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Scientific Article

Effects of biochar on soil fertility and the morphometry and production of elephant grass cultivars

Biochar na fertilidade do solo, morfometria e produção de cultivares de capim elefante

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ABSTRACT - Among the various forage species used in ruminant feeding, elephant grass (*Pennisetum purpureum* Schum.) is notable as it is a perennial plant and has a high potential for dry matter production. The present study evaluated the performance of elephant grass cultivars and soil chemical characteristics under different biochar addition levels and at different evaluation times under irrigation in the dry season. The treatments were arranged in a factorial randomized complete block design (CBD) and analyzed in a split-plot design according to cultivar (BRS Capiaçu and BRS Kurumi) x biochar dose (0, 8, 16 and 24 t ha^{-1}); the subplots consisted of four evaluation times (71, 225, 335 and 447 days after application of biochar), with four replicates. The soil chemical characteristics were evaluated without inclusion of the time factor according to a CBD in a 2 x 4 factorial scheme, with 4 replications. The attributes analyzed were soil fertility, morphometry and elephant grass yield. The performance of the cultivars improved at 225 days (2nd evaluation) and 335 days (3rd evaluation) after biochar application. The biochar doses did not significantly increase morphometric attributes, cultivar productivity or soil fertility. The application of biochar did not improve the yield attributes or crude protein of elephant grass cultivars under the conditions of this study.

Keywords: *Pennisetum purpureum*. Soil conditioner. Soil fertility. Irrigation. Cation exchange capacity.

RESUMO - Entre as diversas espécies forrageiras utilizadas na alimentação de ruminantes, o capim elefante (*Pennisetum purpureum* Schum.) se destaca por ser perene e de elevado potencial de produção de matéria seca. Objetivou-se com o presente trabalho avaliar o desempenho de cultivares de capim elefante e características químicas do solo sob diferentes níveis de biochar e épocas de avaliação sob irrigação na época da seca. Os tratamentos foram dispostos em delineamento em blocos casualizados (DBC) em esquema fatorial, e analisado em parcelas subdivididas, sendo as parcelas, as cultivares BRS Capiaçu e BRS Kurumi x doses de biochar (0, 8, 16 e 24 t ha^{-1}), e as subparcelas, quatro épocas de avaliação (71, 225, 335 e 447 dias após aplicação do biochar), com quatro repetições. Para avaliação de características químicas do solo o delineamento não teve o fator épocas, sendo analisado em DBC em fatorial 2 x 4, com 4 repetições. Os atributos analisados foram a fertilidade de solo, a morfometria e o rendimento de capim elefante. Nas avaliações aos 225 (2ª) e 335 (3ª) dias após aplicação de biochar houve melhor desempenho das cultivares. As doses de biochar não aumentaram significativamente atributos morfométricos, de produtividade das cultivares e fertilidade do solo. A aplicação de biochar não melhora os atributos de produtividade e proteína bruta das cultivares de capim elefante nas condições deste estudo.

Palavras-chave: *Pennisetum purpureum*. Condicionador de solo. Fertilidade do solo. Irrigação. Capacidade de troca catiônica.

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INTRODUCTION

Population growth has increased the demand for food, and cattle ranching is a major source of animal protein. The principal and least expensive feeds for ruminants are grasses derived from forage plants capable of producing large volumes of biomass with high nutritional and low fiber contents, which are selected to achieve high animal productivity (SAMPAIO et al., 2017).

The number of tropical forage cultivars has increased greatly in recent decades, and they have diverse agronomic, morphological and physiological traits. Among the various species used as ruminant feeds, elephant grass (*Pennisetum purpureum* Schum.) is important because it is a perennial forage species with high potential for dry matter production and is cultivated in all tropical and subtropical regions (PEREIRA et al., 2008). Elephant grass has many versatile uses and can be supplied to animals directly in a trough or as silage and grazing (PEREIRA et al., 2021), and it is also considered a very promising species for energy production from biomass (FLORES et al., 2012).

Among elephant grass cultivars, the cultivar BRS Capiaçu was developed to meet the requirements for cutting (green cut) and silage, boasting high production potential, good nutritive value and ease of mechanization. Another notable cultivar is BRS Kurumi, which is characterized by its small size and suitability for grazing, with high nutritive value and ease of handling compared to other cultivars of elephant grass (PEREIRA et al., 2021).

The most influential factors on animal productivity in tropical regions are variations in forage quality and production due to irregular rainfall. The use of irrigated grasses is a way to alleviate the problem of variations in animal performance throughout the year, and elephant grass (*Pennisetum purpureum* Schum.) is an important forage species among grasses (ALVES, 2017).

Another factor is the low fertility of the soils. Tropical soils, especially cerrado soils, are mostly characterized by high weathering, low natural fertility, acidity, low cation exchange capacity, low base saturation and high aluminum saturation (SOUSA; LOBATO, 2004; OLIVEIRA; JACOMINE; COUTO, 2017).

Fertility management requires strategies that increase the technical and economic efficiency of the production systems used (BENEDUZZI et al., 2022). One of the ecologically viable alternatives to increase agricultural production is the use of resources that are already available or whose transformation into available forms causes little impact on the environment. In this sense, biochar is a notable soil conditioner. According to Alkharabsheh et al. (2021), biochar or black carbon is a solid organic material that can be obtained from different agricultural or organic products, such as wood, crop residues, animal manure and sewage sludge, by means of pyrolysis under a wide temperature range (300–1000 °C) and under partial or anaerobic conditions.

Biochar can improve soil fertility by increasing negative charges (cation exchange capacity, CEC), increasing pH, and consequently reducing Al^{3+} and phosphorus fixation, as well as by improving soil physical and biological properties. In addition, biochar presents good potential for mitigating climate change (carbon sequestration) and remediating soils contaminated by heavy metals and other pollutants (ADEYEMI; IDOWU, 2017; SILVA et al., 2017).

Under the hypothesis that biochar can improve soil fertility and thus the productivity of elephant grass, the present study aimed to evaluate the performance of elephant grass cultivars and soil chemical characteristics under different levels of biochar addition at different evaluation times under irrigation in the dry season.

MATERIALS AND METHODS

The experiment was conducted from March 2021 to June 2022 at the Instituto Federal Goiano - Campus Ceres (latitude 15°20'56.06” S, longitude 49°36'19.85” W and altitude 571 m).

In the experimental period, the months of September and October 2021, June to July 2021 and May 2022 showed extreme temperature values. Total rainfall was 2,038.34 mm from March 2021 to June 2022. According to Jacques (1994), the development of elephant grass is affected at temperatures above 35 °C and below 10 °C.

