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Correction of soil compaction using wood ash in safflower crop

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Abstract

Soil compaction is a big limitation to food production in agriculture. Wood ash is an agro-industrial residue generated by the burning of biomass in boilers for energy production. It can be used as a corrective agent and fertilizer of the soil. In this context, the objective of this study was to evaluate the root system of safflower cultivated under bulk density levels and wood ash doses in dystrophic Oxisol. The experiment was conducted in a greenhouse with a randomized block design under a 5x5 factorial scheme composed of 5 wood ash doses (0, 8, 16, 24, 32 g dm^{-3}) and 5 bulk density levels (1.0, 1.2, 1.4, 1.6, 1.8 Mg m^{-3}) with 4 replicates. The soil was collected from 0-0.20 m depth layer. Later it was incubated with the respective wood ash doses. Each experimental unit consisted of a pot made of three PVC (polyvinyl chloride) rings, in which the layers of 0.1-0.2 m were compacted. At 75 days after emergence, the plants were cut, their roots washed and the volume and dry mass checked. The results were submitted to analysis of variance and subsequent regression test, both at 5% probability. Soil densities negatively influenced the root system development and culture of safflower. Application of wood ash doses of 20 to 24 g dm^{-3} significantly improved root development of plant.

Keywords: Alternative Fertilizer; Bulk Density; *Carthamus tinctorius* L.; Soil compaction; Soil conditioner.

Introduction

With increase of agricultural mechanization, the extent of areas with problems related to physical soil has also been increased. The subsurface compaction is among the most important ones. This type of compaction is difficult to diagnose and the main strategy for recovery is through cultural practices such as subsoiling, plowing and grazing (Freddi et al., 2009).

A number of less aggressive techniques such as crop rotation can be used to solve this problem, in which plants with the most aggressive root system are used. These plants are capable of breaking the compacted soil layer. Rotation with different species, besides facilitating the management of pests and diseases provides a greater nutrients cycling and exploring different soil profiles and depths (Hojati et al., 2011). In this context, the study of the root system development is less explored yet. This area of study has fundamental significance on production system but scientists have significantly ignored its importance.

In order to improve soil physical quality, investments on techniques that can increase soil organic matter are highly also desired. In addition to contributing to soil chemical aspects, organic matter is strongly correlated with soil physical-water characteristics. In addition to crop rotation methods, incorporating (combining) of industrial residues can significantly promote nutrients direct availability, as well as organic matter contents in the soil (Alakuku et al., 2003; Calonego, 2011).

The wood ash comes from the burning process under high temperatures without the control of oxygen, resulting in a material of varied composition. Generally, it has a high content of Ca, Mg and K, as well as improvements in the physical and hydraulic properties of the soil (Darolt et al., 1993; Islabão et al., 2016).

Nadian et al. (1997) and Shierlaw and Alston (1984) found that soils with high subsurface density equivalent to 1.6 Mg m^{-3} can directly affect development of clover (*Trifolium subterraneum* L.) and corn roots, respectively. The plants present smaller and thicker roots when cultivated in denser soils close to 1.2 Mg m^{-3}.

Bonfim-Silva et al. (2018b) and Paludo et al. (2018) evaluated safflower genotypes in different soil density levels. They verified that the cultivars show distinct levels of tolerance to bulk density, with a significant decrease in the volume and the root mass of the plants when they are cultivated in soil densities higher than 1.2 Mg m^{-3}.

Bonfim-Silva et al. (2018), evaluated addition of wood ash in the development of safflower cultivated in latosol typical of the Brazilian Cerrado. They verified a positive linear increase of 69% in the dry mass of the roots of the plant, being justified mainly by the supply of nutrients such as K, P, Ca, correction of soil acidity, as well as soil conditioning properties.

The development of plant root is directly affected by the addition of wood ash to the soil due to the characteristics of the material that guarantee the correction of the soil acidity, improvements in the physical-water characteristics, consequently the root development of the plants (Islabão et al., 2016).

The objective of this study was to evaluate the effect of bulk density levels combined with wood ash doses on the safflower root system cultivated in Oxisol.

Results and discussion

Root volume

There was no significant interaction between bulk density levels and wood ash doses for safflower root system (Fig 1).

