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Wood Ash as a Corrective and Fertilizer in Safflower Crop in Oxisol of Brazilian Cerrado

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Abstract

This study aimed at estimating the wood ash as a corrective and fertilizer in the safflower crop. This study was done with respect to the development, growth, and production of safflower in response to the wood ash doses applied to Oxisol of the Brazilian Cerrado biome. Adopting the completely randomized design and using five wood ash doses (0, 8, 16, 24, 32 g dm^{-3}) and six replicates, the experiments were performed under greenhouse conditions. Each experimental unit included a 2 dm^3 pot, filled with soil that had been incubated earlier for 30 days. The variables studied included soil pH, plant height (cm), stem diameter (mm), number of leaves ($plant^{-1}$), SPAD index, internal and external diameters of the chapters (cm), number of chapters ($plant^{-1}$), chapters dry mass (g pot^{-1}), shoot dry mass (g pot^{-1}), volume (cm^3 pot^{-1}) and root dry mass (g pot^{-1}) Analysis of variance and subsequent regression test were performed for all the data using SISVAR software, at 5% probability for both. The variables internal and external diameter of the chapters and root volume showed no significant differences. The soil pH revealed a significant effect of the wood ash application tending towards linearity, as did the other vegetative variables of plant height, stem diameter, number of leaves and SPAD index. The productive constituents exhibited improved development when the wood ash was applied to the soil in doses of around 24 g dm^{-3} or more.

Keywords: agricultural residue, *Carthamus tinctorius* L., biomass burning, alternative fertilizer

1. Introduction

Safflower, with Asia and Africa being the centers of origin, has a long history of domestication since 2000 BC and was principally utilized as a yellow food and textile dye (Chapman et al., 2010). Its rural character is warranted, particularly due to its deep root system, which enhances the tolerance level of this plant under water-deficit conditions (Hojati et al., 2011). In cases of no-tillage systems, when crop rotation is required, and particularly in those cultivars highly suitable as a second crop, safflower provides a viable substitute in these production systems (Goedert et al., 2002; EMBRAPA, 2013).

To sustain and optimize the maximum productive potential, fertilizers were introduced to raise or at least maintain the yield of the agricultural systems. Issues like water table contamination, and absence of phosphate and limestone reserves, are matters of concern. In such scenarios, the application of agroindustry-generated solid waste can be a more sustainable substitute and has been producing remarkable results in the literature (Fixen, 2009; Pantano et al., 2016).

Organic fertilizers have found use when combined with or even completely independent of the mineral fertilizers. Thus, the ashes arising from a combustion process that lacks any type of temperature and oxygen controls produce a residue with an abundance of calcium, magnesium and potassium carbonates (Osaki & Darolt, 1991). Besides neutralizing the soil acidity, it also supplies the soil with nutrients. Most often, such waste does not end-up at the right place and is dumped in undesirable sites.

This study aimed at assessing the wood ash as both a corrective and fertilizer in the safflower crop development, growth and yield, when it is added in different doses to the Oxisol.

2. Material and Methods

2.1 Overview and Experimental Design

The experiments were carried out under greenhouse conditions in the Federal University of Mato Grosso, Campus of Rondonópolis, with the coordinates of latitude 16°28′150″ S and longitude 50°38′08″ W at an altitude of 284 m. During the experimental period, the mean air temperature and relative humidity were 27 °C and 81%, respectively. Employing the completely randomized experimental design, application of five wood ash doses (0, 8, 16, 24 32 g dm^{-3}) and six replicates were done. Each experimental unit included a 2 dm^3 pots which were filled with soil drawn from a layer 0-0.20 m deep, in a region supporting the Cerrado vegetation. The soil was gathered from an area characterized by Oxisol (EMBRAPA, 2013; Soil Survey Staff, 2014).

2.2 Soil Characterization and Preparation

The chemical and granulometric characterization was done based on the EMBRAPA (1997) guidelines, and showed the following features: pH ($CaCl_2$) = 4.0; OM = 20.6 g kg^{-1}; P = 1.1 mg dm^{-3} ($Mehlich^{-1}$); K = 43 mg dm^{-3}; Ca = 0.5 cmolc dm^{-3}; Mg = 0.3 cmolc dm^{-3}; Al = 1.2 cmolc dm^{-3}; H + Al = 7.4 cmolc dm^{-3}; CTC = 8.3 cmolc dm^{-3}; Zn = 0.3 mg dm^{-3}; Cu = 1.2 mg dm^{-3}; Fe = 152 mg dm^{-3}; Mn = 7.4 mg dm^{-3}; B = 0.2 mg dm^{-3} and S = 8 mg dm^{-3}; 425 g kg^{-1} sand; 100 g kg^{-1} silt and 475 g kg^{-1} clay.