The experimental design was a randomized complete block design (CBD) in a factorial scheme (2 cultivars x 4 doses of biochar), and split plots were implemented, with the plots corresponding to cultivars x doses and the subplots corresponding to the four evaluation times, with four replications. The cultivars tested were BRS Capiaçu and BRS Kurumi; the biochar doses were 0, 8, 16 and 24 t ha^{-1}; and the evaluation times were 71, 225, 335 and 447 days after the application of biochar. For the evaluation of soil chemical characteristics, the time factor was not included, and analyses were performed according the original design, that is, CBD in a 4 x 2 factorial scheme with 4 replications.

The plots containing the forage cultivars BRS Capiaçu and BRS Kurumi were implemented in 2019 with dimensions of 3 x 3 m each, with 4 rows spaced 1 m apart. The biochar was produced from charcoal from fully reforested eucalyptus wood and presented the following chemical characteristics: pH (in H_2O) 6.8; organic matter: 1.95 g dm^{-3}; calcium: 7.0 $cmol_c$ dm^{-3}; magnesium: 2.1 $cmol_c$ dm^{-3}; potassium: 764.5 mg dm^{-3}; phosphorus: 78.7 mg dm^{-3}; base saturation: 85.9%. The biochar was applied locally and incorporated (10 cm) next to the rows of tussocks, which were planted in two linear meters of three rows of each plot, except in the treatment without biochar. The borders were discarded, and only the central line (at the 1.0 m center) of each experimental plot was evaluated. The biochar doses were defined based on the study by Silva et al. (2011).

The soil in the area was classified as eutrophic red nitosol according to Santos et al. (2018). In January 2021, sampling was performed in each plot in the 0-0.20 m layer with 4 individual samples per composite sample to determine soil fertility. The following physicochemical characteristics (means) were obtained: 525, 167 and 308 g kg^{-1} of clay, silt and sand, respectively; pH (H_2O): 5.6; organic matter: 26.68 g dm^{-3}; calcium: 5.87 cmo $_c$ dm^{-3}; magnesium: 2.45 $cmol_c$ dm^{-3}; potassium: 0.20 $cmol_c$ dm^{-3}; phosphorus: 6.18 mg dm^{-3}; base saturation: 73.3%.

Maintenance fertilization was performed immediately after each standardization cut throughout the experiment. These cuts were made close to the soil on the dates shown in Table 1.

Table 1. Cutting and evaluation dates, regrowth period and biochar incubation time between evaluations.

Evaluation	Standardization cut date	Evaluation date	Regrowth period (days)	Biochar incubation time (days)
1	03/18/2021	06/03/2021	77	71
2	08/02/2021	11/04/2021	94	225
3	12/07/2021	02/22/2022	77	335
4	02/23/2022	06/14/2022	111	447

After the first standardization cut, the cultivar BRS Capiaçu was fertilized with 75, 90 and 75 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, using the formulation (N:K) 20-00-20 and single superphosphate. After 30 days, 75 kg ha^{-1} N (urea) and 105 kg ha^{-1} K_2O (KCl) were applied. For BRS Kurumi, 50, 90 and 50 kg ha^{-1} of N, P_2O_5 and K_2O were applied, respectively, using 20-00-20 and simple superphosphate, and after one month, 50 and 70 kg ha^{-1} of N and K_2O, respectively, were applied via urea and KCl. For the second standardization cut, fertilization consisted of the application of 75 and 50 kg ha^{-1} N-urea and, after 1 month, 60 and 40 kg ha^{-1} of K_2O-KCl for the cultivars BRS Capiaçu and BRS Kurumi, respectively. The fertilization schemes for the third and fourth cuts followed the doses used in the first. All fertilizations were performed according to the guidelines of Sousa and Lobato (2004) for forage grass cultivation areas considering nutrient exports of 9.95 and 6.56 t ha^{-1} cut $^{-1}$ dry mass for BRS Capiaçu and BRS Kurumi, respectively.

Irrigation was managed according to climate conditions; daily evaporimetric readings were performed in a Class A tank located at the meteorological station of IF Goiano - Campus Ceres. A localized irrigation method (drip irrigation) was used with perforated tape placed on the soil surface in the row of tussocks with drippers spaced 20 cm apart, with a working pressure of 1 bar and a flow rate of 1.6 L h^{-1} per dripper. The mean drip evapotranspiration (Kc=0.8 and wetted area fraction=0.3) was 1.03 mm day^{-1}, the mean applied water depth was 4.8 mm irrigation^{-1}, and the mean irrigation interval was 4 days for all treatments, totaling 224.6 mm applied in the experimental period. At the end of the second and third evaluations, there was no need for irrigation due to the rainfall in the preceding period.

Evaluations were performed when the plants reached approximately 2 m in height for the cultivar BRS Capiaçu and 0.80 m for the cultivar BRS Kurumi based on the flag leaf. After cutting the plants in the useful area of each plot close to the ground, the material was weighed, the tillers were counted, and 10 subsamples were randomly separated to determine the other attributes. Soil sampling to evaluate the effect of biochar application was performed in the 0 to 0.2 m layer at the end of the experimental period (June 2022), with a composite sample (3 subsamples) for each plot at 0 to 0.2 m, and the data were subjected to statistical analysis.

The attributes evaluated were as follows: stem diameter (SD), determined using a digital caliper; plant height (PH), height to the flag leaf determined using a tape measure at 5 points within the useful area to calculate the plot mean; number of tillers (NT); number of leaves (NL); dry matter content (DMC), determined after previous determination of fresh mass at 65 °C for 72 h under forced ventilation, grinding to 1 mm in a Willye mill and humidity correction at 105 °C for 24 h; green leaf yield (GLY); green mass yield (GMY); dry mass productivity (DMP); leaf-stem ratio (L/S), determined with fresh material; and crude protein (CP), analyzed according to the *Kjeldahl* method (YASUHARA; NOKIHARA, 2001). To evaluate the effect of biochar application, the following soil parameters were analyzed at the end of the experiment: pH in water, soil organic matter (SOM), calcium, magnesium, aluminum, potential acidity (H+Al), phosphorus, potassium, cation exchange capacity (CEC), base saturation (V%) and Al saturation (m), according to Teixeira et al. (2017).

The data were subjected to analysis of variance (ANOVA), Tukey's test for the means was applied to assess significance among the treatments, and regression analysis was performed for doses and evaluation times using Sisvar software.

RESULTS AND DISCUSSION

Analysis of the morphometric and production attributes of elephant grass (Table 2) revealed that PH was the only response variable affected by biochar dose ($p<0.01$). The attributes NT, NL, DM, DMC, DMP, L/S and GMP ($p<0.05$) were affected by the cultivar ($p<0.01$) regardless of biochar dose; DMP responded only to cultivar ($p<0.01$) and dose ($p<0.05$), and SD had no effect among the treatments tested. In Table 2, it can also be seen that for all attributes, except SD, NT, GMP and L/S, the response of the cultivar depended on the evaluation time. All attributes were influenced in isolation by season, and there was no effect of the interactions of biochar dose x season or dose x cultivar x season.