After checking the root volume in each layer, it was verified that bulk density influenced the root development in the 0-0.1m and 0.2-0.3m layers and total roots volume (Table 3).

Root volume in layers

The root volume in 0-0.1m layer was adjusted to linear regression model as a function of the wood ash doses (Fig 2A). As for bulk density, root volume was representative for quadratic regression model (Fig 2B) with maximum volume point, when the plants were cultivated at a bulk density of 1.27 Mg m^{-3}.

For root volume in 0.1-0.2 layer, no significant difference was observed for wood ash doses as well as for bulk density levels with a mean of 7.5 g. When root volume in 0.2-0.3m layer was evaluated, a significant difference was observed for bulk density levels, with decreasing linear adjustment (Fig 3).

Total root volume

Evaluation of total root volume of safflower showed an isolated difference between the treatments. The root volume of plants showed a linear decreasing as a function of the bulk density levels. For the wood ash doses, the root adjustment was representative quadratic regression model, verifying the maximum volume point of roots at dose 24.23 g dm^{-3}, getting a volume of 34.97 ml (Fig 4AB).

Barbosa et al. (2018), evaluated the performance of sugar cane in different managements and soil classes. They identified that plants cultivated in clay soil show a critical bulk density limit of 1.25 to 1.7 Mg m^{-3}, which severely restrict the root system. Cury et al. (2014), evaluated cultivation systems with and without application of limestone in Oxisol southeastern region of Brazil. They verified that the adoption of no-tillage and the addition of limestone to the system could increase soil fertility, especially, sugarcane root dry mass during periods of drought and rainy season. The authors correlate this variation in the number of roots, mainly to periods of scarcity or water surplus. Thus, the maintenance of water can be associated with organic matter present in a no-tillage system, which is superior to conventional, where there is soil rotation and exposure of the organic matter to the weather, as well as the hydrophilic capacity of wood ash system maintenance. The use of organic fertilizers or the adoption of conservation techniques promoted the root development of plants up to 34% for wheat and 33% for barley, comparing conventional and minimum soil tillage systems (Hu et al., 2018). Bonfim-Silva et al. (2015c) evaluated development of the cotton cultivated with wood ash doses in Oxisol. They observed that the increase of plants roots dry mass had a quadratic behavior, obtaining maximum roots dry mass when the plants were fertilized with 10 g dm^{-3} of wood ash.

Upper root development in conservationist systems can be justified beyond the organic matter support, providing nutrients, as well as improvements in the physical-water properties of the soil, by the addition of residues of organic origin (Pereira et al., 2016; Hu et al., 2018).

Karakas et al. (2017), evaluated hydroponic tomato cultivation on substrates with use of olive biochar with different carbonization marches. They verified better plant development when cultivated with "biochar" produced at 500 °C. One of the possible justifications for this superior performance could be attributed to the structure of material and nano and micro particles in macro-porous structures. It favors the development of microorganisms, along with high resistance to degradation of the material that provides the best root development.

Roots dry mass

Analysis of roots dry mass of safflower plants showed an isolated significant difference in both bulk density levels and wood ash doses (Table 2).

Roots dry mass layer in layers

The wood ash doses and bulk density levels influenced the root volume in the 0-0.1 m layer. The wood ash doses on roots dry mass showed a quadratic regression adjustment in 0-0.1 m layer, with a maximum residue point of 20.52 g dm^{-3}, providing 2.03 g pot^{-1} (Fig 5A). Similarly, bulk density levels provided the maximum value of root dry matter in the 0-0.1m layer of 1.7 g pot^{-1} when the plants developed at bulk density of 1.12 Mg m^{-3} (Fig 5B).

The roots dry mass in the 0.1-0.2m layer had a linear decreasing behavior as a function of the bulk density levels, and no statistical difference was observed between the applied wood ash doses as the roots dry mass in the present layer (Fig 6).

As for the root dry mass in the 0.1-0.2m layer, there was no significant difference between wood ash doses in the subsequent of 0.2-0.3m. Bulk density levels were adjusted to the decreasing linear regression model in the roots dry mass in the evaluated layer (Fig 7).

