

Phosphorus availability in soil amended with biochar from rice rusk and cattle manure and cultivated with common bean

Disponibilidade de fósforo em solos adubados com biochar de casca de arroz e de esterco bovino e cultivado com feijoeiro

William Gleidson Alves Torres¹ , Fernando Colen¹ , Sugandha Dogra Pandey² ,
Leidivan Almeida Frazão¹ , Reginaldo Arruda Sampaio¹ , Luiz Arnaldo Fernandes^{1*} 

¹Universidade Federal de Minas Gerais/UFMG, Instituto de Ciências Agrárias, Montes Claros, MG, Brasil

²Universidade Federal de Minas Gerais/UFMG, Departamento de Química, Belo Horizonte, MG, Brasil

*Corresponding author: luizmcmg@gmail.com

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ABSTRACT

The soils of the Brazilian Savanna are generally acidic and have low availability of nutrients, so the use of alternative inputs to improve their fertility should be investigated. The objectives of this study were to evaluate the potential of biochars from rice husk (BHR) and from bovine manure (BCM) in increasing phosphorus availability and their effects on soil chemical properties and in common beans plants. The experiments were carried out in a completely randomized design, in a 4x2+3 factorial scheme with four replicates. The treatments were four biochar doses (1, 2, 3 and 4% m/v), two biochars (BRH and BCM) and three additional treatments (C1, no liming and no fertilization; C2, addition of Ca and Mg carbonate and NPK fertilizers and; C3, addition of Ca and Mg silicate and NK fertilizers). In the highest doses of BRH there was an increase of 2.7, 5.3 and 2.5 times in the P content extracted by Mehlich 1 and quantified by colorimetry, by Mehlich 1 and quantified by spectroscopy and by ion exchange resin and quantified by spectroscopy, respectively. For the highest doses of BCM, the increases in P content were 51.3, 289.2 and 88.4 times greater than in C1, respectively, according to the methods described for BRH. The biochars increased soil pH, CEC, nutrient content and the growth of bean plants compared to C1, especially BCM. However, the production of dry matter was significantly lower than that obtained in C2.

Index terms: Soil fertility; pyrolysis; *Phaseolus vulgaris* L.; silicon.

RESUMO

Os solos do Cerrado Brasileiro são geralmente ácidos e com baixa disponibilidade de nutrientes, portanto, o uso de insumos alternativos para melhorar fertilidade deve ser investigado. Os objetivos deste estudo foram avaliar o potencial dos biochars de casca de arroz (BHR) e de esterco bovino (BCM) no aumento da disponibilidade de fósforo e seus efeitos nas propriedades químicas do solo e nas plantas de feijoeiro. Os experimentos foram conduzidos em delineamento inteiramente casualizado, em esquema fatorial 4x2+3, com quatro repetições. Os tratamentos foram quatro doses de biochar (1, 2, 3 e 4% m/v), dois biochars (BRH e BCM) e três tratamentos adicionais (C1, sem calagem e sem fertilização; C2, adição de carbonato de Ca e Mg e Fertilizantes NPK e; C3, adição de silicato de Ca e Mg e fertilizantes NK). Nas maiores doses de BRH houve aumento de 2,7, 5,3 e 2,5 vezes no teor de P extraído por Mehlich 1 e quantificado por colorimetria, por Mehlich 1 e quantificado por espectroscopia e por resina de troca iônica e quantificado por espectroscopia, respectivamente. Para as doses mais altas de BCM, os aumentos no conteúdo de P foram 51,3, 289,2 e 88,4 vezes maiores que em C1, respectivamente, de acordo com os métodos descritos para o BRH. Os biochars aumentaram o pH do solo, a CEC, os teores nutrientes e o crescimento do feijoeiro em relação ao C1, especialmente o BCM. No entanto, a produção de matéria seca foi significativamente menor do que a no C2.

Termos para indexação: Fertilidade do solo; pirólise; *Phaseolus vulgaris* L.; silício.

INTRODUCTION

The use of biochar in agriculture is justified by the possibility of recycling large quantities of organic waste (Abdelhafez; Li; Abbas, 2014) and its potential of reducing contaminants associated with these residues (Ahmad et al., 2014; Waqas et al.,

2014; Gwenzi et al., 2015). Biochar is a term idealized from the knowledge of the Indian Black Earth found in the Amazon Region (Lehmann; Rondon, 2006), defined as a carbon-rich product obtained from the thermochemical transformation of biomass in a free environment or with a low concentration of oxygen (Kookana et al., 2011).

