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Biochar pellets as soil conditioner on the growth of Urochloa brizantha BRS Paiaguás[1]

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ABSTRACT - The use of biochar in agriculture remains controversial due to the amounts applied and the small size of the particles which can cause respiratory problems when inhaled. With the aim of evaluating the effects of cattle manure biochar (CMB) on the chemical attributes of the soil and on plant growth and nutrition, a greenhouse experiment was conducted, with *Urochloa brizantha* 'BRS Paiaguás' grown in pots over five crop cycles, in weathered soil (Oxisol). CMB pellets, both enriched and not enriched with potassium phosphate (PK), were produced using cassava starch as the binder, in a ratio of 2:2:1 (biochar: PK fertiliser: binder) and 4:1 (biochar: binder), respectively. The CMB was produced at a pyrolysis temperature of 450 °C. The experimental design was completely randomised in a 2 x 2 x 2 + 1 factorial scheme, with five replications. The treatments were non-pelletised and pelletised CMB, with and without liming, and with and without PK, and an additional treatment with no fertiliser. The CMB improved the chemical properties of the soil, correcting acidity, increasing nutrient availability and improving the production of *Urochloa brizantha* 'BRS Paiaguás'. The use of CMB enriched with phosphorus and potassium behaved as a slow-release organomineral fertiliser in *Urochloa brizantha* 'BRS Paiaguás'.

Key words: Organomineral. Slow-release fertiliser. Use of waste. Pyrolysis.

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INTRODUCTION

Mineral fertilisers are widely used to achieve high productivity, which in the long term promotes the depletion of natural resources, and imbalances in the environment (PATHY; RAY; PARAMASIVAN, 2020). In this respect, biochar offers a sustainable alternative for reducing pressure on natural resources, and for safely disposing of organic waste in the environment.

The term biochar, inspired by the so-called ‘Terra Preta de Índio’ in the Amazon region, refers to a solid material, rich in carbon, obtained through the thermochemical transformation of biomass with little or no oxidising agent, a process known as pyrolysis (ALMEIDA *et al*., 2022; BRTNICKY *et al*., 2021). During pyrolysis, the lignocellulosic material aromatises and the functional groups that contain oxygen are reduced, affording the carbon greater stability (HE *et al*., 2021). Unlike charcoal, biochar is applied to the soil, with the aim of conditioning the soil environment to increase the carbon stock, the cation and water retention capacity, and the availability of nutrients (AGBEDE; OYEWUMI, 2022; BISTA *et al*., 2019).

The use of biochar is justified by the possibility of recycling large amounts of organic waste, reducing the risk of pollution associated with disposing of these materials in the environment (BISTA *et al*., 2019). In addition, unlike incorporating organic waste into the soil, biochar increases carbon storage in the soil as the material has a high concentration of stable carbon, which reduces the emission of polluting gases into the atmosphere (GWENZI *et al*., 2016).

However during application, biochar is lost through drift because of the small size of the low-density particles, which may result in the poisoning of those carrying out the application due to inhaling any toxic compounds in the biochar dust (LI; BAIR; PARIKH, 2018).

In an attempt to get around the limitations of using high doses and reduce the effects of the dust, one alternative is to produce biochar pellets enriched with nutrients, similar to organomineral fertilisers. In this respect, the first hypothesis is that, even in small quantities, biochar enriched with nutrients acts as a soil conditioner. The second hypothesis is that pelletisation eliminates or reduces the emission of dust, and affords gradual release of the nutrients. The aim of this study, therefore, was to evaluate the effects of applying cattle manure biochar on the chemical properties of the soil and on the growth of *Urochloa brizantha* ‘BRS Paiaguás’.

MATERIAL AND METHODS

The experiment was conducted in two phases. The first phase involved developing a protocol for the production of biochar pellets, while the second phase included the cultivation of *U. brizantha ‘BRS Paiaguás’*.

The biochar used in the experiment came from cattle manure (CMB) collected in an area reserved for feeding dairy cows at the Institute of Agricultural Sciences (ICA) of the Federal University of Minas Gerais (UFMG), Brazil. From this raw material, spheres measuring approximately 4 cm in diameter were prepared manually and then dried at 103 ± 2 °C for 48 h to constant weight to ensure they were completely dehydrated.

To produce the biochar, the dried spheres were placed in a hermetically sealed steel container in an industrial muffle furnace and subjected to slow pyrolysis (ALMEIDA *et al*., 2022). The pyrolysis reactor was adjusted to a heating rate of 5 °C min^{-1}, until reaching 450 °C, remaining at that temperature for 30 min, which is the residence time for the biomass to produce the CMB. The biochar was cooled to room temperature inside the muffle furnace and then crushed and sieved through a 0.25 mm mesh.

The biochar was characterised (Table 1) as per the method described by Rajkovich *et al*. (2012): the total C and total N content were determined by dry combustion at 950 °C using an elemental analyser, and the other nutrients by inductively coupled plasma mass spectrometry (ICP-MS) following digestion in a microwave oven at 175 ± 5 °C for 4.5 to 10 min.

