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Characteristics of two *Panicum maximum* grass cultivars fertilized with ash from wood grown in tropical soils

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Abstract

It is estimated that the livestock sector accounts for about 40% of the value of global agricultural production. Livestock plays an essential role in maintaining food security as the sector contributes around 13% of calories and 28% of protein demands required by humans worldwide. Fertilization of tropical pastures with wood ash emerges as a sustainable practice that can contribute to better nutrient cycling, increased production, and reduced dependence on mineral resources. In this context, the aim of this study was to evaluate the production characteristics of two *Panicum maximum* grass cultivars fertilized with ash from wood grown in tropical soils of the Brazilian Cerrado. The experimental design was in randomized blocks in a factorial arrangement 5x2 with five doses of wood ash (0, 8, 16, 24, and 32 g kg^{-1}) and two cultivars of *Panicum maximum* (cv. BRS Zuri and cv. Mombasa), with six replications. The experiment was carried out in 5 dm^3 pots for 120 days. The wood ash used in the experiment comes from the combustion of eucalyptus (*Eucalyptus* sp.) logs in a boiler. The application of wood ash in acidic tropical soils increased leaf area, tillering, leaf dry mass, stem dry mass, and root volume in Mombasa and BRS Zuri cultivars of *Panicum maximum* grass, with maximum production at a dose of 32 g kg^{-1}. The application of wood ash in acidic tropical soils offers potential as a sustainable strategy to increase production in forage production area for animal consumption in grazing, given the growing demand for beef. In addition, it properly and safely disposes of waste and recycles nutrients extracted by the crops.

Keywords: solid waste; sustainability; forage grasses; Cerrado, *Panicum maximum*.

Abbreviations: Al_Aluminum, B_Boron, Ca_Calcium, CEC_Cation exchange capacity, Cu_Copper, DAE_Days after emergence, Fe_Iron, H_Hydrogen, K_Potassium, Mg_Magnesium, M_Aluminum saturation, MM_Mineral matter, NP_Neutralization power, OM_Organic matter, TRNP_Total relative neutralizing power, S_Sulfur, V_Base saturation, Zn_Zinc.

Introduction

It is estimated that the livestock sector accounts for about 40% of the value of global agricultural production (FAO, 2017; FAO, 2018). Livestock plays an essential role in maintaining food security, as the sector contributes about 13% of calories and 28% of protein demands worldwide through the supply of meat, milk, and eggs, in addition to their contribution to agricultural production (FAO, 2011; Hashem et al., 2020).

Brazil is one of the main food producers and exporters in the world, and therefore plays a prominent role in food security in the world. Brazil has the second largest cattle herd in the world, with approximately 220 million animals (United States Department of Agriculture – USDA, 2020) and has established itself as the world's largest exporter of beef, according to the Brazilian Beef Exporters Association (ABIEC, 2020). Brazilian beef exports (*in natura* and processed) reached the record of 2.02 Mt in 2020, an 8% increase compared to the 1.88 Mt traded in 2019 (CEPEA, 2020; MAPA, 2020).

The main feed source for the Brazilian cattle herd is pasture, and 95% of slaughtered animals are raised, reared, and finished exclusively on pasture (Lobato et al., 2014). In general, Brazilian pastures do not meet the cattle nutritional requirements as they are not properly managed. This causes a reduction in their production, compromising the sustainability and profitability of the activity and causing a decline in the pasture carrying capacity (Cunha et al., 2008; Freitas et al., 2016; Araújo et al., 2010; Dill et al., 2015). Thus, to increase the production of Brazilian pasture areas, given the growth in demand for meat, it is necessary to properly manage pasture areas, especially with fertilization. However, Brazil imports a large part of the fertilizers used in agriculture; it is the largest importer of nitrogen (N) and phosphorus (P), and the second-largest importer of potassium (K), with approximate values of 4.65 Mt, 3.20 Mt, and 6.03 Mt, respectively (FAOSTAT, 2020). In the last 30 years, its imports of NPK fertilizers increased by 32 %, 50 %, 68 %, and 77 % in 1988, 1998, 2008, and 2018, respectively (ANDA, 2019; Farias et al., 2020). Thus, countries that import large volumes of chemical fertilizers, such as Brazil, need to rethink their agricultural production systems and promote the development of a more sustainable and self-sufficient production system.

