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Cultivation of *Urochloa brizantha* under different soil densities and doses of wood ash[1]

Cultivo de *Urochloa brizantha* sob diferentes densidades de solo e doses de cinzas vegetal

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HIGHLIGHTS:
Soil compaction at the 5-cm depth layer reduced the reproductive growth of Paiaguás grass.
The maximum dose of wood ash (20.42 g dm^{-3}) resulted in the highest production of shoot dry mass.
The root system was affected by soil compaction.

ABSTRACT: Soil compaction is a recurring problem in agriculture that ultimately leads to a reduction in crop productivity. However, the application of agro-industrial residues from the burning of plant biomass can improve the chemical and physical properties of soil. The objective of this study was to evaluate the growth of Paiaguás grass under different soil densities and wood ash doses. The experiment was carried out in a randomized block design, under a 5 × 5 factorial scheme, with five soil compaction values (1.0, 1.2, 1.4, 1.6, and 1.8 Mg m^{-3}) and five doses of wood ash (0, 8, 16, 24, and 32 g dm^{-3}), with four replicates. A soil density greater than 1.2 Mg m^{-3} reduced the dry mass of Paiaguás grass. The wood ash dose of 20.42 g dm^{-3} led to the highest shoot dry mass. Root growth was highest at a wood ash dose of 16.52 g dm^{-3}.

Key words: forage production, physical attribute, solid waste

RESUMO: A compactação do solo é um problema recorrente na agricultura, levando à redução da produtividade das culturas. Diante disso, a aplicação de resíduo agroindustrial da queima de biomassa vegetal pode melhorar as propriedades químicas e físicas do solo. O objetivo deste trabalho foi avaliar o crescimento do capim paiaguás sob diferentes densidades do solo e doses de cinzas vegetal. O experimento foi conduzido em blocos casualizados, em esquema fatorial 5 × 5, composto por cinco valores de compactação do solo (1,0, 1,2, 1,4, 1,6 e 1,8 Mg m^{-3}) e cinco doses de cinza vegetal (0, 8, 16, 24, 32 g dm^{-3}), com quatro repetições. Densidades do solo acima de 1,2 Mg m^{-3} reduzem a massa seca do capim paiaguás. A dose de cinza de madeira de 20,42 g dm^{-3} apresenta o maior valor de massa seca da parte aérea. O crescimento da raiz é maior na dose de cinza de madeira de 16,52 g dm^{-3}.

Palavras-chave: produção de forragem, atributo físico, resíduo solido

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Introduction

Pastures are the main sources of food for cattle herds; therefore, the concern with the productivity of these areas is constantly increasing, and proper soil management is required for forage production (Souza et al., 2019). Pastures also protect the soil, provide organic matter, and maintain fertility and good soil conditions (Calonego et al., 2011).

Although livestock contributes to the food supply, its threats to agricultural sustainability are associated with several factors, including soil compaction via animal trampling (Hu et al., 2020), which leads to high pressure on the soil surface. Such factors lead to a decrease in the volume of unsaturated soils (Gurgel et al., 2020).

According to Torres et al. (2012), the pressure exerted by cattle during grazing can reach approximately 0.21 MPa for a 500 kg cattle, while an excavator exerts only 0.02 MPa of pressure. Thus, cattle trampling can degrade the physical quality of the soil in a cropping system (Hu et al., 2018).

The effects of soil compaction on root system development and growth can have irreversible consequences, such as limited root elongation rate, shallow root systems, (Colombi & Keller, 2019), and a decline in productivity.

To identify methods for the physical and chemical maintenance of soils, residues from agro-industries have been added to soils, including wood ash, which can correct soil pH, provide nutrients (Darolt et al., 1993), and reduce soil density (Martinez-Santos et al., 2019).

Bonfim-Silva et al. (2022) found an interaction between the factors analyzed in their study, with a wood ash dose of 25 g dm^{-3} and soil density of 1.2 Mg dm^{-3} identified to enable the best crop growth. The objective of this study was to evaluate the growth of Paiaguás grass under different soil densities and wood ash doses.

Material and Methods

The experiment was conducted from September 2021 to February 2022 in a protected environment at the Universidade Federal de Rondonópolis-UFR, geographically positioned at 16° 27' 50.36" S and 54° 34' 49.34" W, and an altitude of 289 m. The experiment was carried out in a randomized block design in a 5 × 5 factorial scheme corresponding to five soil densities (1.0, 1.2, 1.4, 1.6, and 1.8 Mg m^{-3}) and five wood ash doses (0, 8, 16, 24, and 32 g dm^{-3}) according to Martinez-Santos et al. (2019), with four blocks. The experimental units were composed of two cylindrical rings of polyvinyl chloride, 192 mm in diameter and 200 mm in height, which were joined by a transparent tape, leading to a total volume of 6.28 dm^3.