Table 1 - Characterisation of the cattle manure biochar

Caracteristic	Value
pH	9.8
Electrical conductivity (µScm^{-1})	411
Ash (%)	36.2
Total Carbon (g kg^{-1})	167.9
Total Nitrogen (g kg^{-1})	6.43
P (g kg^{-1})	32.67
K (g kg^{-1})	5.40
Ca (g kg^{-1})	19.33
Mg (g kg^{-1})	23.22
Na (g kg^{-1})	1.08
S (g kg^{-1})	0.70
Fe (mg kg^{-1})	375.3
Zn (mg kg^{-1})	100.4
Mn (mg kg^{-1})	82.08
Cu (mg kg^{-1})	15.28
B (mg kg^{-1})	6.64

During the first phase, CMB was used together with potassium phosphate mineral fertiliser, KH_2PO_4 (PK). Cassava starch was used as the binding component to promote consistency of the granules. From earlier tests, the proportions determined for the production of pelletised organomineral fertiliser was 40% fertiliser, 40% biochar and 20% binder. For the treatments with pelletised biochar with no added fertiliser, the proportion was 80% biochar to 20% binder.

The fertiliser was ground and mixed with biochar and cassava starch. Distilled water was then added to the mixture, which was homogenised in a mortar to a paste-like consistency. The mixture was transferred to a polyethylene mould containing holes 5.0 mm in diameter and 5.0 mm in height. The mould filled with the mixture was placed in an oven to dry at 65 °C for 30 min (SANTOS *et al*., 2019; TORRES *et al*., 2020).

For the second phase, was conducted in a greenhouse, with *Urochloa brisantha* 'BRS Paiaguás' in pots of 1.5 dm^3. The soil used in the experiment was collected in the 0 to 20 cm layer of an Oxisol from an area of native Cerrado.

The physical and chemical properties of the soil were characterised as per Teixeira *et al*. (2017): sand = 780 g kg^{-1}, silt = 100 g kg^{-1}, clay = 120 g kg^{-1}, pH in water = 5.6, available phosphorus (Mehlich 1) = 1.3 mg kg^{-1}, remaining phosphorus = 37.3 mg L^{-1}, potassium (Mehlich 1) = 11.4 mg kg^{-1}, calcium = 1.07 $cmol_c$ dm^{-3}, magnesium = 0.44 $cmol_c$ dm^{-3}, aluminum = 0.05 cmolc dm^{-3}, hydrogen = 0.98 $cmol_c$ dm^{-3}, base saturation (V) = 58.49%, cation exchange capacity at pH 7.0 (T) = 3.32 $cmol_c$ dm^{-3}, and soil organic carbon (SOC) = 0.49 dag kg^{-1}.

The treatments were arranged in a 2 x 2 x 2 + 1 factorial scheme, with five replications (n = 45), in a completely randomised design, comprising non-pelletised and pelletised biochar, with and without a soil acidity corrector, and with and without the addition of mineral fertiliser (PK), and an additional treatment of natural soil (Figure 1).

Figure 1 - Representation of the experimental treatments. (A) natural soil; (B) non-pelletised biochar, with no liming or fertiliser; (C) non-pelletised biochar, with no liming and with fertiliser; (D) non-pelletised biochar, with liming and with no fertiliser; (E) non-pelletised biochar, with liming and fertiliser; (F) pelletised biochar, with no liming or fertiliser; (G) pelletised biochar, with no liming and with fertiliser; (H) pelletised biochar, with liming and with no fertiliser; (I) pelletised biochar, with liming and fertiliser

