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Productive characteristics and structure of Paiaguás grass pasture fertilized with wood ash in the Brazilian Cerrado

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Abstract

The use of wood ash as a fertilizer is a practice that helps in the management of soil fertility. Our objective was to evaluate the potential use of wood ash on structural and productive characteristics of paiaguás grass (*Urochloa brizantha*) pasture. The experiment was carried out at the Federal University of Rondonópolis, Brazilian Cerrado. Treatments were five wood ash doses: 0, 8, 16, 24, and 32 t ha^{-1} and two application strategies (wood ash incorporated into the soil and wood ash not-incorporated). Wood ash doses significantly affected ($p<0.05$) the evaluated response variables. Forage yield ranged from (mean ± standard error) 6.98±0.34 to 8.99±0.53 t DM ha^{-1}. The highest productivity (11.10±0.46 t DM ha^{-1}) was obtained at a wood ash rate of 24 t ha^{-1}. The leaf area index was also higher (9.39±1.02) in the 24 t ha^{-1} wood ash dose. On the other hand, the leaf/stem ratio decreased with the application rate of wood ash and varied from 1.41±0.05 to 1.09±0.07 in the absence of wood ash (dose 0) and at the highest dose, respectively. In general, wood ash positively influenced ($p<0.05$) the structural characteristics and yield of *U. brizantha* cv. Paiaguás. Wood ash doses that provided the highest crop yield were between 16 and 24 t ha^{-1}. The incorporation of wood ash into the soil increased pasture regrowth time. Therefore, it is recommended to apply wood ash superficially in established pastures.

Keywords: Leaf area index; safe disposal of agro-industrial residues; soil management; *Urochloa brizantha*, wood ash in agriculture.
Abbreviations: TDMY_total dry mass yield, SDM_stem dry mass, LDM_leaf dry mass, LSR_leaf-stem ratio, LAI_leaf area index, LApT_leaf area per tiller, AGR_absolute growth rate, ANOVA_analysis of variance.

Introduction

Brazil has the largest commercial cattle herd in the world, exceeding 218 million head (IBGE, 2020). These values represent Brazil's ability to position itself as the main supplier of beef to the world, currently occupying the position of the largest exporter in terms of volume shipped, in addition to revealing the chain's competence in improving its production models to meet market needs (ABIEC, 2021). The country has enormous potential for beef production-based-pasture systems, which form the basis of cattle food. Pasture is the most practical and economical way of producing and offering food to the herds.
Adequate soil fertility is a critical factor in the longevity of pastures. In addition, it can affect degradation, as degraded pastures usually present soils with low fertility, which requires nutrient replacement to maintain the productive potential (Martinello and Berardo, 2007; Almeida et al., 2021).
Correct management practices must be used to guarantee pasture perenniality and achieve high levels of animal production. In this sense, planning soil fertilization is one of the primary measures for the adequate establishment and maintenance of pastures. In addition, fertilizer is used to meet plant nutritional needs and promote better plant development, reducing the risk of degradation (Silva et al., 2013; Dias-Filho, 2014).
The application of wood ash in agricultural soils has received increasing interest from current research (Liang et al., 2022). It is shown to be a viable and ecologically correct alternative, as it allows the use of the residue, in addition to returning to the environment part of the nutrients extracted by plants and stored in the biomass that had been removed for burning (Ferreira et al., 2012).
Wood ash can be used in agriculture as a liming material and soil fertilizer, providing plant nutrients (Gagnon and Ziadi, 2020). According to Gagnon and Ziadi (2020), wood ash was a significant direct source of P, K, and Mg. Also, the authors demonstrated that forest-derived liming by-products, like wood ash, can efficiently remediate soil acidity and improve soil fertility.
In the soil-plant system, the participation of wood ash, being an alkaline material, has a direct effect on the reduction of soil acidity, neutralizing aluminum toxicity (Al^{3+}), increasing the availability of nutrients in the soil solution and the cation exchange capacity (Maeda et al., 2017; Bonfim-Silva et al., 2019a). Some field studies showed the feasibility of using wood ash to increase forage production (Bougnom et al., 2012; Espírito Santo et al., 2018; Schlichting et al., 2021;

Bedaso et al., 2022). In a greenhouse experiment, the application of wood ash positively affected the production of "Paiaguás" grass (Bonfim-Silva et al., 2018). The authors worked with wood ash doses of 0, 8, 16, 24, and 32 g dm^{-3} and verified better results at 23.94 g dm^{-3} for the shoot dry mass (23.84 g).