An Oxisol soil (United States, 2014) that corresponds to a Latossolo Vermelho-distrófico in the Brazilian Soil Classification System (EMBRAPA, 2018) was used in this study. The soil was collected under Cerrado vegetation at a layer of 0-0.2 m depth and sieved through a 2.0 mm mesh prior to chemical and granulometric characterization of the soil (Table 1).

After collection, the soil was packed in 10 dm^3 plastic bags containing the respective doses of wood ash. To ensure reaction of the material, the soil moisture was maintained at 60% of the maximum water retention capacity in the soil using the gravimetric method (Bonfim-Silva et al., 2022), the plastic bags were also kept sealed. The incorporation of soil with wood ash is a commonly used method for soil correction in fertile areas, according to Bonfim-Silva et al. (2022).

After a 30-day reaction of the residue with the soil, the plastic bags were opened, and the assembly of the experimental units was initiated with the respective treatments and soil densities.

The eucalyptus wood ash used in the experiment was obtained from ovens in the food industry, and the temperature during the combustion process was approximately 850 °C. Wood ash is characterized as a corrective and fertilizer (Alcarde & Rodela, 1996), according to Table 2.

At the bottom of the cylindrical ring, a mesh screen with a 1 mm opening was fixed to cover the entire base, enabling draining of the water and retention of the soil content inside the pot. The 5 cm layer (upper cylinder) was compacted using a P15ST hydraulic press, with an overload of 15 tons, according to the standard for all experimental units.

The 10 cm layer (bottom cylinder) was completed with approximately 3.14 dm^3 of soil, which corresponded to a density of 1.0 Mg m^{-3}. To estimate the mass of the soil used in each cylinder, the mass of dry soil required to reach each density of soil (Eq. 1) was calculated for the first time, followed by the mass of wet soil to be added to the compressed layer (Eq. 2).

$$Ds = \frac{Mss}{Va} \leftrightarrow Mss = Va \cdot Ds \quad (1)$$

Table 1. Chemical and granulometric attributes of Latossolo Vermelho distrófico (Oxisol) in the 0-0.20 m depth layer from an area under Cerrado vegetation

pH	P	K	S	Ca	Mg	Al	H + Al	SB	CEC	OM	V	m	Sand	Silt	Clay
$CaCl_2$	(mg dm^{-3})			($cmol_c$ dm^{-3})						(g kg^{-1})	(%)		(g kg^{-1})		
4.3	1.5	18	2	0.5	0.2	0.6	4.8	0.8	5.6	21.3	13.5	44.4	570	100	330

P - Phosphorus; K - Potassium; S - Sulfur; Ca - Calcium; Mg - Magnesium; H - Hydrogen; Al - Aluminum; CEC - Cation exchange capacity; SB - Sum of bases; OM - Organic matter; V - Base saturation; M - Aluminum saturation

Table 2. Chemical attributes of wood ash

pH	RPTN	PN	N	P_2O_5	K_2O	Ca	Mg	Fe	Cu	Mn	B	Zn	SO_4
$CaCl_2$	(%)		(g kg^{-1})										
10.67	24.76	30	4.9	7.9	32.5	49.6	42.0	7.2	0.1	0.4	0.4	0.2	6.0

RPTN - Relative power of total neutralization; PN - Neutralizing power; N - Nitrogen; P_2O_5 - Phosphorus in neutral ammonium citrate and water (CNA + water); K_2O - Potassium; Ca - Calcium; Mg - Magnesium; Fe - Iron; Cu - Total copper; Mn - Total manganese; B - Total boron; Zn - Total zinc; SO_4 - Sodium where

Ds - soil density ($Mg\ m^{-3}$);
MSS - dry soil mass (kg); and,
Va - ring volume ($3.14\ dm^{-3}$).

$$MSU = MSS \cdot \theta m \quad (2)$$

where:

MSU - moist soil mass; and,
θm - moisture based on mass.

As wood ash contains phosphorus and potassium, no other fertilizers were applied, except 200 mg dm^{-3} nitrogen (Bonfim-Silva et al., 2015), which was applied at 7, 14, and 21 days after plant emergence, at doses of 50, 75, and 75 mg dm^{-3}, respectively.

Urochloa brizantha has a high dry matter production, easy adaptation, and satisfactory vegetative growth throughout the year (Biazatti et al., 2020). After the cylindrical ring was prepared, 30 seeds were distributed in each experimental unit at a depth of 2 cm. Five days after sowing, the plants were found to germinate. Thinning was carried out six and nine days after seedling emergence. Thereafter, five plants remained per pot.

