



## Liming and biochar on sorghum growth and Arenosol chemical properties in the Semiarid environment

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**ABSTRACT:** This research evaluated the effect of liming (with and without) and biochar (with and without) on sorghum cv. BRS Ponta Negra growth and Arenosol chemical properties in the Semiarid environment. The experimental design was in randomized blocks, with treatments in a 2x2 factorial scheme, corresponding to the application or not of lime (0 and 2.5 t ha<sup>-1</sup>) and biochar (0 and 12.5 t ha<sup>-1</sup>). Biochar was produced from cashew branches. The experiment was conducted in 16 m<sup>2</sup> plots where the forage sorghum cultivar BRS Ponta Negra was cultivated. The soil chemical characteristics, the production attributes, and the structural characteristics of the sorghum cultivar studied were evaluated. There was no interaction between factors. The use of biochar increased the pH and Ca and P contents in the soil and contributed to increasing the panicle mass (2.51 t ha<sup>-1</sup> of DM). Lime application affected the soil Ca content as the dose of 2.5 t ha<sup>-1</sup> resulted in higher values of culm diameter (15.25 mm), panicle mass, and culm mass (2.63 and 7.50 t ha<sup>-1</sup> of DM, respectively). Therefore, these results allowed to outline strategies for the use of limestone and biochar for forage production in semiarid environments in sandy soils. Because, these materials improve some chemical attributes of the soil and the production of forage sorghum. It is noteworthy that edaphoclimatic conditions can change the response patterns observed in this research. Therefore, research in other regions is essential.

**Key words:** carbon, conditioners, soil fertility, Sorghum bicolor.

### Efeito da calagem e do biochar no crescimento do sorgo e nas propriedades químicas do Neossolo Quartzarênico no ambiente Semiárido

**RESUMO:** Este trabalho teve como objetivo avaliar o efeito da calagem (com e sem) e do biocarvão (com e sem) sobre o crescimento e a produção de forragem do sorgo forrageiro cv. BRS Ponta Negra e nas propriedades químicas do Neossolo Quartzarênico no ambiente Semiárido. O delineamento experimental foi em blocos casualizados, com tratamentos em esquema fatorial 2x2, correspondendo a aplicação ou não do calcário (0 e 2,5 t ha<sup>-1</sup>) e do biocarvão (0 e 12,5 t ha<sup>-1</sup>). O biochar era produzido a partir de galhos de caju. O experimento foi conduzido em parcelas de 16 m<sup>2</sup> onde foi cultivada a cultivar de sorgo forrageiro BRS Ponta Negra. Foram avaliadas as características químicas do solo, os atributos de produção e as características estruturais da cultivar de sorgo estudada. Não houve interação entre os fatores. O uso do biochar aumentou o pH e os teores de Ca e P no solo e contribuiu para o aumento da massa da panícula (2,51 t ha<sup>-1</sup> de MS). A aplicação de calcário afetou o teor de Ca no solo, assim a dose de 2,5 t ha<sup>-1</sup> resultou em maiores valores de diâmetro do colmo (15,25 mm), massa da panícula e massa do colmo (2,63 e 7,50 t ha<sup>-1</sup> de MS, respectivamente). Portanto, esses resultados permitem traçar estratégias de uso do calcário e biochar para produção forrageira em ambientes semiáridos com solos arenosos. Pois, essas matérias melhoram alguns atributos químicos do solo e a produção do sorgo forrageiro. Vale ressaltar que as condições edofoclimáticas podem alterar os padrões de resposta observados nesta pesquisa. Portanto, a pesquisa em outras regiões é essencial.

**Palavras-chave:** carbono, condicionadores, fertilidade do solo, Sorghum bicolor.

## INTRODUCTION

The seasonality of forage production has been one of the greatest challenges faced by cattle

raisers in semi-arid regions (HUANG et al., 2016). In these regions, sorghum (*Sorghum bicolor* (L.) Moench) emerges as an alternative to maize (*Zea mays*) for producing more forage and being more

adapted to adverse conditions, showing greater resistance to water stress and lower nutritional demand (DIAS et al., 2001; FERNANDES et al., 2020a). However, most of the time, care is not taken into account to ensure the success of production, correction and soil fertilization, making the activity unfeasible.