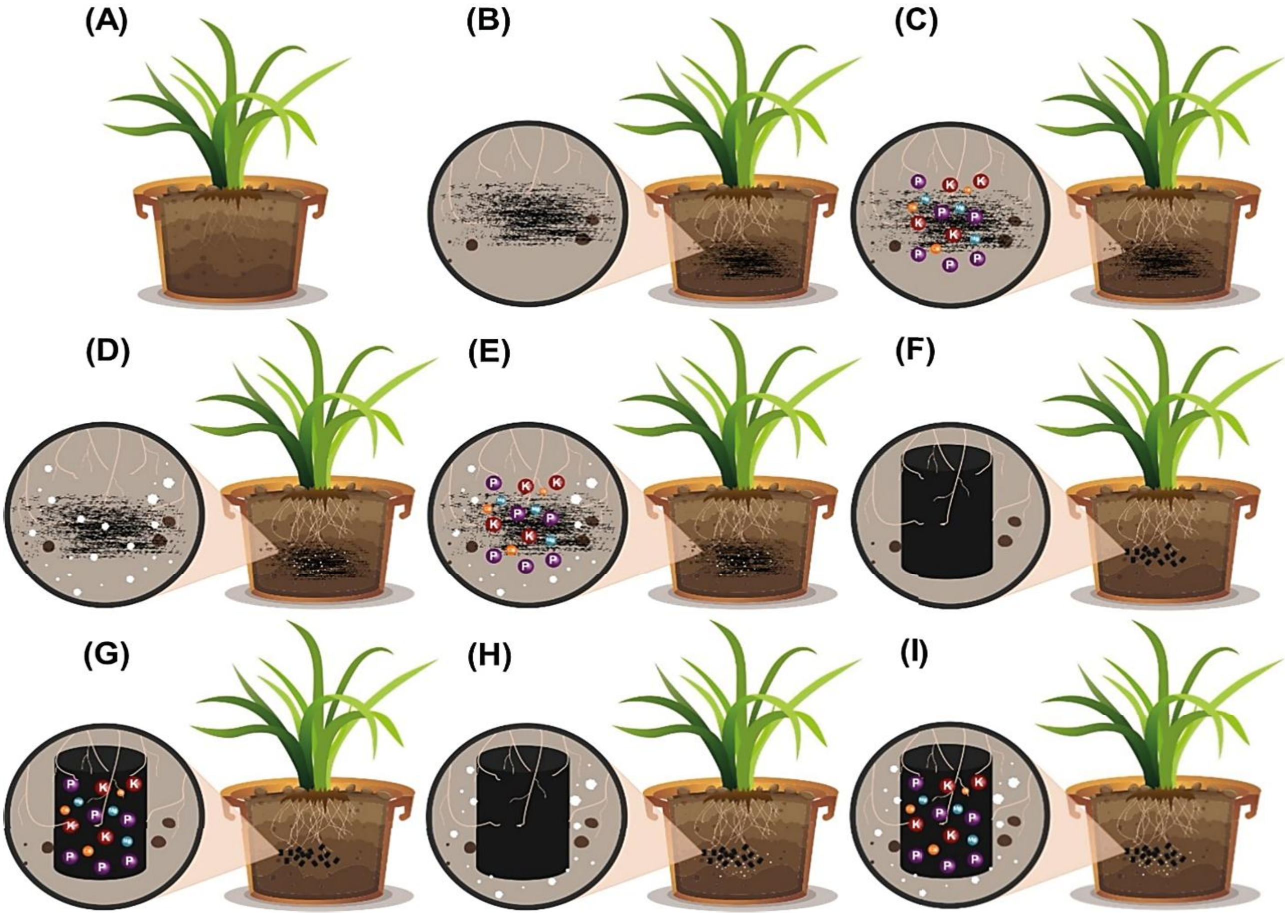

Table 2 - Treatments and applied quantities of biochar and fertiliser with phosphorus and potassium

Control	Pelletised	Liming	Fertiliser	Amount
Additional treatment: Natural soil	Non-pelletised	No Liming	No Fertiliser	5.8 g pot^{-1} biochar
			With Fertiliser	5.8 and 1.31 g pot^{-1} biochar and PK, respectively
		With Liming	No Fertiliser	5.8 and 1.5 g pot^{-1} biochar and limestone, respectively
			With Fertiliser	5.8, 1.5 and 1.31 g pot^{-1} biochar, limestone and PK, respectively
	Pelletised	No Liming	No Fertiliser	7.2 g pot^{-1} pellets
			With Fertiliser	14.43 g pot^{-1} pellets
		With Liming	No Fertiliser	7.2 and 1.5 g pot^{-1} pellets and limestone, respectively
			With Fertiliser	14.43 and 1.5 g pot^{-1} pellets and limestone, respectively

For the treatments with added acidity corrector, 1.5 g limestone (calcium and magnesium carbonate in a ratio of 4:1, Ca:Mg) was applied per pot to raise the base saturation to 60%. The incubation period of the corrective was 30 days, during which time the soil moisture was maintained close to field capacity. Mineral fertiliser was applied at a rate of 200 mg dm^{-3} P and 250 mg dm^{-3} K (Table 2).

Ten seeds of *U. brisantha 'BRS Paiaguás'* were sown per pot. Thinning was carried out 13 days after sowing, leaving five plants per pot, which were grown for 129 days. During this period, the aerial part of the plants was cut five times depending on their growth, defining the cutting height as per the recommendations for pasture management, i.e. 20 cm above ground level whenever the height reaches 40 cm.

As the N concentration of the biochar was low, a top dressing of nitrogen was applied, using 45 mg dm^{-3} N in the form of urea after each cutting (Table 1).

After each cutting, shoot dry matter was determined in a forced air circulation oven at 65-70 °C for 72 hours; the macro- and micronutrient content of the leaf blade was also determined. The accumulated amount of each nutrient in the aerial part of the plants were estimated by multiplying the levels of each nutrient by the production of dry matter.

Root dry matter and the chemical attributes of the soil were determined after the fifth cut at the end of the cultivation period (TEIXEIRA *et al*., 2017).

The Shapiro-Wilk test and Levene's test were used to verify the normality and homogeneity of the data, respectively. The treatments were compared using the F-test at 5%, and the additional treatment was compared to the other treatments using Dunett's test at 5%. The R v. 3.6.3 statistical software (R Development Core Team) was used.

RESULTS AND DISCUSSION

Chemical attributes of the soil

The application of cattle manure biochar (CMB) to the soil, whether in pelletised or non-pelletised form and irrespective of liming or fertilisation, reduced soil acidity. Likewise, the application of agricultural limestone, both with or without CMB or PK fertiliser, raised the soil pH to close to seven. In the treatments that included biochar, soil pH values were significantly higher compared to the control treatment (Table 3). While in the liming treatments, the soil pH increased close to neutral, regardless of whether the biochar was pelletised or not (Table 3).

Correction of the soil acidity by the CMB can be attributed to its alkaline pH, possibly due to the presence of basic cations, such as Ca^{+2}, Mg^{+2} and K^{+}, in the ash in the form of alkali metal oxides and hydroxides from the pyrolysis process (TORRES *et al*., 2020). The presence of basic compounds in the CMB ash, such as oxides, e.g. CaO, MgO and K_2O, and hydroxides, such as $Ca(OH)_2$, $Mg(OH)_2$ and KOH, is clearly related to the alkaline pH of the biochar (Table 1). In this respect, the higher the ash content, the higher the pH value of the biochar (SARFARAZ *et al*., 2020). The percentage ash in the CMB was 36.2%, a relatively high value, which explains the pH of 9.8 (Table 1).