Irrigation was performed daily to maintain the soil moisture. Fifteen days after plant emergence, irrigation was carried out through the lower part of the pots, depositing water according to the demand of the crop, whose water had risen by capillarity.

The evaluations were performed using three cuts of the aerial parts of the plants at 30, 60, and 90 days after emergence. The soil pH, shoot and root dry mass, and root volume were evaluated (the last two in the third cut). Two pH readings were performed, before sowing and 90 days after emergence, in a 0.01 M $CaCl_2$ solution using a pH meter.

The dry mass of the aerial part was obtained from each cut of the plants at 5 cm from the soil, placed in paper bags, and transferred to a forced ventilation oven at 65 °C for 72 hours. The samples were weighed using a semi-analytical balance to determine the dry mass.

The root dry mass was determined in the last cut. Thereafter, the root was washed in running water to remove the soil, dried in a forced ventilation oven, and weighed; the value is presented as grams per pot. To determine the root volume, the root was added to a 1000 mL beaker containing 500 mL of water, the difference in water volume was equivalent to the root volume in cm^3.

Data were subjected to a normality test to verify whether the errors followed a normal distribution. Subsequently, the data were subjected to analysis of variance, followed by regression analysis at $p \leq 0.05$. The data were analyzed using R Studio software (R Development Core Team, 2018).

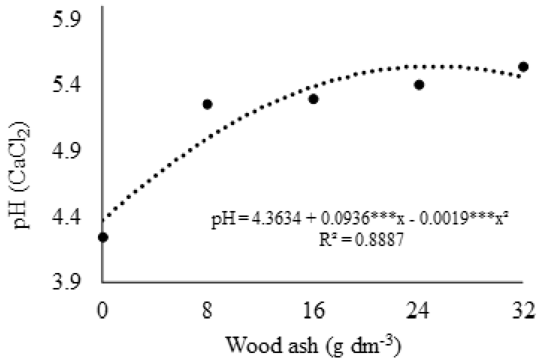
Results and Discussion

According to analysis of variance (Table 3), the soil pH before sowing was significantly different from that found after the addition of wood ash ($p \leq 0.05$), adjusting to the quadratic regression model (Figure 1). In fact, the soil pH increased by 1.22 units from pH 4.3 (Table 1) to pH 5.52 after the addition of 24.63 g dm^{-3} wood ash.

Table 3. Summary of the analysis of variance results for soil pH

SV	DF	F value
pH before sowing		
Dose	4	17.33^{***}
Density	4	1.09^{ns}
Dose × Density	16	0.67^{ns}
Error	72	
CV (%)		10.77
pH 90 days after plant emergence		
Dose	4	64.87^{***}
Density	4	1.48^{ns}
Dose × Density	16	1.82^{*}
Error	72	
CV (%)		5.72

Significant at * - $p \leq 0.05$; *** - $p \leq 0.001$ by F test; ns - Non-significant; SV - Source of variation; DF - Degree of freedom; CV - Coefficient of variation



*** - Significant at $p \leq 0.001$ by the F test

Figure 1. pH ($CaCl_2$) of soil subjected to doses of wood ash at 30 days after incubation

