ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.27, n.4, p.241-249, 2023
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n4p241-249

Soil quality indicators for *Urochloa brizantha* fertilized with wood ash[1]

Indicadores de qualidade do solo sob cultivo de *Urochloa brizantha* adubada com cinza de madeira

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HIGHLIGHTS:
The use of wood ash increased P and K concentrations in the soil and activity of the acid phosphatase enzyme.
The management of wood ash incorporation is directly linked to soil density.
Wood ash reduced soil bulk density by up to 9.66%, favoring root growth.

ABSTRACT: The objective was to evaluate the effect of wood ash dose and application management on soil quality attributes in a Cerrado area cultivated with *Urochloa brizantha*. The experiment was carried out in a randomized block design in a 5 × 2 strip-plot scheme and four repetitions. The ash doses were 0, 8, 16, 24, and 32 t ha^{-1}, and the application management considered wood ash that is incorporated and not incorporated into the soil. The P, K, and pH values of the soil increased with an increase in the doses of wood ash. The soil bulk density decreased by 9.66% with the wood ash doses of 24 and 32 t ha^{-1} incorporated into the soil. Owing to an increase in the soil pH, a wood ash dose of greater than 16 t ha^{-1} decreased the enzymatic activity. A wood ash dose of 24 t ha^{-1} resulted in better conditions for the soil, improving its quality and contributing to the balance and dynamics between the chemical, physical, and biological attributes of the soil, which led to the reduced density and greater availability of P in the soil.

Key words: ash management, phosphatase enzyme, soil improvers, paiaguás grass

RESUMO: O objetivo foi avaliar o efeito da dose e do manejo de aplicação de cinzas de madeira nos atributos de qualidade do solo em uma área de Cerrado cultivada com *Urochloa brizantha*. O experimento foi realizado em blocos casualizados, no esquema em faixas 5 × 2 e quatro repetições. As doses de cinzas foram de 0, 8, 16, 24 e 32 t ha^{-1}, e o manejo de aplicação considerou cinza de madeira incorporada e não incorporada ao solo. Os valores de P, K e pH do solo aumentaram com o aumento das doses de cinza de madeira. A densidade do solo diminuiu 9,66% com as doses de cinzas de madeira de 24 e 32 t ha^{-1} incorporadas ao solo. Devido ao aumento do pH do solo, dose de cinzas de madeira maior que 16 t ha^{-1} diminuiu a atividade enzimática. Uma dose de cinza de madeira de 24 t ha^{-1} resultou em melhores condições para o solo, melhorando sua qualidade e contribuindo para o equilíbrio e a dinâmica entre os atributos químicos, físicos e biológicos do solo, o que levou à redução da densidade e maior disponibilidade de P no solo.

Palavras-chave: manejo de cinza, enzima fosfatase, melhoradores do solo, capim paiaguás

• Ref. 266559 – Received 02 Aug, 2022
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• Accepted 02 Nov, 2022 • Published 10 Nov, 2022
Editors: Geovani Soares de Lima & Walter Esfrain Pereira

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Introduction

Pasture is considered to be the main cover in Brazilian soils, and the balance between the soil, plant, and animal systems is essential for optimizing plant production. The maintenance of pastures ensures the replacement of nutrients and soil conservation, leading to the extraction of nutrients with reduced losses by erosion or leaching for the systems (Pereira et al., 2018; Cruz et al., 2022).

Studies have confirmed that the use of plant biomass combustion materials in agriculture, when incorporated into the soil, positively affects the soil and plants, as the materials possess a high nutrient composition and corrective character for the soil (Bonfim-Silva et al., 2019; Bonfim-Silva et al., 2020).

Vegetable ash is a residue generated by the burning of plant biomass in industries. The volume of ash produced is high, and alternatives for safe disposal and use are indispensable (Martins Filho et al., 2020). When the ash is incorporated into the soil, it causes changes in several attributes, such as increased microporosity and water retention in the soil, reduced macroporosity, soil compaction, and acidity, which positively influence microbial diversity and activity (Arruda et al., 2016; Li et al., 2018).

Studies aimed at the evaluation and use of wood ash in pasture areas are limited, and considering the knowledge of the changes that the ash causes to the soil, the monitoring and evaluation of the interactions that occur in the chemical, physical, and biological processes of the soil have become fundamental. The adopted management practices have affected these factors, influencing the quality of the soil and plant production.

This study aims to evaluate the effects of wood ash doses and application management on soil quality attributes in a Cerrado area cultivated with *Urochloa brizantha*.

Material and Methods

This study was conducted in the experimental field of the Universidade Federal de Rondonópolis (UFR), Rondonópolis, MT, Brazil, located at 16° 27' 38.94" S and 54° 34' 57.01" W, 287 m altitude, from December 2019 to March 2021.