Developing sustainable waste management strategies is essential to prevent large volumes of organic waste from being improperly disposed of in the environment (Jones and Healey 2010). The region of the Brazilian Cerrado biome is recognized as a saddler for the country's agribusiness, and has numerous industries for processing its agricultural products, which use wood as a source of energy for the processing of their agricultural products, which after combustion gives rise to the wood ash. The wood ash produced in this region comes mainly from the wood of eucalyptus (*Eucalyptus* sp.) logs in a boiler, which has high levels of Ca, Mg, P, K, B and S and low levels of heavy metals, which enhances its use in agriculture, as a liming agent for the soil and a source of nutrients for plants.

The application of wood ash in pastures may be a sustainable alternative to chemical fertilizers, especially in tropical soils that are acidic and poor in nutrients, due to the high concentrations of P, Ca, Mg and K present in wood ash (Demeyer et al., 2001; Gibczyñska et al., 2014). Wood ash fertilizer can contribute to (i) neutralize soil pH, (ii) increase the availability of nutrients to plants (Espirito Santo et al., 2018; Schlichting et al., 2021), (iii) recycle nutrients extracted by plants, (iv) mitigate an environmental problem regarding residual wood ash, which is especially important considering the growing use of biofuels for energy production (Vassilev et al., 2013; Souza et al., 2017), and (v) reduce dependence on imports of chemical fertilizers.

In this context, the aim of this study was to evaluate the production characteristics of two *Panicum maximum* grass cultivars fertilized with ash from wood grown in tropical soils of the Brazilian Cerrado.

Results

Leaf area

Fertilization with doses of wood ash increased the production characteristics of the Mombasa and BRS Zuri cultivars of the *Panicum maximum* grass in the three cuttings evaluated, and the responses showed no significant difference between the cultivars (Figure 1). The 8 g kg^{-1} dose of wood ash led to an increase in leaf area compared to the control treatment (in which there was no growth of grass plants). The largest leaf area of 4500 cm^2 pot^{-1} was observed at the highest dose of wood ash applied (32 g kg^{-1}) in the first cutting. The leaf area of the cv. Mombasa and BRS Zuri decreased in the second and third cuttings in all the wood ash doses compared to the first cutting.

Tillers

Tillering of the Mombasa and BRS Zuri cultivars were increased with the application of wood ash (Figure 1). The 32 g kg^{-1} dose increased the number of tillers by 30% compared to the 8 g kg^{-1} dose. In general, the three cuttings of the *Panicum maximum* grass showed constant tillering in all doses of wood ash applied.

Leaf:stem

The leaf:stem ratio was similar for the Mombasa and BRS Zuri cultivars in the first cutting at all ash levels (Figure1). In the second cutting, the highest leaf:stem ratio of 6.9 was observed at the dose of 32 g kg^{-1}. In the third cutting, wood ash doses of 16 g kg^{-1} in the Mombasa cultivar and 24 g kg^{-1} in the BRS Zuri cultivar showed the highest leaf:stem ratios, at 6.9 and 14, respectively.

Dry mass

Stem dry mass of *Panicum maximum* cultivars increased with the application of wood ash (Figure 2). In the 8 and 16 g kg^{-1} doses of wood ash, the stem dry mass was 6 and 7.5 g pot^{-1}, respectively, in the Mombasa cultivar. In the BRS Zuri cultivar, the 8 g kg^{-1} dose of wood ash had a stem dry mass of 6 g pot^{-1}, while at the dose of 16 g kg^{-1}, the dry mass was 9 g pot^{-1}.

The application of doses of wood ash provided a constant leaf dry mass for the three cuttings performed in the *Panicum maximum* grass (Figure 2). The leaf dry mass of the Mombasa and BRS Zuri cultivars increased along with the doses of wood ash applied to the soil. The 24 and 32 g kg^{-1} doses of wood ash led to the highest dry mass values of around 17 g pot^{-1} for the cv. Mombasa and BRS Zuri in the first and second cutting.