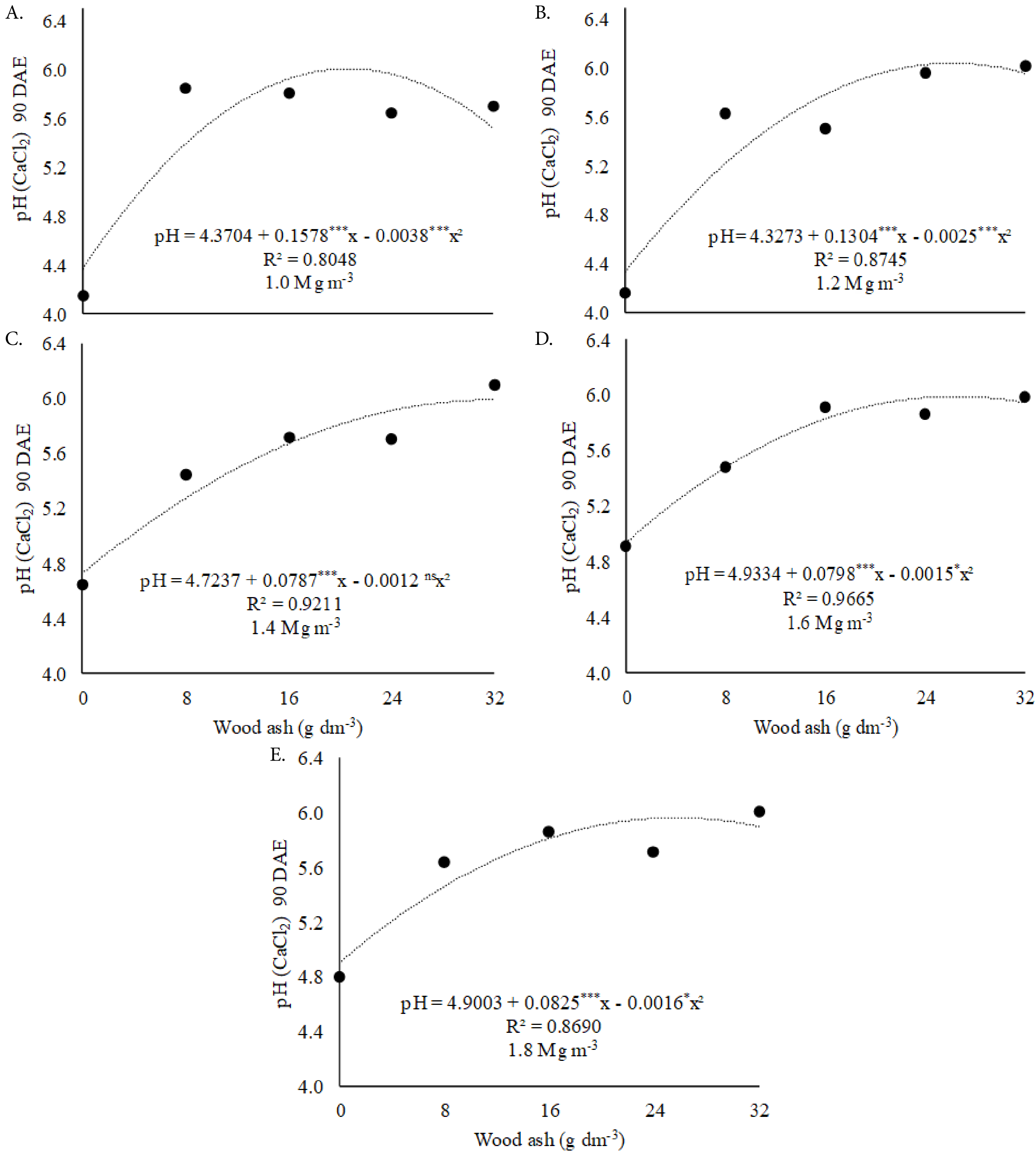
The amount of calcium present in wood ash is one of the factors that explain the increase in soil pH before sowing. Calcium is a chemical element used to neutralize soil acidity and improve fertility and nutrient availability for plants. Biazatti et al. (2020) observed a direct influence of soil pH correction on the availability of all nutrients required for production.

Johansen et al. (2021) observed improved plant growth owing to the combined effect of increased pH and nutrient availability. According to Malavolta et al. (1997), the ideal pH range of soils for agriculture is 5.0 to 6.0.

The high level of calcium carbonate in wood ash is important for increasing the soil pH to non-toxic levels, favoring the development of forage grass. According to Bang-Andreasen et al. (2017), the addition of wood ash to the soil strongly increases soil pH and electrical conductivity, with a pH change from acidic to neutral at 22 t ha^{-1} and alkaline at 167 t ha^{-1}.

At 90 d after plant emergence, a significant interaction was observed between the wood ash dose and soil density (Figure 2). By evaluating the wood ash within each soil density level, a wood ash dose of 26.08 g dm^{-3} and a soil density of 1.2 Mg m^{-3} were found to provide the highest soil pH (Figure 2B).

The soil pH increased due to contact between the calcium present in wood ash and soil moisture, which produced Ca^{2+} with a weak base and strong base. After the calcium carbonate dissociation reaction, the products react with hydrogens in soil colloids, releasing water and carbon dioxide (Raij, 2011), ultimately neutralizing the acidity of the soil.



* and *** - Significant at $p \leq 0.05$, and $p \leq 0.001$ by the F test, respectively; ns - Non-significant difference; x - Wood ash

Figure 2. Soil pH ($CaCl_2$) as a function of wood ash dose within each soil density at 90 days after emergence

The large amount of calcium in wood ash (Table 2) triggered the power to correct soil acidity, corroborating the results of Bonfim-Silva et al. (2020), who reported that the highest dose of wood ash applied to the soil resulted in the highest pH value.

A similar result was obtained by Mercl et al. (2020), who evaluated the effect of ash on the chemical attributes of soil whose pH was found to increase. Therefore, wood ash has a high power to neutralize acidity and increase soil pH (Bonfim-Silva et al., 2018), as observed in the present study.

For the shoot dry mass at 30, 60, and 90 days after plant emergence, an interaction was found between the factors according to the analysis of variance (Table 4).