In the literature, there are several benefits of incorporating biochar into the soil and improving chemical, physical and biological properties (Chan et al., 2007; Uzoma et al., 2011; Albuquerque et al., 2014), remediation of organic and inorganic contaminants (Méndez et al., 2012; Albuquerque et al., 2014) and incorporation of more stable carbon forms into the soil (Kookana et al., 2011; Paz-Ferreiro et al., 2018).

Some authors have verified the increase in the availability of phosphorus in soils fertilized with biochar and these increase in phosphorus might be associated with the soluble silica present in the biochars ashes (Liu et al., 2014) and in raising the pH and cation exchange capacity of acidic soils with capacity for phosphorus fixation (Silva et al., 2017; Zelaya et al., 2019). This effect of biochars on the phosphorus availability is important especially in highly weathered and acidic soils where a strong interaction between phosphate anions (H_2PO_4^- and HPO_4^{2-}), iron and aluminum oxyhydroxides happens, decreasing phosphorus availability in the plants with time (Yuan; Xu, 2012; Abdala et al., 2015). Also, on more sandy soil of the Brazilian Cerrado, with less phosphorus fixation capacity than the more clayey ones, due to the low availability of this nutrient, there is a great concern about phosphate fertilization (Donagemma et al., 2016). According to Petter and Mandari (2012), the use of biochar as a soil conditioner in the Brazilian savannah is a promising future alternative to improve soil properties and crops production.

Thus, the effects of biochar on the availability of phosphorus in the soil are especially important because the natural sources of this nutrient are non-renewable, finite and must be exhausted in the next 50-100 years (Cordell; Drangert; White, 2009). Some authors have reported significant increases in the availability of phosphorus in soils fertilized with biochar (Silva et al., 2017; Zelaya et al., 2019), but the mechanisms that justify these increases are not clear enough.

In this study we hypothesized that biochars are (i) sources of phosphorus and soluble silicon,

that influences the availability of soil phosphorus, (ii) acts as a soil conditioner, improving its chemical properties and (iii) contributes to increasing the dry matter productivity of common bean plants. Thus, the objectives of this study were to evaluate the potential of biochars from bovine manure and from rice husk in increasing phosphorus availability and their effects on soil chemical properties and in common beans production, as indicator plant.

MATERIAL AND METHODS

The study was carried out in two stages, at the Institute of Agricultural Sciences (ICA) of the Federal University of Minas Gerais, Brazil. In the first stage, the treatments were incubated in the soil and in the second stage bean plants were grown. The experiments were carried out in pots, under greenhouse conditions in a completely randomized design, in a 4x2+3 factorial scheme (four doses of biochar, two types of biochar and three additional treatments) with four replicates (n=44), as outlined in Table 1.

The doses of each biochar were 1, 2, 3 and 4% mass of biochar / volume of soil (m/v), which corresponded to 17.86, 35.71, 53.57 and 71.43 $\text{cm}^3 \text{dm}^{-3}$ for the rice husk biochar and 18.52, 37.04, 55.56 and 74.04 $\text{cm}^3 \text{dm}^{-3}$ for the cattle manure biochar. The Additional treatments (controls) were: control 1, no liming and no fertilization; control 2, addition of calcium carbonate, magnesium carbonate and nitrogen, phosphorus and potassium mineral fertilizers and; control 3, addition of calcium and magnesium silicate and nitrogen and potassium mineral fertilizers. In the control treatment 2 (C2) were added calcium and magnesium carbonate (Ca:Mg 4:1 ratio), in order to increase the soil base saturation to 60% and 120 mg dm^{-3} of phosphorus in the form of ammonium phosphate. For the control treatment 3 (C3), calcium and magnesium silicate (34.9% CaO, 9.9% MgO and 22.4% soluble SiO_2) were used to increase soil base saturation to 60%.

Table 1: Scheme of treatments used in the experiments.

Biochars										
Biochar from cattle manure				Biochar from rice husk				Additional treatments*		
Doses (% m/v)				Doses (% m/v)						
1	2	3	4	1	2	3	4	C1	C2	C3

* C1 (no liming and no fertilization); C2 (addition of Ca and Mg carbonate, N, P and K); C3 (addition of Ca and Mg silicate and N and K).

The superficial layer of 0 to 20 cm of depth of an Oxisol, classified according to Brazilian Soil Classification System (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 2018), under Cerrado vegetation (Brazilian Savanna) was used. The physical and chemical soil properties, determined according to Teixeira et al. (2017), were: surface layer texture classified as Sandy Loam (sand = 780 g kg⁻¹; silt = 100 g kg⁻¹; clay = 120 g kg⁻¹; pH (H₂O) = 5.0; available phosphorus (resin method) = 1.8 mg dm⁻³; potassium = 17 mg dm⁻³; calcium = 0.25 cmolc dm⁻³; magnesium = 0.12 cmolc dm⁻³; aluminum = 0.42 cmolc dm⁻³; base saturation = 12.7%; cation exchange capacity pH 7.0 = 3.25 cmolc dm⁻³ and soil organic carbon = 10.6 g kg⁻¹. The remaining phosphorus, 28 mg L⁻¹, was determined according to Alvarez et al. (2000).