Table 2. Summary of the analysis of variance (mean square) results for the morphometric attributes and yield of elephant grass cultivars under different biochar doses and evaluation times.

VF	DF	SD	PH	NT	NL	DMC
Dose	3	10.74^{ns}	593.70*	90.02^{ns}	1.95^{ns}	0.0004^{ns}
Cultivar (CV)	1	18.42 ^{ns}	165960.01**	7626.13**	125.41**	0.0420**
Dose x CV	3	12.65 ^{ns}	970.57**	22.40^{ns}	1.05^{ns}	0.0006^{ns}
Season (SE)	3	223.10*	28769.26**	2808.0**	122.15**	0.0959**
Dose x SE	9	4.34 ^{ns}	239.40^{ns}	176.47^{ns}	1.28^{ns}	0.0006^{ns}
CV x SE	3	16.43 ^{ns}	2274.34**	595.27^{ns}	8.02*	0.0032**
Dose x CV x SE	9	11.77 ^{ns}	408.57^{ns}	205.04^{ns}	2.01^{ns}	0.0004^{ns}
CV% plot	-	23.06	8.09	24.17	19.76	10.90
CV% subplot	-	20.19	16.09	31.53	15.44	13.52
VF	**DF**	**GLP**	**GMP**	**DMP**	**S/L**	
Dose	3	66.54^{ns}	1060.04^{ns}	36.80*	0.125ns	
Cultivar (CV)	1	150.21^{ns}	3671.32*	409.32**	4.444**	
Dose x CV	3	75.01^{ns}	839.29^{ns}	19.09ns	0.001ns	
Season (SE)	3	2039.24*	16185.00*	218.92**	2.306**	
Dose x SE	9	22.92^{ns}	243.03^{ns}	10.18ns	0.044ns	
CV x SE	3	174.82*	1068.66^{ns}	74.54**	0.164ns	
Dose x CV x SE	9	32.30^{ns}	385.09^{ns}	13.87ns	0.042ns	
CV% plot	-	34.73	39.67	33.84	23.02	
CV% subplot	-	39.43	41.20	41.70	31.20	

VF – Variation factor. DF – degree of freedom. **Significant at 1%, *significant at 5% and ^{ns} not significant.

PH varied as a function of time, probably because climatic factors that influence plant growth varied (SILVA, SBRISSIA; PEREIRA, 2015) throughout the year, so the cubic regression model best represented the data (Figure 2).

The highest growth rate occurred at the third evaluation (335 days), when the climatic conditions in October/November or spring/summer in the central-west region are considered optimal for forage growth (EUCLIDES et al., 2014; SILVA, SBRISSIA; PEREIRA, 2015).

At the fourth evaluation (447 days after biochar application), the plants grew (PH) less, which may be associated with the unfavorable climatic conditions of the period, such as the lower temperatures from April onwards and the decreasing photoperiod (Figure 1) due to the proximity of the winter solstice (June 21). According to Moreno et al. (2014), the high yield potential of C4 plants in tropical regions depends on high temperatures and other conditions, such as adequate light and humidity, that stimulate plant growth.

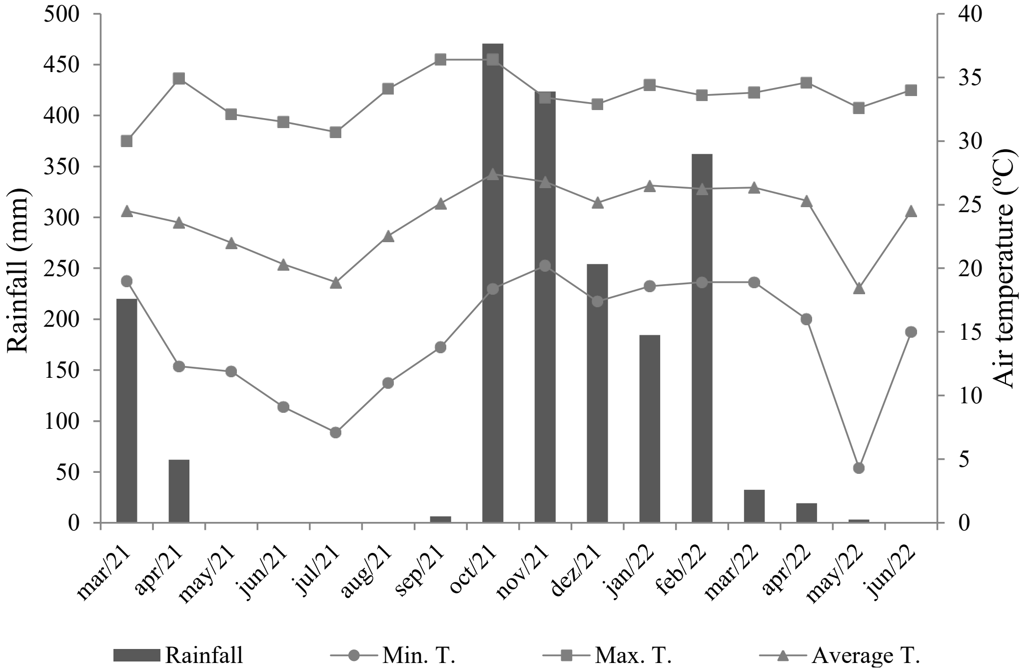

Figure 1. Rainfall and minimum, maximum and average temperatures during the experiment at the Goiano Federal Institute - Ceres Campus, Ceres, Goiás, Brazil.

