cationic micronutrients, such as $Zn(OH)_2$. In addition, biochar has a high capacity to adsorb these elements, and is used for the remediation of soils contaminated by heavy metals. Therefore, it is important to define the most adequate biochar dose for plants.

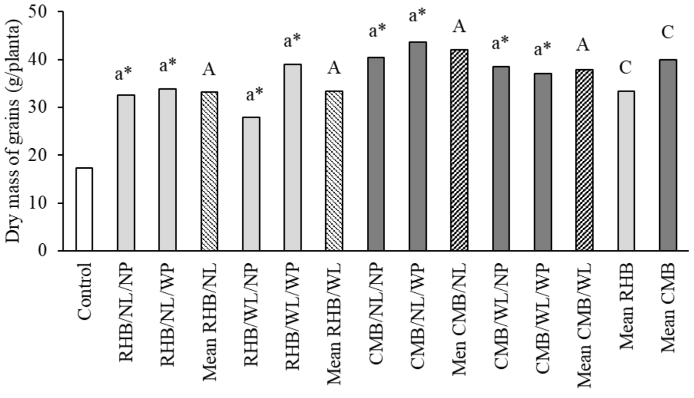

Figure 1. Grain dry mass of common bean plants in the control, cattle manure (CMB) and rice husk biochar (RHB) treatments, without and with liming and with and without phosphorus. Means with an asterisk (*) differ from the control treatment by Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments without and with phosphorus, within treatments without and with liming by the F test. Capital letters "A" and "B" indicate treatments without and with liming, and capital letters "C" and "D" indicate RHB and CMB.

The macronutrient contents in the bean leaves in the control treatment were generally lower than those in the other treatments. There were no differences between treatments for leaf N and K contents (Table 4). These results can be attributed to the fact that all treatments received fertilization with these elements. Leaf

P content in treatments with CMB, regardless of the application of phosphate fertilizer, was higher than that in RHB (Table 4). The higher P content of bean plants in treatments with CMB was due to the greater availability of this nutrient in the soil, as discussed previously.

The highest Ca and Mg contents were observed in the liming treatments (Table 4). Regardless of liming, the highest Mg content was obtained with CMB. The leaf sulfur (S) content was not influenced by liming, and the highest values were obtained with CMB application (Table 3).

Table 4. Nitrogen (N) phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) content in the leaves of common bean plants, in control treatments, and in treatments with rice husk (RHB) and cattle manure biochar (CMB), without (NC) and with liming (WC), and without (NP) and with phosphate fertilizer (WP).

Treatments			N	P	K	Ca	Mg	S
			---------------------------			g kg^{-1}	------------------------------	
Control			32.6	2.8	31.4	19.7	1.5	1.1
RHB	NC	NP	32.4a	3.1b	32.6a	20.8a	2.1b*	1.6a*
		WP	34.6a	5.6a*	34.6a*	20.6a	2.8a*	1.7a*
		Mean	33.5A	4.4B	33.6A	20.7B	2.5B	1.7A
	WC	NP	35.7a	4.2b*	35.6a*	34.7a*	5.7a*	1.8a*
		WP	36.4a	6.9a*	35.9a*	35.8a*	6.1a*	1.8a*
		Mean	36.1A	5.6A	35.8A	35.3A	5.9A	1.8A
	Mean		34.8C	5.0D	34.7C	28.0C	4.2D	1.7D
CMB	NC	NP	42.4a*	7.8a*	40.3a*	25.6a*	3.6a*	2.3a*
		WP	41.2a*	6.9a*	40.8a*	26.7a*	4.3a*	2.4a*
		Mean	41.8A	7.4A	40.6A	26.2B	4.0B	2.4A
	WC	NP	37.5a	5.1b*	40.4a*	38.9a*	6.7a*	2.2a*
		WP	37.0a	6.7a*	40.2a*	37.5a*	7.2a*	2.1a*
		Mean	37.3A	5.9B	40.3A	38.2A	7.0A	2.2A
	Mean		39.5C	6.6C	40.4C	32.2C	5.5C	2.3C

Means with an asterisk (*) differ from the control treatment according to Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without phosphorus, and within treatments without and with liming by the F test. Capital letters "A" and "B" compare treatments without and with liming and capital letters "C" and "D" compare RHB and CMB.

Higher leaf contents of K, Ca, and Mg were observed by Farhangi-Abriz and Torabian (2018) in the common bean after the application of biochar. Likewise, Yao et al. (2019) found that biochar significantly contributed to the greater uptake of N, P, and K by bean plants (*Phaseolus calcaltus*). Increases in the leaf nutrient content of plants can be attributed to the contribution of biochar in the neutralization of toxic aluminum, increase in CEC, and, consequently, in nutrient retention and nutrient availability for plants.

In general, the addition of soil acidity correctives did not influence the contents of foliar micronutrients, except for Cu, whose content in the treatment with CMB and liming was lower than in the treatment without liming. Regardless of liming and phosphate fertilization, the highest levels of B were obtained with the application of CMB, whereas for Cu, Fe, Mn, and Zn, there was no effect of the biochar type (Table 5).

Biochars can immobilize metals in their negative surface electrical charges, thus reducing metal bioavailability. However, in the present study, despite having a higher CEC, CMB functioned as a source of micronutrients for common bean plants (Table 5). The bioavailability of cationic micronutrients and trace elements is influenced by biochars, as they are considered strong adsorbents of these elements due to their high aromaticity, specific surface area, and ability to raise soil pH. In this sense, biochars are widely used for the remediation of soils contaminated by heavy metals (He et al., 2019).