In this sense, the correction of soil acidity is a major factor in increasing crop yields (SOMAVILLA et al., 2021). Lime is one of the most important agricultural inputs and has been widely used to correct surface soil acidity (LOCHON et al., 2019). Its application increases the soil pH, neutralizes aluminum, and increases macronutrient availability for plants, keeping soil fertility balanced (FERNANDES et al., 2020b). It is also considered a great source of Ca and Mg, promoting favorable conditions for increasing the biological activity of the soil and for the development of the root system of plants (GURGEL et al., 2020). Lime is a product with relatively low cost compared to other agricultural inputs, and its benefits last for more than one crop cycle due to its low solubility (SOMAVILLA et al., 2021), making its use even more attractive to the producer.

Biochar is another low-cost input used in agricultural production systems (ZEESHAN et al., 2020; SHAKOOR et al., 2021). It can be produced from crop residues and materials with good availability on the property. It is defined as the product of the thermal decomposition of biomass in an anaerobic environment for application in agricultural soils (VERHEIJEN et al., 2010). This substance that results from plant burning is rich in pyrogenic carbon, increasing soil cation exchange capacity (CEC), besides being chemically stable, remaining active in the soil for several years (KÄTTERER et al., 2019), unlike fresh organic matter, which decomposes faster (MARIMON JUNIOR et al., 2012).

The consequences of adding biochar to the soil, in the chemical aspect, include the release of nutrients contained in it, greater soil nutrient retention, the mitigation of extreme soil pH values, and the retention and neutralization of contaminants (KÄTTERER et al., 2019; ZEESHAN et al., 2020). In the physical aspect, it improves soil structure, favoring infiltration, water and air storage, and increasing the soil volume explored by the roots, besides significantly reducing soil loss through erosion (KALU et al., 2021; LIANG et al., 2021). Another important aspect is the better destination and use of urban organic solid waste (tree pruning residues, sewage sludge), agricultural waste (crop residues, bagasse, and sugarcane straw), industrial waste (paper and cellulose), or materials of animal origin, such as bones and manure (MANGRICH et al., 2011).

Taking into account that liming is essential to increase the yields of agricultural and forage crops (LOCHON et al., 2019; FERNANDES et al., 2020b) and that biochar offers several agricultural and environmental benefits (KALU et al., 2021; ZEESHAN et al., 2020; SHAKOOR et al., 2021). However, there are few reports on the use of liming in association with limestone and biochar in the cultivation of forage sorghum in sandy soils in semi-arid environments. Our hypothesis is that the application of limestone in association with biochar improves the chemical attributes of the soil, promoting increases in sorghum production. In this perspective, this study evaluated the growth and production of forage sorghum and the soil chemical attributes in response to the application or not of lime and biochar.

## MATERIALS AND METHODS

The assay was performed at the Jundiá Agricultural School – Academic Unit Specialized in Agricultural Sciences of the Federal University of Rio Grande do Norte (EAJ-UFRN), located in the municipality of Macaíba/RN (5° 51' S, 35° 21' W). The climate of the region is classified as *As* (tropical with a dry season), according to the classification by Köppen, with a mean annual temperature of 26 °C. The soil in the area is classified as Arenosol (FAO, 2015). Before the start of the experiment, 20 soil samples were collected from the entire area at a depth of 0-20 cm and sent for physical and chemical characterization (Table 1). The soil in the experimental area showed a sandy texture, with nutrient content base saturation and pH range (5.5 and 6.5) according to the needs of the sorghum crop.

The species used was the forage sorghum (*Sorghum bicolor* L.) cv. BRS Ponta Negra. The experimental design was in randomized blocks with five replications. The treatments corresponding to the application or not of lime (0 and 2.5 t ha<sup>-1</sup>) and biochar (0 and 12.5 t ha<sup>-1</sup>) in a 2x2 factorial arrangement. Each experimental plot had 16 m<sup>2</sup> (4x4 m), composed of four planting rows spaced 1.0 m apart, with the two central rows considered as the useful area. Or calcarium applied to present the following characteristics: 20% CaO%, 15% MgO% and 80% power relative total neutralization power. Biochar supplied 11.69, 111.5 and 1.68 kg ha<sup>-1</sup> of N, P and K, respectively.

Biochar was produced from cashew branches (*Anacardium occidentale*) through rapid pyrolysis as described by BRIDGWATER (2012).

Table 1 - Soil chemical and physical attributes at 0-20 cm depth.

pH	P	Ca	Mg	K	Na	H+Al	T	V	Sand	Silt	Clay	
(H <sub>2</sub> O)	mg dm <sup>-3</sup>	-----cmol <sub>c</sub> dm <sup>-3</sup> -----							%	-----g kg <sup>-1</sup> -----		
5.8	19.40	1.50	0.74	0.23	0.03	1.80	4.37	57.2	904.4	70.6	25.0	

T: cation-exchange capacity at pH 7.0; V: base saturation.