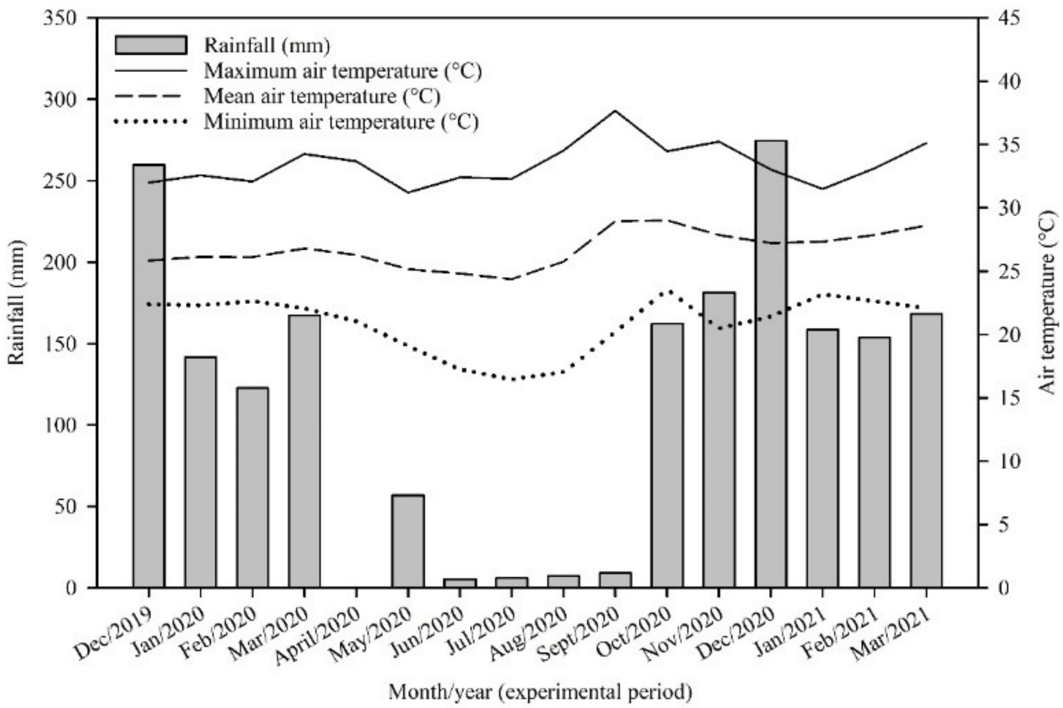
According to the Köppen classification, the predominant climate type in the region is tropical monsoon, as Aw is characterized by hot and humid weather, with two well-defined seasons (beginning in September): one rainy and another dry, varying from three-five months. During the experimental period, the total rainfall was 1876 mm, considering a mean monthly rainfall of 117 ± 22.91 mm (mean ± standard error) and average air temperature of 27.16 ± 1.16 °C (Figure 1).

The soil of the area was classified as Oxisol soil (United States, 2014), which corresponds to the Latossolo Vermelho distrófico in the Brazilian soil classification system (EMBRAPA, 2018).

The application of ash to the experimental area was performed in November 2018, 1 month after sowing. The seeds of *Urochloa brizantha* cv. BRS Paiaguás. All the plots received wood ash (source of K and P) and were fertilized with nitrogen (100 kg of N ha^{-1}), parceled in three equal applications during plant cutting.

The paiaguás grass was added to three cuts of the vegetative part to simulate the grazing and removal of green matter from the area. The cuts occurred during the rainy season of each year: February, March, and April 2019 (pasture establishment period); January, February, and March 2020 (first year of pasture maintenance); and January, February, and March 2021 (second year of pasture maintenance).

The maintenance period of the experiment was initiated in December 2019, with the reapplication of wood ash and nitrogen fertilization throughout the experimental area.



Source: Adapted from INMET, Brazil

Figure 1. Rainfall (mm) and air temperature (°C) during the experimental period of December 2019 to March 2021

Table 1. Chemical and particle-size characterization of wood ash and Oxisol collected from the 0-0.20 m layer, in the experimental area

Variable	Unit	Value
Wood ash		
pH ($CaCl_2$)	-	10.67
NP	%	30.00
RNP	..	24.76
N	g kg^{-1}	4.90
P_2O_5	..	7.90
K_2O	..	32.50
Ca	..	49.60
Mg	..	42.00
S	..	6.00
Fe	..	7.20
M.M	..	546.40
Granulometry: 4.8 mm	%	0.48
Granulometry: 2.0 mm	..	3.07
Granulometry: 1.0 mm	..	10.53
Density	g cm^{-3}	0.40
Oxisol		
pH ($CaCl_2$)	-	3.70
OM	g kg^{-1} mg dm^{-3}	27.10
P	..	1.60
K	..	42.40
S	cmol$_c$ dm^{-3}	6.10
Ca	..	0.65
Mg	..	0.25
Al	..	0.95
H + Al	..	6.00
SB	..	1.01
CEC	%	7.01
V	..	14.41
Sand	g kg^{-1}	395
Silt	..	175
Clay	..	430

NP - Neutralizing power; RNP - 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; P - Phosphorus; K - Potassium; Al - Aluminum; H - Hydrogen; CEC - Cation exchange capacity at $pH_{7.0}$; OM - Organic matter; MM - Mineral matter; V - Base saturation; m - Aluminum saturation; Fe - Iron

The use of nitrogen in the experiment was justified by the composition of wood ash with a low concentration of the nutrient, which is volatilized during the wood combustion process.