A significant interaction was identified at 30 days after plant emergence. In fact, the highest dry mass of the aerial part of plants (4.0 g per pot) was achieved at a wood ash dose of 21.89 g dm^{-3} and soil density of 1.2 Mg m^{-3} (Figure 3).

The combination of wood ash effect and favorable soil conditions for plant development resulted in a satisfactory shoot dry mass rate. However, soils with impediments to

Table 4. Summary of the analysis of variance results for shoot dry mass at 30, 60, and 90 days after plant emergence

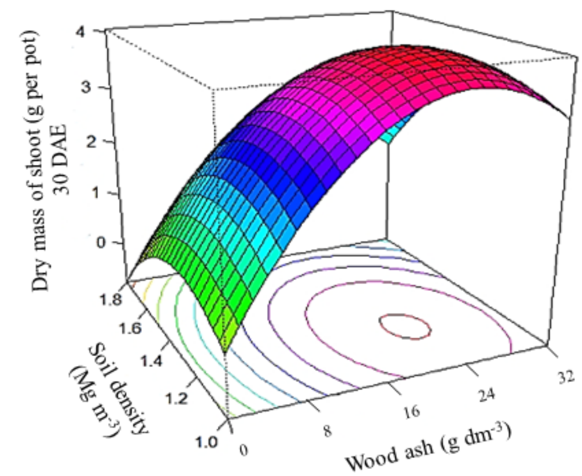
SV	DF	F value
Cut at 30 days after plant emergence		
Dose	4	83.54***
Density	4	25.69***
Dose × Density	16	2.84***
Error	72	
CV (%)		27.27
Cut at 60 days after plant emergence		
Dose	4	21.44***
Density	4	4.04***
Dose × Density	16	1.22ns
Error	72	
CV (%)		50.28
Cut at 90 days after plant emergence		
Dose	4	19.68***
Density	4	11.58***
Dose × Density	16	1.80*
Error	72	
CV (%)		38.95

Significant in: * - $p \le 0.05$; *** - $p \le 0.001$ by the F test; ns - Non-significant difference; SV - Source of variation; DF - Degree of freedom; CV - Coefficient of variation

$$MSPA = -8.943114286^{***} + 0.334429018^{***}x + 15.079687500^{***}ds - 0.026781250x.ds - 0.006882254^{***}x^2 - 5.86361607ds^2$$

$R^2 = 0.7406$

CV = 27.27%



*** - Significant at $p \le 0.001$ by the F test; x - Wood ash; ds - Soil density

Figure 3. Dry mass of the shoot of Paiaguás grass, as a function of wood ash dose and soil density in the first cut

root development caused higher energy expenditure for plant growth, which led to low plant development.

Wood ash is a viable partial or total replacement for mineral fertilizer. Notably, in the present study, wood ash was used as a soil corrector. As a result, nutrients were made available to the soil, as observed in the aforementioned study, thereby leading to good results for the dry mass of shoots.

These results can be attributed to the improvement in soil fertility after the addition of wood ash, such as an increase in essential nutrients for plant development and the favoring of empty spaces in the system after the addition of the residue, ultimately allowing better oxygen flow and consequently better root development. Studies have also shown that wood ash causes positive changes in soil fertility (Bonfim-Silva et al., 2015).

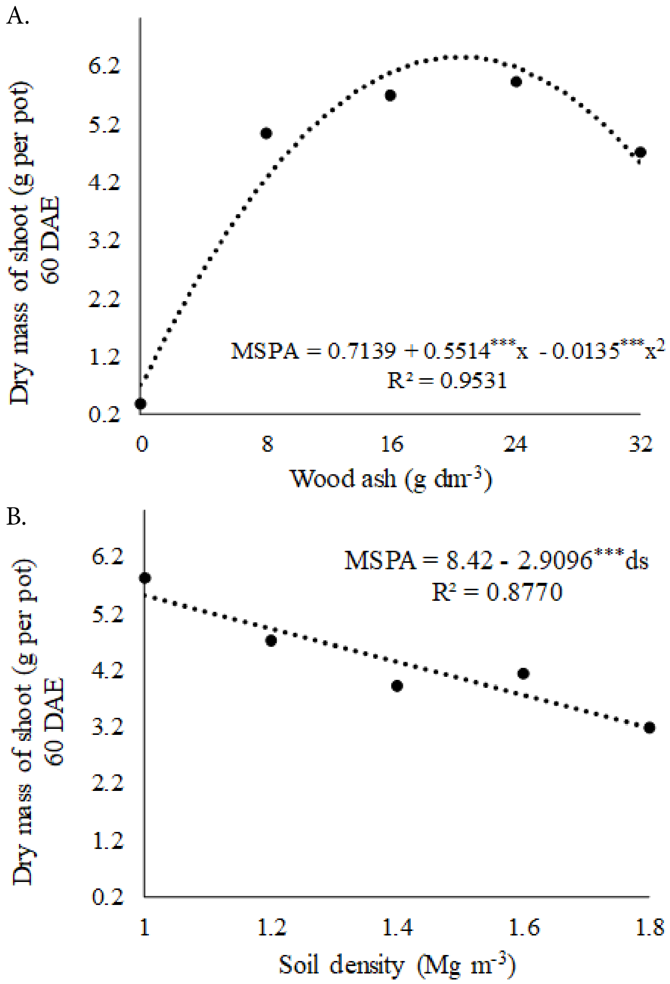
The increase in soil pH by wood ash results in improved soil fertility, ie nutrients such as P, K and Ca (Ondrasek et al., 2021), which play a role in crop production and development. Potassium has numerous functions, such as enzyme activation in the plant, thereby potentiating the division of molecules and becoming essential for the proper growth of roots and shoots. Further, calcium is directly responsible for the elongation of plant cells.