Roots total dry mass

The evaluation of the roots total dry mass demonstrated an isolated effect for wood ash doses and bulk density levels. Maximum root dry mass of 5.23 g pot^{-1} was observed when the soil was cultivated with an estimated wood ash dose content of 20.90 g dm^{-3} (Fig 8A). As in the 0.1-0.2 and 0.2-0.3 layers, the total root dry mass presented a linear adjustment decreasing (Fig 8B).

The root dry mass values observed in this study were lower than found in the study by Paludo et al. (2018), which

Table 1. Chemical and granulometric characterization of the oxisol in the layer 0-0.2 m (Rondonópolis-MT, 2017).

pH	P	K	S	Ca	Mg	Al	SB	CTC	M.O	V	m	Sand	Silt	Clay
$CaCl_2$	mg dm^{-3}			$cmol_cdm^{-3}$					g kg^{-1}	%		g kg^{-1}		
4.0	1	43	8	0.5	0.3	1.2	0.9	8.3	29	11	57	507	116	377

Fig 1. Distribution of safflower roots as a function of wood ash doses (8, 16, 24, 32 g dm^{-3}) and bulk density levels, from left to right inside each image (1.0; 1.2, 1.4, 1.6, 1.8 Mg m^{-3}).

Table 2. Chemical Characterization of the wood ash (Rondonópolis-MT, 2017).

pH	PN	N	$_2O_5$	K_2O		ᛁg	Ͻ$_4$	Si	Mn		ɘ	Cr	As	Hg
$CaCl_2$	---%---	----------------------------- g kg^{-1}--------------------------------									----- ----(mg kg^{-1}) ------			
10.7	28.0	0.3	0.9	3.5	.3	2.1	0.2	7.4	0.4	0.1	.0	.0	2.1	0.1

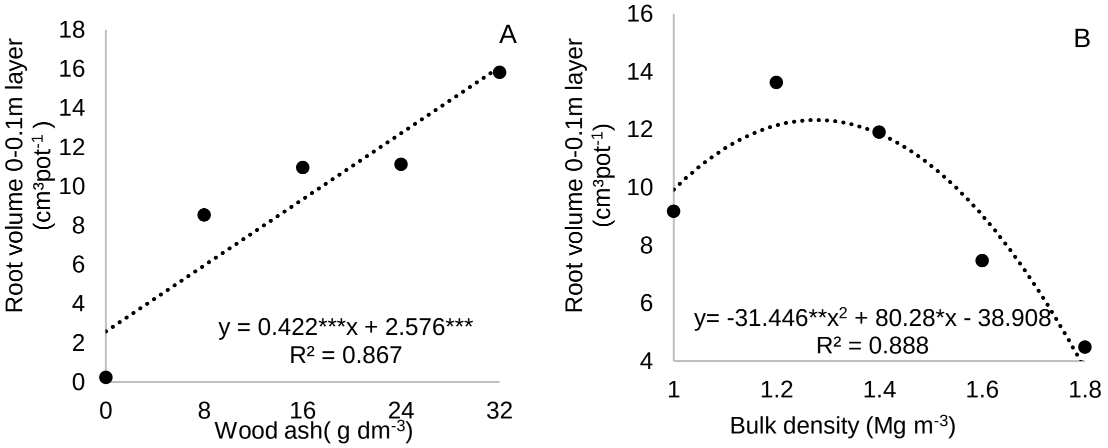

Fig 2. Root volume 0-0.1m layer (cm^3 pot^{-1}) as a function of wood ash doses (A) and bulk density levels (B) in dystrophic Oxisol. *, **, *** Significant at 5, 1 and 0.1% probability, respectively.

Table 3. Summary of variance analysis of root volume.