Roots

The soil without application of wood ash (control) showed no root development in the Mombasa cultivar and limited development in the cv. BRS Zuri (Figure 2). The 24 g kg^{-1} dose of wood ash exhibited the largest volume of roots, at 12000 cm^2 pot^{-1} and 13500 cm^2 pot^{-1} in the cv. Mombasa and BRS Zuri, respectively. There was a reduction in root volume at the 32 g kg^{-1} dose of wood ash in the cv. Mombasa of *Panicum maximum* grass.

Discussion

Plant growth, development, and production mainly depend on nutrient availability and soil chemical properties, especially soil pH. The pH of the wood ash used in this study is 10.7 (Table 2). Thus, due to its alkaline character, the application of wood ash increased the pH of the soil used in the study from 3.7 (Table 1) to an average pH value of 6 (data not shown). Soil pH directly governs soil reactions and, in general, pH values between 5.5 and 6.5 are favorable for plant development, as this pH range increases the availability of the macronutrients N, P, K, Ca, Mg, and S (Neina, 2019).

In our study, fertilization with wood ash increased all the production parameters of the *Panicum maximum* grass. The increase in grass leaf area already at the lowest dose of wood ash (8 g kg^{-1}) demonstrates the fertilization potential of wood ash, since grass did not grow in the control treatment (no wood ash).

The effect of wood ash in increasing leaf area is associated with nutrients available in the ash, such as Ca, K, Mg, Si, Al, P, Mn, and S (Table 2). These nutrients not only nourish the plant, but also favor greater uptake of N by *Panicum maximum* plants (Bonfim-Silva et al., 2013; Brais et al., 2015). This is reflected in an increase in the leaf area index, in the use of solar radiation and, consequently, in accumulation of dry matter (Figure 2). Espírito Santo et al. (2018) showed a 20% increase in chlorophyll content, through the SPAD reading, of *Brachiaria brizantha* cv. Marandu with wood ash fertilization at a dose of 15 Mg ha^{-1} grown in acidic soil.

The effect of fertilization with wood ash on the stability of the number of tillers was observed in the three cuttings

Table 1. Chemical and particle-size characterization of the Dystrophic Red Oxysol collected in the 0-20 cm layer.

pH	OM	P	K	S	Ca	Mg	Al	H+Al	SB	CEC
CaCl	g kg^{-1}	---mg dm^{-3}---			--------------------------cmolc dm^{-3}---------------------					
3.7	27.1	1.6	42.4	6.1	0.6	0.25	0.95	6.0	1.0	7.0
V	M	Zn	Mn	Cu	Fe	B	Sand*	Silt*	Clay*	
--------%--------		-------------mg dm^{-3}---------------					----------g kg^{-1}----------			
14.4	48.4	1.3	9.8	0.3	41	0.25	395	175	430	

Ca = calcium, Mg = magnesium, S = sulfur, Zn = zinc, Cu = copper, Mn = manganese, B = boron, Fe = iron, P = phosphorus, K = potassium, Al = aluminum, H = hydrogen, CEC = cation exchange capacity at pH 7.0, OM = organic matter, V = base saturation, M = aluminum saturation. *Particle size determined by the Bouyucos method – NaOH + sodium hexametaphosphate dispersant.