The mineral composition of the raw material (RAJKOVICH *et al*., 2012) and the pyrolysis temperature are responsible for the content and composition of the ash in biochars (SOUZA *et al*., 2021) and, consequently, the ability of biochars to neutralise soil acidity, as found in this study. In addition to the increase in pH, at higher pyrolysis temperatures there is a greater reduction in volatile materials, greater concentration of the inorganic fraction, greater dissolution of water-soluble salts and, consequently, higher values for electrical conductivity (SANTOS *et al*., 2019).

Table 3 - pH, Mehlich phosphorus (P), exchangeable potassium (K), exchangeable calcium (Ca) and exchangeable magnesium (Mg) in soil incubated with pelletised and non-pelletised cattle manure biochar, with and without acidity corrector, and with and without fertiliser

Treatment			pH	P	K	Ca	Mg
			-	mg dm^{-3}	mg dm^{-3}	cmol$_c$ dm^{-3}	cmol$_c$ dm^{-3}
Control			5.6	1.3	11.4	1.07	0.44
Non-pelletised	No Liming	No Fertiliser	6.0 a*	3.4 b*	11.4 b	1.47 a*	0.48 a
		With Fertiliser	6.0 a*	74.6 a*	22.8 a*	1.69 a*	0.47 a
		Mean	6.0 B	39.0 A	17.10 A	1.58 B	0.38 B
	With Liming	No Fertiliser	7.0 a*	5.8 b*	22.8 a*	1.76 b*	0.54 b*
		With Fertiliser	7.0 a*	81.4 a*	28.5 a*	2.06 a*	0.82 a*
		Mean	7.0 A	43.6 A	25.7 A	1.91 A	0.68 A
	Mean		6.5 C	41.3 D	21.4 D	1.75 C	0.53 C
Pelletised	No Liming	No Fertiliser	6.2 a*	4.9 b*	11.4 b	1.30 b*	0.67 a*
		With Fertiliser	6.6 a*	401.3 a*	410.7 a*	1.67 a*	0.45 b
		Mean	6.4 B	203.1 A	211.1 A	1.49 B	0.56 B
	With Liming	No Fertiliser	7.1 a*	5.4 b*	17.1 b*	1.90 a*	0.74 a*
		With Fertiliser	7.0 a*	420.3 a*	376.4 a*	2.14 a*	0.65 a*
		Mean	7.0 A	212.9 A	196.75 A	2.02 A	0.70 A
	Mean		6.7 C	207.9 C	203.9 C	1.75 C	0.63 C

Mean values followed by an asterisk (*) differ from the control by Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without fertiliser, and within treatments, with and without liming by F-test ($p < 0.05$). Uppercase letters 'A' and 'B' compare treatments with and without liming; uppercase letters 'C' and 'D' compare biochar with and without pelletisation by F-test ($p < 0.05$)

In the case of tropical soils, which are highly weathered and acidic due to the replacement of exchangeable bases by H^+ or AI^{+3} ions, applying biochar can be considered an alternative for mitigating the effects of soil acidity and ensuring crop productivity (APORI *et al*., 2021; YAO *et al*., 2019). However, the doses of biochar must be adjusted so that the pH of the soil does not exceed 6.6 to avoid any harmful effects to the plants, such as reducing the availability of cationic micronutrients due to precipitation reactions (BRTNICKY *et al*., 2021).

The available P content of each treatment that included the application of biochar, both in pelletised or non-pelletised form, was higher than in the control treatment (Table 3). The P content of the soil fertilised with pelletised biochar with PK were 420.3 and 401.3 mg kg^{-1}, in the treatments with and without liming, respectively (Table 3). On the other hand, applying non-pelletised biochar with PK fertiliser resulted in a P content of 81.4 and 74.6 mg kg^{-1}, respectively, with and without liming (Table 3). It was found that pelletising the biochar, especially together with the use of phosphate fertiliser, helped to increase the available P content of the soil compared to the corresponding treatment with non-pelletised biochar, with 207.9 and 41.3 mg kg^{-1}, respectively (Table 3), a variation of 403.39%.

The increase in available P in the soil with the application of CMB, whether pelletised or not, is primarily due to its presence in the biochar, since the nutrient is only volatilised at pyrolysis temperatures of approximately 700 °C. Biochars, in addition to being sources of P, reduce the phosphate fixation reactions in soils due to the negative surface electrical charges of anionic functional groups, while the soluble silica present in biochars competes for the phosphorus fixation sites (TORRES *et al*., 2020). The increase in available P in treatments corrected with biochar may also be related to the increase in soil pH and alkaline metals, which reduce P adsorption reactions to the Fe and Al oxides found in large quantities in the most-weathered tropical soils, such as Oxisols (APORI; BYALEBEKA, 2021).

The high levels of available P in treatments with pelletised CMB with P and K fertiliser show that the P in the pellet was released more slowly in order to avoid fixation reactions in the soil (KIM; HENSLEY; LABBÉ, 2014). Some authors consider the formation of cation bridges between the biochar matrix and the phosphorus. CMB has high levels of cations, such as Ca and Mg (Table 1), which could favour this type of connection and contribute to a slower release of phosphorus into the soil (LUO *et al*., 2021). Furthermore, in the case of weathered and acidic soils, the acidic pH of the medium can interfere with the surface charges of organic groups in the biochar pellets by protonation, which increases the affinity of the pellets for P, with a weaker binding energy in relation to P retention by inner-sphere complexation (FRAZÃO *et al*., 2019).