The cattle manure used as biochar feedstock was collected in a dairy cow feeding area. From fresh manure beads approximately 4 cm in diameter were produced and dried at 103±2 °C until complete dehydration. For the biochar production, the dried beads were packed in a steel box inside an industrial muffle oven. The temperature was elevated at a rate of approximately 5 °C/min until 450 °C (temperature was controlled by a thermocouple inserted in the center of the carbonized mass) with a residence time of 30 min. For the rice husk biochar production, the same procedures described for the dried cattle manure beads were adopted. Both biochar from cattle manure and from rice husk were mechanically ground and passed through a 0.25 mm mesh sieve for chemical characterization and application to the soil.

The Feedstocks were characterized as nutrients concentrations according to Tedesco et al. (1995). Rice husks (mean, n = 4): 3.1 g kg⁻¹ total N, 4.7 g kg⁻¹ P; 10.6 g kg⁻¹ Ca, 14.8 g kg⁻¹ Mg, 0,05 g kg⁻¹ S. Cattle manure (mean, n = 4): 17.4 g kg⁻¹ total N, 29.6 g kg⁻¹ P; 25.0 g kg⁻¹ Ca, 6.4 g kg⁻¹ Mg, 4.3 g kg⁻¹ S.

The two biochars were characterized as pH, density and electrical conductivity, according to Rajkovich et al. (2012). The ashes were determined according to the procedure described in ASTM D1762-84; the carbon and nitrogen total were determined by elemental analyzer and; the others nutrients and trace elements were determined by ICP-MS/MS after microwave digestion, according to USEPA 3051 method. The biochars characterization and amounts of nutrients and trace elements added to the soil by the respective biochars are shown in Table 2.

The soil and the respective treatments were conditioned in one-liter pots and incubated for 20 days with the humidity maintained close to the field capacity. After the incubation period the soil of each pot was homogenized and

a sample was taken for chemical analysis. Fertilization with 100 mg dm⁻³ of potassium and 36 mg dm⁻³ of nitrogen in the form of potassium nitrate was applied in all treatments except for C1. The soils were returned to the pots and four common bean seeds (*Phaseolus vulgaris* L.) were sown. Seven days after sowing, thinning occurred, leaving only two plants per pot, which were cultivated for 50 days, maintaining the soil humidity close to the field capacity.

During the growing season three cover fertilizations were performed at 13, 26 and 34 days of sowing, with 45 mg dm⁻³ of nitrogen in the form of urea, except for C1.

At the end of the experimental period the plants were harvested, separated in shoot and roots, washed with distilled water and packed in a paper bag. Then they were dried in a forced air circulation oven at 65-70 °C (±72 hours) until constant mass to obtain the dry matter production.

In the soil samples from each pot, collected after 20 days of incubation (first stage), the following analyzes were performed, according to Teixeira et al. (2017): total carbon by dry combustion method using an elemental analyzer; pH in water; phosphorus extracted by Mehlich 1 solution and quantified by colorimetry with ammonium molybdate, phosphorus extracted by Mehlich 1 solution and by ion exchange resin and quantified by spectrometry (inductively coupled plasma mass spectrometry - ICP-MS/MS); aluminum, calcium and magnesium exchangeable; cation exchange capacity; base saturation and; soluble silicon.

Data were submitted to analysis of variance and, when significant, biochars were compared by the F test (p <0.5) and each dose were compared individually with each control treatments by Dunnett's test (P <0.05). For the biochar doses, regression equations were adjusted. Statistical analysis was performed using the software R.

RESULTS AND DISCUSSION

The biochars from cattle manure (BCM) and from rice husk (BRH) increased total soil carbon (TSC) when compared to treatments C1 (no liming and no fertilization), C2 (with application of calcium carbonate and of magnesium, N, P and K) and C3 (with application of calcium and magnesium silicate, N and K), except at the 1% BRH dose that was similar to the control treatments (Table 3). The BRH and BCM doses increased linearly the total soil carbon and there were no differences between the biochars for this variable (Table 3). Increases in total soil carbon were predictable, since biochars are sources of this element (Table 1). In addition, biochars incorporate more stable forms of carbon into the soil in order to increase their stocks over time (Gwenzi et al., 2016).

