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SOIL SCIENCE

Biochar from *Caryocar brasiliense* as a soil conditioner for common bean plants

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ABSTRACT: *In recent years there has been a growing interest in the use of organic waste in agriculture. In this way, was aimed with this study to evaluate the biochar from pequi shell (Caryocar brasiliense Cambess) on the soil chemical properties and on the production and nutrition of common bean plants. The experiment was carried out in pots with soil (4 dm³ ~ 5,44 kg), in a completely randomized experimental design, 4 x 3 + 2 factorial scheme, with four replications. The treatments were four doses of biochar (0.0, 2.5, 5.0, 7.5 and 10.0 % v/v), three different particle size (G1, <0.5 mm; G2, 0.5-1,0 mm and G3, 1.0-2.0 mm) and two control treatments, one without and another with addition of soil corrective acidity. The biochar from pequi shell acted as a corrective of soil acidity and as a source of potassium for the plants. However, in higher doses of biochar there was a decrease in bean plants production due to nutritional imbalances.*

Key words: *biocarbon, organic fertilization, organic waste, waste recycling.*

Biochar de casca de *Caryocar brasiliense* como condicionador do solo para o feijoeiro

RESUMO: *Nos últimos anos, tem aumentado o interesse crescente pelo uso de resíduos orgânicos na agricultura. Dessa forma, objetivou-se com este estudo avaliar o biochar e a casca do pequi (Caryocar brasiliense Cambess) nas propriedades químicas do solo e na produção e nutrição de plantas de feijoeiro. O experimento foi realizado em vasos com solo (4 dm³ ~ 5,44 kg), em delineamento experimental inteiramente casualizado, em esquema fatorial 4 x 3 + 2, com quatro repetições. Os tratamentos foram quatro doses de biochar (0,0, 2,5, 5,0, 7,5 e 10,0 % v/v), três tamanhos de partículas diferentes (G1, <0,5 mm; G2, 0,5-1,0 mm e G3, 1,0-2,0 mm) e dois tratamentos controle, um sem e outro com adição de corretivo da acidez do solo. O biochar de casca do pequi atuou como corretivo da acidez do solo e como fonte de potássio para as plantas. Entretanto, em doses mais elevadas de biochar, houve uma diminuição na produção das plantas de feijão devido aos desequilíbrios nutricionais.*

Palavras-chave: *biocarvão, adubação orgânica, resíduo orgânico, reciclagem de resíduos.*

INTRODUCTION

Agriculture and plant extractivism produce large quantities and diversities of organic waste that can be used by the agricultural activity itself, in order to reduce the pressure on natural resources and to promote the adequate disposal of these materials. In the Brazilian Savanna biome the collection of pequi fruits (*Caryocar brasiliense* Cambess) is very common and generates a considerable income for the families of traditional small farmers, being much used in the regional cooking. Approximately 70% of the average weight of the fruit is composed by shell, which after the withdrawal of the seeds, commercial part, is discarded in the environment without any disposal criteria.

Some destinations for pequi shell, such as feed use, have already been tested. However, no positive results were obtained (SILVA et al., 2016). Other uses found in the literature are the adsorbent use of dyes and in biorefineries (RAMBO et al., 2015). Another important alternative for the disposal of pequi shells in the environment would be pyrolysis with subsequent incorporation into the soil. The technology of pyrolysis for waste management has as main byproduct the biochar, which improves the physical, chemical and biological soil properties (LEHMANN et al., 2006; ALBUQUERQUE et al., 2014). In addition, pyrolysis acts positively in the treatment and reuse of waste generated in several activities, contributing to solve problems of waste and its environmentally correct disposal (ABDELHAFEZ et al., 2014).

The advantage of using biochar in waste management is the final reduction of waste volume and the incorporation of more stable forms of carbon

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in the soil (GWENZI et al., 2016; SHENG et al., 2016). Blocking the natural route of the carbon cycle by biochar provides environmental benefits and contributes to the development of a circular economy (HU et al., 2021).

The objective of this study was to evaluate the biochar produced from pequi shells on soil chemical properties and on the production and nutrition of common bean plants (*Phaseolus vulgaris* L.).