The experiment was carried out in a randomized block design in a 5 × 2 strip-plot scheme and five doses of wood ash (0, 8, 16, 24, and 32 t ha^{-1}) (Table 1) and two types of wood ash application for the soil (incorporated into the soil with light harrow and not incorporated). Each experimental plot comprised subplots of 72 m^2 (12 × 6 m) and 36 m^2 (6 × 6 m). The useful area of each subplot was 30.25 m^2 (5.5 × 5.5 m).

The evaluations were performed in two consecutive agricultural years of pasture maintenance: 2019/20 and 2020/21. Samples were collected before the first cut and after the third cut of the grass in December 2019, March 2020, December 2020, and March 2021.

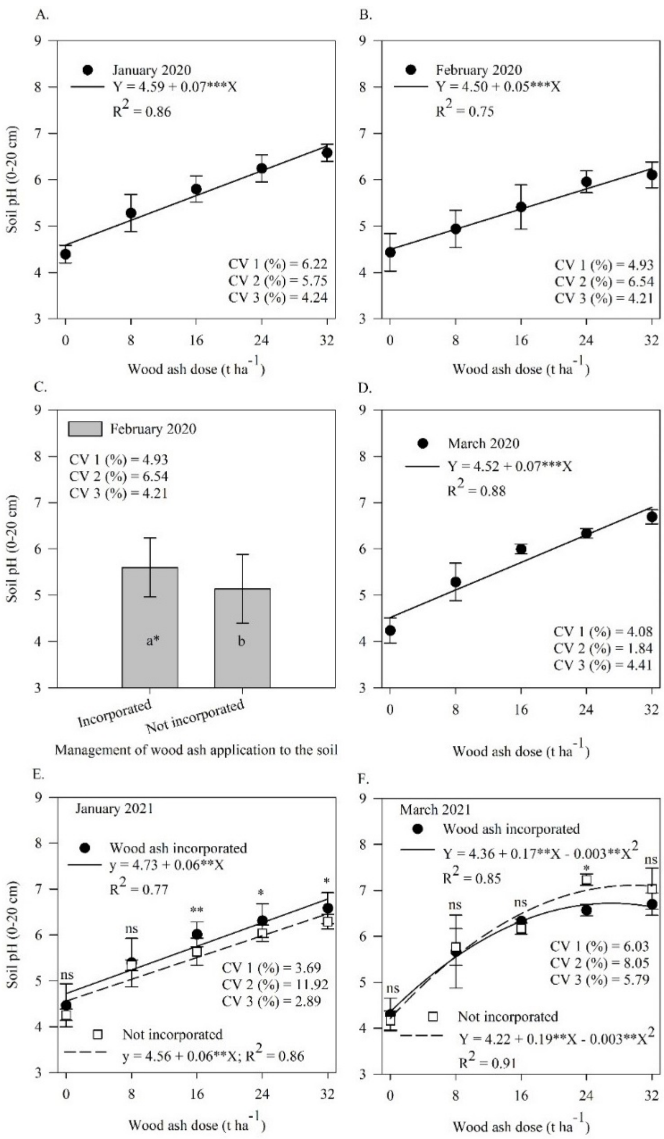
The variables analyzed were soil pH, phosphorus (P), potassium (K), soil density, and acid phosphatase activity. Unlike other variables, soil pH was evaluated before and after the grass was cut, which occurred in January, February, and March during the two years of maintenance. pH, P, K, and soil density were analyzed according to the methodology described by EMBRAPA (2017). The acid phosphatase activity was quantified according to the methodology proposed by Tabatabai & Bremner (1969).

The results were subjected to residual normality testing, analysis of variance (ANOVA), Tukey´s test, and regression ($p \leq 0.05$) using R (R Development Core Team, 2018).

Results and Discussion

During the two years of evaluation, the pH value in the 0-0.2 m depth layer exhibited an increase in changes as the application of the doses of ash increased, regardless of the application management (Figures 2A, B and D).

In the first year, only in the second cut, there was a significant difference in the application management, with the ash incorporated into the soil promoting greater changes with regard to pH in the second cut (Figure 2C). In the first and third cuts of the second year, there was an interaction between



Vertical bars represent the standard deviation of the mean of the four values.
** - Significant at p ≤ 0.01 based on the F test

Figure 2. Soil pH in the first (A), second (B and C), and third cuts (D) of the 2019-2020 cycle and the first (E) and third cuts (F) of the 2020-2021 cycle of paiaguás grass as a function of wood ash doses and application management