Table 2: Characterization of biochar from rice husk (BRH) and biochar from cattle manure (BCM), amounts of BRH and BCM, nutrients and trace elements added to the soil by the respective biochars. Mean (n = 4).

Attribute	Biochar characterization		Biochar and nutrient and trace elements added to the soil								
	BRH	BCM	BRH doses (% m/v)				BCM doses (%m/v)				
			1	2	3	4	1	2	3	4	
pH	7.3	9.8	-	-	-	-	-	-	-	-	-
Elec. Conduc. (mS cm ⁻¹)	178	411	-	-	-	-	-	-	-	-	-
Density (g dm ⁻³)	0.56	0.54	-	-	-	-	-	-	-	-	-
Ashes (%)	24.5	36.2	-	-	-	-	-	-	-	-	-
Volatile comp. (%)	65.4	43.5	-	-	-	-	-	-	-	-	-
Fix carbon (%)	6.2	12.7	-	-	-	-	-	-	-	-	-
Biochar (g dm ⁻³)	-	-	10	20	30	40	10	20	30	40	
Total C (g dm ⁻³)	91.84	167.9	1.64	3.28	4.92	6.56	3.11	6.22	9.33	12.44	
Total N (g dm ⁻³)	1.96	6.43	0.04	0.07	0.10	0.14	0.12	0.24	0.36	0.48	
P (g dm ⁻³)	14.17	32.67	0.25	0.51	0.76	1.01	0.61	1.21	1.82	2.42	
K (g dm ⁻³)	1.90	5.40	0.03	0.07	0.10	0.14	0.10	0.20	0.30	0.40	
Ca (g dm ⁻³)	12.10	19.33	0.22	0.43	0.65	0.86	0.36	0.72	1.07	1.43	
Mg (g dm ⁻³)	18.14	23.22	0.32	0.65	0.97	1.30	0.43	0.86	1.29	1.72	
Na (g dm ⁻³)	<0.01	1.08	<0.01	<0.01	<0.01	<0.01	0.02	0.04	0.06	0.08	
S (g dm ⁻³)	0.32	0.70	0.01	0.01	0.02	0.02	0.01	0.03	0.04	0.05	
Fe (mg dm ⁻³)	7.22	375.3	0.13	0.26	0.39	0.52	6.9	13.9	20.8	27.8	
Zn (mg dm ⁻³)	21.50	100.4	0.38	0.77	1.15	1.54	1.86	3.72	5.58	7.44	
Mn (mg dm ⁻³)	44.91	82.08	0.80	1.60	2.41	3.21	1.52	3.04	4.56	6.08	
Cu (mg dm ⁻³)	9.63	15.28	0.17	0.34	0.52	0.69	0.28	0.57	0.85	1.13	
B (mg dm ⁻³)	2.24	6.64	0.04	0.08	0.12	0.16	0.12	0.25	0.37	0.49	
Ni (mg dm ⁻³)	21.28	0.30	0.38	0.76	1.14	1.52	0.01	0.01	0.02	0.02	
Cd (mg dm ⁻³)	0.15	0.33	<0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	
Pb (mg dm ⁻³)	0.16	0.42	<0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	

For the soil pH it was verified that the addition of biochar decreased the soil acidity as compared to the treatment C1, except for doses 1 and 2% of BRH (Table 3). The 3% and 4% BRH doses had similar effects to that of silicate (C3) and that of carbonates (C2), respectively. The BCM, regardless of the dose, increased the soil pH to values higher than the carbonates (C2) and the silicate (C3). The soil pH increased linearly with biochar doses, and the BCM was more effective in correcting the soil acidity than the BRH (Table 3). These results indicate that, although there are differences between the biochars, they have acted as corrective of soil acidity.

The effects of biochars on increasing soil pH are related to the ash produced during the pyrolysis process (Steenari; Karlsson, Lindqvist, 1999; Glaser; Lehmann;

Zech, 2002; Silva et al., 2017). Ashes are rich in bases, such as potassium carbonate (KHCO₃) and calcium carbonate (CaCO₃), which act as soil acidity correctives and raise the exchangeable base contents (Domingues et al., 2017).

The biochars reduced the soil exchangeable aluminum, but there was no effect of the doses. The BCM completely neutralized the exchangeable aluminum, possibly due to its higher ash content (Table 3). On the other hand, the BRH, although it reduced the exchangeable aluminum in relation to the treatment C1, had less effect than the treatment C2 and C3 as a corrective of the soil acidity. The reduction of more toxic forms of aluminum by biochars is related to the conversion of Al⁺³ to Al(OH)²⁺, Al(OH)₂⁺ and Al(OH)₃ by precipitation reactions with

pH increase and by adsorption reactions of $\text{Al}(\text{OH})_2^+$ and $\text{Al}(\text{OH})_2^+$ monomers on the carboxyl groups present in the biochars (Qian; Chen; Hu, 2013; Tang et al., 2013).