MATERIALS AND METHODS

The biochar was produced from the external mesocarp and the epicarp of pequi fruits (*Caryocar brasiliense* Cambess), denominated by shells. The shells were dried to determine the nutrient content (MALAVOLTA et al., 1997) and for the production of biochar (Table 1). The pyrolysis was carried out in a muffle furnace at 450 °C of temperature, in the absence of oxygen. The temperature was elevated at a rate of approximately 5 °C/min and the residence time was 30 min, followed by quenching in distilled water, at 20 °C. Biochar was characterized (Table 1) as pH, density and electrical conductivity, according to RAJKOVICH et al. (2011); ashes according to ASTM methodology D1762-84 (ASTM, 2007); carbon and nitrogen, according to the USEPA 3051 method (USEPA, 1996).

The biochar was crushed and sieved in three different particle size, according to Brazilian Norms that specify the technical requirements and the corresponding test methods for the metal sieves (ABNT, 2010): <0.5 mm (G1); 0.5-1.0 mm (G2); 1.0 - 2.0 mm (G3).

For the growing of the common bean plants, 4 dm^{-3} pots were filled with the surface layer of a Oxisol with the following attributes, determined according to TEIXEIRA et al. (2017).: pH in water, 4.1; P Mehlich 1, 0.23 mg dm^{-3}; K, 20 mg kg^{-3}; Ca, 3.6 mmol$_c$ dm^{-3}; Mg, 1.4 mmol$_c$ dm^{-3}; Al, 7.0 mmol$_c$ dm^{-3}; CTC, 40 mmol$_c$ dm^{-3}; organic carbon, 47 g kg^{-3}; Mn, 0.9 mg kg^{-3}; Zn, 0.8 mg kg^{-3}; Cu, 0.14 mg kg^{-3}; sand, 780 g kg^{-1}; silt, 100 g kg^{-1}; clay, 120 g kg^{-1}.

The experimental design was completely randomized, 4x3+2 factorial scheme, with four

Table 1 - Characterization of shell and biochar from pequi shell (BCP) and doses of biochar.

Characteristic	Shell	BCP	Characteristic	Shell	BCP
Moisture %	11.94	4.55	Cu (mg kg^{-1})	4	90
pH	-	8.65	Mn (mg kg^{-1})	16	150
C (g kg^{-1})	-	590.93	Fe (mg kg^{-1})	97	170
N (g kg^{-1})	5.8	10.2	B (mg kg^{-1})	17	700
C/N	-	59/1	Zn (mg kg^{-1})	9	260
P (g kg^{-1})	0.3	0.01	Electric cond. (dS cm^{-1})	-	0.94
K (g kg^{-1})	7.7	10.39	Density G1 (kg dm^{-3})	-	0.38
Mg (g kg^{-1})	0.1	0.01	Density G2 (kg dm^{-3})	-	0.20
Ca (g kg^{-1})	0.1	0.01	Density G3 (kg dm^{-3})	-	0.16
S (g kg^{-1})	0.3	0.05	Ashes (%)	-	5.19
Particle size*	--------------------------------------Doses of biochar (% v/v)--------------------------------------				
G1, G2 and G3	2.5	5.0	7.5	10	
---Doses of biochar (dm^3 per pot)---					
G1, G2 and G3	0,1	0,2	0,3	0,4	
---Doses of biochar (g per pot)--					
G1	38	76	114	152	
G2	20	40	60	80	
G3	16	32	48	64	

*particles size: G1; <0.5 mm; G2, 0.5-1.0 mm; G3, 1.0 - 2.0 mm. **pot = 4 dm^3.

replications. The treatments were four doses of biochar (0.0, 2.5, 5.0, 7.5 and 10.0% v/v), three different particle size (G1, G2 and G3) and two control treatments, one without C1) and another with limestone addition (C2). The quantities of biochar in each treatment, in dm^3 per pot and in grams per pot are shown in table 1.

In the C2 treatment was applied limestone (20% CaO and 13% MgO) to raise the soil exchangeable base saturation to 60%. In all treatments 300 mg dm^{-3} of phosphorus was applied as single superphosphate. The quantity of soil acidity corrective applied in treatment C2 was 1.72 g dm^{-3} of soil (6.84 g per pot).

In each experimental unit (pot) two bean plants were cultivated. During the experimental period the soil humidity was maintained close to the field capacity and three cover fertilizations were performed at 12, 22 and 32 days after sowing. At each cover fertilization, 40 mg dm^{-3} of N was applied as urea. In the first and third cover fertilization, 30 mg dm^{-3} of K was applied as potassium chloride.

On 75 days after sowing, the plants were harvested, separated in shoot and roots, washed with distilled water and dried in an oven with forced circulation of air at 65 ºC until constant mass. The shoot was analyzed for nutrient content, according to MALAVOLTA et al. (1997). The soil of each pot was homogenized and a sample was taken for chemical analysis, according to TEIXEIRA et al. (2017).