The use of CMB pellets enriched with mineral fertiliser contributed to higher levels of exchangeable K in the soil, both with or without the application of soil acidity corrector, corresponding to 376.4 and 410.7 mg dm^{-3}, respectively (Table 3). Similar to the phosphorus, the highest levels of K were obtained with the application of CMB pellets, particularly with PK fertilisation, of 203.9 and 21.4 mg dm^{-3}, with and without pelletisation, respectively. (Table 3).

The greater specific surface area of the non-pelletised CMB may have contributed to a greater adsorption of potassium on the negative electrical charges of the micropores, releasing the nutrient more slowly into the soil. Furthermore, K is itself capable of catalysing the production of surface oxygenated compounds in the biochar matrix, which are converted into carboxylic and phenolic groups that increase the density of negative charges to retain cations in the structure (DOMINGUES *et al*., 2020). Some authors have found potassium fertilisers to be more efficient when applied together with biochars due to fewer losses from leaching (ORAM *et al*., 2014).

The calcium levels in treatments that included the application of biochar, regardless of pelletisation or liming, were higher in relation to the control treatment. Furthermore, irrespective of biochar pelletisation or mineral fertilisation, the levels of calcium and magnesium were higher in the liming treatments (Table 3). The joint application of CMB and limestone therefore helped significantly to increase the levels of calcium and magnesium in the soil.

Increases in the levels of Ca and Mg in the treatments with CMB and agricultural limestone are related to the presence of these nutrients in the biochar (Table 1) and in the acidity corrector. The elements Ca and Mg also contribute to the slower release of the organomineral fertiliser, since they stabilise the mineral nutrients in the biochar matrix by electrostatic surface attraction, precipitation, or ion exchange, and increase the pore structure, forming a greater number of adsorption sites (AN *et al*., 2020).

Calcium and magnesium play an important role in the factors of soil acidity. As discussed above, in this study the exchangeable acidity was neutralised by the use of CMB and limestone, considering that both Ca and Mg from the acidity corrector and from the CMB transported the toxic Al^{+3} into the soil solution that, at a pH greater than 5.5, is precipitated in the form of $Al(OH)_3$ and is no longer available to the plants (SHETTY; PRAKASH, 2020). On the other hand, the highest values for potential acidity (H + Al) were found in treatments with no limestone but with the P and K mineral fertiliser (Table 4).

The increase in potential acidity from the application of mineral fertiliser can be explained by the fertiliser favouring the mineralisation reactions of the soil organic matter, including the CMB, by the addition of P and K, thereby promoting the release of organic acids and H^+ protons in the soil (ADEKIYA *et al*., 2020). Estimates of the cation exchange capacity (CEC) of the soil can be influenced by its potential acidity.

The highest values for CEC were obtained in treatments that included the application of pelletised CMB compared to the treatments with non-pelletised CMB, of 3.94 and 3.34 $cmol_c\ dm^{-3}$, respectively (Table 4). As a result, better responses were obtained in the treatment with liming and pelletised biochar enriched with P and K, which presented a CEC of 4.77 $cmol_c\ dm^{-3}$, an increase of 43.67% compared to the control treatment (Table 4). Due to the addition of basic cations to the cation exchange complex, the liming and CMB treatments, regardless of pelletisation, gave higher values for base saturation (V) (Table 4).

In this study, the CEC was estimated as the sum of Ca, Mg, K, Al and H+Al. The addition of exchangeable bases by the acidity corrector, biochar and PK fertiliser therefore contributed to increase the CEC. Due to the addition of exchangeable bases, the highest values for base saturation (V) were found in the treatments with liming and CMB enriched with PK fertiliser (Table 4). Increases in the CEC in soils amended with biochars are due to the oxidation of surface C groups forming functional groups in the structure of the biochars, which enable basic cations to be adsorbed (DOMINGUES *et al*., 2020).

It was found that, regardless of biochar pelletisation or mineral fertilisation, the highest values for soil organic carbon (SOC), were found in treatments that included the application of CMB with no soil acidity corrector, compared to the control treatment (Table 4). The increase in SOC in treatments with the application of CMB, irrespective of pelletisation, can be explained by the carbon-enriched soil from the CMB, which contributes to an increase in the pool of labile organic carbon in the soil when this is mineralised (APORI *et al*., 2021). In addition to being a source of the element, the organic carbon in biochars has a high degree of aromaticity, due to a reduction in the H/C ratio of the material with pyrolysis and a resistance to biological degradation (SANTOS *et al*., 2019). The level and aromaticity of SOC in the CMB, 167.9 g kg^{-1} (Table 1), certainly helped to retain nutrients in its matrix and increase the CEC of the soil, as discussed above. The lower levels of SOC in the liming treatments can be attributed to losses in the form of carbon dioxide due to heterotrophic microorganisms in the soil promoting the conditions for mineralisation (MOSHARROF *et al*., 2021).

Production and mineral nutrition in *Urochloa brizantha* 'BRS Paiaguás'

During the first crop cycle, it was found that growth in the control treatment was significantly lower compared to the other treatments, and did not reach the cutting height of 40 cm. For the remaining cuts, the production of shoot dry matter (SDM) was lower in the control treatment, compared to the other treatments (Table 5).