The soil phosphorus availability extracted by the Mehlich 1 solution and determined by colorimetry (P Mehl. C) and by ICP-MS/MS (P Mehl E) and extracted by ion exchange resin and determined by ICP-MS/MS (P Res.), in the treatments that received BRH, regardless of dose, were higher than those obtained in C1 and C3, where this nutrient was not added (Table 3). On the other hand, the soil phosphorus availability in the BRH treatments was lower than in the C2 that received 120 mg dm^{-3} of this element as ammonium phosphate. Despite the small increase, soil P availability increased linearly with BRH doses (Table 3). For the treatments with BCM, except for the 1% biochar dose, soil P availability (Mehl. C, P Mehl. E and P Res.) was higher than in treatments C1, C2 and C3 (Table 3).

Different methodologies of phosphorus determination were used in this study since both the extractor and the high concentrations of silica

present in the biochar could influence the phosphorus quantification. The Mehlich 1 extract is influenced by the phosphorus-fixation soil capacity and can extract forms of phosphorus not available, linked to calcium, when compared to ion exchange resin. For phosphorus quantification, colorimetry and spectrometry were used. In the colorimetric method, both phosphorus and silicon react with the molybdate, which results in the formation of the phosphorus-molybdate and the silica-molybdic complex, respectively, which absorb the same wavelength (Caballero et al., 2017). Thus, the presence of silicate from biochar can underestimate the availability of phosphorus in the soil. To eliminate the interference of phosphorus and other elements in the determination of silicon, organic acids, such as tartaric and oxalic acids, are generally added (Nolla et al., 2010). In the phosphorus analysis, ascorbic acid is used as a reducing agent for the phosphate reaction with molybdate in an acid medium (Santos; Silva; Griebeler, 2014).

Table 3: Regression equations adjusted for total carbon (TC), pH in water, exchangeable aluminum, available phosphorus extracted by the Mehlich 1 solution and determined by colorimetry (P Mehl C) and by plasma spectroscopy (P Mehl E) and extracted by ion exchange resin and determined by plasma spectroscopy (P Res) and silica soluble (Si) in the soil after biochar application.

Attribute	C1	C2	C3	Biochar from rice husk					Biochar from cattle manure				
				1	2	3	4	Mean	1	2	3	4	Mean
TC g kg^{-1}	10.32a	10.62b	10.12c	10.20abc	11.91	14.22	17.90	13.57A	11.12	15.11	15.12	17.60	14.74A
				$y = 7.21 + 2.542^{**}x$ $R^2 = 0.97$					$y = 9.99 + 2.021^{**}x$ $R^2 = 0.90$				
pH - water	4.90a	5.50b	5.21c	5.00a	5.05a	5.25c	5.55b	5.21B	5.80	6.41	7.03	7.51	6.69A
				$y = 4.75 + 0.185^{**}x$ $R^2 = 0.92$					$y = 5.25 + 0.575^{**}x$ $R^2 = 0.99$				
Al cmolc dm^{-3}	0.47a	0.01b	0.07c	0.22	0.30	0.22	0.20	0.24A	0.00	0.00	0.00	0.00	0.00B
				$y = 0.24$					$y = 0.0$				
P Mehl. C mg dm^{-3}	0.69a	14.31b	0.53c	0.89	1.10	1.33	1.87	1.30B	10.59	21.11	156.25	177.5	91.36A
				$y = 0.51 + 0.317^{**}x$ $R^2 = 0.94$					$y = -67.61 + 63.587^{**}x$ $R^2 = 0.87$				
P Mehl. E mg dm^{-3}	0.33	20.92	0.36	0.73	0.92	1.41	1.75	1.20B	15.75	30.52	67.6	98.42	53.07A
				$y = 0.32 + 0.355^{**}x$ $R^2 = 0.98$					$y = -18.2 + 28.509^{**}x$ $R^2 = 0.98$				
P Res. E mg dm^{-3}	1.60	26.01	3.00	2.4	2.6	3.2	4.1	3.08B	12.08	27.40a	81.44	142.23	65.79A
				$y = 1.65 + 0.57^{**}x$ $R^2 = 0.93$					$y = -45.34 + 44.449^{**}x$ $R^2 = 0.96$				
Si mg dm^{-3}	1.08	1.02	1.74c	1.42	1.58	1.74c	2.00	1.69A	1.03	1.50	2.13	3.16	1.96A
				$y = 1.21 + 0.19^{**}x$ $R^2 = 0.98$					$y = 0.20 + 0.702^{**}x$ $R^2 = 0.97$				

C1 (no liming and no fertilization); C2 (addition of Ca and Mg carbonate, N, P and K); C3 (addition of Ca and Mg silicate and N and K).