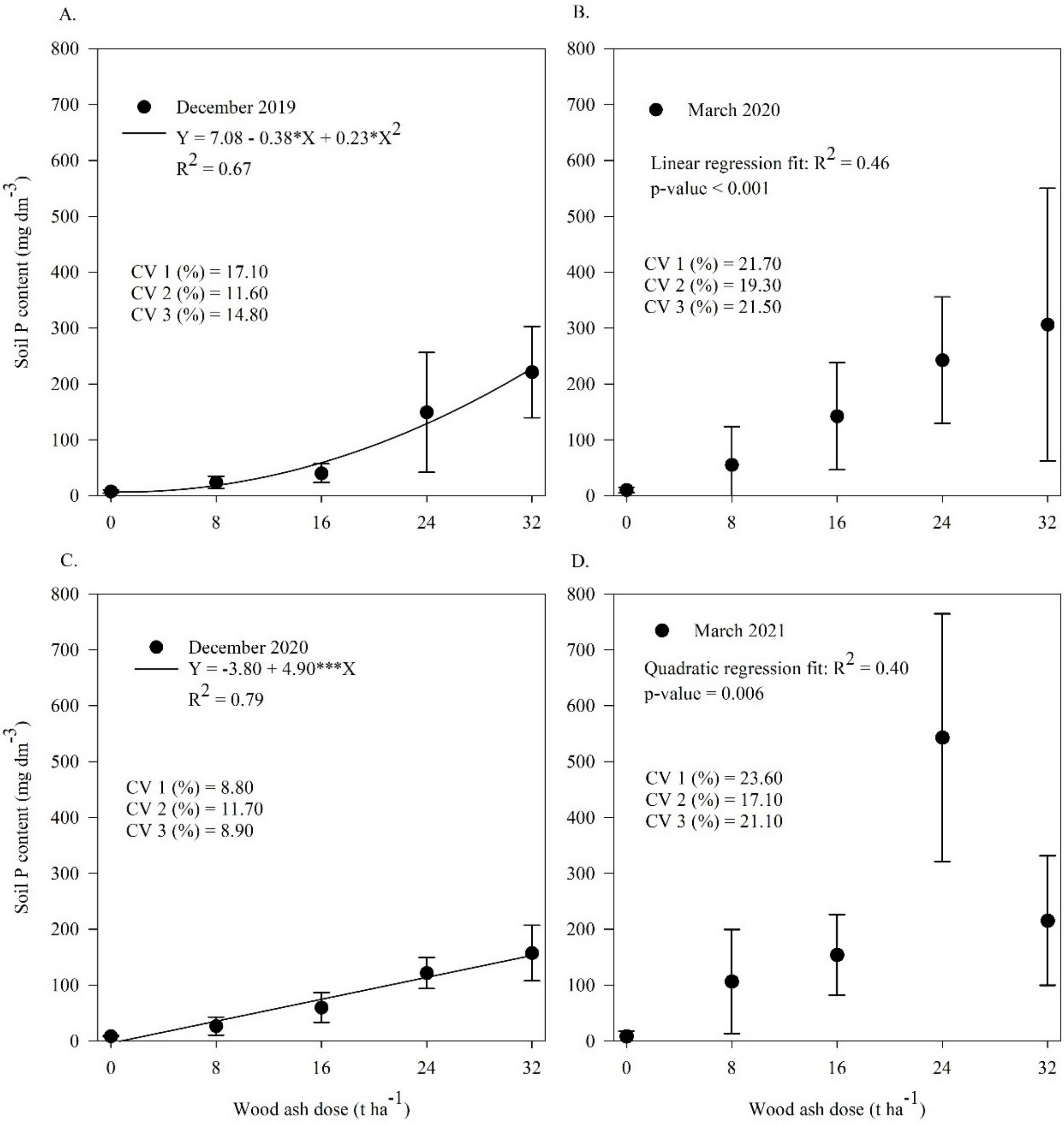
the factors; in the first cut, the ash dose increased the pH value, with a linear effect of an increase in regression (Figure 2E). In the third cut, an ash dose of 16 t ha^{-1} incorporated, and even when not incorporated, into the soil promoted better soil pH (Figure 2F).

Soil pH is a limiting factor for crop development because it is directly linked to the dynamics of nutrients and microbial activity in the soil. For most crops, the ideal pH for plants to reach their maximum potential lies between 5.5 and 6.5. In this pH range, macronutrients, such as P, K, Ca, and Mg, are readily available (Bonfim-Silva et al., 2020; Johansen et al., 2021).

Studies on acidity neutralization based on alkaline waste generated from the pulp and paper industry have shown that using wood ash as a fertilizer and soil conditioner combats acidity, increases base saturation, and improves the nutritional status of plants (Royer-Tardif et al., 2019). The ash content, surface alkalinity, and presence of alkali elements, e.g., Ca, Mg, and K, in the composition of wood and pig biochars directly impacts soil pH (Chen et al., 2020).

The increase in soil pH can be attributed to the high content of Ca and Mg present in the plant ash, which undergoes reactions in the soil and transforms into carbonates. In the presence of water, carbonates react with dissociating ions and release hydroxides, which neutralize acidity and reduce aluminum toxicity (Indiramma et al., 2020).

In the first and second evaluations, the phosphorus concentration in the soil increased with the application of vegetal ash, and the doses of ash gradually increased the P present in the soil. In December 2019, there was an increase of 96.92%, reaching a concentration of 230.44 mg dm^{-3} of P in the soil (Figure 3A). In the second year of maintenance, in December 2020, the P content in the soil without wood ash was extremely low (i.e., 153 mg dm^{-3} of P), showing a 100% increment at a dose of 32 tha^{-1} (Figure 3C).