This result can be explained by the low initial availability of nutrients in the soil, while the greater growth when applying CMB can be attributed to the increase in soil pH and nutrient availability (BISTA *et al*., 2019), since biochars act as conditioners of the chemical properties of the soil due to a high capacity for retaining nutrients on the surface of the particles and inside the pores (MUSTAFÁ *et al*., 2022).

At the first cut, the highest values for SDM were obtained in the treatments with non-pelletised biochar, production being 18.28% higher compared to the pelletised biochar. SDM production was 1.86 and 2.20 g pot^{-1} in the biochar treatments with and without pelletisation, respectively (Table 5). On the other hand, the treatments with pelletised biochar showed increases at the second and third cuts, demonstrating at the third cut, a significantly greater response, with a mean SDM production of 3.18 g pot^{-1}, which equals a difference of 19.55%, in relation to the treatments with non-pelletised biochar (Table 5).

Throughout the experimental period, each of the treatments that included the application of CMB, whether in pelletised or non-pelletised form, and regardless of liming or fertilisation with P and K, showed an accumulated production of shoot dry matter (TSDM) greater than the control treatment for the sum of the five cuts (Table 5). Regardless of CMB pelletisation or the application of mineral fertiliser, the highest values for TSDM were obtained with the liming treatments, with mean values of 11.06 and 11.86 g pot^{-1} for the non-pelletised CMB and pelletised CMB, respectively (Table 5). Similarly, the highest values for TSDM were obtained in treatments that included the application of P and K, regardless of CMB pelletisation or liming, of 12.10, 13.26, 11.44 and 14.46 g pot^{-1}, for non-pelletised CMB with no liming, non-pelletised CMB with liming, pelletised CMB with no liming, and pelletised CMB with liming, respectively (Table 5).

Table 4 - Exchangeable acidity (Al), potential acidity (H+Al), potential CEC (T), base saturation (V) and soil organic carbon (SOC) in soil incubated with non-pelletised or pelletised cattle manure biochar, with and without the application of acidity corrector, and with and without the application of fertiliser

Treatment			Al	H + Al	T	V	SOC
			cmol$_c$ dm^{-3}			%	dag kg^{-1}
Control			0.05	1.03	3.32	58.49	0.49
Non-pelletised	No Li-ming	No Fertiliser	0	1.07 b	3.05 b	65.00 a	0.69 a*
		With Fertiliser	0	1.36 a*	3.38 a	59.73 a	0.55 a*
		Mean	0	1.22 A	3.22 A	62.37 A	0.62 A
	With Li-ming	No Fertiliser	0	0.76 a*	3.11 b	75.74 a*	0.49 a
		With Fertiliser	0	0.87 a	3.83 a*	77.19 a*	0.49 a
		Mean	0	0.82 B	3.47 A	76.47 A	0.49 B
	Mean		0	1.02 C	3.34 D	69.42 C	0.56 C
Pelletised	No Li-ming	No Fertiliser	0	1.04 b	3.04 b*	65.73 a	0.62 a*
		With Fertiliser	0	1.30 a*	4.47 a*	70.91 a*	0.62 a*
		Mean	0	1.17 A	3.76 B	68.32 A	0.62 A
	With Li-ming	No Fertiliser	0	0.79 b*	3.47 b	77.27 a*	0.55 a
		With Fertiliser	0	1.02 a	4.77 a*	78.65 a*	0.55 a
		Mean	0	0.91 A	4.12 A	77.96 A	0.55 A
	Mean		0	1.04 C	3.94 C	73.14 C	0.59 C

Mean values followed by an asterisk (*) differ from the control by Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without fertiliser, and within treatments, with and without liming by F-test ($p < 0.05$). Uppercase letters 'A' and 'B' compare treatments with and without liming; uppercase letters 'C' and 'D' compare biochar with and without pelletisation by F-test ($p < 0.05$)

Table 5 - Shoot dry matter (SDM) for the five crop cycles (cuts), total shoot dry matter (TSDM) and root dry matter (RDM) in *Urochloa brisantha* 'BRS Paiaguás', in soil incubated with non-pelleted or pelletised cattle manure biochar, with and without the application of acidity corrector, and with and without the application of fertiliser

Treatment			1 st Cut	2 nd Cut	3 rd Cut	4 th Cut	5 th Cut	TSDM	RDM
			g pot^{-1}						
Control			0.00	0.49	0.48	0.22	0.08	1.27	0.71
Non-pelletised	No Liming	No Fertiliser	1.91 b*	2.07 b*	1.79 b*	0.89 b*	0.58 b*	7.24 b*	2.65 b*
		With Fertiliser	2.31 a*	3.07 a*	2.82 a*	2.09 a*	1.81 a*	12.10 a*	3.37 a*
		Mean	2.11 A	2.57 A	2.31 B	1.49 B	1.19 B	9.67 B	3.01 B
	With Liming	No Fertiliser	1.86 b*	2.04 b*	2.36 b*	1.53 b*	1.04 b*	8.83 b*	3.51 a*
		With Fertiliser	2.72 a*	2.81 a*	3.66 a*	2.38 a*	1.69 a*	13.26 a*	3.33 a*
		Mean	2.29 A	2.43 A	3.01 A	1.96 A	1.37 A	11.06 A	3.42 A
	Mean		2.20 C	2.50 C	2.66 D	1.72 C	1.28 C	10.36 C	3.22 C
Pelletised	No Liming	No Fertiliser	1.63 a*	2.44 b*	2.74 b*	1.23 b*	0.60 b*	8.64 b*	2.04 b*
		With Fertiliser	1.25 a*	2.82 a*	3.23 a*	2.70 a*	1.44 a*	11.44 a*	2.53 a*
		Mean	1.44 B	2.63 A	2.99 B	1.97 A	1.02 B	10.05 B	2.29 B
	With Liming	No Fertiliser	1.86 b*	2.56 b*	2.87 b*	1.18 b*	0.78 b*	9.25 b*	2.67 a*
		With Fertiliser	2.68 a*	3.09 a*	3.89 a*	2.82 a*	1.98 a*	14.46 a*	2.76 a*
		Mean	2.27 A	2.83 A	3.38 A	2.00 A	1.38 A	11.86 A	2.71 A
	Mean		1.86 D	2.73 C	3.18 C	1.98 C	1.20 C	10.95 C	2.50 D