The data were submitted to analysis of variance and when significant, the different particle sizes were compared by the Scott Knott test ($P < 0.5$). For the biochar doses, regression equations were adjusted and each dose was individually compared with the C1 and C2 treatments by the Dunnett's test ($P < 0.5$).

RESULTS AND DISCUSSION

There was an effect of the interaction between treatments ($P < 0.05$) on total carbon, active acidity (pH), exchangeable acidity (Al), cation exchange capacity (CEC) and base saturation (V) (Table 2). The addition of biochar from pequi shell, regardless of particle size, increased the total soil carbon in relation to the controls treatments C1 (without biochar and without limestone) and C2 (without biochar and with limestone) (Table 2). With the increase of the biochar doses there was a linear increase of total soil carbon and, there were no differences between the biochar particle size for this variable (Table 2).

Biochars, in addition to increasing the content, incorporate more stable aromatic forms of carbon to the degradation by the soil microorganisms, so as to increase the stock in the soil and to reduce the emissions of this element in gaseous forms (GWENZI et al., 2016; SHENG et al., 2016).

The increase of soil pH by biochar in relation to the treatment C1, suggest that biochar acting as a corrective of the soil acidity (Table 2). In relation to the treatment C2, the dose of 5 and 7.5% of biochar with G1 granulometry (less than 0.5 mm) had the same effect of the limestone and, at the dose 10% was superior. Biochar particles size G2 (0.5-1.0 mm) and G3 (1.0-2.0 mm), from the 7.5% dose, had similar effects to the limestone applied in C2 on the soil pH (Table 2). However, according to the quantity of biochar applied per pot at a dose corresponding to 5% v/v (Table 1), it would be necessary to incorporate 76 Mg ha^{-1} of biochar (granulometry less than 0.5 mm), in the layer 0 – 20 cm deep. Despite the positive effects as a soil acidity corrective, a source of nutrients for plants and incorporation of more stable forms of carbon in the soil, the amounts of biochar to be applied are relatively high, which can make agricultural use unfeasible (MAROUSEK,. et al., 2017).

The results of this study corroborate with those obtained by other authors (CHEN et al., 2017) and indicate that the lower the particle size the greater the reactivity of the biochar particles and the greater the rate of release of adsorbed exchangeable bases (NOYCE et al., 2016).

In treatments where higher pH values were obtained, lower levels of exchangeable aluminum were observed (Table 2). With increasing doses of biochar, regardless of particle size, exchangeable aluminum decreased linearly (Table 2). However, in G1 particle size the reduction in exchangeable aluminum was higher than in the other treatments. On the other hand, very small particles, smaller than 100μ, can cause some kind of risk to human health due to inhalation of dust (GELARDI et al., 2019).

The reduction of exchangeable aluminum with biochar application is probably related to the precipitation reactions at higher pH (Table 2). At higher soil pH Al^{3+} is converted to less toxic forms (Al(OH)$^{2+}$, Al (OH)$_2^+$ and Al (OH)$_3$) (QIAN et al., 2013). Some authors report the effects of biochar on exchangeable acidity. In this case, the Al(OH)$^{2+}$ and Al(OH)$_2^+$ can be adsorbed on the functional groups (carboxylic, hydroxy, etc.) present in the biochar particles, thus reducing their toxic effects on plants (QIAN et al., 2013; TANG et al 2013). However, in

Table 2 - Total carbon (TSC), pH, exchangeable aluminum, total cation exchange capacity (CEC) and exchangeable bases saturation (V) of the soil in control treatments C1 and C2, and doses of biochar from pequi schell with different particles sizes.