Thus, the objective was to evaluate the structural and productive characteristics of "Paiaguás" grass pasture in response to soil application management of wood ash in Brazilian Cerrado.

Results and discussion

The incorporation of wood ash in the pasture maintenance period (2019-2020) negatively affected the time of plant regrowth. We found that in the plots where there was harrowing, plant regrowth occurred mainly after the last pasture evaluation cut (after March 2020). Mechanical damage to shoots and roots contributed to the severe reduction in biomass production and increased regrowth time (Phiri et al., 2001). As a consequence, more time was needed for the natural crop re-establishment. Soares Filho et al. (1992) evaluated pasture recovery techniques and observed a significant decrease in shoot and root production in *Brachiaria decumbens* using the harrowing technique.

Pasture productive traits:

Total dry mass yield (TDMY)

Response variables varied ($p<0.05$) as a function of wood ash doses. For total dry mass yield – TDMY (t DM ha^{-1}), there was a significant difference in the first, second and third cuts. There was an increase in forage production with wood ash application. In the first cut, the wood ash rate at 21.25 t ha^{-1} provided productivity of 8.53 t ha^{-1}. In the second cut, 20 t ha^{-1} of wood ash provided 8.12 t ha^{-1} of dry mass productivity, while for the third cut, the ash dose of 16.25 t ha^{-1} provided 14.82 t ha^{-1} of dry mass yield (Fig. 1).

These results indicate the importance of soil fertilization with wood ash for higher yields since the absence of ash (dose 0) showed low forage yield concerning doses applied.

Similar results were reported by Bonfim-Silva et al. (2017) when incorporating wood ash into the soil, evaluating the effects of fertilization with wood ash rates of 0, 5, 10, 15, and 20 g dm^{-3} on "Piatã" grass production. The authors pointed out an increase of 94% in the shoot dry mass compared to the treatment without ash. Similar results were also obtained by Bonfim-Silva et al. (2019b) when they worked with "Paiaguás" grass combining ash rates of 0, 8, 16, 24, and 32 g dm^{-3} and soil water tensions.

Stem dry mass (SDM)

Stem dry mass (SDM) was affected by wood ash rates. Data were fitted to the quadratic regression model in the second and third cuts. There was no effect in the first cut (Fig. 2). For the second cut, the maximum response for stem yield (3.31 t ha^{-1}) occurred at a wood ash rate of 21.67 t ha^{-1}, representing an increase of 72.39% concerning the absence of ash (dose 0). In the third cut, the wood ash dose of 24 t ha^{-1} provided a stem dry mass of 10.29 t ha^{-1}, an increase of 87.43% in relation to the treatment with no wood ash.

We found that wood ash positively affected fertilization for Paiaguás grass, increasing its production. Thus, these results demonstrate the importance of this solid residue as a fertilizer. The present study corroborates the results of research carried out by Bonfim-Silva et al. (2019b), who observed significant increases in stem dry mass production. The wood ash doses increased by 83.12% and 86.83%, respectively, for the first and second cuts, the production of Paiaguás grass when comparing wood ash dose of 32 g dm^{-3} with no soil fertilization (dose 0).

Wood ash used in agriculture as fertilizer contains phosphorus, potassium, calcium, and magnesium, among other nutrients that influence the development and production of plants (Bonfim-Silva et al., 2011). Nutrient concentrations in plant tissues reflect the influence of soil fertility (Santini et al., 2019). Bonfim-Silva et al. (2013) verified a linear effect in stem dry mass production of "marandu" grass fertilized with wood ash.

Leaf dry mass (LDM)

Leaf dry mass (LDM) was adjusted to the quadratic regression model only in the first and third cuts. In contrast, in the second cut, there was no significant difference ($p>0.05$) (Fig. 3). For the first cut, the wood ash dose of 21.25 t ha^{-1} provided a leaf dry mass of 4.55 t ha^{-1}, in the third cut the maximum wood ash dose was 18.75 t ha^{-1} and which provided the highest leaf dry mass yield (4.83 t ha^{-1}).

Adjusting the quadratic model for the leaf dry mass corroborates the results Bonfim-Silva et al. (2015) observed when evaluating wood ash rates (0, 3, 6, 9, 12, and 15 g dm-3) in dystrophic Red Latosol on development of *Urochloa brizantha* cv. piatã and *U. brizantha* cv. Paiaguás. A quadratic effect was also observed in the leaf dry mass production in the first and second cuts.