			RV 0-0.1m	RV 0.1-0.2m	RV 0.2-0.3m	TRV
SV	DF.1	DF.2	MS	MS	MS	MS
Block	3	3	446.71***	144.10	842.16***	3289.23***
(wa)	4	3	656.72***	45.54	154.25	3940.42***
(bd)	4	4	260.55*	160.74	344.89*	1631.60**
wa x bd	16	12	47.51	69.26	226.82	482.15
Error	72	57	102.93	85.32	144.72	394.84
CV(%)			108.7	123.12	111.997	83.03
Average			9.33	7.5	10.74	23.93

Subtitle: RV 0-0.1m, RV 0.1-0.2m, RV 0.2-0.3m, TRV (Root volume for 0-0.1m, 0.1-0.2m, 0.2-0.3m layers and total root volume, respectively). SV (Source of Variation); D.F 1 (degree of freedom for 0-0.1m layer); D.F. 2 (degree of freedom for layers 0.1-0.2; 0.2-0.3m and total volume) M.S. (Medium Square), wa (wood ash), bd (bulk density), CV (coefficient of variation) *, **, *** Significant at 5, 1 and 0.1% probability.

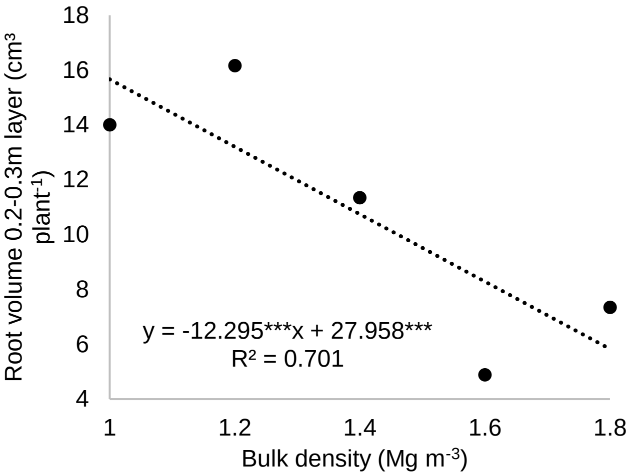

Fig 3. Root volume 0.2-0.3m layer (cm^3 pot^{-1}) as a function of bulk density levels in dystrophic Oxisol. *, **, *** Significant at 5, 1 and 0.1% probability, respectively.

Table 4. Summary of variance analysis for root dry mass.

			RDM 0-0.1m	RDM 0.1-0.2m	RDM 0.2-0.3m	TRDM
SV	DF.1	DF.2	MS	MS	MS	MS
Block	3	3	0.467	1.54	10.03*	20.43**
(wa)	4	3	13.01***	0.75	5.05	88.18***
(bd)	4	4	5.67***	6.02***	13.07**	53.15***
wa x bd	16	12	0.97	0.52	2.94	9.98
Error	72	57	0.64	0.89	3.00	6.90
CV(%)			60.54	120.4	105	77.71
Average			1.32	0.92	1.65	3.38

Subtitle: RDM 0-0.1m, RDM 0.1-0.2m, RDM 0.2-0.3m, TRDM (Root dry mass for 0-0.1; 0.1-0.2; 0.2-0.3 layer and total root dry mass, respectively). SV (Source of Variation) D.F 1 and 2 (degrees of freedom for RDM 0-0.1m and others, respectively). M.S. (Mean square), wa (wood ash), bd (bulk density), CV (coefficient of variation) *, **, *** Significant at 5, 1 and 0.1% probability.