Vertical bars represent the standard deviation of the mean of the four values. * - Significant at p ≤ 0.05; *** - Significant at p ≤ 0.001 based on the F test

Figure 3. P concentration in the soil. The first (A) and last evaluations (B) of the 2019-2020 cycle and first (C) and last evaluations (D) of the 2020-2021 cycle of paiaguás grass as a function of wood ash doses and application management

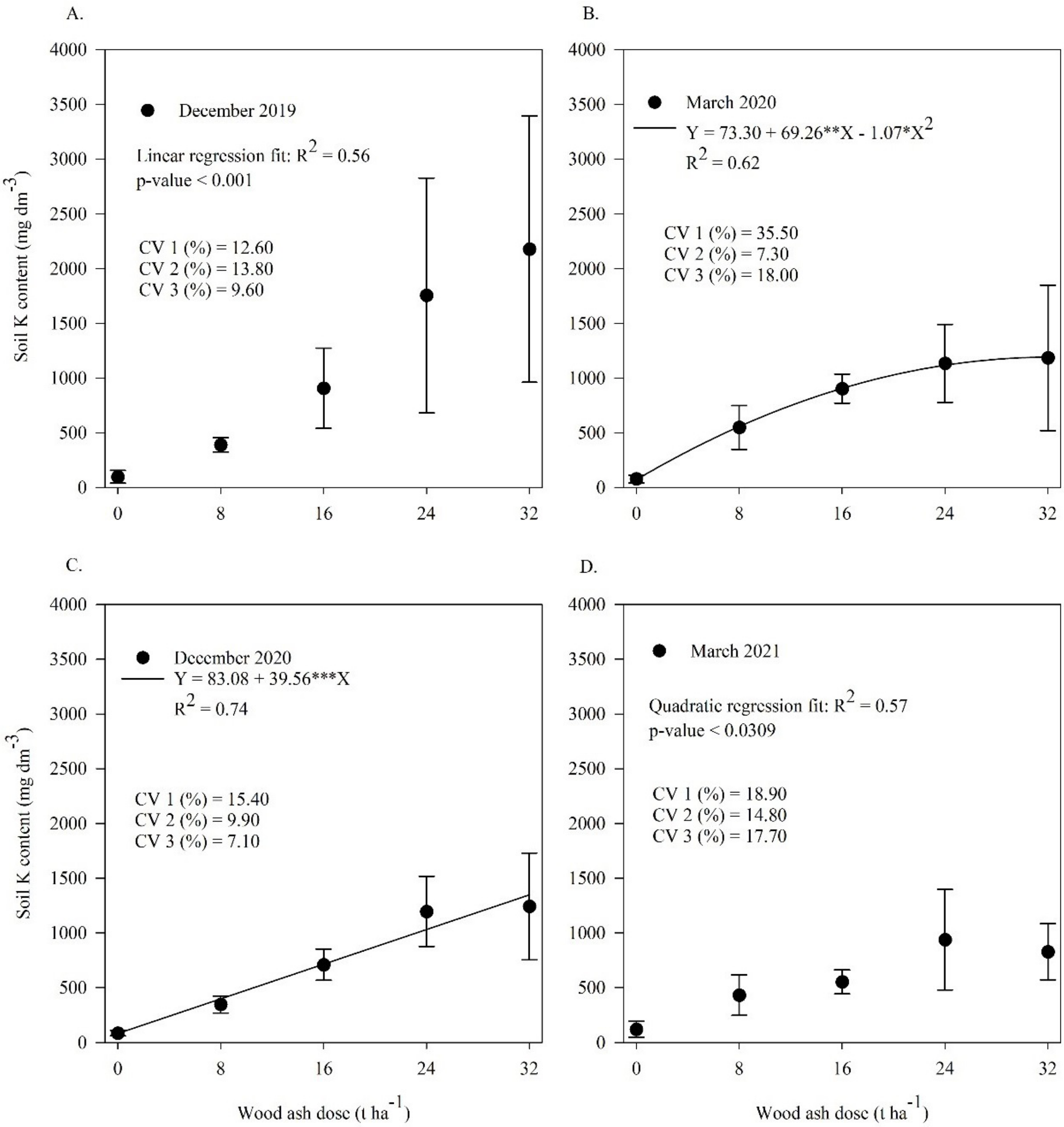
According to Figures 3B and D, at the end of the third cut of the grass in the two years of evaluation, it was not possible to determine an adequate fit for the regression curves of the ash doses, presenting determination coefficients of 0.46 and 0.40 and their respective equations, i.e., $Y = -4.40 + 9.73x$ and $Y = -37.45 + 28.85x - 0.57x^2$. However, the ash dose of 24 t ha^{-1}, regardless of management, exhibited high values of P in the soil when compared to other doses (Figure 3D).

In a study on the fertilizing effect of phosphorus in biomass ash, it was observed that regardless of heterogeneity in the composition of the residue, rye ashes, and rye straw ashes, P concentrations were 10.5 and 1%. The fertilizing potential of the phosphate present in the ash is compatible with that of the mineral fertilizer triple superphosphate (Schiemenz et al., 2011).