The soil was gathered and incubated in plastic bags after adding in the specific wood ash doses needed for each treatment. Post incubation, the soil was watered and maintained at 60% of the maximum water retention capacity of the soil and incubated for a 30-day period. The wood ash used originated from food industry boilers. The wood ash was analyzed for its action as a fertilizer (Osaki & Darolt, 1991). The following chemical characteristics were identified: pH = 10.7; PN = 28%; N = 0.3%; P_2O_5 = 0.9%; K_2O = 3.4%; Ca = 3.3%; Mg = 2.1%; SO_4 = 0.4; Si 27.4%; Mn = 0.04%; B = 0.01%; Fe = 1.03%; Cr = 7.98 mg kg^{-1}; As = 0.21 mg kg^{-1} and bulk density of wood ash was 0.45 Mg m^{-3}.

2.3 Experimental Units and Fertilization

After incubating the soil plus wood ash, this mixture was transferred from the plastic bags to the pots of the experimental units and conditioned. In each pot, ten seeds were sown, and thinning was done at 7 and 15 days after plant emergence until a final population of three plants per pot was reached. As the wood ash nutrient content of the plant was low, no fertilizer was applied except for nitrogen. With urea as the source, the nitrogen was applied in a 150 mg dm^{-3} dose. This experiment was performed using three different applications of nitrogen, at 15, 30 and 45, days after plant emergence to meet the needs of the plant (Bonfim-Silva et al., 2015b).

2.3 Response Variables

Plant height was measured in centimeters, from the plant collar at the soil level to the apex, while stem diameter was measured where the transverse measurement of the stem was taken at 2 cm height, and number of leaves was recorded by counting, with values recorded in units per plant. Using a chlorophyll meter (SPAD-502) the relative chlorophyll content (SPAD index) was noted in the two leaves of the middle one-third randomly selected from each plant, and calculating the average, later. The external diameter of the flowers and the transverse measurement of the corolla of the chapters were assessed in millimeters, utilizing a digital caliper, and finally, the numbers of chapters and branches per plant were recorded.

At this time, as most of the pots already contained at least one fully opened chapter, the safflower plants were cut. Plant cutting was performed close to the soil level and the chapters were manually separated from the other aerial parts. After placing them in paper bags they were transported to the greenhouse and subjected to forced air circulation at 65 °C for 72 hours. Once they were dried, the plant material was weighed, and the dry mass of both the shoot and chapters was ascertained.

The root volume was assessed in cm^3. The roots were first washed in a sieve, and their volume was measured in a graduated cylinder by difference was the volume of roots. Next, the roots were packed in paper bags, identified and oven dried, adopting the same procedure used for the aerial parts.

2.3 Statistical Analyzes

Once the data were collected, the findings were submitted to statistical analysis using the SISVAR statistical program (Ferreira, 2011), with the analysis of variance and regression test being done at significance level-up to 5% probability.

3. Results

Wood ash doses were observed to raise the soil pH by up to 22%, on comparing the control treatment to the soil fertilized with a dose of 32 g dm^{-3} (Figure 1).

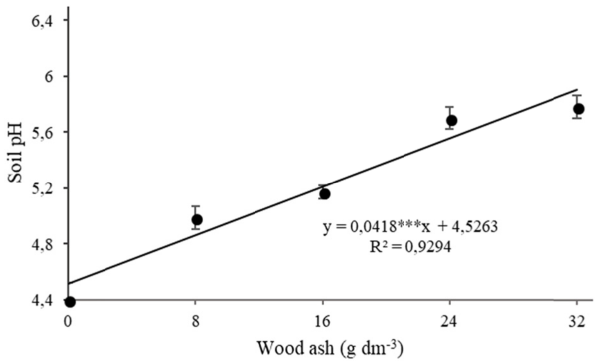

Figure 1. Soil pH at sowing in response to the wood ash dose applied. *** Significant at 0.1% probability. CV(%) (Coefficient of variation): 3.18%

All the evaluation times tested revealed that the variable plant height showed a linear response to the plant wood ash doses applied. After the third evaluation, the wood ash doses caused a rise in the plant height to up to 58%, when the 32 g dm^{-3} dose was added, compared to the control treatment lacking the wood ash fertilization (Figure 2).