Afterward, the coal was crushed in a stationary forage machine equipped with a 0.5 mm mesh sieve. Particle size standardization was performed to homogenize and facilitate uniform distribution of the material in the area. Samples of the material were sent to the Biomass and Biofuels Laboratory of UFRN, where the immediate chemical analysis (Table 2) was performed in order to determine the Moisture Content (MC), the Volatile Material Content (VMC), the Fixed Carbon Content (FCC), and the Ash Content (AC), according to the methodology described in the ASTM D1762-84 guidelines (ASTM, 2007). Macro and micronutrient analyses were performed at the Soil, Water, and Plant Laboratory of UFRSA. The contents of P, K, Cu, Mn, Fe, and Zn were determined by nitro-perchloric digestion, whereas the N content was determined by sulfuric solubilization (CARMO et al., 2000).

The experiment was conducted in 2012. Prior to the experiment, the experimental area contained a *Brachiaria brizantha* cv. Xaraés grazed by sheep. Pastures received 80 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> and 50 kg ha<sup>-1</sup> of K<sub>2</sub>O annually. The seeds were sown in furrows, with 15 seeds per linear meter. Biochar and lime were applied to the bottom of the furrow at sowing, according to the respective treatment. Throughout the experiment, irrigation was provided daily by a conventional sprinkler system with a 4 mm irrigation depth, and the area was kept free of spontaneous plants through manual weeding.

The evaluations were conducted 90 days after sowing, when the sorghum reached the ideal cut-off point for silage (35% dry matter). Thus, at the end of the crop cycle, the following chemical attributes in the soil were determined: exchangeable calcium and magnesium, obtained with a 1.0 mol L<sup>-1</sup> KCl extracting solution, with readings performed by spectrometry and flame photometry, respectively; available phosphorus and exchangeable sodium and potassium, obtained with the Mehlich-1 extracting solution, with readings performed by colorimetry and

flame photometry, respectively. Subsequently, the soil organic carbon was determined by calorimetry using the Walkley-Black method, while the pH in water was determined by the potentiometric method (TEIXEIRA et al., 2017).

At 90 days after sowing, the structural characteristics of sorghum were evaluated. Plant height was determined with a ruler by considering the length from ground level to the tip of the last expanded leaf in the tiller. Culm diameter was measured with a digital caliper in the lower-third region of three different tillers. The number of live leaves was obtained by counting the fully expanded leaves in the tiller. Leaf length was measured on the last expanded leaf of three different tillers. Tiller density was determined by counting all tillers in the useful area, with values corrected for tiller m<sup>-2</sup>.

The plants were cut close to the ground and weighed on a digital scale for the determination of production. Afterward, the whole material was manually separated into leaf blades, culms, and panicles and then weighed again and placed in a forced-air oven at 55 °C for 72 hours, after which it was possible to determine the dry matter content, given by the ratio between dry mass and fresh mass; the leaf/culm ratio; and the estimated production per unit of area. The total forage mass was given by the sum of the leaf, culm, and panicle masses.

The data were subjected to analysis of variance using the statistical software SISVAR 5.6 (FERREIRA, 2011). The following model was used in the statistical analysis:  $Y_{ijk} = \mu + B_i + C_j + B_k + (C*B)_{jk} + \alpha_{ijk}$ . In which,  $Y_{ijk}$ = observation in block  $i$ , dose of lime  $j$  in the dose of biochar  $k$ ;  $\mu$ = overall mean effect;  $B_i$ = block effect  $i$ ,  $i= 1$  to 5;  $C_j$ = lime dose effect  $j$ ,  $j= 0$  and 2.5 t ha<sup>-1</sup>;  $B_k$ = biochar dose effect  $k$ ,  $k= 0$  and 12.5 t ha<sup>-1</sup>;  $(C*B)_{jk}$ = effect of the interaction between the dose of lime  $j$  and the dose of biochar  $k$ ;  $\alpha_{ijk}$ = random error associated with each observation  $ijk$ .

Table 2 - Chemical composition of the biochar of *Anacardium occidentale*.