	------Control------		Size	-----------------------------Doses of biochar (% v/v)-----------------------------				
	C1	C2		2.5	5.0	7.5	10	Mean
Total Carbon g kg^{-1}	5.71 A	6.10 B	G1	9.62	12.64	17.15	20.53	14.98a
					$y = 0.56+0.14923^{**}x$		R^2=0.99	
			G2	9.81	10.86	14.74	19.74	13.79a
					$y = 0.53+0.134^{**}x$		R^2=0.93	
			G3	9.04	9.91	17.92	19.32	14.05a
					$y = 0.43+0.155^{**}x$		R^2=0.89	
pH	4.1 A	5.00 B	G1	4.57	4.90B	5.30B	5.72	5.12a
					$y = 4.16+0.154^{**}x$		R^2=0.99	
			G2	4.40	4.75	4.77B	5.02B	4.74b
					$y = 4.26+0.0760^{**}x$		R^2=0.91	
			G3	4.45	4.77	4.75	4.90B	4.72b
					$y = 4.39+0.0530^{**}x$		R^2=0.80	
Al $cmol_c$ dm^{-3}	0.6 A	0.16 B	G1	0.38	0.19B	0.09	0.01	0.17b
					$y = 0.54-0.0588^{**}x$		R^2=0.96	
			G2	0.41	0.310	0.26	0.18 B	0.29a
					$y = 0.59-0.0546^{**}x$		R^2=0.95	
			G3	0.42	0.29	0.27	0.21B	0.25a
					$y = 0.59-0.0544^{**}x$		R^2=0.94	
CEC $cmol_c$ dm^{-3}	4.14 A	4.24 B	G1	4.12AB	3.93AB	4.30AB	4.22AB	4.14a
					y = 4.14		-	
			G2	4.47AB	3.65AB	3.73AB	3.72AB	3.89a
					y = 3.89		-	
			G3	4.14AB	4.00AB	4.18AB	4.01AB	4.08a
					y = 4.08		-	
V %	23.08 A	52.2 B	G1	29.5A	40.50	46.54B	58.75B	43.81a
					$y = 20.38+3.75^{**}x$		R^2=0.90	
			G2	28.75A	37.75	38.75	46.25B	37.86a
					$y = 24.50+2.14^{**}x$		R^2=0.98	
			G3	29.75A	39.01	40.45	43.75B	38.25a
					$y = 27.375+1.74^{**}x$		R^2=0.87	

Capital letters A and B in the line compare the treatments C1 and C2, respectively, with each of the doses of biochar by the Dunnett test ($P < 0.05$). Absence of capital letters A and B means that the doses of biochar differ from treatments C1 and C2, respectively. Means followed by the same lowercase letter in the column do not differ from each other by the Scott Knott test ($P < 0.05$). C1 = no application of limestone and biochar; C2 = with application of limestone and without biochar; G1 = particle size <0.5 mm; G2 = particle size between 0.5 - 1.0 mm; G3 = particle size between 1.0 - 2.0 mm.

this study, no increase in soil CEC was observed with the application of biochar (Table 2).

Soil CEC values in treatments with biochar application, regardless of dose and particle size, did not differ from treatments C1 and C2 (Table 2). Under natural conditions, the increase of CEC in biochar fertilized soils is related to the slow and progressive oxidation of the oxygenated functional groups (hydroxyl, carbonyl and carboxyl) present on the surface of the aromatic rings (NGUYEN et al., 2017). Fresh biochars are not always able to reproduce the effects of Amazonian Black Earth on CEC soil unless they are treated with aggressive agents (ozone, hydrogen peroxide, strong acids, etc.) (MIA et al., 2017) or activated by injection of dry air during the pyrolysis process (SULIMAN et al., 2016), for example.

On the other hand, soil exchangeable bases saturation (V), regardless of particle size, increased with the application of biochar, being at doses 10% similar to the value found in treatment C2 (Table 2), due to the increase of soil K, Ca and Mg (Table 3). In this study, soil CEC was estimated by the sum of exchangeable bases (Ca^{+2}, Mg^{+2} and K^{+}) and potential acidity (H^{+} and Al^{3+}). According to this concept, CEC is defined as the amount of cations adsorbed at pH 7.0, that is, at pH 7 the acidity components will be neutralized and the charges made available will be occupied by the exchangeable bases. Soil base saturation (V) was estimated by the relationship between the sum of exchangeable bases and CEC, in percentage. In both biochar and liming treatments, there was total or partial neutralization of the components of soil acidity (H^{+} and Al^{3+}) and the addition of exchangeable bases. On the other hand, there was no addition of extra negative electrical charges by the biochar (functional groups carboxylic, hydroxy, etc.), which explains the increase in the values of soil base saturation in the treatments with biochar and limestone (Table 2).

There was an effect of the interaction between treatments ($P < 0.05$) on soil nutrient availability (Table 3). Soil potassium contents in the biochar treatments were higher than in the treatments C1 and C2 and increased linearly with the doses, being the highest values obtained in G1 particle size (Table 3). This higher availability of potassium in the smaller particles is related to the quantities applied, since in this study volume and non-mass were used, and the lower the particle size, the higher the density (Table 1). In addition, the lower the particle size, the greater the contact surface with the soil (CHEN et al., 2017), which may have favored the release of potassium from the biochar. In this context, we highlight, based on the results of this study, the importance of particle size and density of biochar for the definition of doses to be applied. For example, at doses of 2.5% v/v, the amounts of biochar applied were 76, 40 and 32 g per pot for the C1, G2 and G3 particle sizes, respectively (Table 1).