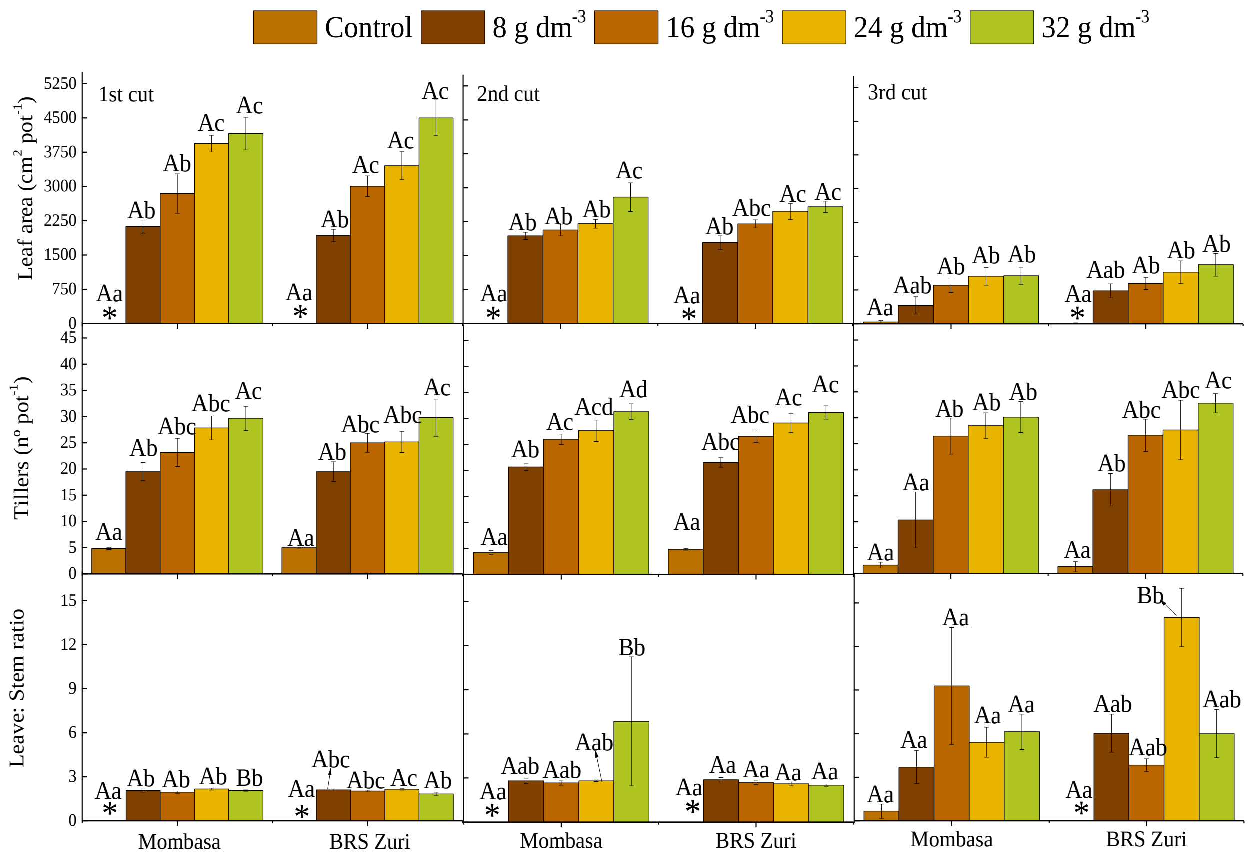

Figure 1. Leaf area, tillers, leave: stem ratio of *Panicum maximum* cv. Mombasa and BRS Zuri grass fertilized with five doses of wood ash (0, 8, 16, 24 and 36 g dm-3), the 0 dose is control treatment, in the first cut (30 DAE), second cut (60 DAE) and third cut (90 DAE). The colored bars represent the doses of wood ash applied to the soil. Upper case letters compare the cultivars Mombasa and BRS Zuri. Lowercase letters compare wood ash doses, according to Tukey test ($P < 0.05$). Error bars represent error (n = 6). *There was no growth and development of *Panicum maximum* grass plants.

Table 2. Chemical composition of wood ash.

pH	NP	TRNP	N	P_2O5	K_2O	Ca	Mg	Zn	Cu
$CaCl_2$	------%------		--------------------------------g kg^{-1}--------------------------------						
10.7	30.0	24.8	4.9	7.9	32.5	49.6	42.0	0.2	1.0
Mn	B	S	Fe	MM	Particle size			Density	
					4.8 mm	2.0 mm	1.0 mm		
-----------------g kg^{-1}-----------------					--------------%---------------			g dm^{-3}	
0.4	0.4	6.0	7.2	546.4	0.5	3.1	10.5	0.4	

NP = neutralizing power, TRNP = total relative neutralizing power, N = nitrogen, P_2O_5 = phosphorus, K_2O = potassium, Ca = calcium, Mg = magnesium, S = sulfur, Zn = zinc, Cu = copper, Mn = manganese, B = boron, Fe = iron, MM = mineral matter.