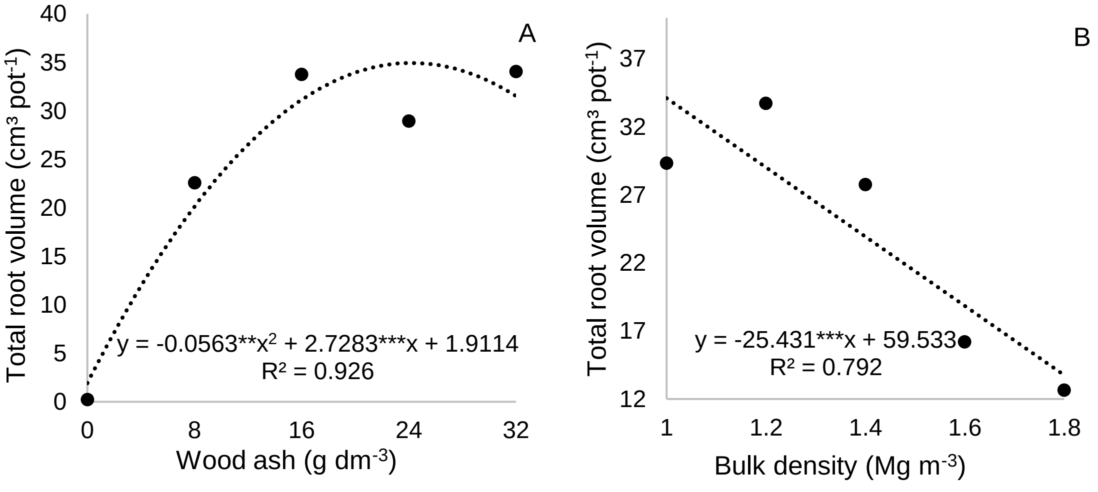

Fig 4. Total root volume (cm^3 pot^{-1}) as a function of combinations of wood ash doses (A) and bulk density levels (B) in dystrophic Oxisol. * **, *** Significant at 5, 1 and 0.1% probability, respectively.

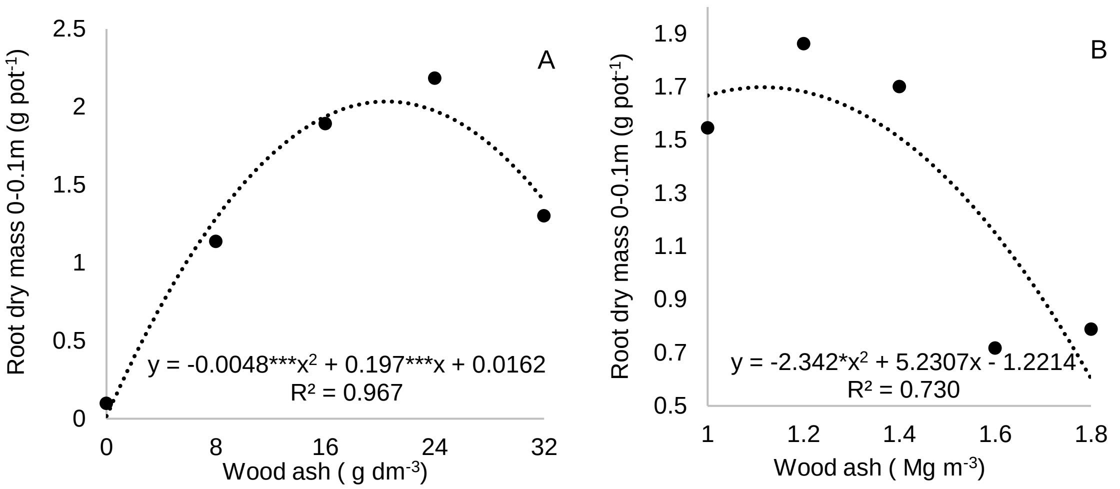

Fig 5. Root dry mass 0-0.1m layer (g pot^{-1}) as a function of wood ash (A) and bulk density levels (B) in dystrophic Oxisol. * **, *** Significant at 5, 1 and 0.1% probability, respectively.

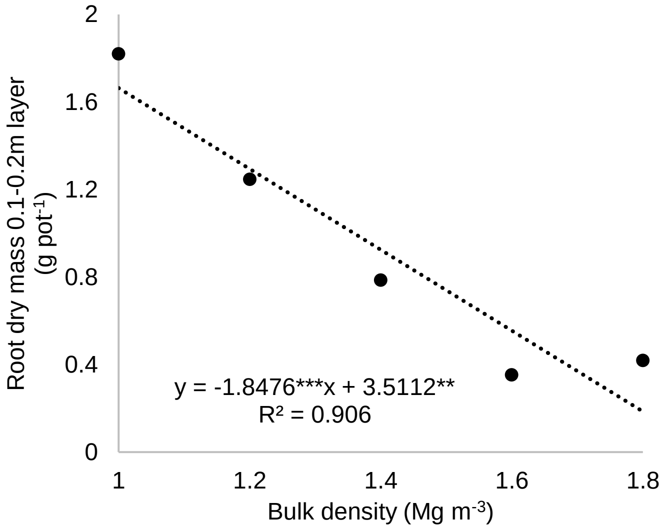

Fig 6. Root dry mass 0.1-0.2m layer (g pot^{-1}) as a function of bulk density levels in dystrophic Oxisol. **, *** Significant 1 and 0.1% probability.