Because of the effects of CMB as a corrective for soil acidity and, mainly, as a source of phosphorus, in Experiment II, the doses of this biochar for common bean plants were evaluated. According to the regression equation, except for base saturation, soil attributes increased linearly with CMB dose (Table 6). These results can be explained by the effects of biochar on the correction of soil acidity factors and its role as a source of nutrients (Alves et al., 2021). Furthermore, as discussed previously, biochar can decrease the soil P fixation capacity. There was an increase in the remaining P value, which corroborated the available P results (Table 2). The remaining phosphorus method allows the estimation of the phosphorus fixation capacity by soil (Alvarez et al., 2000), from a single value (60 mg L^{-1} of P) from the P adsorption curve.

The significant increase in the contents of P available in the soil with the addition of biochar could be due to the following factors: biochar functioned as a source of P; there was an increase in soil pH, the presence of carboxylic groups reduced P fixation through precipitation and adsorption; with the addition of soluble silica, silicon competed with P for clay adsorption sites.

Table 5. Boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) content in the leaves of common bean plants, in control treatments, and in treatments with rice husk (RHB) and cattle manure biochar (CMB), without (NC) and with liming (WC) and without (NP) and with phosphate fertilizer (WP).

Treatments			B	Cu	Fe	Mn	Zn
						mg kg^{-1}	
Control							
RHB	NC	NP	80a	7.2a	322a	201a	37a
		WP	84a	7.3a	318a	204a	40a*
		Mean	82.0a	7.3a	320.0a	202.5a	38.5a
	WC	NP	93a	6.9a	332a	200a	43a*
		WP	88a	7.0a	325a	199a	45a*
		Mean	90.5a	7.0a	328.5a	199.5a	44.0a
	Mean		86.3B	7.1A	324.3A	201.0A	41.3A
CMB	NC	NP	125a*	7.2a	387a*	238a	44a*
		WP	130a*	6.5a	376a*	215a	51a*
		Mean	127.5a	6.9b	381.5a	226.5a	47.5a
	WC	NP	128a*	5.8a	354a	213a	46a*
		WP	128a*	5.6a	341a	209a	42a*
		Mean	128.0a	5.7a	347.5a	211.0a	44.0a
	Mean		127.8A	6.3A	364.5A	218.8A	45.8A

Means with an asterisk (*) differ from the control treatment according to Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without phosphorus, and within treatments without and with liming by the F test. Capital letters "A" and "B" compare treatments without and with liming and capital letters "C" and "D" compare RHB and CMB biochars.

Table 6. Equation fitted to soil pH, phosphorus (P), phosphorus remaining (P rem), potassium (K), calcium (Ca), magnesium (Mg), cation exchange capacity (CEC), base saturation (V), and total carbon (CT) as a function of manure biochar doses.

Characteristics	Equation	R²	Maximum value	% increase over zero dose
pH[1]	$y = 0.375^{**}x + 4.58$	099	7.58	65.50
P (mg dm^{-3})	$y = 17.037^{**}x + 1.136$	0.95	137.43	11997.89
P rem (mg L^{-1})	$y = 1.4985^{**}x + 37.702$	0.94	49.69	31.80
K (mmol$_c$ dm^{-3})	$y = 0.985^{**}x + 1.86$	0.88	9.74	423.66
Ca (mmol$_c$ dm^{-3})	$y = 2.225^{**}x + 4.46$	0.94	22.26	399.10
Mg (mmol$_c$ dm^{-3})	$y = 1.115^{**}x + 1,08$	0.99	10.00	825.93
CEC (mmol$_c$ dm^{-3})	$y = 3.285^{**}x + 19.00$	0.92	45.28	138.32
V (%)	$y = -1.5641^{**}x^2 + 20.342^{**}x + 25.809$	0.98	88.44	242.68
CT (g kg^{-1})	$y = 0.415^{**}x + 4.56$	0.95	7.88	72.81

**significant according to t-test ($p < 0.01$).

Bean grain dry matter production (MSGR) was fitted to a quadratic model as a function of biochar dose (Figure 2). According to this model, maximum grain production (6.42 g) occurred at a biochar dose of 5.46%. The increase in dry matter production with the application of CMB is certainly related to the effects of biochar which result in the improvement of chemical, physical, and biological properties of the soil. Biochar can also influence plant metabolism, changing the production of compounds related to plant growth (Viger, Hancock, Migletta, & Taylor, 2015) and the efficiency of nutrient acquisition (Di Lonardo et al., 2013).

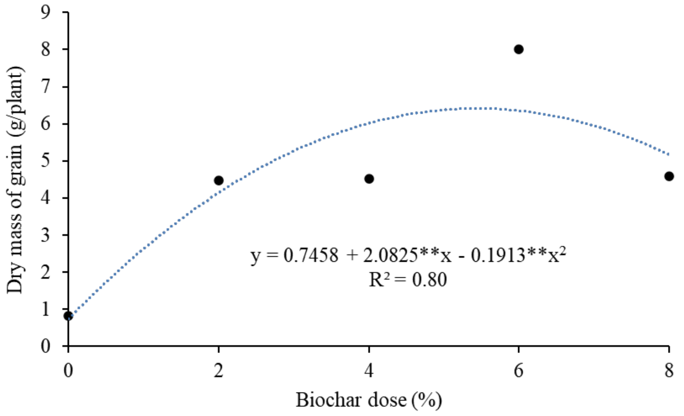

Figure 2. Equation fitted to grain dry mass of common bean plants as a function of cattle manure biochar doses. **significant according to t-test ($p < 0.01$).

Conclusion

Rice husk biochar, as a conditioner of soil chemical properties, had less pronounced effects than cattle manure biochar. Cattle manure biochar functioned as a corrective for soil acidity and a source of nutrients (mainly phosphorus). A dose corresponding to 5.46% of the soil volume led to the maximum grain production by common bean plants.

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