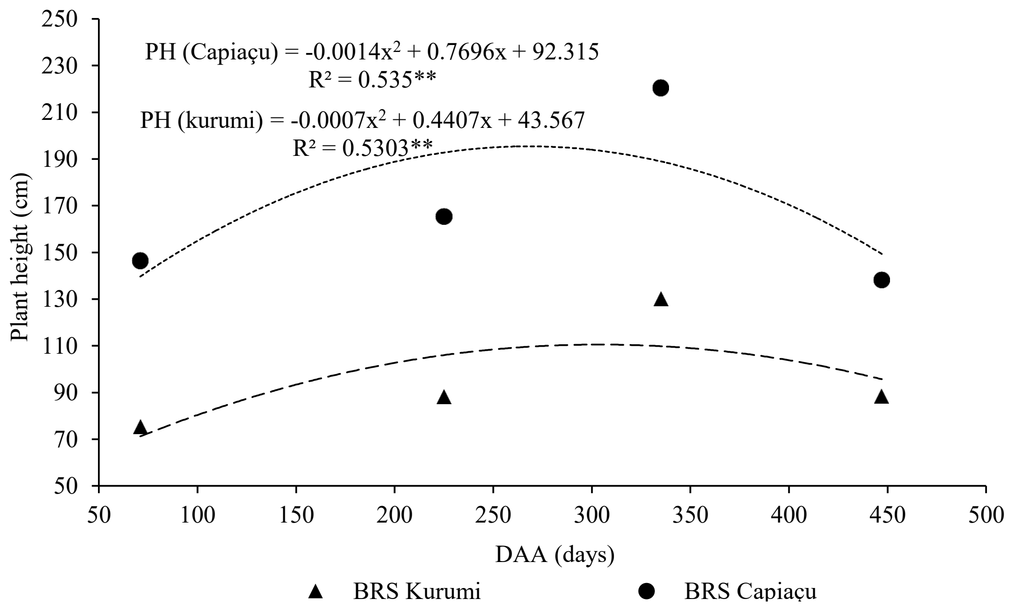

Figure 2. Plant height of the elephant grass cultivars BRS Kurumi and BRS Capiaçu as a function of the number of days after biochar application (days after application - DAA)

Regarding NL, the cubic model fit the data for the two cultivars (Figure 3), with the same behavior as PH. This may have occurred due to the correlation between PH and NL (r = 0.68**, BRS Kurumi); i.e., the greater the height is, the greater the number of internodes and the greater the emission of new leaves, which varies throughout the year. However, the best results in the third evaluation and the worst results in the fourth evaluation show that the moisture factor (irrigation) alone did not completely eliminate seasonality compared to the other evaluated seasons, which agrees with the study by Lopes et al. (2005) on irrigated elephant grass fertilized with nitrogen and potassium.

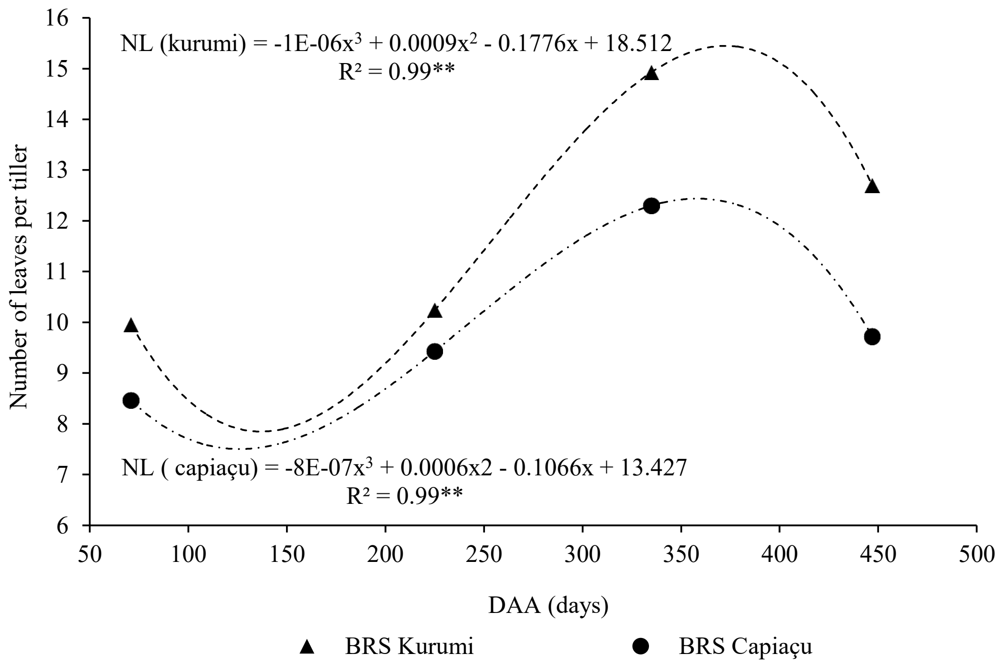

Figure 3. Number of leaves per tiller (number) of the elephant grass cultivars BRS Kurumi and BRS Capiaçu as a function of the number of days after biochar application (days after application - DAA)

The curves of dry matter content (DMC) versus evaluation time (Figure 4) for the two cultivars fit the quadratic model. The cultivar BRS Capiaçu exhibited higher DMC values than BRS Kurumi. This can be explained by the distinct characteristics of the two cultivars, where BRS Kurumi is shorter and has a lower fiber content, while BRS Capiaçu is tall with a higher stem weight. Although the weight of the leaves does not differ much, the weight of the stalks is the main factor responsible for the total weight (RIBEIRO et al., 2009).

The lowest DMC was observed at 195 days (2nd evaluation) after the application of biochar for the cultivar BRS Capiaçu, with 15.4%. For the cultivar BRS Kurumi, the lowest DMC was reached at 271 days, with a value of 9.4%.

The lower DMC values at 2nd evaluation may be because the plants reached the predefined height at a time of high stimulus for growth and thus had a higher water content and, consequently, lower matter content, which agrees with the study by Santos, Silva and Queiroz Filho (2001) on purple elephant grass. At the last evaluation, the opposite may have occurred, as there was a longer interval (111 days) to reach cutting height due to the lower growth rate attributed to the decrease in temperatures in May 2022.

According to Pereira et al. (2021), after 90 days of regrowth, the cultivar BRS Capiaçu tends to reach a DM content of 18 to 20%. In the study by Leal (2019), the cultivar BRS Kurumi reached 16% DM at 75 days in the rainy season. The results obtained in the present study are relatively consistent with the above studies, except at the second and fourth evaluations, which had lower and higher DMCs, respectively, probably influenced by climatic factors. At the second evaluation, the increase in temperature and the beginning of the rainy season with high rainfall volume in November 2021 (see Figure 1 and Table 1) may have delayed the time of maximum DM accumulation.

Retore et al. (2021) found that the DM content of BRS Capiaçu grass increased with increasing cutting age because as the plant matures, there is a decrease in the proportion of leaves in relation to stalks and, consequently, an increase in DM content.

In weed management, the cutting age influences the yield and quality. The longer the interval between cuts is, the greater the amount of DM, but the lower the nutritive value of the forage (MONÇÃO et al., 2019).

Regarding GLY, BRS Capiaçu presented lower values than BRS Kurumi. The GLY values of BRS Kurumi and BRS Capiaçu reached a maximum during the second evaluation (94 days of regrowth) at 255 and 278 days, with 29.57 and 27.44 t ha^{-1}, respectively. From these points on, there was a reduction in GLP for both cultivars (Figure 5). Retore et al. (2021) also observed a higher proportion of leaves for BRS Capiaçu plants managed with cutting intervals of 90 days.