On the other hand, soil Ca and Mg were higher than in the C1 treatments and lower in the C2 treatment. For these nutrients, only in the G1 particle size the contents of Ca and Mg increased linearly with the doses of biochar. For G2 and G3 treatments there were no differences between doses (Table 2). These results are attributed to the ashes of the biochars, which are rich in bases, such as potassium ($KHCO_3$) and calcium carbonates ($CaCO_3$), which act as soil acidity correctives and increase the exchangeable base contents (DOMINGUES et al., 2017). Again, we highlight the importance of particle size in biochar dose recommendations. Due to the different densities, the amounts of biochar applied in the G1 treatment, in grams per pot, was 2.4 times greater than in the G3 treatment (Table 1), justifying the higher values of nutrients and ashes in the G1 treatment (Table 3).

The available soil phosphorus in the treatments with biochar application were higher than those obtained in the treatments C1 and C2 (Table 3). With the increase of the biochar doses, there was a linear increase in the availability of phosphorus, regardless of the particles sizes (Table 3).

The increase in soil pH and the functional groups of the biochar may have contributed to the lower soil phosphorus fixation (SILVA et al., 2017; ZELAYA et al., 2019). Some studies also report that the silica present in the biochars ashes block the phosphate adsorption sites of the clays and also contribute to the desorption of the fixed phosphorus (WANG et al., 2018).

For micronutrients, Mn, Cu and Zn, in general way, there was no difference between treatments (Table 3). Although they are sources of micronutrients for plants, depending on the feedstock, biochars are used in the remediation of soils contaminated by trace elements (ZHANG et al., 2013). In this case, the cationic micronutrients are immobilized by the functional groups of biochars and by precipitation reactions, due to the increased of soil pH, and a reduction in the availability of these elements to plants is expected (BEESLEY et al., 2011).

There was an effect of the interaction between treatments ($P < 0.05$) on common bean dry mass (Figure 1) and on nutrient contents in the shoot of the common bean plants (Table 4). For the common bean, smaller dry mass of roots (DMR) and shoot (DMS) were obtained in treatment C1, while the larger ones were obtained in treatment C2 and in the lower doses of biochar (Figure 1). With the increase of biochar doses, regardless of particle size, there was a linear reduction in the production of DMR.

Table 3 - Potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), manganese (Mn), copper (Cu) and zinc (Zn) in soil fertilized with doses of biochar from pequi in different particles sizes.

	-------------Control-----------		Size	-------------------------Doses of biochar (% v/v)--------------------------				
	C1	C2		2.5	5.0	7.5	10	Mean
K mg dm^{-3}	20.0 A	32.75 B	G1	93.50	182.50	261.25	344.67	220.48a
				$y = 12.42+33.29^{**}x$			$R^2=0.99$	
			G2	63.50	108.33	154.25	215.50	135.40b
				$y = 9.91+ 20.07^{**}x$			$R^2=0.99$	
			G3	61.00	109.25	128.53	206.25	126.26b
				$y = 12.5+18.2^{**}x$			$R^2=0.94$	
Ca cmolc dm^{-3}	0.71 A	1.17 B	G1	0.74A	0.80A	1.00B	1.00B	0.885a
				$y = 0.64+0.0392^{**}x$			$R^2=0.87$	
			G2	0.74A	0.81A	0.84A	0.86A	0.814c
				$y = 0.81$			-.	
			G3	0.76A	0.84A	0.85A	0.95B	0.852b
				$y = 0.85$			-	
Mg cmolc dm^{-3}	0.18 A	0.95 B	G1	0.23A	0.30	0.33	0.60	0.36a
				$y= 0.08+0.0459^{**}x$			$R^2=0.82$	
			G2	0.29	0.25A	0.30	0.30	0.28b
				$y = 0.29$			-	
			G3	0.24A	0.23A	0.25A	0.23A	0.20c
				$y = 0.24$			-	
P mg dm^{-3}	0.71 A	1.17 B	G1	10.75	10.24	14.11	19.03	13.54a
				$y = 2.97+1.602^{**}x$			$R^2=0.88$	
			G2	11.67	12.80	17.74	19.07	15.32a
				$y = 3.84+1.7116^{**}x$			$R^2=0.86$	
			G3	11.78	12.78	14.09	16.55	13.80a
				$y = 4.38+1.3596^{**}x$			$R^2=0.78$	
Mn mg dm^{-3}	0.80 A	1.22 B	G1	0.97AB	0.93AB	1.11AB	1.04AB	1.01a
				$y = 1.01$			-	
			G2	0.95AB	1.05AB	0.90AB	0.98AB	0.97a
				$y = 0.97$			-	
			G3	0.93AB	0.84AB	0.98AB	0.92AB	0.92a
				$y = 0.92$			-	
Cu mg dm^{-3}	0.15 A	0.17 B	G1	0.14AB	0.15AB	0.16AB	0.16AB	0.15a
				$y = 0.15$			-	
			G2	0.16AB	0.16AB	0.16AB	0.16AB	0.16a
				$y = 0.16$			-	
			G3	0.17AB	0.17AB	0.17AB	0.16AB	0.17a
				$y = 0.17$			-	
Zn mg dm^{-3}	0.28 A	0.37 B	G1	0.29AB	0.26AB	0.24AB	0.64AB	0.36a
				$y= 0.36$			-	
			G2	0.34AB	0.39AB	0.34AB	0.34AB	0.35a
				$y= 0.35$			-	
			G3	0.27AB	0.26AB	0.21AB	0.4 AB	0.26b
				$y = 0.29$			-	