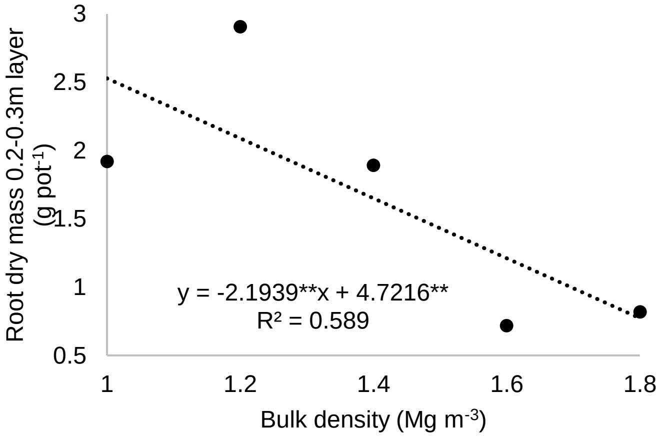

Fig 7. Root dry mass 0.2-0.3m layer (g pot^{-1}) as a function of bulk density levels in dystrophic Oxisol. *** Significant 0.1% probability.

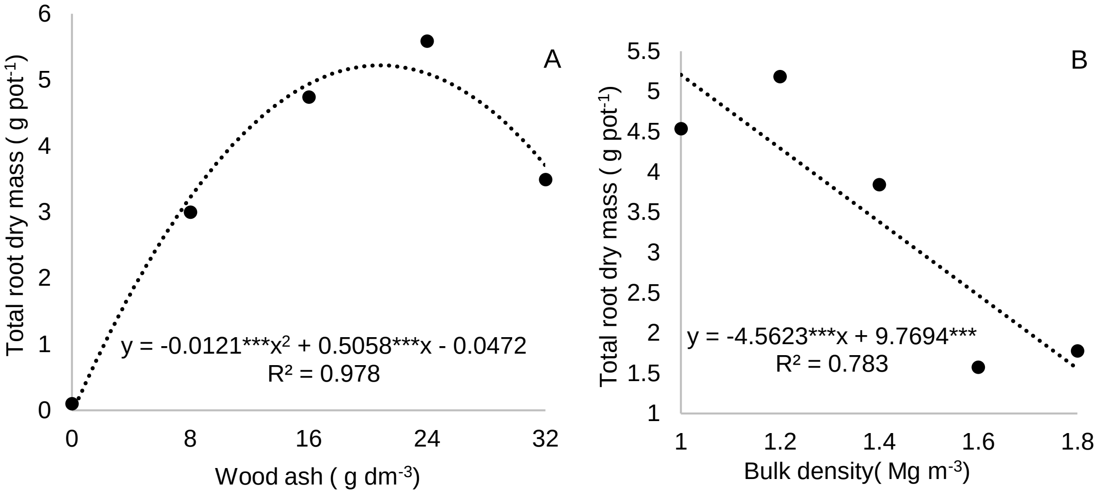

Fig 8. Total root dry mass (g pot^{-1}) as a function of combinations of wood ash doses (A) and bulk soil density levels (B) in dystrophic Oxisol. *, **, *** Significant at 5, 1 and 0.1% probability, respectively.

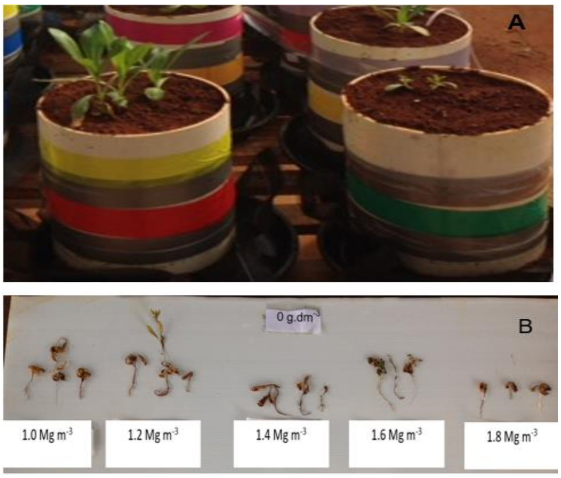

Fig 9. Safflower plants submitted to 0g dm^{-3} of left wood ash, and 24 g dm^{-3} right at 15 days after emergence (A); Safflower plants fertilized with 0g dm^{-3} of wood ash as a function of bulk density levels (B).