FCC	AC	VMC	MC	N	K	P	Cu	Mn	Fe	Zn
-----%-----				-----g kg <sup>-1</sup> -----		-----mg kg <sup>-1</sup> -----				
57.6	16	21	5.4	9.35	1.34	89.2	0.21	32.3	185.0	18.5

FCC: Fixed Carbon Content; AC: Ash Content VMC: Volatile Material Content; MC: Moisture Content.

## RESULTS

There was no interaction ( $P > 0.05$ ) between biochar and lime doses for any of the variables. Regarding soil chemical properties, no effect ( $P > 0.05$ ) of biochar and lime was observed on the organic carbon, Mg, K, and Na contents (Figure 1), with respective means of 8.91 g kg<sup>-1</sup>, 1.15 cmol<sub>c</sub> dm<sup>-3</sup>, 29.0, and 18.5 mg dm<sup>-3</sup>. Soil pH differed ( $P < 0.05$ ) only as a function of biochar. The application of biochar promoted an increase of 1.06 in soil pH.

Phosphorus content was only affected ( $P < 0.05$ ) by the application of biochar. The use of 12.5 t ha<sup>-1</sup> promoted a 46.40% increase in the P content in the soil compared to not using biochar (0 t ha<sup>-1</sup>). There was an isolated effect ( $P < 0.05$ ) of biochar and lime on the soil Ca contents, with higher concentrations of this nutrient being observed when using biochar (12.5 t ha<sup>-1</sup>) and lime (2.5 t ha<sup>-1</sup>), compared to the control treatment (Figure 1).

The use of biochar did not influence ( $P > 0.05$ ) any of the structural parameters of sorghum. In turn, the use of lime increased ( $P < 0.05$ ) the diameter of the stalk and the number of live leaves by 1.78 cm and 1.23 leaves tiller<sup>-1</sup>, respectively (Table 3).

The dry matter content, the leaf mass, and the leaf/culm ratio were not affected ( $P > 0.05$ ) by the use of lime and biochar (Table 4). Panicle mass was influenced ( $P < 0.05$ ) by the doses of lime and biochar, with higher values being observed with the application of 2.5 and 12.5 t ha<sup>-1</sup>, respectively (Table 4). Culm mass and forage mass were only influenced ( $P < 0.05$ ) by the application of lime, showing the highest values with the use of 2.5 t ha<sup>-1</sup>.

## DISCUSSION

The perceived effects of proper use of lime include, in addition to correcting soil acidity, stimulating microbial activity, improving symbiotic N fixation by legumes and increasing the availability of

most nutrients for plants (SOMAVILLA et al., 2021). Conversely the use of biochar as a soil conditioner, improving soil pH, CEC, organic matter and nitrate retention, in addition to N uptake by the plant, improving the efficiency of nitrogen fertilizer use (QAYYUM et al., 2019). These factors can increase the productivity of crop-growing and forage crops (NGUYEN et al., 2021). In the present study, liming and/or the use of biochar promoted changes in pH and concentrations of Ca and P in the soil. In addition, there was an increase in V% of 3.0 percentage points.

The increase of about 21% in pH for the dose of 12.5 t ha<sup>-1</sup> in relation to not using biochar (0 t ha<sup>-1</sup>) demonstrated its potential to reduce soil acidity. This result is due to an increase in electrical conductivity due to the release of ions bound to the surface of the biochar (JEFFERY et al., 2011; QAYYUM et al., 2019). The increase in soil pH with the addition of Biochar is well reported in the literature (DAI et al., 2014; NGUYEN et al., 2021). However, the magnitude of the change in this parameter can be determined by its relative difference between the tested soil and the added biochar. Conversely, it is known that lime is one of the main inputs recommended for correcting soil acidity; although, the dose used may have been insufficient for this effect to be verified.

The high phosphorus content in the biochar (Figure 1) explains the increase of this nutrient in the soil when using this conditioner. Biochar has high P contents, varying according to the origin of the biomass and the pyrolysis conditions (BRIDGWATER, 2012). This nutrient is made available more slowly through biochar, considering its slow mineralization rate given by the high C:N ratio, making it more stable in the soil-plant system (LEHMANN & JOSEPH, 2009). Another explanation may be related to the increase in soil pH promoted by biochar. This effect can lead to an increase in P availability due to the reduction of its fixation by iron and aluminum oxides at low pH (NGUYEN et al., 2021).