Capital letters A and B in the line compare the treatments C1 and C2, respectively, with each of the doses of biochar by the Dunnett test ($P < 0.05$). Absence of capital letters A and B means that the doses of biochar differ from treatments C1 and C2, respectively. Means followed by the same lowercase letter in the column do not differ from each other by the Scott Knott test ($P < 0.05$). C1 = no application of limestone and biochar; C2 = with application of limestone and without biochar; G1 = particle size <0.5 mm; G2 = particle size between 0.5 - 1.0 mm; G3 = particle size between 1.0 - 2.0 mm.

Table 4 - Nutrient contents in the shoot of the bean in the control treatments C1 and C2, and doses of biochar from pequi with different particle size.

	--------Control---------		Size	---------------------------------Biochar doses (% v/v)---------------------------------				
	C1	C2		2.5	5.0	7.5	10	Mean
N g kg^{-1}	13.26A	14.88B	G1	13.14AB	11.61 A	11.088	10.833	11.67a
				$y = 13.529 - 0.2977^{**}x$			$R^2 = 0.87$	
			G2	17.57	13.19AB	12.64AB	10.88	13.57a
				$y = 18.723 - 0.8241^{**}x$			$R^2 = 0.88$	
			G3	14.54AB	11.82A	11.98A	12.08AB	12.61a
				$y = 12.61$			-	
P g kg^{-1}	2.06A	1.98B	G1	2.32AB	2.47	2.54	2.28AB	2.40a
				$y = 2.40$			-	
			G2	2.35AB	2.28AB	2.47	2.59	2.43a
				$y = 2.43$			-	
			G3	2.25AB	2.35AB	2.32AB	2.48	2.36a
				$y = 2.36$			-	
K g kg^{-1}	8.78A	10.02B	G1	41.05	43.62	66.43	81.52	58.16a
				$y = 22.10 + 5.7687^{**}x$			$R^2 = 0.93$	
			G2	36.04	37.79	47.86	53.74	43.86a
				$y = 28.07 + 2.5265^{**}x$			$R^2 = 0.94$	
			G3	31.01	38.84	44.65	51.29	41.45a
				$y = 24.79 + 2.6666^{**}x$			$R^2 = 0.99$	
Ca g kg^{-1}	21.87A	30.31B	G1	11.47	8.47	6.89	6.00	8.21b
				$y = 12.70 - 0.7196^{**}x$			$R^2 = 0.94$	
			G2	12.82	9.47	9.29	9.42	10.25a
				$y = 12.845 - 0.4152^{**}x$			$R^2 = 0.71$	
			G3	15.03	11.64	11.37	9.88	11.28a
				$y = 15.91 - 0.6288^{**}x$			$R^2 = 0.91$	
Mg g kg^{-1}	1.64A	3.62B	G1	1.16	0.99	0.78	0.7	0.91a
				$y = 1.305 - 0.0636^{**}x$			$R^2 = 0.97$	
			G2	1.21	1.065	0.95	0.93	1.04a
				$y = 1.2775 - 0.0382^{**}x$			$R^2 = 0.92$	
			G3	1.207	1.07	0.97	0.845	1.02a
				$y = 1.3195 - 0.0474^{**}x$			$R^2 = 0.99$	
Zn mg kg^{-1}	29.93A	21.43B	G1	34.36A	36.63A	33.11A	33.01A	34.02a
				$y = 34.02$			-	
			G2	29.56	30.78A	30.99A	33.08A	31.10a
				$y = 31.10$			-	
			G3	31.44A	31.61A	32.07A	33.45A	32.14a
				$y = 32.14$			-	
Cu mg kg^{-1}	12.09A	12.44B	G1	12.43AB	12.98AB	13.79AB	14.53Ab	13.43a
				$y = 13.43$			-	
			G2	12.67AB	12.63AB	12.91AB	13.13 AB	12.84a
				$y = 12.84$			-	
			G3	12.46AB	12.63AB	12.98AB	13.31AB	12.83a
				$y = 12.83$			-	
Mn mg kg^{-1}	327.21A	124.98B	G1	193.47	107.15B	77.55	69.26	111.86b
				$y = 212.42 - 16.089^{**}x$			$R^2 = 0.85$	
			G2	233.2	146.12B	143.5B	121.4B	161.06a
				$y = 245.55 - 13.52^{**}x$			$R^2 = 0.81$	
			G3	199.57	198.35	182.31	175.66	188.97a
				$y = 210.92 - 3.5108^{**}x$			$R^2 = 0.93$	