evaluated safflower genotypes and bulk density levels, found an average value of 30 g pot^{-1} when the plants developed in soil with a density of 1.0 Mg m^{-3}. However, it is worth mentioning that the plants did not present any restrictions from the nutritional viewpoint during their development, having only the bulk density levels and the genotypes as sources of variation. Paludo et al. (2018), observed no significant differences in the 0.1-0.2m layer. However, in 0.2-0.3m and 0.0-0.1m layers the root volume behaved linearly and quadratic, respectively.

In the present study, we observed that the roots dry mass in all the layers had a linear adjustment decreasing except in the layer 0-0.1 m. These results are in agreement with those found by Bonfim-Silva et al. (2015b) that evaluated the development of *Canavalia ensiformis* with the same bulk density levels and using soil collected in the same area. They observed that, with the increase of the bulk density the smaller pore space between the particles made it difficult to absorb water and nutrients in addition to oxygen reduction, consequently causing inferior root development.

Bonfim-Silva et al. (2018), studied the safflower development cultivated in the same soil type of this experiment and with the same wood ash doses. They verified that the root dry mass was higher when the plants developed at the maximum dose of 32 g dm^{-3} wood ash. It was very similar to that found in the present study. In addition to providing nutrients, wood ash acts as a corrective agent for soil acidity, as well as aluminum, a toxic element for root development (Singh et al., 2017).

Reichert, et al. (2018), evaluated resistance to compaction and the recovery capacity in Oxisol submitted to crop rotation systems. They verified that soils with higher organic matter contents are more resistant to compaction and recovery more easily from compaction conditions.

Soil organic matter increases soil stability and soil mechanical strength and decrease bulk density. These alterations improve water retention and reduce soil penetration resistance (Ekwue, 1990).

Nunes et al. (2016) evaluated development of corn roots under soil water stresses and density levels. They verified that higher levels of bulk density cause smaller macroporosity, and consequently, less dry mass and the corn roots volume. These are mainly due to the smaller porous space and the smaller storage of water, which affect distribution and root development.

Braida et al. (2008) highlighted that greater amount of water and pores in the soil increase the soil elasticity, favoring soil recovery to the compaction process. When the wood ash is added to the soil, even compacted, aeration points are created since the material has low density and expansion (Karmakar et al., 2009) which favors empty spaces in the system, allowing the oxygen flow and root development.

Materials and methods

Location of experiment

The experiment was conducted in a greenhouse, located in the municipality of Rondonópolis-MT, coordinates 16º 28 '150 "S, 50º 38' 08" W and altitude of 284 m. During the experiment conduction, the averages of temperature and humidity were 27° and 81%, respectively.

Experimental unit, wood ash doses and soil compaction

The experiment was conducted in a randomized block design with a 5x5 factorial scheme, with five doses of wood ash (0, 8, 16, 24, 32 g dm^{-3}) and five levels of bulk density (1.0, 1.2, 1.4, 1.6, 1.8 Mg m^{-3}) with 4 replicates.

Each experimental unit consisted of three PVC rings (polyvinyl chloride) with 200mm diameter and 100mm height, jointed by tape "silver tape" totaling 9.4 dm^3 in volume. The rings were jointed with the 0.1-0.2 m layer being compacted.