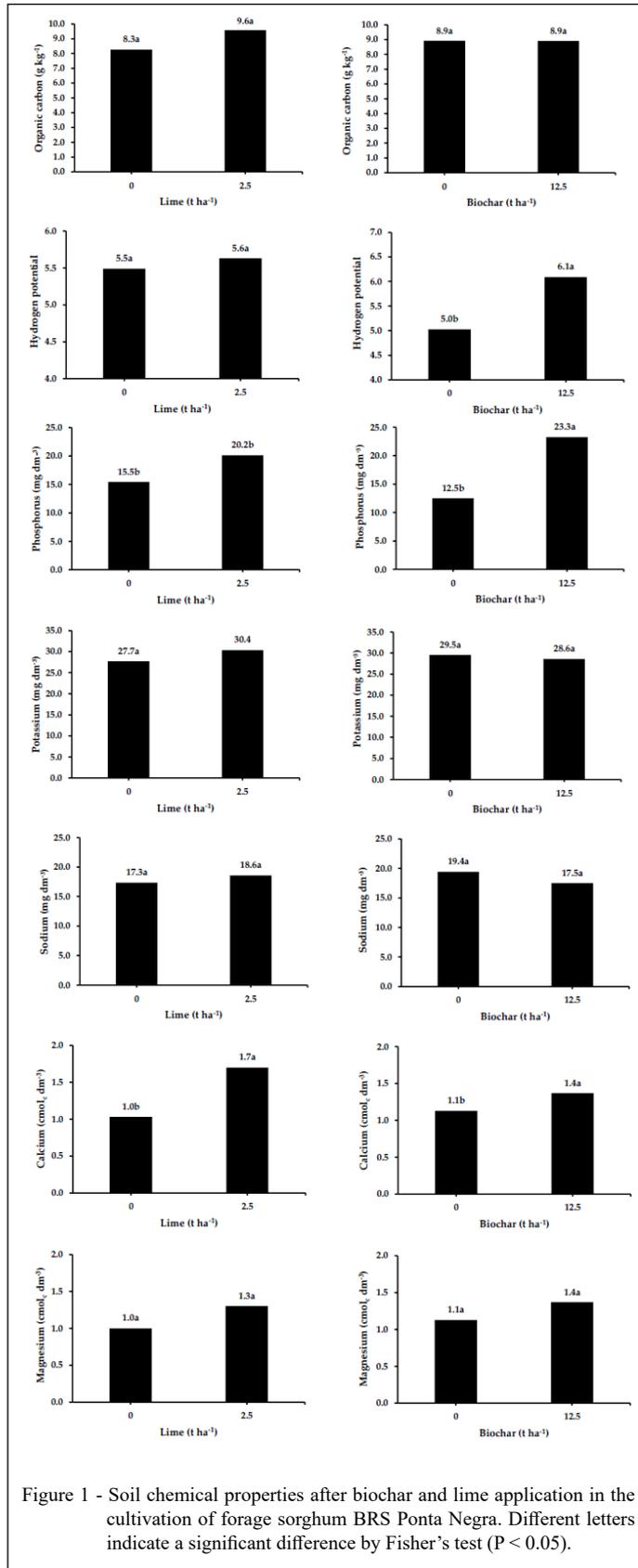


Figure 1 - Soil chemical properties after biochar and lime application in the cultivation of forage sorghum BRS Ponta Negra. Different letters indicate a significant difference by Fisher's test ( $P < 0.05$ ).

Table 3 - Growth parameters of sorghum grown under levels of lime and biochar.

Variables	-----Lime (t ha <sup>-1</sup> )-----		-----Biochar (t ha <sup>-1</sup> )-----		--CV (%)--
	0	2.5	0	12.5	
Plant height (m)	1.63 <sup>a</sup>	1.70 <sup>a</sup>	1.66 <sup>a</sup>	1.67 <sup>a</sup>	9.75
Culm diameter (mm)	13.47 <sup>b</sup>	15.25 <sup>a</sup>	14.33 <sup>a</sup>	14.39 <sup>a</sup>	12.60
Tiller density (tiller m <sup>-2</sup> )	25.03 <sup>a</sup>	25.09 <sup>a</sup>	25.65 <sup>a</sup>	24.46 <sup>a</sup>	17.63
Number of live leaves (leaves tiller <sup>-1</sup> )	7.40 <sup>b</sup>	8.63 <sup>a</sup>	8.03 <sup>a</sup>	7.91 <sup>a</sup>	10.66
Leaf length (cm)	68.93 <sup>a</sup>	75.63 <sup>a</sup>	70.63 <sup>a</sup>	73.69 <sup>a</sup>	10.91

Means followed by different letters in the row differ from each other by Fisher's test ( $P < 0.05$ ), within each source of variation. CV: coefficient of variation.