This opposite behavior to that of DMC may be due to the interval between cuts, as more green material than senescent material is present when the regrowth time to reach the predefined cutting height is shorter. The observed behavior can also be attributed to the climatic characteristics of the evaluation period, which had higher temperatures and a longer photoperiod. At the last evaluation, in addition to leaf senescence being higher due to the longer regrowth period, the field was attacked by spittlebug (*Deois flavopicta*).

The productivity of leaves (or blades) has drawn the attention of technicians and researchers aiming to optimize pasture management with appropriate modification of the stocking rate (BARBERO et al., 2014). According to Euclides et al. (2014), when an animal consumes more leaves and fewer stalks, it ingests forage of better nutritional quality, resulting in higher animal performance. This may guide management strategies to favor a shorter period between standardization cuts of forage to maximize the consumption of grass tips (PARIS et al., 2016).

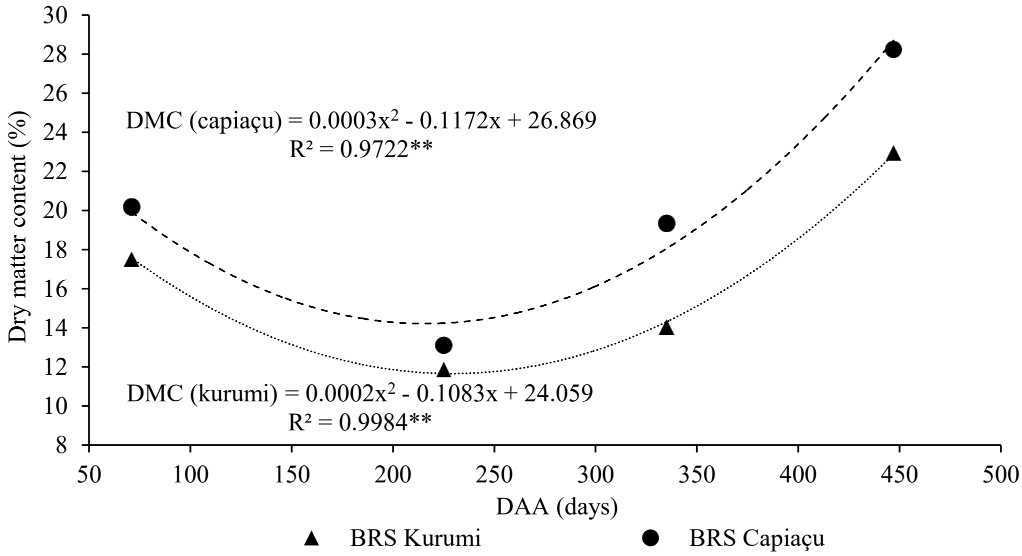

Figure 4. Dry matter content of elephant grass cultivars BRS Kurumi and BRS Capiaçu as a function of the number of days after biochar application (days after application - DAA).

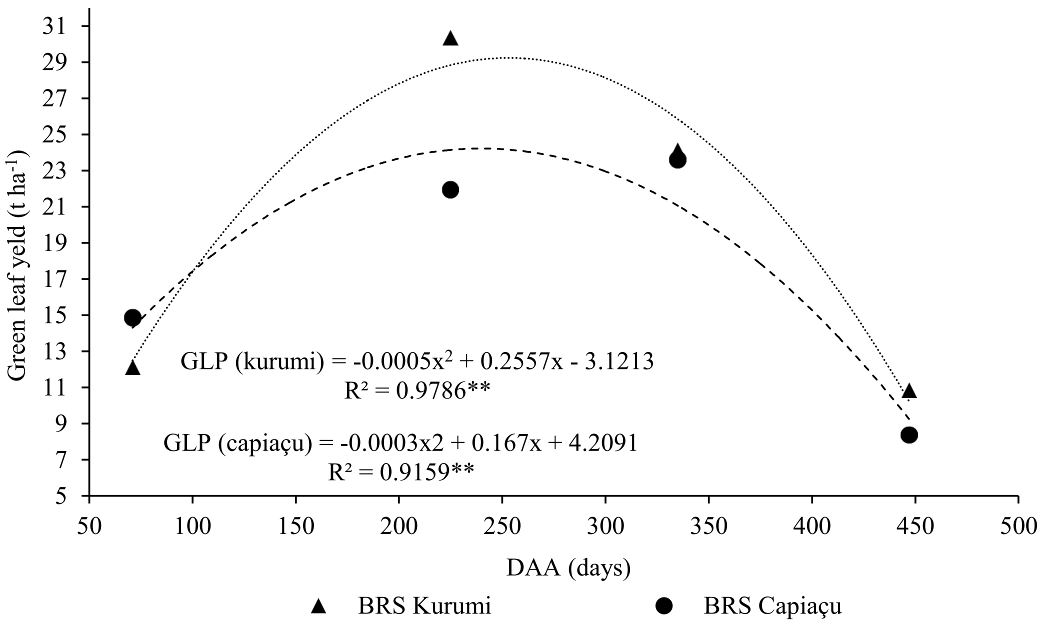

Figure 5. Green leaf productivity of the elephant grass cultivars BRS Kurumi and BRS Capiaçu as a function of the number of days after biochar application (days after application - DAA).

The dry mass productivity (DMP) (Figure 6) of BRS Capiaçu also fluctuated as a function of time. The evaluations at the transition between the dry/rainy season and the rainy season showed better results, especially at the second evaluation, eleven months after biochar application. For the cultivar BRS Kurumi, the DMP was lower than that for Capiaçu, but it was more stable throughout the experimental period. As in other attributes of this study, DMP showed an increasing trend over time, reaching the maximum value at 281.9 days.

In the cultivar x dose interaction for PH (Figure 7), the values for BRS Capiaçu decreased with increasing biochar dose, with a reduction of 13.8% between the control and the treatment with the highest dose (24 t ha^{-1}). BRS Kurumi had no significant fit to models up to the 3rd order.

Petter et al. (2012), when testing the effect of various biochar concentrations on the production of *Eucalyptus citriodora* seedlings, did not observe a significant effect of biochar application on PH. However, for *E. urophylla*, concentrations of 30% and 60% v/v resulted in the lowest PH values.