Regarding the unique effect of wood ash at 60 days after plant emergence, the adjustment of the dry mass of shoot was described by a quadratic regression model, with a maximum of 6.34 g per pot at an ash dose of 20.42 g dm^{-3} (Figure 4A).

The result of the treatment with wood ash may be related to the correct recommendation of wood ash, which causes an increase in growth of the plant; this is because wood ash provides the necessary nutrients for fundamental processes of the plant, such as photosynthesis, respiration, and protein synthesis (Bonfim-Silva et al., 2018).

Regarding soil density, 60 days after plant emergence, the dry mass of the shoots of Paiaguás grass reduced as the level of compaction increased. The highest soil density of 1.8 Mg m^{-3} led to a dry mass of 3.37 g per pot (Figure 4B).

Of note, the pressure exerted on the soil can increase the resistance to penetration by culture roots due to the decrease



*** - Significant at $p \le 0.001$ by the F test; ns - Non-significant difference; x - Wood ash; ds - Soil density

Figure 4. Dry mass of the shoot of Paiaguás grass under doses of wood ash (A) and soil densities (B) in the second cut

in porosity, as mentioned by Colombi & Keller (2019). The effects of these agents directly reflect the growth of the shoot and reduce the expansion of the plant's root system, which requires increased fertilization rates to compensate for the lower volume of exploited soil.

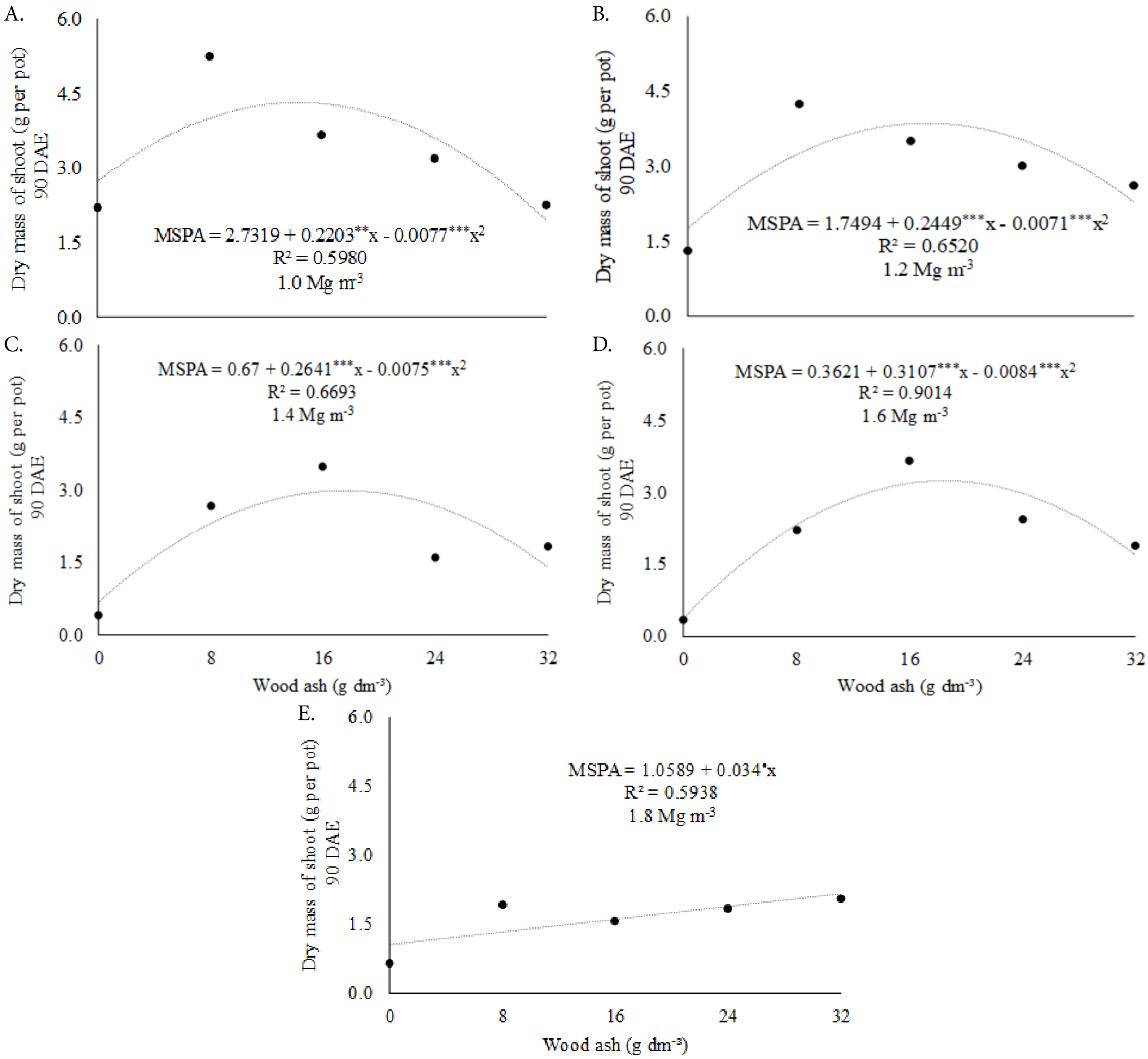
Paiaguás grass produced a lower shoot dry mass under conditions of high soil density. These results can be explained by the fact that as the soil density increases, there is less pore space between the soil particles, making it difficult for plants to absorb nutrients and water. Further, oxygen and root development are reduced, thereby affecting plant growth (Martinez-Santos et al., 2019).