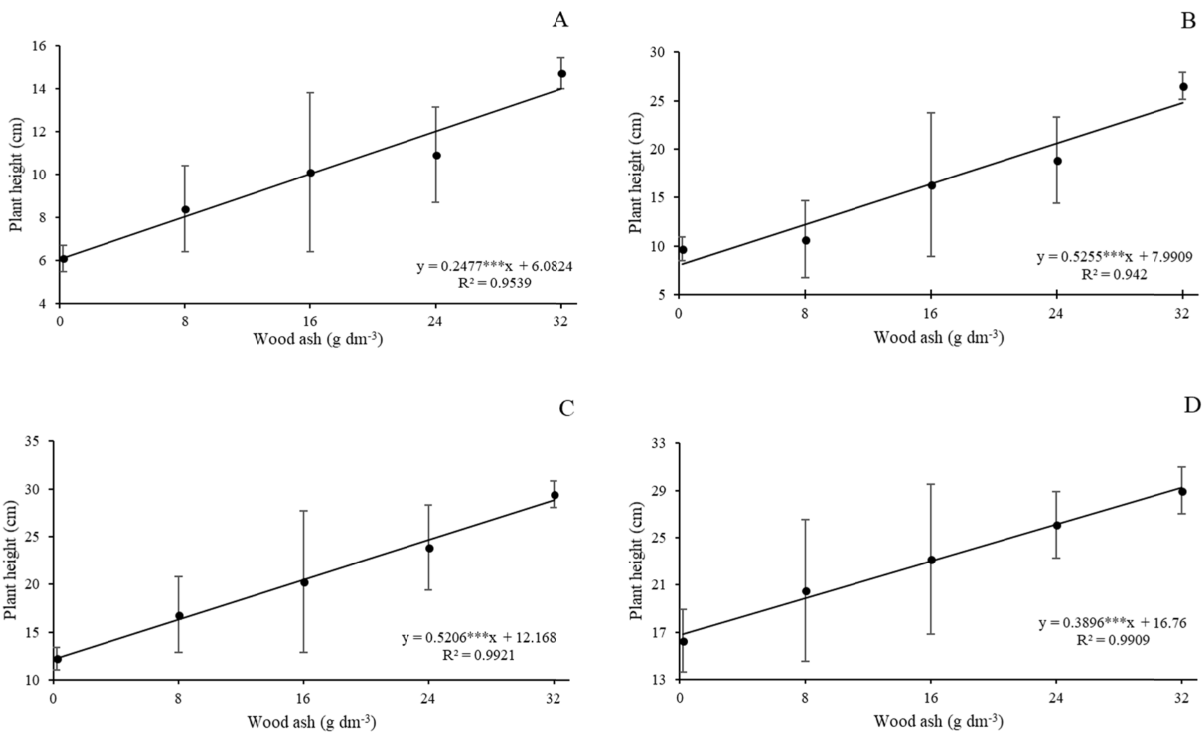

Figure 2. Safflower (*Carthamus tinctorius* L.) plant height in response to the wood ash applied at 15 (A), 30 (B), 45 (C) and 55 (D) days after emergence. CV(%) (Coefficient of variation): A = 21.1%, B = 25.6%, C = 21.0%, D = 18.4%; *** Significance of 0.1%

On analysis of the variable number of leaves, a difference in the evaluation times at 15 and 45 days after the emergence of the plants was observed. However, no significant effect was noted at the evaluation done at the cutting phase 55 days after the emergence, with an overall mean of 23.17 cm. The measurements were taken at 15 days after plant emergence was adjusted to the quadratic regression model, with the maximum at 31.9 g dm^{-3}. However, at 30 and 45 days after plant emergence, the adjustment for the number of leaves was done to the linear regression model, implying that the increase was in response to the wood ash doses applied (Figure 3). The wood ash doses induced the maximum number of leaves at 45 days after emergence of the plants, and after the highest plant wood ash dose was applied to the soil a maximum of 15 leaves per plant was noted. The yield was 64% higher when compared with the control treatment where wood ash fertilization was lacking.