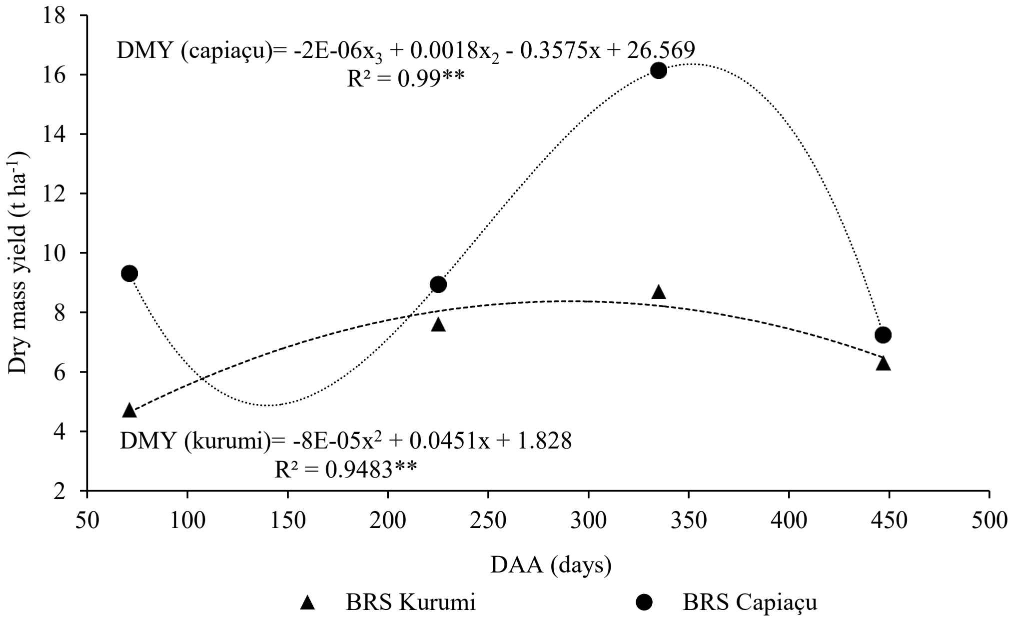

Figure 6. Dry mass yield of the elephant grass cultivars BRS Kurumi and BRS Capiaçu as a function of the number of days after biochar application (days after application - DAA).

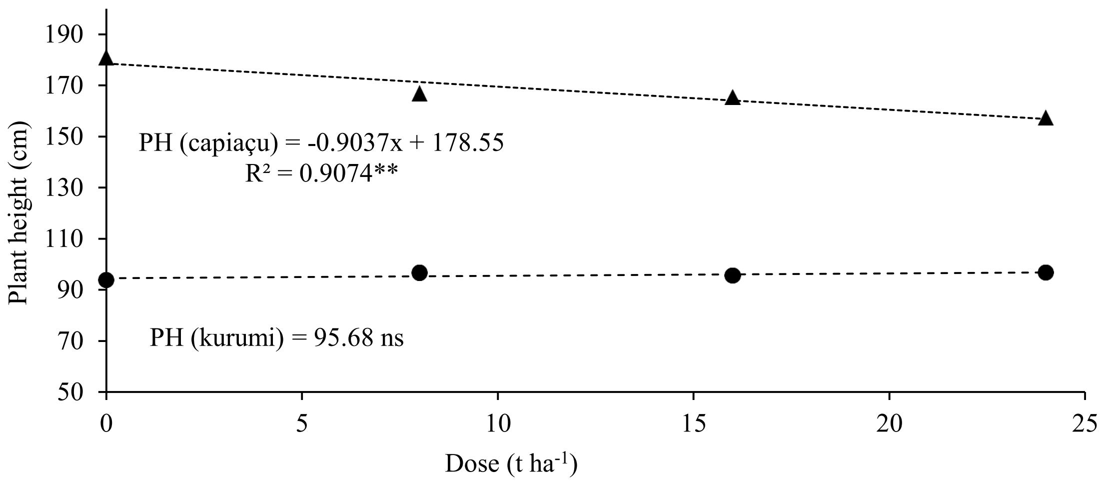

Figure 7. Plant height of elephant grass cultivars BRS Kurumi and BRS Capiaçu as a function of biochar dose.

Analyzing the isolated effect of biochar dose revealed that DMP (Figure 8) decreased by 28.8% between the control and the treatment with the highest dose. This may have occurred due to the hydrophobic effect of biochar, which repels moisture near the roots due to its aromatic structure, which may be influenced by the original structure of the wood used to prepare the biochar (GONDIM et al., 2018), as well as the aging time. The soil incubation time was not sufficient for the reactions to occur and produce positive results (ANDRADE et al., 2015).

Zimmerman, Gao and Ahn (2011) found that the addition of biochar produced from different raw materials at different temperatures clearly affected the soil. This was attributed by the authors to the decomposition (mineralization) of the biochar itself, as measured by the evolution of CO2, as well as to interactive effects with the soil. The authors highlighted the importance of the time required for the soil+biochar mixture to stabilize, the so-called biochar maturation process.

Some authors found a short-term effect of the addition of biochar on the yield of several crops (AGEGNEHU; NELSON; BIRD, 2016; GONZAGA et al., 2018; ZHANG et al., 2016). Major et al. (2010) evaluated the effect of biochar (from commercial wood) at doses of 0, 8 and 20 Mg ha^{-1} on cation retention and yield of soybean and corn in an Oxisol in Colombia over four years. An increase in productivity was observed from the second year onwards, and the greatest difference between the biochar treatments and the control was observed in the fourth year after application. The productivity improvements were mainly attributed to the increases in pH and nutrient retention in the soil.

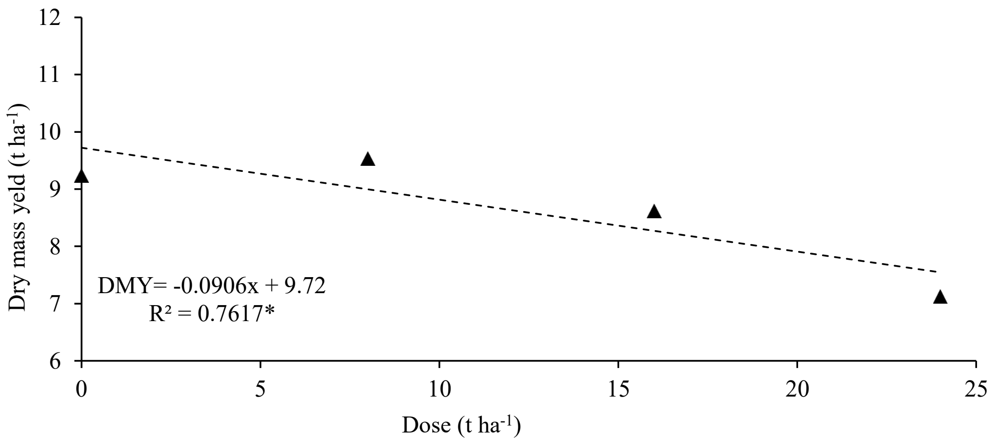

Figure 8. Drymass yield of the elephant grass cultivar BRS Capiaçu as a function of biochar dose.