Lowercase letters in the row compare each control treatments with each of the doses of biochar. No lower case letters indicate significant differences between the control treatments and the doses of biochar. Means followed by the same letter do not differ by Dunnett test ($P < 0.05$). The mean doses of biochar followed by the same capital letter in the line do not differ from each other by the F test ($P < 0.05$).

According to the results of the soil analysis of the C1 and C3 treatment, it was verified that the silicon added as calcium and magnesium silicate did not interfere in the determination of the phosphorus available by the different methods used in this study, since there were no differences between the treatments and between colorimetric and spectrophotometric methods (Table 4). Thus, biochars increased significantly the soil phosphorus availability. In addition to the fact that biochars are sources of phosphorus, increasing the pH in order to reduce the phosphorus fixations reactions and the silicon competition by the clay adsorption sites (Carvalho et al., 2001) may explain the high availability of this nutrient in C3 treatment, which received silicate application and, in the treatments with BCM, which has higher ash and silicon contents (Table 3). According to the remaining phosphorus values (28 mg L^{-1}) under natural conditions, the soil has median phosphorus fixation capacity. The remaining phosphorus is a faster and simpler method to estimate the phosphorus fixation capacity, adapted by Alvarez et al. (2000) from the technique known as single-value sorption (Rogeri et al., 2017).

Other authors also verified an increase in the availability of phosphorus using biochar as a soil amendment due to the addition of this nutrient by the biochar itself, increasing the soil pH and the organic matter, which decreases P-fixation reactions (Yuan; Xu, 2012; Abdala et al., 2015; Silva et al., 2017).

In relation to the soluble silicon, it was verified that the addition of silicate (C3 treatment) increased the availability of this element in the soil, when compared to the treatments C1 and C2 (Table 3). The biochars also increased the availability of soluble silicon in the soil higher than the C3 treatments. For the two biochars there was a linear increase in the availability of soluble silicon with the doses and there were no differences between them. Rice husk and cattle manure have silicon in their compositions, since grasses are plants that accumulate this element in their tissue. Thus, biochars are considered sources of slow release of silicon to the soil (Wang; Xiao; Chen, 2018).

In addition to the effects on phosphorus availability, silicon can react with exchangeable forms of aluminum, reducing the effects of soil acidity on plants (Qian; Chen, 2014). The silicon can also react with the carbon of the biochar itself and increase its stability in the soil (Wang; Xiao; Chen, 2018).

For the exchangeable potassium, higher values were obtained in the treatments with biochars in relation to C2 and C3 treatments (Table 4), where this nutrient was

added via mineral fertilizers. For both BRH and BCM, there was a linear increase in potassium with biochars doses. For exchangeable calcium and magnesium, the values obtained in the BRH treatments were lower than those observed in C2 and C3 treatments, which received application of these nutrients via soil acidity correctives (Table 4). On the other hand, in the BCM treatments, the calcium and magnesium values were higher than the C2 and C3 treatments. A linear increase of calcium was observed with the BRH and BCM doses and linear increase of magnesium with the BCM doses. Thus, the BCM provided to the soil greater amounts of exchangeable bases (K, Ca and Mg) than BRH (Table 4).

Certainly, due to the reduction of soil acidity and the increase in the exchangeable bases, there was a linear increase in the cation exchange capacity (CEC) and bases saturation (V) with the biochar application (Table 4). However, the values of CEC and V in BRH treatments were higher than those obtained in C2 and C3 treatments only in the dose of 4%. On the other hand, for BCM, already in the first dose (1%) CEC and V were higher than C2 and C3 treatments (Table 4).

The biochars reduced the soil exchangeable aluminum, but there was no effect of the doses. The BCM completely neutralized the exchangeable aluminum, possibly due to its higher ash content (Table 3). On the other hand, the BRH, although it reduced the exchangeable aluminum in relation to the treatment C1, had less effect than the treatment C2 and C3 as a corrective of the soil acidity.

For shoot (SDM) and roots dry mass (RDM), larger yields were observed in C2 and C3 treatments (Table 5). However, in the biochars treatments the SDM and RDM were higher than in the C1 treatment (no liming and no fertilization). Although the plants did not present visual symptoms of phosphorus deficiency and the soil availability in the treatments with BCM were high, a possible explanation was that plant productivity was limited by phosphorus and other possible effects of soil acidity correctives, since the treatments with biochar did not receive application of these inputs. As observed for phosphorus, no other visual symptoms of nutritional deficiency or toxicity were found in common bean plants.