Given the results of leaves dry mass production of Paiaguás grass, it was found that wood ash positively increased its production. Furthermore, the nutrients in the wood ash supplied the plant needs and contributed to their better development, as observed by Hansen et al. (2017).

Pasture structural traits:

Leaf-stem ratio (LSR)

The leaf-stem ratio (LSR) showed significant differences only in the second and third forage cuts. The results fitted the decreasing linear regression model. For the second cut, the leaf-stem ratio was reduced by 25.87% when compared to the treatment in the absence of ash (dose 0) (Fig. 4).

In the third cut, the wood ash dose of 32 t ha^{-1} reduced the leaf-stem ratio by 21.51% compared to the absence of ash (dose 0). It was observed that at the highest wood ash rates leaf-stem ratio decreased due to the greater growth of plants to produce longer and heavier tillers, to the detriment of leaf mass. Leaf-stem ratio is considered one of the most important structural characteristics of the pasture. This relationship, associated with canopy height, is considered a characteristic influenced by management, which determines the efficiency of forage use (Castagnara et al., 2011).

According to Pinto et al. (1994), the high leaf-stem ratio can better meet the nutritional requirements of cattle herds. Conversely, when this ratio is low, i.e., with more stems than leaves, forage quality will be negatively affected, modifying the behavior of grazing animals and their forage consumption (Rodrigues et al., 2017).

Leaf area index (LAI)

For the leaf area index (LAI), there was a significant difference in the first and third herbage cuts. The maximum

Table 1. Maximum (MaxT), minimum (MinT) and average (AvT) air temperatures and monthly rainfall during experimental period: December 2019 to March 2020

Month	MaxT (ºC)	MinT (ºC)	AvT (ºC)	Rainfall (mm)	*ETo (mm)
December	3.00	22.40	25.84	259.80	125.88
January	32.57	23.60	26.15	141.80	140.46
February	32.08	22.64	26.13	122.60	116.84
March	34.26	22.08	26.62	167.40	134.05

Source: National Institute of Meteorology (INMET). *ETo was estimated according to Penman-Monteith method (Allen et al., 1998).

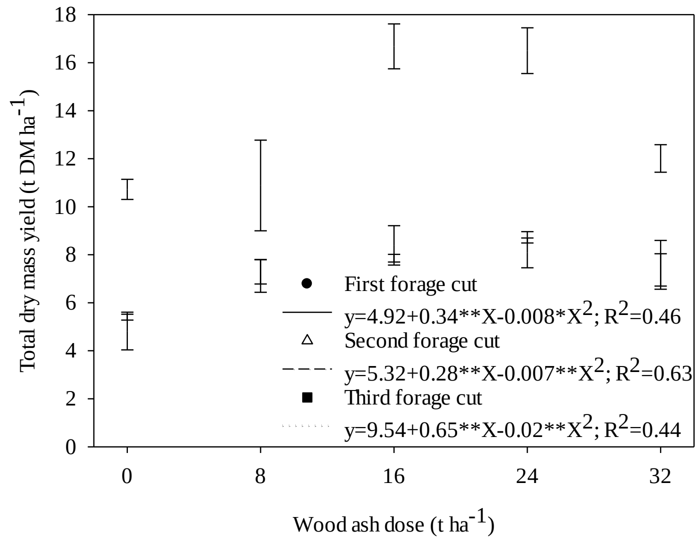

Fig 1. Total dry mass yield (t DM ha^{-1}) of *Urochloa brizantha* cv. BRS "Paiaguás", in the second year of production (2020), as a function of wood ash doses applied to the soil surface (not-incorporated into the soil). **1%, *5% and 'ns' not significant. Vertical bars are the standard error of the mean.