In a study by Mercl et al. (2020), wood ash was a valuable alternative for soil acidity correction; however, its phosphate fertilizing capacity was extremely low owing to its chemical composition, and phosphorus availability only improved by the addition of ash with P-solubilizing microorganisms, *Penicillium* sp. PK112 and *Trichoderma harzianum* OMG08.

According to Figures 4A and D, the first and last evaluation during the maintenance of the paiaguás grass, it was not possible to determine an adequate fit for the regression curves of the ash doses, presenting determination coefficients of 0.56 and 0.57 and their respective equations: $Y = -38.33 + 69.02x$ and $Y = 107.16 + 44.73x - 0.65x^2$.

In addition to soil P, the potassium (K) concentration increased with the application of wood ash to the soil. In the two years of pasture maintenance, an increase was observed owing to the doses of wood ash used in the experiment. In March 2020, during the period of the third cut of paiaguás grass, the results followed a quadratic regression pattern, exhibiting a maximum dose of 32.36 t ha^{-1} of wood ash, with



Vertical bars represent the standard deviation of the mean of the four values. * - Significant at $p \leq 0.05$; ** - Significant at $p \leq 0.01$; *** - Significant at $p \leq 0.001$; ns - Non-significant based on the F test

Figure 4. K concentration in the soil. The first (A) and last evaluations (B) of the 2019-2020 cycle and first (C) and last evaluations (D) of the 2020-2021 cycle of the paiaguás grass as a function of wood ash doses and application management

an increase of 93.86% in the contribution of K to the soil. In December 2020, the data exhibited a rising linear regression pattern with an increase of 93.84%. The K contents of the soil for the highest dose were 1193.94 and 1348.95 mg dm^{-3}, respectively (Figures 4B and C).

The K concentration in the soil showed the same response pattern in the second year of the evaluation, performed before the first cut of the grass, in which the treatments increased its presence in the soil as a function of the dose and management used. After the 3rd cut in the second year, the results maintained an increasing linear trend, but with a 70% reduction in the K content of the soil in the first year of maintenance (Figure 4D).

The application of wood ash to soil tends to increase the levels of K in the soil. Regardless of the origin, the forms of K in the ash composition resulting from the combustion of the initial material are sensitive to leaching and can be lost over time (Brais et al., 2015; Noyce et al., 2016).

While analyzing the environmental performance of various alternatives for the disposal of wood fly ash, Costa et al. (2022) observed an increase in the absolute amount of K in the ash from 41.4 to 47.0 g kg^{-1}. However, the bioavailability of K is not related to the absolute amount in the ash because a part is available to plants, ranging from 18 to 51% of the total K in the ash.

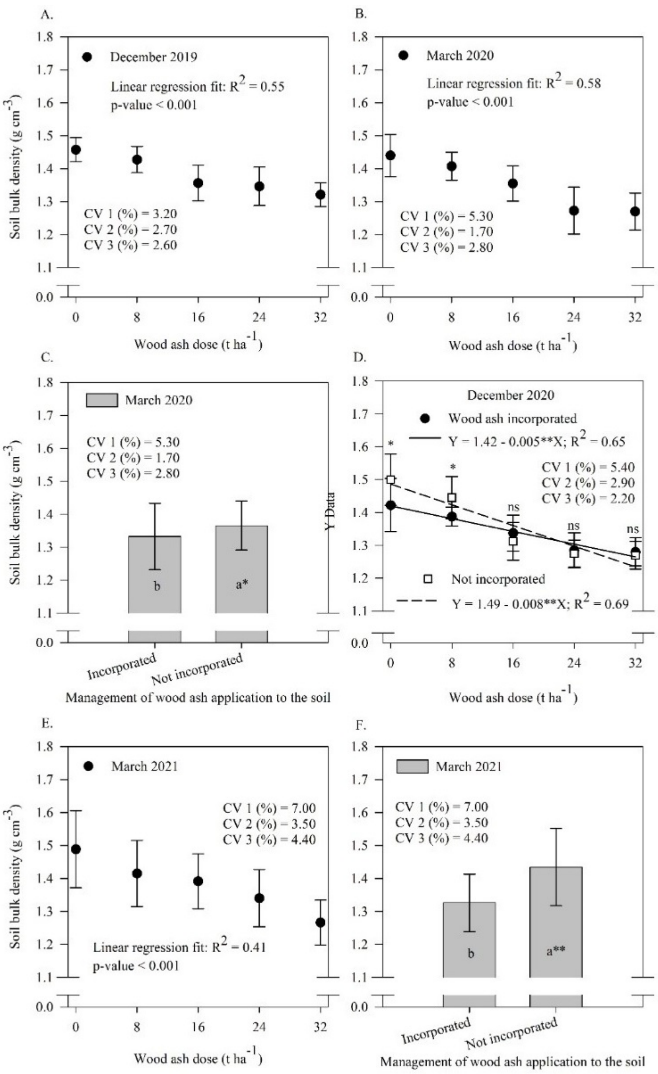
Sbruzzi (2017) verified an increase in soil K concentration with the use of forest biomass ash in the production of beans and corn. The K contents were 26.85 and 62.38 mg dm^{-3} in the ash doses of 0 and 18 t ha^{-1}, respectively, with an increment of 132%.