Mean values followed by an asterisk (*) differ from the control by Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without fertiliser, and within treatments, with and without liming by F-test ($p < 0.05$). Uppercase letters 'A' and 'B' compare treatments with and without liming; uppercase letters 'C' and 'D' compare biochar with and without pelletisation by F-test ($p < 0.05$)

There was no effect from pelletisation throughout the five crop cycles, with the TSDM being 10.95 g pot^{-1} in the treatments with pelletised CMB, and 10.36 g pot^{-1} with the non-pelletised CMB (Table 5). Although there were no significant differences in the sum of the five cuts regardless of liming or fertilisation with NPK, the highest production of TSDM was obtained with pelletised CMB enriched with P and K mineral fertiliser, together with correction of the soil acidity by liming, 14.46 g pot^{-1} (Table 5).

The lower production of SDM at the first cut in treatments with the application of CMB pellets showed that the release of nutrients by the pelletised biochar was slower compared to the non-pelletised biochar. As a result, the TSDM of these treatments was greater, especially with the addition of PK fertiliser and liming, since, unlike commercial fertilisers, biochar-based pelletised fertilisers are characterised by a slow and controlled release of nutrients into the soil, which, in the long term, allows better nutrient use by the plants. This change in nutrient release dynamics by pelletised biochar enriched with PK is desirable, as it can avoid the loss of K from mineral fertiliser through leaching, and reduce P fixation, especially in highly weathered, acidic soils that have a low CEC, and are rich in kaolinite and Fe and Al oxides (Santos *et al*., 2019).

In the case of P absorption by the plants, the controlled release of nutrients and the lower solubility of the organomineral fertiliser are important characteristics in soils with a high phosphate adsorption capacity, such as Oxisol, as they prevent any increase in the non-labile P pool over time, a pool that is not in equilibrium with the P in the soil solution due to the formation of surface binuclear complexes that reduce the availability of the nutrient (FRAZÃO *et al*., 2019).

This study showed that the joint application of CMB regardless of pelletisation, the use of agricultural lime, or mineral fertiliser, contributed to an increase in the production of BRS Paiguás grass. Several studies have pointed to the importance of applying biochar together with soil acidity correctors and mineral fertilisers (MOSHARROF *et al*., 2021; YAO *et al*., 2019); if applied alone, large amounts of biochar would be needed to have the same effect as liming and mineral fertilisers, which would make the use of carbonised material unfeasible over large areas of agricultural crops (MAROUŠEK *et al*., 2017).

Other authors have pointed out the benefits of biochar in increasing the production of plant biomass due to influencing the expression of genes involved in the biosynthesis and regulation of the cell wall, resulting in increased levels of lignin and hemicellulose, and an increase in silica accumulation (MIAO *et al*., 2023).

In relation to the root system, higher values for RDM were found in treatments with non-pelletised biochar, with an increase of 28.80% in relation to treatments with pelletised biochar (Table 5). Treatments that included liming were superior to treatments with no liming regardless of the use of mineral fertiliser, with values of 3.42 and 2.71 g pot^{-1} for non-pelletised CMB and pelletised CMB, respectively.

The application of CMB, especially non-pelletised CMB, together with agricultural lime, contributes to root growth. Some authors have verified the effect of biochar on the root system, particularly in increasing the number of fine roots, which then favours an increase in nutrient absorption efficiency (TORRES *et al*., 2020). Another important characteristic of biochar is its persistence in the soil, which increases the porosity, moisture content and nutrient availability, in addition to reducing the apparent density of the soil, preventing compaction, and increasing root penetration (AGBEDE; OYEWUMI, 2022).

Compared to the control treatment, the accumulated quantities of macronutrients in the shoots, considering the five cuts, were greater in treatments that included CMB, regardless of pelletisation (Table 6). There was no significant difference between the treatments with or without pelletisation. On the other hand, the greatest macronutrient accumulation was seen in treatments with liming and the application of P and K mineral fertiliser (Table 6).

There was no difference in micronutrient accumulation in the shoots between the treatments with and without biochar pelletisation and the treatments with and without liming (Table 7). On the other hand, micronutrient accumulation was greater with CMB regardless of pelletisation compared to the control treatment. The highest values were obtained with the treatments that included PK mineral fertiliser (Table 7).

The combinations of CMB, liming and PK fertiliser led to a greater accumulation of macronutrients in BRS Paiaguás grass due to the greater availability of nutrients and greater biomass production in these treatments. Furthermore, the adsorption of micronutrients on the biochar particles may have reduced their precipitation reactions at higher pH values, contributing to their gradual release throughout the crop cycle, similar to chelates.