Capital letters A and B in the line compare the treatments C1 and C2, respectively, with each of the doses of biochar by the Dunnett test ($P < 0.05$). Absence of capital letters A and B means that the doses of biochar differ from treatments C1 and C2, respectively. Means followed by the same lowercase letter in the column do not differ from each other by the Scott Knott test ($P < 0.05$). C1 = no application of limestone and biochar; C2 = with application of limestone and without biochar; G1 = particle size <0.5 mm; G2 = particle size between 0.5 - 1.0 mm; G3 = particle size between 1.0 - 2.0 mm.

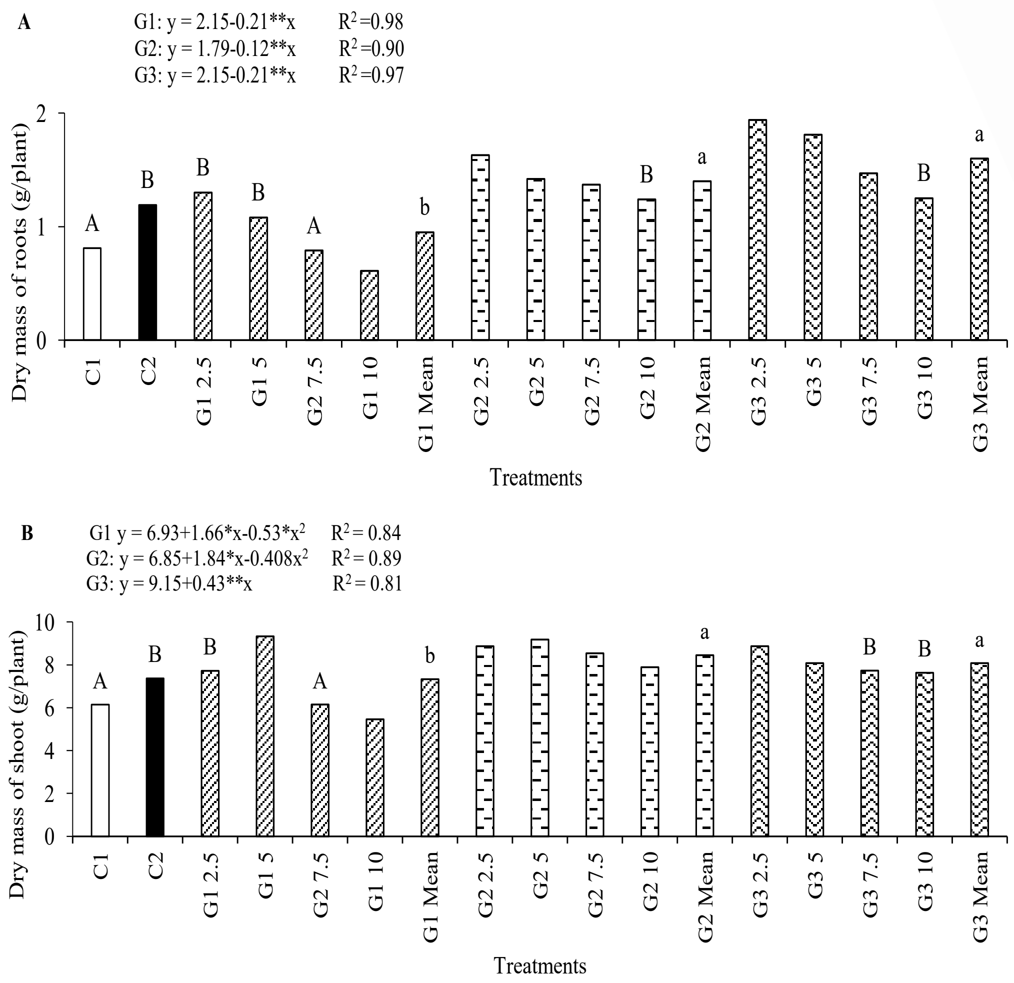

Figure 1 - Production of dry mass of roots (A) and shoot (B) by bean plants in the control treatments C1 and C2, and doses of biochar from pequi with different particle size.

Capital letters A and B in the line compare the treatments C1 and C2, respectively, with each of the doses of biochar by the Dunnett test ($P < 0.05$). Absence of capital letters A and B means that the doses of biochar differ from treatments C1 and C2, respectively. Means followed by the same lowercase letter in the column do not differ from each other by the Scott Knott test ($P < 0.05$). C1 = no application of limestone and biochar; C2 = with application of limestone and without biochar; G1 = particle size <0.5 mm; G2 = particle size between 0.5 - 1.0 mm; G3 = particle size between 1.0 - 2.0 mm.

The reduction of dry mass production of bean plants with biochar doses, especially in G1 treatment, may be associated to the increase of potassium contents in the soil (Table 3). High levels of this element may have caused nutritional imbalances, mainly of calcium and magnesium. In this context, it was observed that the potassium contents in the tissues of the aerial part of the plants were larger than in the C1 and C2 controls and increased linearly with the increase of the biochar doses (Table 4). On the other hand, the calcium and magnesium contents in the plants, regardless of particle size, decreased with biochar doses and were lower than in C1 and C2 treatments.

The imbalance of the calcium, magnesium and potassium relationship in the soil compromises plant nutrition, since the excess of one of these elements inhibits the absorption of the others by the plants (RHODES et al., 2018).

Another possibility for the reduction of dry mass production by the bean plants with increasing doses of biochar is the possible presence of phytotoxic organic compounds produced during pyrolysis, which may impair seed germination and plant growth (HAGNER et al., 2016).