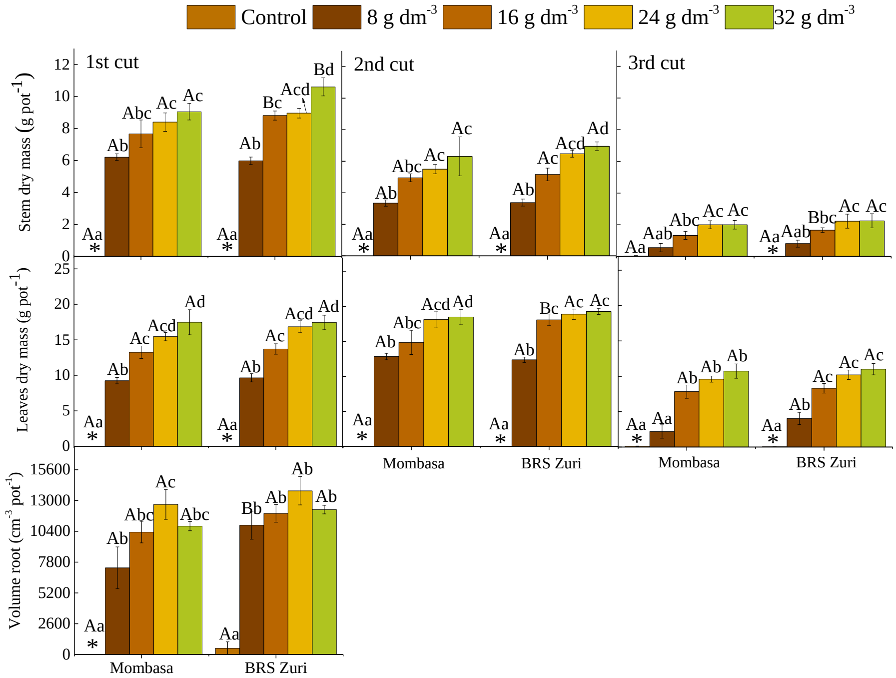

Figure 2. Stem dry mass, leaves dry mass, volume root of *Panicum maximum* cv. Mombasa and BRS Zuri grass fertilized with five doses of wood ash (0, 8, 16, 24 and 36 g dm^{-3}), the 0 dose is control treatment, in the first cut (30 DAE), second cut (60 DAE) and third cut (90 DAE). The colored bars represent the doses of wood ash applied to the soil. Upper case letters compare the cultivars Mombasa and BRS Zuri. Lowercase letters compare wood ash doses, according to Tukey test (P < 0.05). Error bars represent error (n = 6). *There was no growth and development of *Panicum maximum* grass plants.

performed on the cv. Mombasa and BRS Zuri. This was probably due to the fact that, in the first cutting, the plant had the macro- and micronutrients necessary for its establishment available, with the formation of the root system and shoot. In subsequent cuttings (second and third cuttings), the already established plant with greater root volume has the ability to take up the larger amount of nutrients made available by the wood ash, and the fact that it suffered the action of the cutting ends up promoting the induction of basal buds, stimulating the growth of tillers (Lavres Júnior and Monteiro, 2003; Rodrigues et al., 2004).

It should be noted that tiller production is a very important structural feature, since it acts as a critical indicator for grass growth. Research has shown that the application of wood ash increases the tillering of forage grasses in tropical climate regions (Bonfim-Silva et al., 2013; Bezerra et al., 2019; Espirito Santo et al., 2018). This corroborates the results obtained in this study, where wood ash played a key role in increasing the production of new tillers in the Mombasa and BRS Zuri cultivar grasses.

In the first cutting, the application of wood ash favored a low leaf:stem ratio at all the doses studied. Although this reduction was observed in the leaf:stem ratio, the results of this study are above the ideal critical limit of 1.00, which is related to the quantity and quality of the forage produced (Pinto et al., 1994). In tropical forage grasses that have rapid stem development, the leaf:stem ratio is an important structural characteristic of pastures (Castagnara et al., 2010), and it can act on the ingestive behavior of animals (Montagner et al., 2009; Tontini et al., 2021), as well as on animal performance under grazing (Tontini et al., 2021).