Table 3 shows the results of Tukey's test for mean growth attributes for the single factors cultivar and dose (not significant). There was a difference between cultivars for all attributes, except for SD and GLP. The cultivar BRS Kurumi, despite being small and having lower green mass productivity than BRS Capiaçu, had notable results for some attributes, such as NT, S/L ratio, GLP and CP, which, according to Pereira et al. (2021), are favorable factors for forage quality.

Regarding soil fertility parameters (Table 4), only CEC showed an effect of the cultivar x biochar dose interaction ($p < 0.05$); however, the models were not significant until the 3rd order. For the isolated factors, cultivar had a significant effect only on K (mg dm^{-3}) ($p<0.05$).

Although not significant, the P content in the soil increased by 66.4% with the addition of 16 t ha^{-1} biochar compared to the control. Madari et al. (2009) also observed an increase in P levels with biochar application in upland rice cultivation in clayey soil.

Table 3. Mean values of growth attributes and production of elephant grass cultivars under various biochar doses.

CV	SD		NT **		NL **		DMC **		GLP	
	-----------cm-----------		-		-		-----------%-----------		-----------t ha^{-1}-----------	
Kurumi	11.97a		59.97a		11.96a		16.60b		19.36a	
Capiaçu	12.73a		44.53b		9.98b		20.22a		17.19a	
DOSE	BRS Kurumi	BRS Capiaçu	BRS Kurumi	BRS Capiaçu	BRS Kurumi	BRS Capiaçu	BRS Kurumi	BRS Capiaçu	BRS Kurumi	BRS Capiaçu
0	11.84	14.07	59.81	45.63	11.86	10.21	0.17	0.20	18.22	19.05
8	12.28	12.93	57.63	43.75	12.18	10.4	0.17	0.20	22.16	17.22
16	11.77	12.75	59.38	43	11.79	9.77	0.16	0.20	18.46	18.57
24	12.01	11.19	63.06	45.75	12.01	9.53	0.16	0.21	18.59	13.93

CV	GMP *		S/L **		CP **	
	---------------------t ha^{-1}---------------------		-		-----------------------%-----------------------	
Kurumi	45.03b		1.22a		8.89a	
Capiaçu	55.74a		0.84b		8.42b	
DOSE	BRS Kurumi	BRS Capiaçu	BRS Kurumi	BRS Capiaçu	BRS Kurumi	BRS Capiaçu
0	42.82	63.93	1.16	0.81	8.62	8.50
8	53.24	55.63	1.19	0.81	8.94	8.50
16	42.87	60.77	1.21	0.83	8.94	8.25
24	41.18	42.63	1.31	0.94	9.06	8.44

Means in the columns were compared by Tukey's test. ANOVA significance: ** $p<0.01$; * $p<0.05$.

Table 4. Mean values of pH, soil organic matter (SOM), Ca, Mg, K, H+Al, Al, CEC, K ppm, P, V and %m determined in routine analysis 472 days after the application of different doses of biochar in cultivars of elephant grass.

	pH	SOM	Ca	Mg	K	H+Al
	-	g kg^{-1}	------------------------------$cmol_c$ dm^{-3}------------------------------			
BRS Kurumi	5.66a	25.98a	6.86a	2.29a	0.11a	2.68a
BRS Capiaçu	5.68a	26.67a	6.94a	2.57a	0.14a	3.20a
Dose (t ha^{-1})						
0	5.73	27.62	6.56	2.39	0.14	2.78
8	5.71	25.94	7.25	2.51	0.10	2.88
16	5.61	26.42	6.61	2.09	0.14	3.01
24	5.62	25.30	7.18	2.72	0.13	3.10
	Al	CEC	K ppm	Q	V	%m
	-----------------$cmol_c$ dm^{-3}-----------------		-------------mg dm^{-3}-------------		--------------%--------------	
BRS Kurumi	0.17a	12.28a	42.39b*	9.09a	73.82a	1.45a
BRS Capiaçu	0.19a	12.50a	57.46a	9.59a	77.83a	1.74a
Dose (t ha^{-1})						
0	0.16	11.86	58.55	7.45	75.62	1.62
8	0.19	12.72	37.30	7.88	77.20	1.75
16	0.20	11.88	54.86	12.39	74.47	1.69
24	0.16	13.10	48.99	9.64	76.02	1.32

Means in the columns were compared by Tukey's test. ANOVA significance: * $p<0.05$.

There were no significant changes in organic matter concentration with the application of biochar, which may be directly linked to the short evaluation period, and additional studies should be conducted.

It was also observed that CEC increased by 10.4% with the application of 24 t ha^{-1} biochar compared to the zero dose. The surface charge characteristics and their development over time will determine the long-term effect on soil aggregation. After some time, biochar usually has a high CEC, which enhances its potential to act as a binding agent of organic matter and nutrients. The high surface area of the biochar may lead to increased water retention, but the effect will depend on the soil texture (KARHU et al., 2011).

CONCLUSIONS

Biochar dose influences the plant height of the elephant grass cultivars BRS Capiaçu and BRS Kurumi. The morphometric and yield attributes of the studied cultivars are affected only by the cultivar type.

The response of the cultivars depends on the time after biochar application. The yield and crude protein did not improve with the application of biochar under the conditions of this study.

The eucalyptus biochar used generally provided a smaller-than-expected effect on soil fertility and elephant grass performance and should be studied with longer reaction times. It is suggested that the biochar be thoroughly mixed in the planting furrow before planting the crop.

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REFERENCES

ADEYEMI, T. O. A.; IDOWU, O. D. Biochar: promoting crop yield, improving soil fertility, mitigating climate change and restoring polluted soils. **World News of Natural Sciences**, 8: 27-36, 2017.

AGEGNEHU, G.; NELSON, P. N.; BIRD, M. I. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. **Soil and Tillage Research**, 160: 1-13, 2016.

ALKHARABSHEH, H. M. et al. Biochar and its broad impacts in soil quality and fertility, nutrient leaching and crop productivity: a review. **Agronomy**, 11, 1-29, 2021.

ANDRADE, C. A. et al. Mineralização e efeitos de biocarvão de cama de frango sobre a capacidade de troca catiônica do solo**. Pesquisa Agropecuária Brasileira**, 50: 407-416, 2015.

ALVES, F. G. S. **Características morfogênicas, estruturais, produção e composição química de capim-elefante cv. Carajás adubado com ureia convencional e protegida**. 2017. 52 f. Dissertação (Mestrado em Zootecnia: Área de Concentração: Nutrição Animal e Forragicultura) – Universidade Federal do Ceará, Fortaleza, 2017.

BARBERO, R. P. et al. Desempenho de novilhos de corte em pastos de capim-tanzânia sob quatro alturas de desfolha. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**. 66: 481-488, 2014.