Table 6 - Accumulation of macronutrients during the five crop cycles of *Urochloa brisantha* 'BRS Paiaguás', in soil incubated with non-pelletised or pelletised cattle manure biochar, with and without the application of acidity corrector, and with and without the application of fertiliser

Treatment			N	P	K	Ca	Mg	S
			g plant^{-1}					
Control			2.04	0.08	1.28	0.42	0.20	0.13
Non-pelletised	No Liming	No Fertiliser	15.55 b*	1.20 b*	12.20 b*	4.15 b*	2.20 b*	1.95 b*
		With Fertiliser	28.07 a*	2.67 a*	24.53 a*	8.39 a*	3.49 a*	3.04 a*
		Mean	21.81 A	1.93 B	18.36 B	6.27 B	2.85 B	2.50 A
	With Liming	No Fertiliser	19.85 b*	2.29 b*	26.49 b*	8.37 b*	5.16 b*	2.30 b*
		With Fertiliser	31.40 a*	4.24 a*	44.07 a*	14.25 a*	7.58 a*	3.45 a*
		Mean	25.63 A	3.26 A	35.28 A	11.31 A	6.37 A	2.88 A
	Mean		23.72 C	2.60 C	26.82 C	8.79 C	4.61 C	2.69 C
Pelletised	No Liming	No Fertiliser	20.21 b*	2.24 b*	17.58 b*	4.73 b*	2.59 b*	2.19 b*
		With Fertiliser	28.26 a*	3.19 a*	30.69 a*	7.71 a*	3.45 a*	2.93 a*
		Mean	24.24 A	2.71 B	24.13 B	6.22 B	3.02 B	2.56 B
	With Liming	No Fertiliser	21.42 b*	2.68 b*	27.61 b*	8.52 b*	5.56 b*	2.45 b*
		With Fertiliser	34.33 a*	4.61 a*	50.34 a*	15.68 a*	7.72 a*	3.57 a*
		Mean	27.88 A	3.65 A	38.98 A	12.10 A	6.64 A	3.01 A
	Mean		26.06 C	3.18 C	31.55 C	9.16 C	4.83 C	2.79 C

Mean values followed by an asterisk (*) differ from the control by Dunnett's test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without fertiliser, and within treatments, with and without liming by F-test ($p < 0.05$). Uppercase letters 'A' and 'B' compare treatments with and without liming; uppercase letters 'C' and 'D' compare biochar with and without pelletisation by F-test ($p < 0.05$)

Table 7 - Accumulation of micronutrients during the five crop cycles of *Urochloa brisantha* ‘BRS Paiaguás’, in soil incubated with non-pelletised or pelletised cattle manure biochar, with and without the application of acidity corrector, and with and without the application of fertiliser

Treatment			B	Cu	Fe	Mn	Zn
			mg plant^{-1}				
Control			1.38	0.62	10.56	7.44	2.85
Non-pelletised	No Liming	No Fertiliser	20.50 b*	7.83 b*	87.87 b*	68.78 b*	44.60 b*
		With Fertiliser	33.75 a*	12.76 a*	148.65 a*	111.24 a*	72.11 a*
		Mean	27.13 A	10.30 A	118.26 A	90.01 A	58.35 A
	With Liming	No Fertiliser	23.98 b*	9.48 b*	104.71 b*	80.91 b*	53.85 b*
		With Fertiliser	36.72 a*	13.99 a*	157.02 a*	124.16 a*	79.46 a*
		Mean	30.35 A	11.74 A	130.86 A	102.53 A	66.66 A
		Mean	28.74 C	11.02 C	124.56 C	96.27 C	62.50 C
Pelletised	No Liming	No Fertiliser	24.61 b*	9.43 b*	105.13 b*	81.54 b*	54.03 b*
		With Fertiliser	32.58 a*	12.35 a*	138.44 a*	107.11 a*	68.33 a*
		Mean	28.60 A	10.89 A	121.79 A	94.33 A	61.18 A
	With Liming	No Fertiliser	25.55 b*	9.65 b*	109.73 b*	86.98 b*	57.36 b*
		With Fertiliser	37.77 a*	14.78 a*	169.73 a*	134.86 a*	86.00 a*
		Mean	31.66 A	12.22 A	139.73 A	110.92 A	71.68 A
		Mean	30.13 C	11.55 C	130.76 C	102.62 C	66.43 C

Mean values followed by an asterisk (*) differ from the control by Dunnett’s test ($p < 0.05$). Lowercase letters in the columns compare treatments with and without fertiliser, and within treatments, with and without liming by F-test ($p < 0.05$). Uppercase letters ‘A’ and ‘B’ compare treatments with and without liming; uppercase letters ‘C’ and ‘D’ compare biochar with and without pelletisation by F-test ($p < 0.05$)

However, it is important to consider that the nutritional status of plants generally depends on the dosage and the level of nutrients available in the biochar, as well as on the species (Chagas; Figueiredo; Paz-Ferreiro, 2021).

CONCLUSIONS

1. Biochar from cattle manure improved the chemical properties of the soil, correcting acidity and increasing nutrient availability and the production of *Urochloa brizantha* ‘BRS Paiaguás’;
2. Cattle manure biochar enriched with phosphorus and potassium behaved as a slow-release organomineral nutrient fertiliser in *Urochloa brizantha* ‘BRS Paiaguás’.

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