Soil density in the pasture area in the first year of evaluation in December 2019 and March 2020 exhibited isolated effects for ash doses (Figure 5A) and ash and application management, respectively (Figures 5B and C). In December 2019 and March 2020 and 2021, no fit was satisfactory for the generated regression curves (Figures 5A, B, and E). The coefficients of determination were 0.55, 0.58, and 0.41, with their respective equations: Y = 1.45 - 0.004x, Y = 1.44 - 0.006x and Y = 1.48 - 0.006x. A reduction in density was observed as the ash dose increased, although the data did not fit the regression curves.

The incorporation of wood ash into the soil resulted in the reduction of soil density in 2019/2020. In the third cut of the grass during the two maintenance years, i.e., March 2020 and 2021, wood ash application without incorporation into the soil increased the soil bulk density by up to 9.66% (from 1.31 to 1.45 g cm^{-3}) compared with the treatment with wood ash incorporation (Figures 5C and F).

During the analyses, it was possible to determine the interaction between the factors in the first evaluation of the second year (December 2020). There was a linear reduction in the soil bulk density. In treatment with wood ash doses higher than 8 t ha^{-1}, there was no difference between the wood ash application strategies and soil (Figure 5D).

Studies on the application of ash and biochar indicate that soil density tends to decrease with an increase in the rate of application of the material to the soil. In addition, density reduction can range from 2 to 35%, where coarse-textured



Vertical bars represent the standard deviation of the mean of the four values. * - Significant at p ≤ 0.05; ** - Significant at p ≤ 0.01; *** - Significant at p ≤ 0.001; ns - Non significant based on the F test

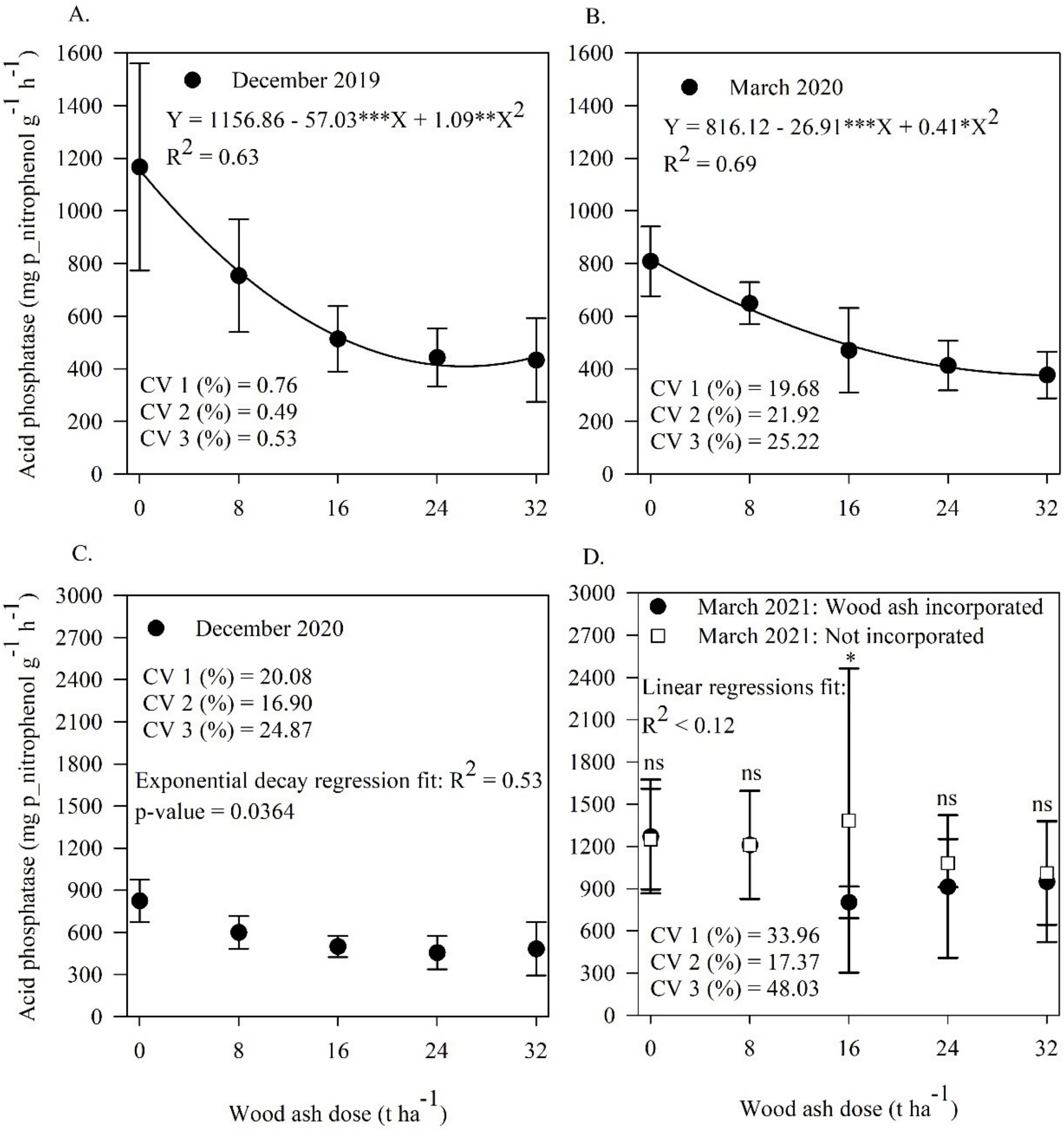
Figure 5. Soil bulk density. The first (A) and last evaluations (B and C) of the 2019-2020 cycle and first (D) and last evaluations (E and F) of the 2020-2021 cycle of the paiaguás grass as a function of wood ash doses and application management