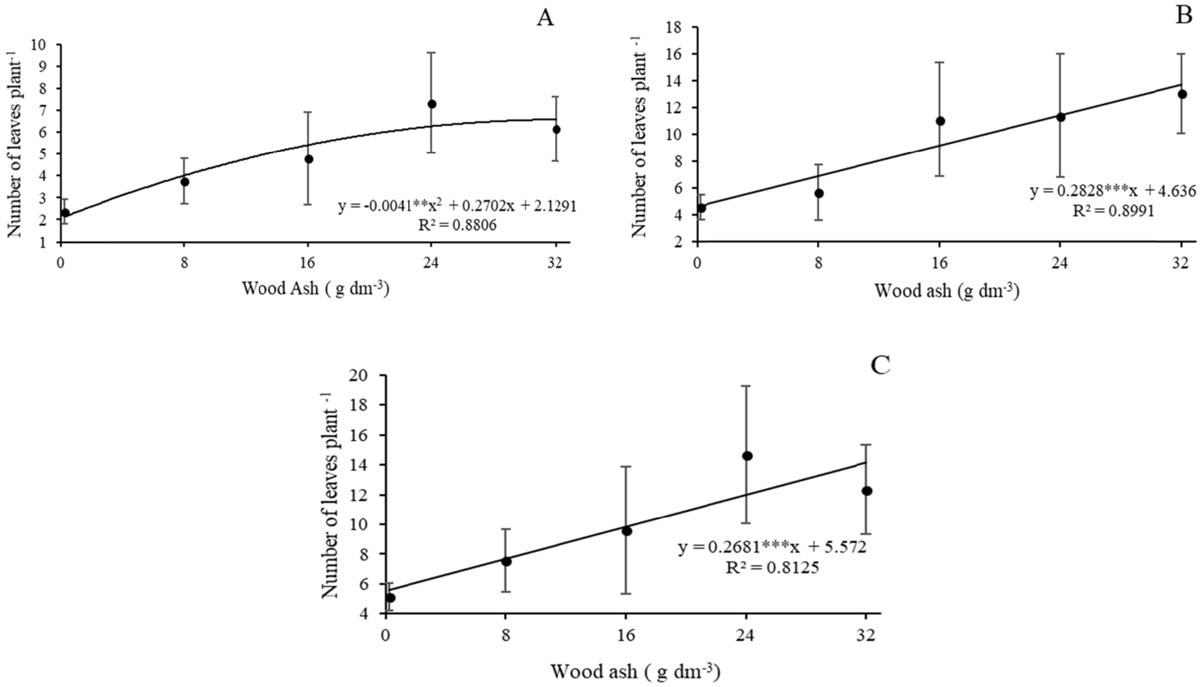

Figure 3. Number of safflower leaves (*Carthamus tinctorius* L.) in response to the wood ash applied at 15 (A), 30 (B) and 45 (C) days after emergence. CV(%) (Coefficient of variation): A = 33.5%, B = 28.3%, C = 33%; ***, ** Significance of 0.1 and 1% respectively

For safflower, a significant difference in the stem diameter was reported at all the assessment periods based on the treatments, except at 55 days after emergence, with an overall mean of 2.03 mm. At all these estimations, the linear regression model was the statistical model which best described the stem diameter behavior. The stem diameter was observed to rise by up to 44.68% at 45 days after emergence (Figure 4).