Table 2. Analysis of wood ash and soil (0.0 - 0.20 m layer) of the experimental area. Rondonópolis – MT, Brazil

Wood ash			Dystrophic Red Latosol (Oxisol)		
Characteristic	Unit	Value	Characteristic	Unit	Value
pH ($CaCl_2$)	-	10.67	pH ($CaCl_2$)	-	3.70
NP	%	30.00	SOM	g kg^{-1}	27.10
RPTN	..	24.76	P	mg dm^{-3}	1.60
N	g kg^{-1}	4.90	K	..	42.40
P_2O_5	..	7.90	S	..	6.10
K_2O	..	32.5	Ca	$cmol_c$ dm^{-3}	0.65
Zn	..	0.20	Mg	..	0.25
Cu	..	1.00	Al	..	0.95
Mn	..	0.40	H+Al	..	6.00
B	..	0.40	SB	..	1.01
Ca	..	49.60	CEC	..	7.01
Mg	..	42.00	V	%	14.41
S	..	6.00	M	..	48.47
Fe	..	7.20	Zn	mg dm^{-3}	1.30
M.M.	..	546.40	Mn		9.80
Density	g cm^{-3}	0.40	Sand*	g kg^{-1}	395
-	-	-	Silt*	..	175
-	-	-	Clay*	..	430

NP=Neutralizing power; RPTN=Relative power of total neutralization; N=Nitrogen; P_2O_5=Phosphorus; K_2O=Potassium; Ca=Calcium; Mg=Magnesium; S=Sulfur; Zn=Zinc; Cu=Copper; Mn=Manganese; B=Boron; P=Phosphorus; K=Potassium; Al=Aluminum; H+Al=potential soil acidity; CEC=Cation exchange capacity at pH 7.0; SOM=Soil organic matter; MM=Mineral matter; V=base saturation; m=Aluminum saturation; SB= sum of bases; Fe=Iron. *Granulometry determined by Bouyoucos method – dispersant NaOH + sodium hexametaphosphate.

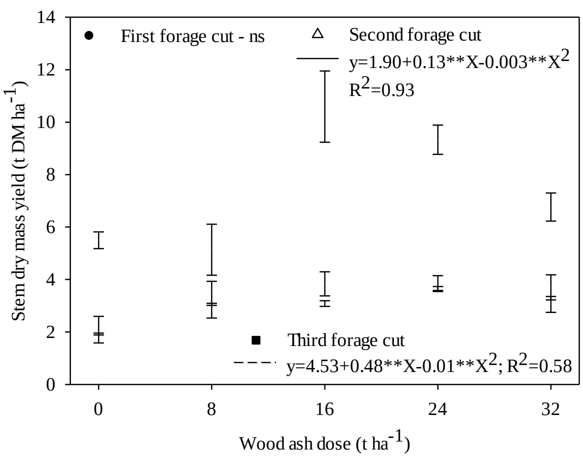

Fig 2. Stem dry mass yield (t DM ha^{-1}) of *Urochloa brizantha* cv. BRS "Paiaguás", in the second year of production (2020), as a function of wood ash doses applied to the soil surface (not-incorporated into the soil). **1%, *5% and 'ns' not significant. Vertical bars are the standard error of the mean.

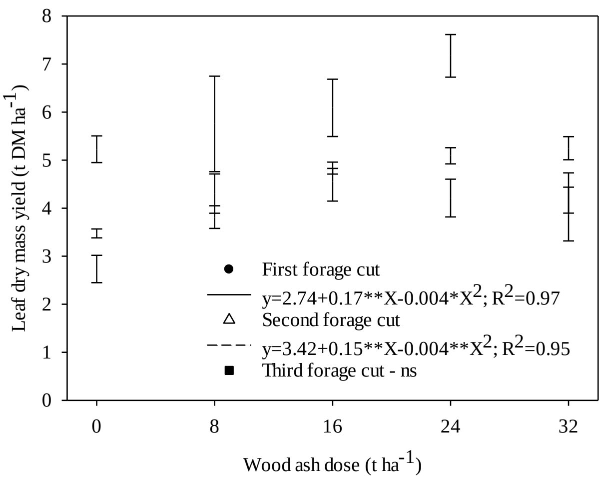

Fig 3. Leaf dry mass yield (t DM ha^{-1}) of *Urochloa brizantha* cv. BRS "Paiaguás", in the second year of production (2020), as a function of wood ash doses applied to the soil surface (not-incorporated into the soil). **1%, *5% and 'ns' not significant. Vertical bars are the standard error of the mean.