The stem and leaf dry mass of the *Panicum maximum* cv. Mombasa and BRS Zuri grasses showed an increase along with the increase in the doses of wood ash in the first cutting (Figure 2). These results follow the tendency of the other production variables evaluated, such as leaf area and number of tillers, which also responded positively to the application of wood ash. This confirms the potential use of fertilization with wood ash in the cultivation of grass, since leaves represent the part of the grass with the highest nutritional value and high levels of crude protein (Castagnara et al., 2010).

Root growth and development in *Panicum maximum* grass were also favored through application of wood ash. This effect can be initially attributed to the pH corrective effect from the and to the nutrients present in the wood ash. In a study on *Urochloa brizantha* BRS Piatã under different doses of wood ash, Bonfim-Silva et al. (2017) observed an increase of 94% in root dry mass compared to the control treatment (no wood ash) with a dose of wood ash of 20 mg kg^{-1}. The authors attributed the increase in roots to the P in the wood ash, as it stimulates faster root growth, which is particularly important during the grass establishment stage. These results are similar to those found in the present study, where the dose of 24 g kg^{-1} of wood ash had the highest root volume in the Mombasa and BRS Zuri cultivars of *Panicum maximum* grass. These increases in root volume were reflected in an increase in grass biomass, as shown above.

Among the basic cations, Ca, K, and P are taken up in significantly higher amounts after the application of wood ash, since it has high concentrations of these elements (Bonfim-Silva et al., 2019; Dourado et al., 2021; Schlichting et al., 2021), as observed in the ash used in the present study (Table 2). Bonfim-Silva et al. (2019) evaluated the concentration of macronutrients in *Urochloa brizantha* grass plants and observed that the application of wood ash favored greater uptake of Ca, P, K, Mg, and S and, consequently, greater concentration of these elements in the shoots.

Among the macronutrients, P presents the most difficulty in increasing its availability to plants. Tropical soils are acid, with mineralogy formed mainly by kaolinite and oxides, which have surface groups Si-OH, Fe-OH, and Al-OH (Melo and Aleoni, 2009), in which P can be strongly adsorbed through the exchange of ligands with the establishment of covalent bonds (Machado and Souza, 2012; Vinha et al., 2021). Thus, most of the P added to the soil is fixed and does not remain readily available for crops to take up (Sanchez, 1976; Driessen et al., 2001). Studies show that wood ash can contribute to increased soil P availability (Tan and Lagerkvist, 2011; Melese and Yli-Halla, 2016). This complex mechanism can occur in two ways, through an indirect effect of increasing the pH or a consequence of the action of silicates and carbonates in the displacement of P or the saturation of P adsorption sites by cations from wood ash (Opala et al., 2010; Kisinyo et al., 2013; Melese and Yli-Halla, 2016).

Thus, the greater production of Mombasa and BRS Zuri cultivars in plots fertilized with wood ash can be explained mainly by the supply of nutrients present in the ash. This nutrient supply favors larger leaf area and root volume, which is reflected in an increase in shoot biomass.

In this way, the use of a residue such as wood ash can contribute to the circular economy, as wood ash used as fertilizer and soil corrector are sustainable options available to meet the growing demand for bioenergy and chemical fertilizers in recent years

Therefore, the use of a residue such as wood ash can contribute to a circular economy. Wood ash used as a fertilizer and soil amendment are sustainable options available to meet the growing demand for bioenergy and chemical fertilizers in coming years (Huotari et al., 2015).

Solutions such as the one presented in this study contribute to achieving the Sustainable Development Goals (SDG) of the Sustainable Development Agenda of the United Nations, especially the SDGs related to ending hunger, achieving food security, improving nutrition, and promoting sustainable agriculture, all of which are interconnected (Marco et al., 2020; Marchant-Forde and Boyle, 2020).

Materials and Methods

Definition of studied area

The experiment was carried out in the southern region of the state of Mato Grosso, the Brazilian state with the largest cattle herd population, about 15% of the cattle in Brazil (IBGE, 2019). The experiment was conducted in a greenhouse at the Federal University of Rondonópolis, 16°27'50.37” S and 54°34'49.32” W, and altitude of 289 m. The climate according to the Köppen classification is Aw, characterized as hot and humid with two well-defined seasons, a dry winter and rainy summer (Alvares, 2014).