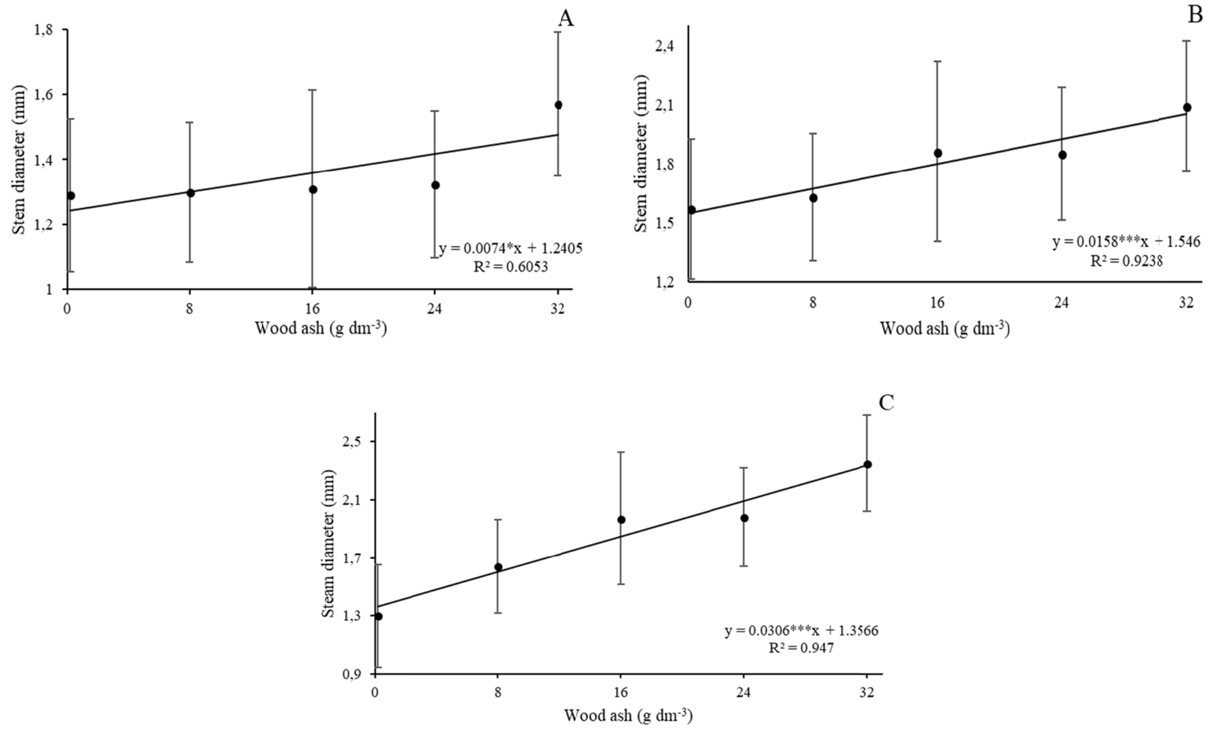

Figure 4. Stem diameter of safflower plant (*Carthamus tinctorius* L.) in response to the wood ash applied at 15 (A), 30 (B) and 45 (C) days after emergence. CV(%) (Coefficient of variation): A = 18.3%, B = 11.6%, C = 18.6%); ***, **, * Significance of 0.1, 1 and 5% respectively

The chlorophyll index (SPAD), at 30 and 45 days after emergence only, revealed a significant difference between treatments; it showed a linear behavior at 30 days and quadratic behavior at 45 days after emergence, with the maximum index value in response to the dose of 28 g dm^{-3} of the wood ash, according to the equation model; the index value shot up by 34.54% in comparison to the treatment lacking the wood ash application. There was no significant difference between the treatments for the evaluations at 15 and 55 days after emergence, with a mean index of 56 and 44 (Figure 5).

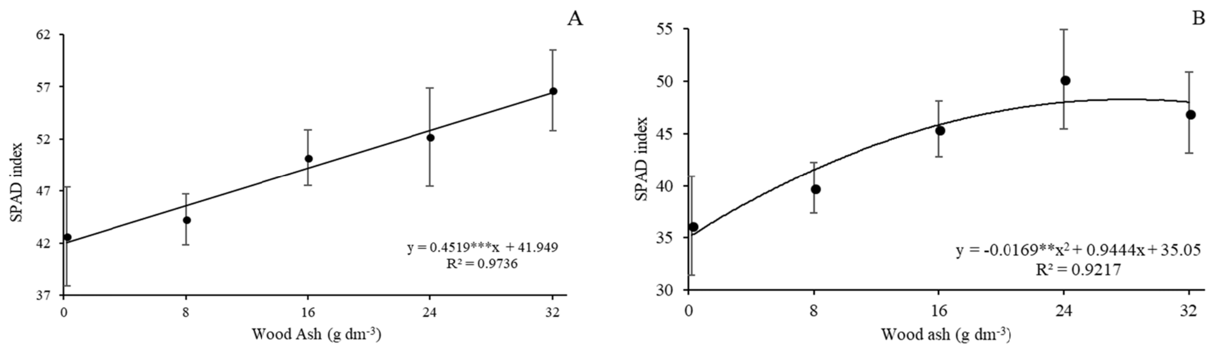

Figure 5. Safflower (*Carthamus tinctorius* L.) chlorophyll (SPAD) index in response to the wood ash applied at 30 (A) and 45 (B) days after emergence. CV(%) (Coefficient of variation): A = 10.3, B = 8.8%; ***, ** Significance of 0.1, and 5% respectively

Regarding the variables number of branches (Figure 6A) and number of chapters (Figure 6B), a significant difference was noted between the wood ash doses applied to the soil, leaning towards a quadratic behavior of regression. In comparison to the control treatment, the optimum wood ash dose of 28.15 g dm^{-3} for the number of branches and 28.34 g dm^{-3} for the number of chapters induced an escalation of 86.91 and 51.67% to number of branches and chapters, respectively. This indicates the likelihood of a correlation between the variables (Figure 6).