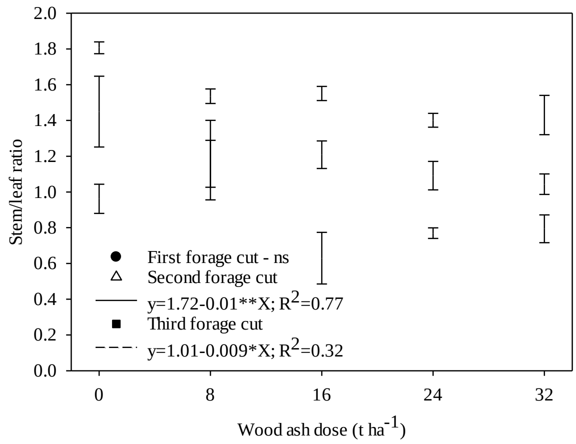

Fig 4. Leaf-stem ratio of *Urochloa brizantha* cv. BRS "Paiaguás", in the second year of production (2020), as a function of wood ash doses applied to the soil surface (not-incorporated into the soil). **1%, *5% and 'ns' not significant. Vertical bars are the standard error of the mean.

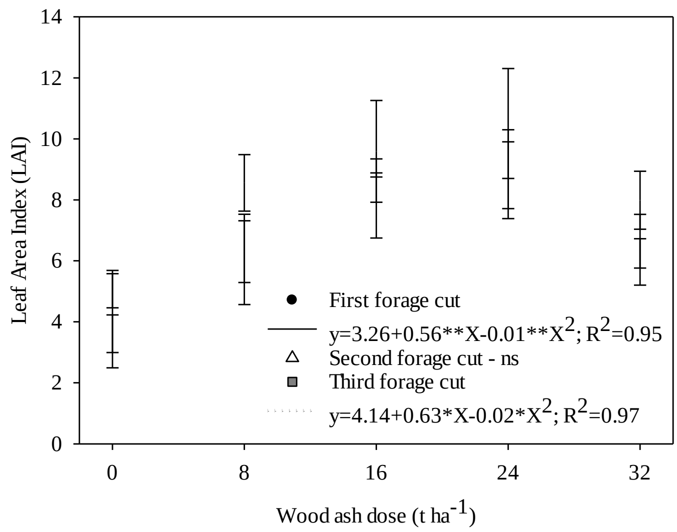

Fig 5. Leaf area index (LAI) of *Urochloa brizantha* cv. BRS "Paiaguás", in the second year of production (2020), as a function of wood ash doses applied to the soil surface (not-incorporated into the soil). **1%, *5% and 'ns' not significant. Vertical bars are the standard error of the mean.

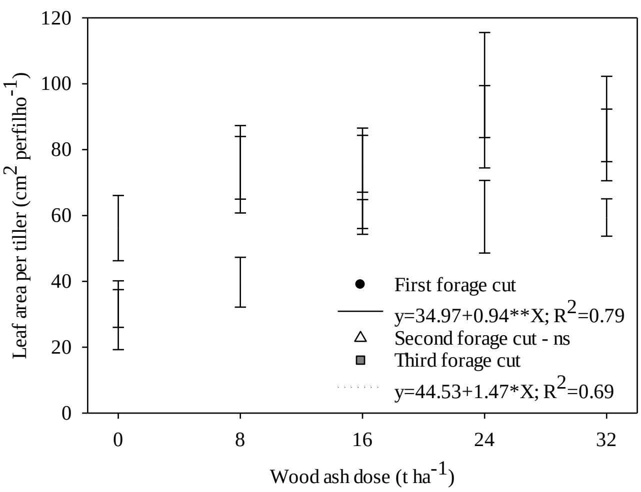

Fig 6. Leaf area per tiller (cm^2 $tiller^{-1}$) of *Urochloa brizantha* cv. BRS "Paiaguás", in the second year of production (2020), as a function of wood ash doses applied to the soil surface (not-incorporated into the soil). **1%, *5% and 'ns' not significant. Vertical bars are the standard error of the mean.

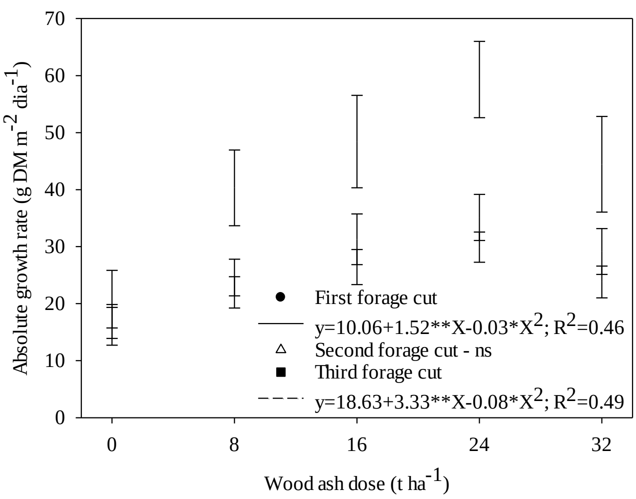

Fig 7. Absolute growth rate (g DM m^{-2} dia^{-1}) of *Urochloa brizantha* cv. BRS "Paiaguás", in the second year of production (2020), as a function of wood ash doses applied to the soil surface (not-incorporated into the soil). **1%, *5% and 'ns' not significant. Vertical bars are the standard error of the mean.