The soil used was a Dystrophic Red Oxysol (EMBRAPA, 2018) collected in the 0-20 cm layer under Cerrado vegetation and sieved through a 4 mm mesh. Over the last four decades, the Cerrado, the second-largest biome in Brazil, with about 200 million hectares (22% of national territory), has become the largest Brazilian source of grain production (soybeans and corn) and area for pastures. Oxisols are the dominant soil class in this biome (EMBRAPA, 2018). The particle-size and chemical characteristics of the soil used are described in Table 1.

Experimental design and Conduction of study

A randomized block experimental design was used in a 5 × 2 factorial arrangement, corresponding to five doses of wood ash (0, 8, 16, 24, and 32 g kg^{-1}) and two cultivars of *Panicum maximum* (cv. BRS Zuri and cv. Mombasa), with six replications. These cultivars were selected because they are recommended for diversification of pastures in intensive animal production systems in the Cerrado biome, due to their ease of establishment, high nutritional value, high response to fertilization, and production potential (Jank et al., 2010; EMBRAPA, 2014).

The wood ash used in the experiment comes from the combustion of eucalyptus (*Eucalyptus sp*.) logs in a boiler and was characterized according to Darolt et al. (1993) (Table 2).

After the application of wood ash doses (8, 16, 24, and 32 g kg^{-1}), the soil remained incubated for 30 days, with soil moisture at 60% of the maximum holding capacity. The maximum soil water holding capacity was established according to Bonfim-Silva et al. (2011a). The pots were kept at 60% of the pot water holding capacity through daily watering (late afternoon) throughout the period of the experiment.

After incubation of the soil with wood ash, 15 seeds of the cv. BRS Zuri and cv. Mombasa of *Panicum maximum* were sown in the experimental units/pots. At 10 days after emergence, the plants were thinned, leaving five plants per pot, which remained until the end of the experiment.

Due to the low N content in the wood ash, the soil was fertilized with 100 mg kg^{-1} of N at ten days after emergence, and again with 100 mg kg^{-1} of N at seventeen days after emergence in all experimental plots. In addition, 100 mg kg^{-1} of N were applied at the time of the first and second cuttings (Bonfim-Silva et al., 2011b).

Variables analyzed

Three cuttings were made of the plant shoots: the cuttings occurred at 30, 60, and 90 days after emergence (DAE). The leaf area was determined by the indirect method with the leaf area meter LI – 3100C. The number of tillers was manually counted in each experimental unit. The leaf and stem dry mass were determined after each cutting. The cuttings at 30 and 60 days after emergence were performed at the height of 5 cm from the ground. and the third and last cut that occurred at 90 days after emergence was performed close to the ground. Subsequently, the material was placed in a forced air ventilation oven at 65ºC for a period of 72 h or until reaching constant weight. The leaf dry mass divided by the stem dry mass constituted the leaf:stem ratio. The root volume was determined after the third cutting (end of the experiment): the roots were washed and with the aid of a graduated cylinder (1000 mL) filled with 500 mL of water, the roots from each experimental unit were inserted, and the difference in volume determined the root volume.

Statistical Analysis

The experiment was carried out with six replications in a randomized block design with factors consisting of doses of wood ash (8, 16, 24, and 32 g kg^{-1}) plus control and two cultivars of *Panicum maximum* (cv. Mombasa and BRS Zuri). Analysis of variance (ANOVA) was performed on the results, and the significance of the sources of variation was evaluated by the F test up to 5% probability. The effects of wood ash doses on the production characteristics of the *Panicum maximum* grass cultivars were evaluated using Tukey's test ($P < 0.05$).

Conclusions

Fertilization with wood ash leads to greater growth and production of *Panicum maximum* cv. Mombasa and BRS Zuri grown in tropical soil. The maximum production of *Panicum maximum* grass was obtained at a dose of 32 g kg^{-1} of wood ash. The application of wood ash to the soil offers potential as a sustainable strategy to increase production in pasture areas in view of the growing demand for beef. It also properly and safely disposes of waste and recycles nutrients extracted by the crops.

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