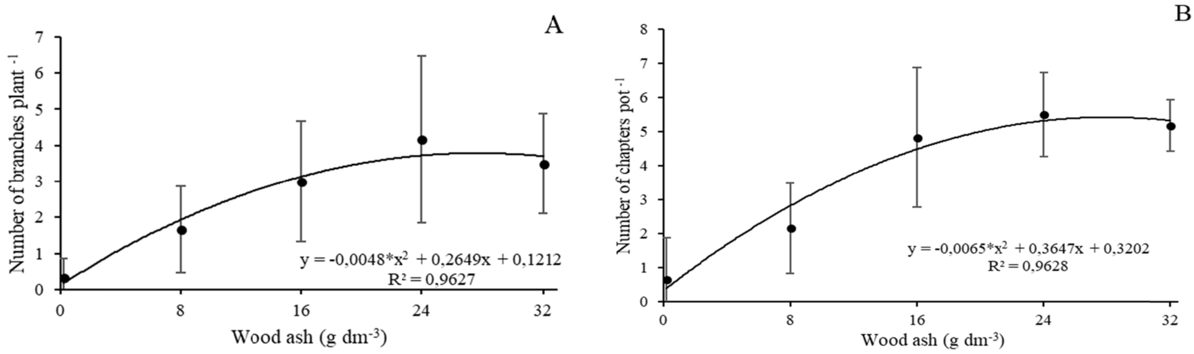

Figure 6. Number of branches (A) and chapters (B) of safflower (*Carthamus tinctorius* L.) as a response to the wood ash doses at 55 days after emergence. CV(%) (Coefficient of variation): A = 66.1, B = 38.2%; * Significance of 5%

For the variables internal and external diameter of chapters, no statistical differences were confirmed being observed an average of 2.28 and 13.29 mm for internal and external diameter, respectively.

The shoot dry mass and chapters of the safflower plants showed significant changes in response to the wood ash doses applied, tending towards a quadratic regression behavior at the optimal wood ash dose of 31.98 g dm^{-3}. This dose resulted in the maximum dry matter accumulation of 0.84 g pot^{-1} in the chapters, a 77% rise when compared with the lack of wood ash application (Figure 7A). The data for the total shoot dry mass, however, revealed a positive linearity, with a 79.43% increase in comparison to the control (Figure 7B).

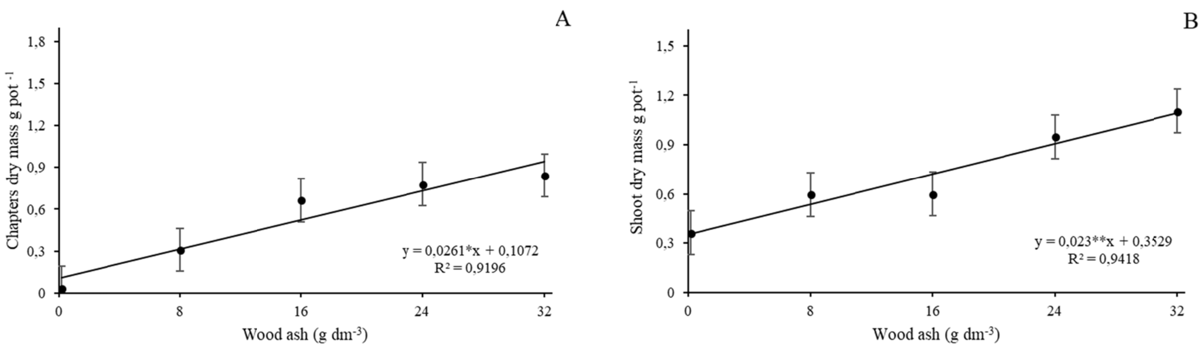

Figure 7. (A) Chapters dry mass (B) Shoot dry mass (*Carthamus tinctorius* L.) in response to the wood ash doses at 55 days after emergence. CV(%) (Coefficient of variation): A = 47.7%, B = 44.3%; **, *, Significance of 1 and 5%

None of the treatments exerted a significant effect on root volume being observed an average of 32.48 cm^3. The findings for root dry mass presents substantial differences for the wood ash doses, adjusted to the linear regression model (Figure 8). Thus, even higher doses of plant wood ash would be needed to induce maximum root output by the plants. Plants grown under 32 g dm^{-3} doses of wood ash revealed 69.6% rise in production when compared with the control treatment of no-added fertilization with this residue.