Previous tests of soil compaction were carried by Fagundes et al. (2014) in the soil collected in the same area of the present experiment, identified an optimum 16% humidity compaction. The soil was compacted with the aid of hydraulic press P 15 ST. The 0-0.1m and 0.2-0.3m layers were added with about 3.14 dm^3 of soil, which roughly equates to the density of 1.0 Mg m^{-3}. In order to estimate the soil volume used, the dry soil volume (Equation 1) was first stipulated, and the water soil mass added to the compacted layers a calculated below (Equation 2):

$$B_d = \frac{D_m}{V_r}$$

$$D_m = V_r . B_d$$

(1)

Where:
D_m= Dry soil mass (Mg)
V_r= Ring volume (3.14 dm^3)
B_d= Bulk density (Mg m^{-3}).

$$W_m = D_m \ (1 + \theta_m)$$

(2)

On what:
Wm= Water soil mass (g);
θ_m= Soil moisture-based mass ($g \cdot g^{-1}$).

In the lower part of the pots we fixed a screen with 1 mm mesh covering its entire base with the help of a rubber, coming from the cross section of the used tire chamber, to drain the water and keep the contents of the pot inside it. Plastic dishes 300 mm in diameter and 50 mm high were placed under each pot.

Once the pots were made, 10 seeds per experimental unit IMA 336 access were sown to a depth of two centimeters. Four days after sowing the plants started the emerging process. Two thinning were used to establish a final population of three plants per pot.

Soil characterization and fertilization

The soil was collected in 0-0.2 m depth under Cerrado vegetation and classified as dystrophic Oxisol (EMBRAPA, 2013). The chemical and granulometric characterization followed methodology recommended by EMBRAPA (1997), presenting the following values (Table 1)

After collection, the soil was packed in plastic bags of 12 dm^3, to which the respective doses of wood ash were added and remaining were sealed for approximately 30 days to occur the reaction of the residue.

The wood ash was obtained from food industry furnaces in which during the combustion process the temperature reached values between 800 and 850 °C, while the combustion started at 250 °C. The wood ash was analyzed as fertilizer proposed by Darolt et al. (1993) and showed the following characteristics (Table 2)

Physical-water analysis of wood ash was performed, following the methodology suggested by the Map (2010), where the following values were observed: wood ash density - 0.45 Mg m^{-3}; particle density - 1.65 g dm^{-3}; water holding capacity - 0.71 cm^3 cm^{-3}.

Due to the chemical characteristics of the wood ash as fertilizer no other fertilizations were carried during the development of the crop, except with the nitrogen which is lost by volatilization in combustion process of wood in boilers. This was supplied at dose of 150 mg dm^{-3} in form of urea and divided into three applications at 15, 30 and 45 days after emergence (proportions of 26, 37 and 37%, respectively), then diluted in aqueous solution to meet the needs of the culture according to Bonfim-Silva et al. (2015a).

The treatments with absence of fertilization with wood ash (0 g dm^{-3}), presented severe chlorosis and later death at 15 days after emergence, (Fig 9A) making it impossible to determine the volume and mass of roots in the layers of 0.1 -0.2 and 0.2-0.3m (Fig 9B).

Evaluation of variables

At 75 days after emergence the plants were cut in to 2 cm height. Subsequently, the pots were disassembled in three layers (rings) washed in running water in a 4 mm sieve to separate the roots from the soil. When the roots were collected, the root volume was calibrated with the aid of a graduated measuring cylinder containing water. The water volume was displaced after the water was placed inside the roots, which was adopted as the root volume. This procedure was carried in each of the layers of 0.10 m and the three parts sum was considered as the total roots volume. After calibrated volume, the roots were placed to dry in forced air circulation oven at 65 °C for 72 hours or until constant weight obtaining dry root mass in the upper, lower, compact and complete ring.

Statistical analysis

After the data collection, the results were submitted to statistical analysis using the statistical program SISVAR (Ferreira, 2010) with analysis of variance and regression test at significance level up to 5% probability. When the interaction between factors was identified, the data were submitted to regression analysis in the SAS software to generate the response surface equation.

Conclusion

There is no interaction between bulk density levels and wood ash doses on the safflower root development. Bulk density levels influence the safflower root system development with linear adjustment decreasing, except for dry mass and root volume in the 0-0.1m layer, which presents a quadratic adjustment with maximum values when the plants develop in soils with density of 1.27 and 1.12 Mg m^{-3}, respectively. Wood ash doses between 20 and 24 g dm^{-3} provide greater root development.

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