According to Santos et al. (2019), although the associations of biochars with soluble phosphate fertilizers increases the soil phosphorus availability, does not always provide greater use efficiency of this nutrient by the plants, which implies, according to the authors, that other strategies should be adopted in order to increase the uptake and utilization of phosphorus by crops on soil amendment with biochars.

Table 4: Regression equations adjusted for potassium (K), calcium (Ca), magnesium (Mg), cation exchange capacity (CEC) and bases saturation (V) in the soil after biochar application.

Attribute	C1	C2	C3	Biochar from rice husk					Biochar from cattle manure				
				1	2	3	4	Mean	1	2	3	4	Mean
K mg dm ⁻³	15.00a	48.01b	73.51c	115	129	148	156	137B	244	348	446	514	388A
				y = 101.5+14.2**x R ² = 0.98					y = 161+90.8**x R ² = 0.99				
Ca cmolc dm ⁻³	0.27a	1.20b	0.98c	0.26a	0.24a	0.31a	0.34	0.29B	1.06c	1.57	1.66	1.75	1.51A
				y = 0.21+0.031**x R ² = 0.77					y = 0.97+0.22**x R ² = 0.82				
Mg cmolc dm ⁻³	0.15a	0.41b	0.39c	0.18a	0.15a	0.17a	0.16a	0.17B	0.29c	0.61	0.92	1.32	0.79A
				y = 0.17					y = -0.07+0.34**x R ² = 0.99				
CEC cmolc dm ⁻³	3.40a	3.46b	3.59c	3.22	3.35a	3.56bc	3.72	3.49B	3.85	4.46	4.71	5.16	4.55A
				y = 3.04+0.161**x R ² = 0.96					y = 3.50+0.418**x R ² = 0.98				
V %	16a	50b	41c	21	20	26	28	23.75B	51b	69	79	85	71A
				y = 17.0+2.71**x R ² = 0.82					y = 43+11.2**x R ² = 0.94				

C1 (no liming and no fertilization); C2 (addition of Ca and Mg carbonate, N, P and K); C3 (addition of Ca and Mg silicate and N and K). Lowercase letters in the row compare each control treatments with each of the doses of biochar. No lower case letters indicate significant differences between the control treatments and the doses of biochar. Means followed by the same letter do not differ by Dunnett test (P <0.05). The mean doses of biochar followed by the same capital letter in the line do not differ from each other by the F test (P <0.05).

Table 5: Regression equations adjusted for shoot (SDM) and root (RDM) dry matter after biochar application and relationship between shoot and root dry matter (SDM / RDM).

Attribute	C1	C2	C3	Biochar from rice husk					Biochar from cattle manure				
				1	2	3	4	Mean	1	2	3	4	Mean
SDM g/ plant	0.42a	3.13b	2.37c	0.53a	0.57	0.76	1.04	0.73B	0.94	1.13	1.30	2.01	1.35A
				y = 0.38+0.282**x R ² = 0.71					y = 0.51+0.338**x R ² = 0.88				
RDM g/plant	0.47a	2.80b	1.91c	0.82	0.86	0.92	1.74	1.09B	1.01	1.35	1.45	2.06	1.47A
				y = 0.295+0.172**x R ² = 0.91					y = 0.66+0.325**x R ² = 0.93				
SDM / RDM	0.89	1.11	1.24	0.63	0.66	0.83	0.60	0.67	0.93	0.84	0.90	0.98	0.92

C1 (no liming and no fertilization); C2 (addition of Ca and Mg carbonate, N, P and K); C3 (addition of Ca and Mg silicate and N and K). Lowercase letters in the row compare each control treatments with each of the doses of biochar. No lower case letters indicate significant differences between the control treatments and the doses of biochar. Means followed by the same letter do not differ by Dunnett test (P <0.05). The mean doses of biochar followed by the same capital letter in the line do not differ from each other by the F test (P <0.05).

Although higher dry mass productions of common bean plants were observed in C2 and C3 treatments, a lower SDM / RDM relationship was observed in the biochars treatments (Table 4). In general, higher root yield has been observed in soils that received biochar application, especially of fine roots (Silva et al., 2017; Zelaya et al., 2019). These results are may be related to changes in plant metabolism (Haider et al., 2015, Virger et al., 2015) and morphology (Razaq et al., 2017), improvement of microorganism-plant relationships (Spokas; Baker; Reicosky; 2010, Song et al., 2016) and in soil physical

properties by biochars (Amendola et al., 2017; Silva et al., 2017), which can favor the greater growth of the plant root system.