Ninety days after plant emergence, the maximum value of shoot dry mass was 4.31 g per pot, which was obtained at a wood ash dose of 14.31 g dm^{-3} and soil density of 1.0 Â Mg m^{-3} (Figure 5A). In contrast, the minimum value of shoot dry mass (2.0 g per pot) was observed at an apparent density of 1.8 Mg m^{-3} (Figure 5E). The lower production may have occurred due to changes in porosity and numerous physical properties related to the processes of storage and transfer of water, air, and heat in the soil (Santos et al., 2018).

According to Santos et al. (2018), these results are related to the location and level of soil compaction. In the present study, the surface layer of the soil was compacted, and the plants could develop their root system in the 5-cm layer and extract water and nutrients needed for shoot growth from the soil matrix.

According to the analysis of variance results (Table 5), the dose of wood ash significantly affected root dry mass ($p \leq 0.05$). In fact, the higher the dose supplied to the soil, the higher the root dry mass (Figure 6).

The results displayed a quadratic behavior, that is, the dose of 16.52 g dm^{-3} resulted in the highest value of root dry mass. These results can be explained by the fact that wood ash contains calcium and phosphorus, which are directly responsible for root and shoot growth, and potentiates molecular division, thereby enabling increased plant development.



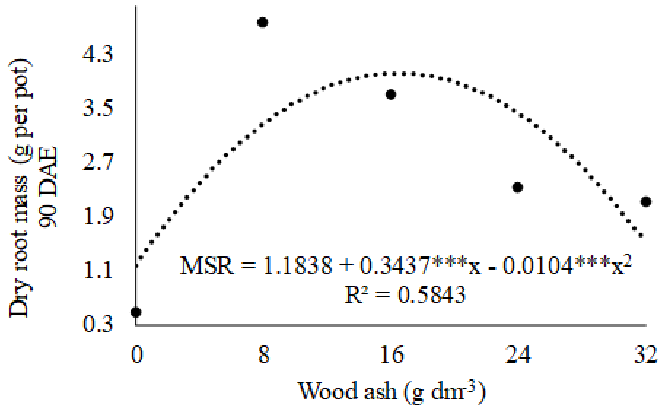
*, ** and *** - Significant at $p \leq 0.10$, $p \leq 0.01$, $p \leq 0.001$ by the F test, respectively; x - Wood ash

Figure 5. Dry mass of the shoot of Paiaguás grass as a function of wood ash doses within each soil density level in the third cut

Table 5. Summary of the analysis of variance results for root dry mass and root volume at 90 days after plant emergence

SV	DF	Dry root mass	Root volume
		F values	
3 Cut at 90 days after plant emergence			
Dose	4	19.11***	25.47***
Density	4	1.21ns	2.67*
Dose × Density	16	1.48ns	1.17ns
Error	72		
CV (%)		62.46	45.62

Significant in: * - p ≤ 0.05; *** - p ≤ 0.001 by the F test; ns - Non-significant difference; SV - Source of variation; DF - Degree of freedom; CV - Coefficient of variation



*** - Significant at p ≤ 0.001 by the F test, x - Wood ash

Figure 6. Dry mass of Paiaguás grass subjected to different doses of wood ash at 90 days after emergence

Reis et al. (2020) described the use of wood ash as a fertilizer to produce *Brachiaria decumbens* biomass and increase the production of root dry matter.