BENEDUZZI, H. M. et al. Fertilizer recommendation methods for precision agriculture – a systematic literature study. **Engenharia Agrícola**, 42, 1-18, 2022.

EUCLIDES, V. P. B. et al. Management for a shorter period of occupancy and higher cutting height of forage crops. **Revista Ceres**, 61: 808-818, 2014.

FLORES, R. A. et al. Adubação nitrogenada e idade de corte na produção de matéria seca do capim-elefante no Cerrado. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 16: 1282-1288, 2012.

GONDIM, R. S. et al. Explaining the water-holding capacity of biochar by scanning electron microscope images. **Revista Caatinga**, 31: 972-979, 2018.

GONZAGA, M. I. S. et al. Positive and negative effects of biochar from coconut husks, orange bagasse and pine wood chips on maize (Zea mays L.) growth and nutrition. **Catena**, 162: 414-420, 2018.

JACQUES, A. V. A. Caracteres morfo-fisiológicos e suas implicações com o manejo. In: CARVALHO, M. M.; ALVIM, M. J.; XAVIER, D. F. (Eds.). **Capim elefante: produção e utilização**. Coronel Pacheco, MG: Embrapa-CNPGL, 1994. v. 1, p. 31-47.

KARHU, K. et al. Biochar addition to agricultural soil increased CH4 uptake and water holding capacity – Results from a short-term pilot field study, **Agriculture, Ecosystems and Environment**, 140: 309-313, 2011.

LEAL, V. N. **Desempenho de cultivares e épocas de corte de capim elefante irrigado em Ceres (GO)**. 2019. 66 f. Dissertação (Mestrado Profissional em Irrigação no Cerrado: Área de Concentração em Irrigação). Instituto Federal de Educação, Ciência e Tecnologia Goiano, Ceres, 2019.

LOPES, R. S. et al. Efeito da irrigação e adubação na disponibilidade e composição bromatológica da massa seca de lâminas foliares de capim-elefante. **Revista Brasileira de Zootecnia**, 34: 20-29, 2005.

MADARI, B. E. et al. Matéria orgânica dos solos antrópicos da Amazônia (Terra Preta de Índio): suas características e papel na sustentabilidade da fertilidade do solo. In: TEIXEIRA, W.G. et al. (Eds.). **As terras pretas de índio da Amazônia: sua caracterização e uso deste conhecimento na criação de novas áreas**. Manaus, AM: Embrapa Amazônia Ocidental, 2009. v. 1, cap. 13, p. 172-188.

MAJOR, J. et al. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. **Plant and Soil**, 333: 117-128, 2010.

MONÇÃO, F. P. et al. Yield and nutritional value of BRS Capiaçu grass at different regrowth ages. **Semina Ciências Agrárias**, 41: 745-755, 2019.

MORENO, L. S. B. et al. Base temperature determination of tropical *Panicum* spp. grasses and its effects on degree-day-based models. **Agricultural and Forest Meteorology**, 186: 26-33, 2014.

OLIVEIRA, V. A.; JACOMINE, P. K.; COUTO, E. G. Solos do Bioma Cerrado. In: CURI, N. et al. (Eds.). **Pedologia: solos dos biomas brasileiros**. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, 2017. v. 1, cap. 4, p. 177-226.

PARIS, W. et al. Productivity and nutritional value of African Star managed with different leaf blade mass. **Acta Scientiarum. Animal Sciences**, 38: 31-36, 2016.

PEREIRA, A. V. et al. **BRS Capiaçu e BRS Kurumi: cultivo e uso**. 1. ed. Brasília, DF: Embrapa, 2021. 117 p.

PEREIRA, A. V. et al. Diversidade genética entre acessos de capim elefante obtida com marcadores moleculares**. Revista Brasileira de Zootecnia**, 37: 1216-1221, 2008.

PETTER, F. A. et al. Biochar como condicionador de substrato para a produção de mudas de eucalipto. **Revista Caatinga**, 25: 44-51, 2012.

RETORE, M. et al. **Manejo do capim BRS Capiaçu para aliar produtividade à qualidade**. 1. ed. Dourados, MS: Embrapa, 2021. 9 p. (Comunicado Técnico, 263).

RIBEIRO, E. G. et al. Influência da irrigação, nas épocas seca e chuvosa, na produção e composição química dos capins napier e mombaça em sistema de lotação intermitente. **Revista Brasileira Zootecnia**, 38: 1432-1442, 2009.

SAMPAIO, R. L. et al. The nutritional interrelationship between the growing and finishing phases in crossbred cattle raised in a tropical system. **Tropical Animal Health and Production**, 49: 1015-1024, 2017.

SANTOS, H. G. et al. **Sistema Brasileiro de Classificação de Solos**. 5. ed. Brasília, DF: Embrapa, 2018. 390 p.

SANTOS, E. A.; SILVA, D. S.; QUEIROZ FILHO, J. L. Composição Química do CapimElefante cv. Roxo Cortado em Diferentes Alturas. **Revista Brasileira de Zootecnia**, 30: 18-23, 2001.

SOUSA, D. M. G.; LOBATO, E. **Cerrado: correção do solo e adubação**. 2. ed. Planaltina, DF: Embrapa, 2004. 416 p.

SILVA, S. C.; SBRISSIA, A. F.; PEREIRA, L. E. T. Ecophysiology of C4 forage grasses: understanding plant growth for optimising their use and management. **Agriculture**, 5: 598-625, 2015.

SILVA, I. C. B. et al. Biochar from different residues on soil properties and common bean production. **Scientia Agricola**, 74: 378-382, 2017.

SILVA, M. A. S.. et al. Efeito da aplicação de biochar sobre propriedades químicas do solo e produtividade de feijoeiro comum irrigado. In: CONGRESSO NACIONAL DE PESQUISA DE FEIJÃO, 10., 2011, Goiânia. **Anais...** Goiânia: Embrapa, 2011. p. 1-4.

TEIXEIRA, P. C. et al. **Manual de métodos de análise de solo**. 3. ed. Brasília, DF: Embrapa, 2017. 574 p.

ZIMMERMAN, A. R.; GAO, B.; AHN, M.-Y. Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils. **Soil Biology and Biochemistry**, 43: 1169-1179, 2011.

ZHANG, D. et al. Biochar helps enhance maize productivity and reduces greenhouse gas emissions under balanced fertilization in a rainfed low fertility inceptisol. **Chemosphere**, 142: 106-113, 2016.

YASUHARA, T.; NOKIHARA, K. High-throughput analysis of total nitrogen content that replaces the classic Kjeldahl method. **Journal of agricultural and food chemistry**, 49: 4581-4583, 2001.