Figure 1 summarizes the effects of biochar application on soil properties and on the production of common bean plants. The relative values were obtained in relation to the reference treatment, Control (100%), which received application of soil acidity correctives and fertilization with N, P and K. For the treatments with biochars, the highest dose was considered (4%). The BRH and BCM biochars significantly increased the contents of total carbon and silicon in relation to the Control 2

treatment (Figure 1) and were efficient in neutralizing soil acidity. However, BRH increased the pH of the soil by 1.36 times in relation to Control 2. In relation to phosphorus, the levels of this element in the soil were 5.47 times in BCM in relation to Control 2, which received phosphate fertilization (Figure 1A).

Biochars increased the values of exchangeable calcium and potassium bases, while BCM also increased the value of exchangeable magnesium in the soil (Figure 1B). Due to the increase in exchangeable bases, the highest

CEC values were obtained in biochar treatments. However, BCM increased potassium by 10.71 times and CEC by 1.5 times compared to Control 2 (Figure 1B).

Although biochars have contributed to the increase in pH and availability of phosphorus, potassium, calcium and magnesium in the soil, the production of common bean plants was lower in biochar treatments. However, it is important to note that the biochars contribute significantly to the growth of plant roots (Figure 1C).

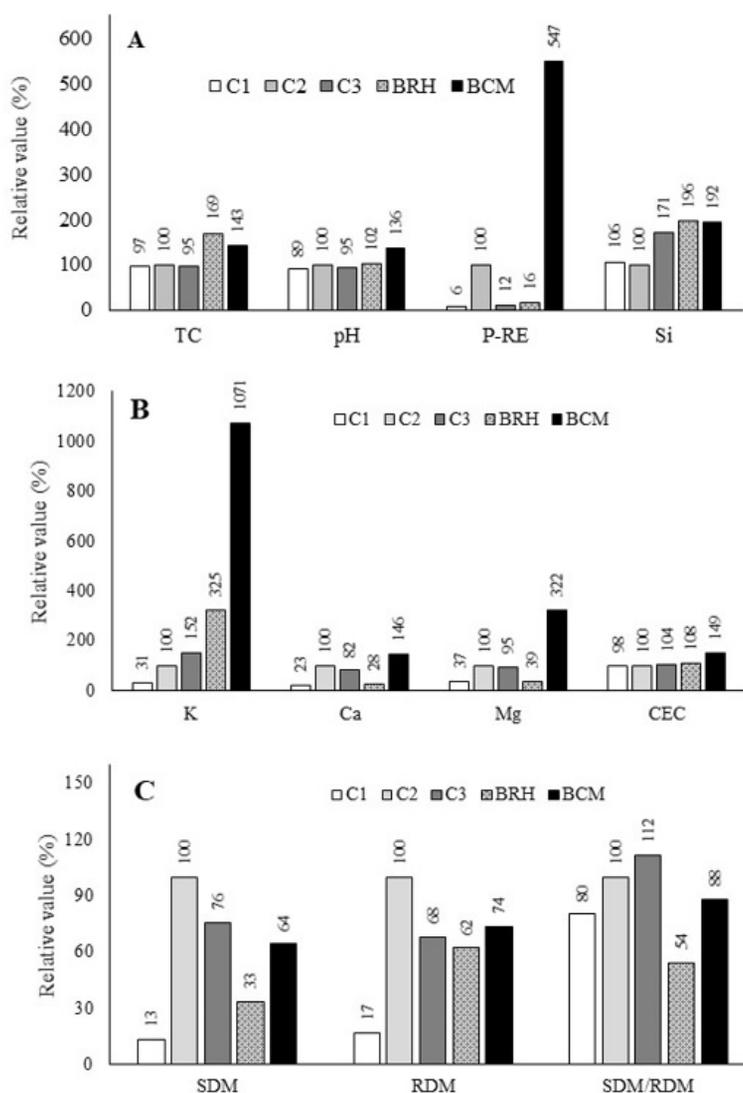


Figure 1: Relative values, calculated from the reference treatment, Control 2 (100%), for the variables total carbon (TC), pH, phosphorus extracted by ion exchange resin and determined by colorimetry (P-RE), soluble silicon (Si), potassium (K), calcium (Ca), magnesium (Mg), cation exchange capacity (CEC), shoot (SDM) and root (RDM) dry matter and relationship between shoot and root dry matter (SDM / RDM) of common bean plants.

CONCLUSIONS

The biochars corrected soil acidity, increased cations exchange capacity of soil, carbon and nutrients especially at the higher doses of biochar from cattle manure. The soluble silica present in the biochar contributed to increase the soil phosphorus availability and did not interfere in the available phosphorus determination method. The common bean production increased in soil amended with biochars, but was lower than that obtained in conventional treatment, where soil acidity correctives and mineral fertilizer were added.

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