The increase in Ca concentrations with the use of liming can be easily explained by the presence of CaO in its composition, which contributed to the increase in the levels of Ca<sup>2+</sup> in the soil (FERNANDES et al., 2020a). Likewise, the addition of biochar may be responsible for the increase in soil Ca concentrations, as reported by CARVALHO et al. (2013) who observed a significant increase in soil Ca content as the dose of biochar was increased from 0 to 32 t ha<sup>-1</sup>.

The increase in panicle mass with the application of the inputs can be justified by the greater nutrient availability for panicle formation (FERNANDES et al., 2020a), especially calcium and phosphorus, which play a crucial role in grain development. REHMAN et al. (2018) also observed an increase in the growth and yield of rice and wheat grains when using biochar, a result that is also attributed by the authors to the greater nutrient availability in the soil. It is worth noting that, in this

type of forage, panicle mass has great relevance, considering that the higher the number of grains, the higher the concentrations of starch and soluble sugars, which are essential for proper silage fermentation (MORAES et al., 2013).

The greater culm thickness development contributed to a significant increase in the mass of this organ with the application of 2.5 t ha<sup>-1</sup> of lime. Thus, the increase in forage mass with lime application results from the increase in the mass of these two components. The high share of the culm in the total forage mass implied a low leaf/culm ratio. The values observed for this ratio were similar to those found by PARENTE et al. (2014) in a study with forage sorghum grown under phosphorus and nitrogen doses. It is worth mentioning that a high culm proportion reduces forage quality and may compromise consumption by animals. Therefore, younger ages and longer cutting lengths may favor

Table 4 - Productive parameters of sorghum grown under levels of lime and biochar.

Variables	-----Lime (t ha <sup>-1</sup> )-----		-----Biochar (t ha <sup>-1</sup> )-----		----CV (%)----
	0	2.5	0	12.5	
Dry matter content (%)	34.68 <sup>a</sup>	35.30 <sup>a</sup>	35.10 <sup>a</sup>	34.82 <sup>a</sup>	9.64
Forage mass (t ha <sup>-1</sup> of MS)	9.54 <sup>b</sup>	12.20 <sup>a</sup>	10.69 <sup>a</sup>	10.98 <sup>a</sup>	14.17
Leaf mass (t ha <sup>-1</sup> of MS)	1.92 <sup>a</sup>	2.06 <sup>a</sup>	2.00 <sup>a</sup>	1.98 <sup>a</sup>	13.78
Culm mass (t ha <sup>-1</sup> of MS)	6.42 <sup>b</sup>	7.50 <sup>a</sup>	7.31 <sup>a</sup>	6.49 <sup>a</sup>	9.42
Panicle mass (t ha <sup>-1</sup> of MS)	1.20 <sup>b</sup>	2.63 <sup>a</sup>	1.38 <sup>b</sup>	2.51 <sup>a</sup>	28.81
Leaf/culm ratio	0.28 <sup>a</sup>	0.30 <sup>a</sup>	0.27 <sup>a</sup>	0.31 <sup>a</sup>	12.85

Means followed by different letters in the row differ from each other by Fisher's test ( $P < 0.05$ ), within each source of variation. CV: coefficient of variation.

greater participation of leaves, providing better quality to the forage.

Thus, the tested hypothesis that the application of limestone associated with biochar improves the chemical attributes of the soil, promoting an increase in sorghum production, is partially corroborated with our results. Therefore, these results allow to outline strategies for the use of limestone and biochar for forage production in semiarid environments with sandy soils. Because, these materials improve some chemical attributes of the soil and the production of forage sorghum. However, in future research it is necessary to study other levels of limestone and biochar in sorghum cultivation in sandy soils. It is noteworthy that edaphoclimatic conditions can change the response patterns observed in this research. Therefore, research in other regions is essential. Furthermore, due to the slower release of nutrients into the soil by the biochar, the results could be more interesting for the next crop cycle. Thus, studies that assess the residual effect of biochar can bring additional information to this research.

## CONCLUSION

The use of biochar and lime improved soil chemical attributes, especially with regard to the supply of calcium, which increased the panicle mass of the sorghum. However, sorghum growth and total production were affected only by limestone use. The use of 2.5 t ha<sup>-1</sup> of lime resulted in an increase in forage production regardless of the use of biochar. However, the effect of biochar may be more interesting in the long term, given the residual effect of biochar.

## DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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## AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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