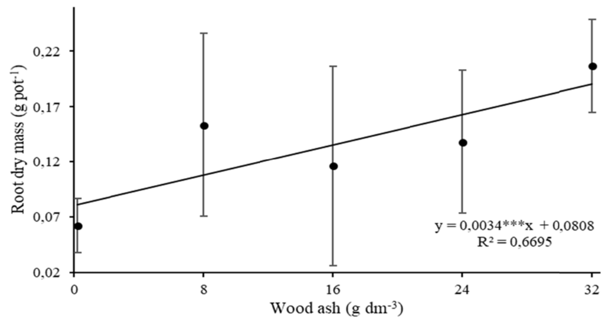

Figure 8. Safflower (*Carthamus tinctorius* L.) root dry mass in response to the plant wood ash applied at 55 days after emergence. CV(%) (Coefficient of variation): 47.3%; ***, the significance of 0.1%

4. Discussion

Soil pH shows a direct correlation with nutrient availability. In the 5 to 5.5 range, most nutrients are available for the plants to absorb (Malavolta, 1997). The corrective influence exerted by the wood ash is related to the high alkalinity, neutralization properties as well as the calcium, potassium and magnesium oxides available in the material, which as in limestone, can neutralize the aluminum and boost the soil pH (Darolt et al., 2003; Quesada et al., 2017; Sirikare et al., 2015).

In their study, Pereira et al. (2016) estimated the effect of the plant wood ash applied in *Gladiolus grandiflorus* cultivated in the Oxisol. They confirmed that when the 32 g dm^{-3} dose of the wood ash was added to the soil, the pH increased by 44% in comparison to the control treatment. The authors also reported increasing linear behavior for the wood ash doses and pH values. It is noteworthy that correcting the soil pH, enables several nutrients such as calcium, magnesium, potassium, and phosphorus, to become available for the plant to absorb, as well as it directly supplies these nutrients, because of the characteristics of the material itself (Varela et al., 2013).

Islabão et al. (2014) in their assessment of the use of rice husk ash for soil acidity correction, reported that although it was less reactive than conventional limestone, the rice husk ash showed 300% more reactivity than the limestone, chiefly because of the solubility of the elements like potassium and sodium oxides available in the plant ash residues.

The findings of the current study concur with those confirmed by Bezerra et al. (2016), conducted in Oxisol collected in the same area, in which they observed that the Marandu grass (*Brachiaria brizantha* cv Marandu), showing a linear response in the variable plant height due to the wood ash doses applied, particularly to the 15 g dm^{-3} dose, the maximum one used in this experiment.

When the soil pH conditions are less than 4, certain nutrients like P, K, Ca, Mg, are present in a form that the plants cannot absorb. When the soil acidity is corrected by raising the pH, these nutrients become available thus facilitating plant development (Sousa & Lobatto, 2005; Raij, 2011).

Bonfim-Silva et al. (2017a) in their work on *Canavalia ensiformis* L. reported similar findings by the plant subjected to the wood ash doses. They confirmed a linear rise in the number of leaves when the plant was raised in soil having features like those of the current experiment.

The increase in the number of leaves is directly related to other characteristics of the plant, such as height. In addition, due to improvements in soil chemical and physical conditions when wood ash was added. Wood ash presents characteristics such as soil pH, soil nutrient availability and soil bulk density decrease (Karmakar et al., 2010; Islabão et al., 2017).

Larger stem diameters were also found by Bonfim-Silva et al. (2015b) who evaluated the development of ornamental sunflower cultivated in soil collected in the same area of the present study, fertilized with wood ash, under controlled conditions, and verified a quadratic response, with maximum diameter when these plants were cultivated using 10 g dm^{-3} of wood ash.

Studies prove that when added to the soil, the wood ash is able to supply calcium and magnesium, functioning as fertilizer (Darolt et al., 1993; Huotari et al., 2006). These elements are the structural constituents of the cell wall and are seen mostly in the stems and roots (Epstein & Bloom, 2006). Thus, the application of fertilizers meeting this requirement can induce a substantial increase in the stem diameter. Souza et al. (2010) reported that when

Brazilian-mogno (*Swietenia macrophylla* King) was cultivated in Oxisol, the stem diameters revealed the highest values.

The SPAD index exerts an indirect effect on the chlorophyll content of the leaves depending upon the green color seen; the darker the leaves, the higher the chlorophyll concentration and, therefore, the greater the value of the index (Gil et al., 2002).

The SPAD reading is positively related to the chlorophyll content and directly linked to the nitrogenous nutrition of the plant, because of the correlation between the chlorophyll index and nitrogen content of the leaves (Costa et al., 2008). When the wood ash is applied to the soil it improves the nitrogen uptake, which may be linked to the magnesium and potassium supplied by this residue (Megda & Monteiro, 2010). Magnesium plays a crucial part in the photosynthetic process, as it is a principal ingredient in the chlorophyll molecule (Hermans & Verbrudgen, 2005; White & Broadley, 2009).