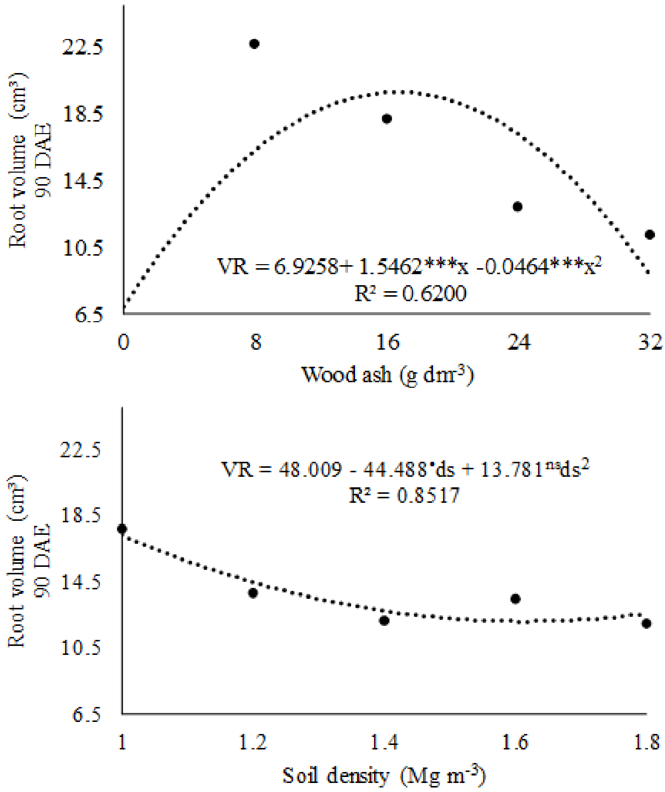
Notably, the dry mass of the root is related to the regrowth capacity of the grasses. The roots and stem contain organic compounds of carbohydrates and act as sources in the source-sink relationship when the leaf residue area is restricted, which occurs after the grass is cut (Cabral et al., 2018).

The volume of root dry mass is linked to the amount of essential nutrients required for the development of culture. The ash of the wood has high levels of these nutrients, which are precursors for growth (Bonfim-Silva et al., 2020). Roots provide a larger area for nutrient and water absorption from the soil, which can lead to a higher shoot growth.

Studies have been carried out using wood ash as a source of fertilizer (Bonfim-Silva et al., 2020). Previously, Dourado et al. (2021) found that wood ash has a significant effect on crop growth and development. In this study, the use of wood ash in the soil led to good results for the cultivation of Paiaguás grass, thereby serving as a viable alternative to fertilizer.

Root volume was found to be significantly influenced by wood ash dose and soil density levels. The highest root volume of 19.81 cm^3 was recorded at a dose of 16.66 g dm^{-3}, adjusted to the quadratic regression model (Figure 7A). This result is attributed to the conditioning effects of wood ash on the soil.

The smallest root volume of 12.10 cm^3 for Paiaguás grass was due to the soil density factor, as represented by the decreasing polynomial regression model (Figure 7B).



* and *** - Significant at p ≤ 0.10, and p ≤ 0.001 by the F test; ns - Non-significant difference; x - Wood ash; ds - Soil density

Figure 7. Root volume of Paiaguás grass as a function of wood ash doses and soil densities in the third cut

These results can be explained by the fact that as soil density increases, there is a low availability of oxygen, causing ethylene production in the roots (Correa et al., 2019). Ethylene is harmful to the plant and acts as a toxin, further affecting the yield and production, decreasing the rate of root elongation, altering the root system, and limiting the rooting depth, ultimately modifying the anatomical shape of the root (Moraes et al., 2020).

The results observed in the present study, demonstrating that Paiaguás grass suffered a reduction in the high density level. Santos et al. (2018) revealed that the isolated effect of soil compaction limits the production of root systems in millet cultivars.

Conclusions

1. Wood ash doses above 20 g dm^{-3} raised the soil pH to 6.03, regardless of the soil density, demonstrating their high power to neutralize soil acidity.
2. Soil density above 1.2 Mg m^{-3} reduced the dry mass of Paiaguás grass.
3. The wood ash dose of 20.42 g dm^{-3} led to the highest shoot dry mass.
4. Root growth was highest at a wood ash dose of 16.52 g dm^{-3}.

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