LAI value (11.10) in the first cut was found with wood ash dose at 28 t ha^{-1}; this represented an increase of 207% compared to the treatment without wood ash (Fig. 5).
For the third herbage cut, maximum LAI (9.10) was found with wood ash rate at 15.75 t ha^{-1}, providing an increase of 125.80% in relation to the treatment with no fertilization (dose 0). This result demonstrates the significant role of wood ash in the behavior of this response variable.
As the LAI increases, the amount of intercepted light also increases. As a result, there is an increase in the photosynthetic canopy capacity up to the critical LAI level; after that, there is greater shading, and this light interception capacity decreases (Pedreira and Pedreira, 2007).
The increase in crop biomass depends on LAI development, which is directly related to plant production, as it is through it that photosynthesis occurs. Thus, factors such as nutrients, soil pH, and soil water availability influence plant growth (Taiz et al., 2021).

Leaf area per tiller (LApT)

Leaf area per tiller (LApT) varied between wood ash rates in the first and third cuts. The data fitted the increasing linear model. The highest ash rate provided an area of 65.08 cm^{-2} $tiller^{-1}$ in the first cut and 91.57 cm^{-2} $tiller^{-1}$ in the third one. For the second herbage cut, there was no significant difference between wood ash rates (Fig. 6).

Absolute growth rate (AGR)

Wood ash doses significantly affected the absolute growth rate (AGR). The results were adjusted to the quadratic regression model in the first and third forage cuts, while in the second cut, there was no significant difference (Fig. 7). In the first cut, wood ash rate at 25.31 t ha-1 provided an AGR of 29.31 g DM m^{-2} day^{-1}, showing an increase of 73.84% in relation to wood ash absence (dose 0). In the third forage cut, the wood ash rate at 20.81 t ha^{-1} provided an AGR of 53.28 g DM m^{-2} day^{-1}. This represented an increase of 176.49% compared to the treatment without wood ash. The high plant growth rates during initial regrowth periods represent a mechanism of grass adaptation because by reducing time to the maximum interception of solar radiation, there is better water use due to the rapid soil shading, which favors intraspecific competitiveness (Lemaire, 2001).
However, both lack and excess of nutrients can harm crop development. Although wood ash has benefits for soil physical properties and plant nutrition, excess ash can harm the soil microbiota, causing phytotoxicity and limiting the availability of mineral nutrients due to its high alkalinity (Scheepers and Toit, 2016).

Materials and methods

Site study, treatments, and experimental design

The experiment was carried out in the field, at the Federal University of Rondonópolis - MT, Brazil, under coordinates 16°27'38.94” S and 54°34'57.01" W. The trial corresponded to the pasture maintenance period (year 2020) of an experiment established in November 2018. The experimental period was within the rainy season, from December 2019 to March 2020.
According to the Köppen classification, the climate type of Rondonópolis is Aw. The locality has a tropical savanna climate with a dry season in autumn/winter and a rainy season in spring/summer (Souza et al., 2013). In the experimental period, meteorological conditions in Rondonópolis indicated rainfall of 691.6 mm, with higher occurrence in December (259.80 mm) (Table 1). The soil of the experimental area was classified as dystrophic Red Latosol (Oxisol) (EMBRAPA, 2018).
The treatments were established in a randomized block design (strip-plot design), arranged in a 5x2 factorial scheme. Treatments were composed by five wood ash doses: 0, 8, 16, 24 and 32 t ha-1 and two wood ash application strategies: wood ash incorporated into the soil, with light harrow, and non-incorporated ash (superficial application), with four replications. The area of each main plot was 72 m2 (12 m x 6 m) and 36 m2 for subplots (6 m x 6 m), while the useful area of each subplot was 30.25 m2 (5.5 m x 5.5 m). The main plots were composed by wood ash doses, and application strategies corresponded to subplots (in strips).
The soil of the experimental area and wood ash were analyzed before applying the treatments, according to EMBRAPA (2017) and MAPA (2017), respectively (Table 2). A dutch auger was used to collect nine simple soil samples (0-0.20 m depth) in the experimental area to obtain a composite sample for initial soil characterization (Table 2). For sampling wood ash, a probe-type auger was used to obtain six samples at different points and depths of the total wood ash mass to constitute a single composite sample. The experimental establishment area is considered new, recently opened in native Cerrado.