Similar to calcium and magnesium, the levels of nitrogen and manganese in the plant also decreased with increasing doses of biochar, regardless of particle size. For the nitrogen, in general there were no differences between the levels obtained in the biochar treatments and those obtained in the C1 and C2 controls.

The high C / N relationship (59/1) of biochar from pequi (Table 1) may have contributed to the immobilization of the available nitrogen in soil microbial biomass (HAGNER et al., 2016; NGUYEN et al., 2017). For the manganese the content observed in the treatment C1 was superior to the other treatments, possibly due to the lower pH of the soil, being this element in forms more available to the plants.

For phosphorus, zinc and copper there was no effect of the doses and granulometry on the contents of these elements in common bean plants (Table 4). Low or no increases in nutrient content, especially micronutrients, in plants by biochar may be related to the low ash content (Table 1). In general, the richer the ashes, the greater the availability of nutrients to the plants (ALBUQUERQUE et al., 2014).

The low or zero increases in nutrient contents, except potassium, in common bean plants (Table 4) are in agreement with the availability of these elements in the soil (Table 3). In this sense, biochar from pequi could be an alternative for mixing with other potassium-poor residues and to incorporate carbon into the soil.

The results obtained confirm the effects of the biochar on the soil carbon, on the factors of soil acidity and on the plants nutrients availability (the pequi shell biochar has shown to be a source of potassium to be considered). As highlighted, the smaller the particle size, for the same volume, the greater the amount of biochar to be applied, en masse, which can enable the use of biochar in agriculture. On the other hand, small particles can hinder the application and cause respiratory problems for the applicators. In this context, research with biochar pellets and enriched with nutrients, such as organomineral fertilizers, is suggested.

CONCLUSION

The biochar from pequi shell corrected the soil acidity and increased the soil exchangeable base contents, mainly of potassium, in the particles smaller than 0.5 mm. Higher doses of biochar, regardless of particle size, decreased dry matter yield and nutrient content in common bean plants, with the exception of potassium.

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DECLARATION OF CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest in relation to the publication of this article.

AUTHORS' CONTRIBUTIONS

All authors had equal participation in conducting the research, analyzing the data and writing the scientific article.

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