soils exhibit a greater density reduction than fine-textured soils (Glab et al., 2016; Alghamdi, 2018).

For the acid phosphatase activity in the soil, an isolated significant effect was observed for the ash doses in the first year of maintenance during the two collection periods, i.e., December 2019 and March 2020, and in the second year of maintenance during the first evaluation made in December 2020 (Figures 6A, B, and C).

A decrease in the activity of the enzyme as a consequence of the increase in the doses of ash applied could have been observed, regardless of the management of the application of ash to the soil in the first three evaluations. Minimum points were found in the doses of 26.16 and 32.81 t ha^{-1} with values of 410.89 and 374.56 mg ρ-nitrophenol g^{-1} h^{-1}, respectively (Figures 6A and B).

In December 2020, during the period before the first cut of the paiaguás grass, the ash doses exhibited an isolated effect on the activity of the phosphatase enzyme; however, the regression curve did not fit any model, deriving a determination coefficient of 0.53 and Y = 457.23 + $368.75^{(-0.13x)}$ (Figure 6C).



Vertical bars represent the standard deviation of the mean of the four values. * - Significant at p ≤ 0.05; **- Significant at p ≤ 0.01; *** - Significant at p ≤ 0.001; ns - Non-significant based on the F test

Figure 6. Acid phosphatase concentration in the soil. The first (A) and last evaluations (B) of the 2019-2020 cycle and first (C) and last evaluations (D) of the 2020-2021 cycle of the paiaguás grass as a function of wood ash doses and application management

During the last evaluation of the second year, there was a statistical difference, with an interaction between treatments, in which the treatment. Although the coefficient of determination was 0.12 for not fitting any regression model, the activity of the acid phosphatase enzyme increased with an application of 16 t ha^{-1}, showing resilience to the new condition and P losses during the vegetative cycles of the grass (Figure 6D).

Noyce et al. (2016) verified that the presence of wood ash can decrease the proportion of fungi and bacteria in the soil, there by affecting the soil microbial community and biochemical processes they perform. Soil microbial activity and all its biochemical processes are influenced, directly or indirectly, by the chemical and physical attributes of the soil. This is because the soil is a dynamic, complex, and open system that maintains constant exchanges of energy and matter that surrounds it (Primieri et al., 2017).

Perucci et al. (2008) studied the chemical, physical, and biochemical soil changes with the addition of 5-20 t ha^{-1} of wood ash and noticed that with regard to control, the phosphatase activity exhibited a significant decrease in both doses, with reductions of 6.6 and 8.5%, respectively. The reduction was smaller than that found in this study, ranging from 58 to 38%, between the control without the addition of ash and the highest dose of 32 t ha^{-1}.

The soil enzymatic activity is a crucial variable of soil health and is sensitive to changes that occur in the environment. Its direct action on the cycling of nutrients, e.g., P, N, and S, ensures a dynamic mechanism of immobilization, mineralization, and immobilization of these nutrients (Nie et al., 2018; He et al., 2019). This enzyme activity response is linked to an increase in pH because at pH > 6, this enzyme can undergo a denaturation process, and phosphate ions are known to detrimentally affect the phosphatase activity (Perucci & Scarponi, 1985).

However, the activity of numerous enzymes can benefit from the elevation of mineral content, nutrients, porosity, and surface area favored by the use of biochar and wood ash, which improves the development of soil microorganisms and enhances water and nutrient retention (Bandara et al., 2020)

Mercl et al. (2020) studied how to improve the efficiency of phosphorus fertilization from wood ash by adding solubilizing fungal strains to acidic soil in the city of Žamberk, Czech Republic. Corroborating the study results, the authors identified a significant reduction in the phosphatase enzyme activity and significant increase in microbial P, which was justified by the sensitivity of the enzyme to alkaline pH and greater immobilization than the mineralization or solubilization of organic forms of P based on soil microorganisms.

Conclusions

1. The application of 24 t ha^{-1} of wood ash increases the concentrations of potassium and phosphorus in the soil.
2. Wood ash neutralizes soil acidity.
3. When wood ash is incorporated into the soil, reduces soil bulk density.

Acknowledgments

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES - 001) for the scholarship and the Universidade Federal de Rondonópolis-UFR that supported this study.

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