Pasture establishment

The pasture establishment was carried out with the application of wood ash in November 2018. After the ash was distributed in experimental plots, light harrowing (~15 cm of soil disturbance depth) was used in the treatments that required wood ash incorporation into the soil. In December, after 30 days, *Urochloa brizantha* cv BRS paiaguás was manually sowed. This 30-d period was necessary to allow the soil-wood ash reaction.
In December 2019, the pasture was cut to a residual height of 15 cm (standardization herbage cut), and the wood ash was reapplied. Wood ash incorporation procedures into the soil were repeated in the same plots of the pasture establishment period (2018-2019). Due to the low nitrogen content of wood ash (Table 2), the pasture was fertilized with 100 kg ha^{-1} of nitrogen (urea). Nitrogen fertilization was split in three applications (January, February, and March 2020) after each herbage cut to evaluate the response variables.

Herbage sampling and response variables

From January to March 2020, forage samples were collected every 30 days. After each evaluation (each forage cutting), pasture was standardized with a 15-cm cutting height in all plots to start a new regrowth cycle. The standardization herbage cut was carried out with a hydraulic mower coupled to a tractor (Agrale 420 4x2 model), and the resulting biomass was manually removed from the plots using rakes.
Response variables were the total forage dry mass (t DM ha^{-1}), stem dry mass (t DM ha^{-1}), leaf dry mass (t DM ha^{-1}), leaf-stem ratio, leaf area index (LAI), leaf area per tiller (cm^2 $tiller^{-1}$) and absolute growth rate (g DM m^{-2} day^{-1}).

Dry mass yield (DMY)

DMY was obtained with forage samples collected at 5 cm height in an area delimited by a 0.25 m^2 metallic frame (0.25

m x 1 m). The frame was positioned at a representative point of each subplot for herbage sampling. The samples were packed in plastic bags and transported to the laboratory for processing. DMY was obtained by the sum of stem and leaves production.

Stem dry mass (SDM), leaf dry mass (LDM), and leaf-stem ratio (LSR)

Stem and leaf production were obtained after the manual separation of fresh plant material into leaf blades and stem+sheath. After separation, the material was placed in paper bags and oven-dried at 55º C until constant mass. Leaf-stem ratio was obtained by the ratio between leaves and stem+sheath dry mass production.

Leaf area index (LAI)

LAI was obtained from a second sample collected in a 30 cm x 30 cm quadrat (900 cm^2). In the laboratory, the fully expanded green leaf blades were manually separated. Expanded leaves were those that presented ligules. Leaf blades were detached from each tiller and scanned in a leaf area integrator model LI-3100C LI-COR. LAI was estimated by the ratio between the total area of one face of the leaves and the area of soil sampled.

Absolute growth rate (AGR)

AGR was estimated by the ratio between total dry mass yield and regrowth period (30 days).

Statistical analyses

Data were submitted to analysis of variance (ANOVA) using SISVAR 5.6 software (Ferreira, 2011). Residuals were normally distributed according to Shapiro-Wilk Test. In plots where wood ash was incorporated into the soil, regrowth occurred late after the pasture evaluation cycle (January to March 2020). This made it impossible to evaluate the plants in these plots. Thus, only the wood ash dose factor was considered in the statistical analysis. When there was a significant difference between doses according to F-test, data were analyzed using linear regression of first and second degrees. All results were considered significant when $p \leq 0.05$.

Conclusions

Wood ash as fertilizer provided an increase in structural and productive characteristics of *Urochloa brizantha* cv. BRS "Paiaguás";

"Paiaguás" grass showed higher forage yield with the application of wood ash doses between 16 and 24 t ha^{-1};

In established pastures, the best application strategy of wood ash is on the soil surface, without incorporation into the soil, to avoid damage to the root system. The incorporation of wood ash with light harrow can delay natural crop re-establishment by at least 90 days.

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