According to Dordas and Sioulas (2009) from their assessment of the response of the safflower plants to the nitrogen doses applied, the chlorophyll index showed an increase in all three cultivars, when a 200 kg ha^{-1} nitrogen dose was applied, as well as a higher nutrient accumulation in the grains and aerial plant parts.

The findings from the current work correspond with those of Bonfim-Silva et al. (2017b). They determined the performance of safflower in response to the phosphorus doses applied, and confirmed similar findings, with quadratic and linear responses at 30 and 45 days after emergence, respectively. Thus, it is evident that it is not the nitrogen alone which influences the index, but the quantity of the other elements presents as well, like phosphorus, potassium, and magnesium, which can cause changes in the chlorophyll activity in the plant, and thus, alter the index.

In their study on safflower genotypes of different soil bulk density levels, Paludo et al. (2017) recorded that the more the number of branches, the higher the number of chapters. They could thus establish a relationship between the number of branches and production of chapters in the plant, apart from a rise in the dry matter of the aerial plant parts.

Bonfim-Silva et al. (2018), on assessing the response of the Mombasa grass raised in the Oxisol, as done in the current work confirmed the quadratic behavior for the variable number of tillers of the forage, for the wood ash dose of 25.78 g dm^{-3}. This finding is almost identical to the results of the present study for branches in the safflower plants. Considering this, the highly improved output in the number of tillers (in comparison to the control treatment without fertilization) is due to the higher nutritional state of the plant, as it is easier for it to express its potential than with the chemical restriction (Kerbauy, 2005).

Bonfim-Silva et al. (2017b) confirmed the phytometric characteristics of the safflower plants raised in the Oxisol on phosphorus doses. The 57.1% linear escalation in the number of plant chapters concurred with the findings of the present study. Normally, when a plant develops with suitable nutritional levels, its vegetative development improves and thus, the greater will be the number of reproductive structures (Ribeirinho et al., 2012).

The highly improved performance of shoot dry mass and therefore that of the safflower chapters occurred due to the abundant availability of phosphorus, potassium, calcium, and magnesium the plant nutrients present in the wood ash, as well as micronutrients. In this study, potassium is found to exert a direct effect on the respiration and transpiration processes in the plants, controlling the stomatal opening and closure and thus, this nutrient present in sufficient quantities increases the plant efficiency in the usage of water and, hence, in better vegetative development (Taiz & Zeiger, 2004).

According to Uchôa et al. (2011), from their assessment of the sunflower genotypes using potassium fertilizers, reported maximum achene yields of 80 kg ha^{-1}. Bonfim-Silva et al. (2015a, 2017a, 2017b) also observed similar findings in their evaluation of the ornamental sunflower, *Vigna unguiculata* and *Canavalia ensiformis*, respectively, reported an escalation in the aerial plant parts in the order of 50, 93 and 66%, respectively, for the shoot dry mass plant parts cultivated in soil supplied with nearly 20 g dm^{-3} of wood ash doses, in comparison with the control treatment.

Bonfim-Silva et al. (2013) in their assessment of the development in Marandu grass in response to the wood ash doses, confirmed that the root dry mass was inclined to rise as the wood ash doses were applied. According to these authors, the more highly improved performance of the dry mass of the plant roots is an effect of the presence of nutrients like phosphorus, which under the soil pH conditions of the control treatment was largely unavailable to the plant. Besides correcting the soil pH, the wood ash also made this nutrient available to the plant. In fact, the wood ash itself also contains substantial quantities of phosphorus, which induces this response (Monteiro et al., 1995; Sousa & Lobato, 2002; Raij, 2011; Islabão et al., 2014).

The plant responses to the wood ash applied is dependent upon many factors. The wood ash quality itself is affected by the original material from which it is made, besides the process it undergoes. The variables like initial soil fertility, organic matter, and soil type also exert a direct influence on the growth and development of the plants supplied with the wood ash doses, besides the water regime provided. Apart from this, there are many advantages of utilizing the plant wood ash for several crops both as a soil conditioner as well as a fertilizer, and its potential use is particularly evident in the recovery of degraded areas.

5. Conclusion

The wood ash was found to act as an effective fertilizer by correcting the soil pH. The safflower plant development and growth were positively affected by fertilization with wood ash applied to the soil. The internal and external diameters of the chapters and root volume, no significant differences were found.

The wood ash doses applied positively affected the productive constituents enabling maximum performance when the soil was fertilized with doses exceeding 24 g dm^{-3}.

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