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Density of soil and nitrogen in production and nutrition of safflower (*Carthamus tinctorius* L.)

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Abstract

The objective of this study was to evaluate the production and nutrition of safflower under different densities of soil and nitrogen rates in Oxisol. The experiment followed a randomized complete block design and was performed in a greenhouse in a factorial 5x5 fractionated scheme (5^2), involving five soil densities (1.0, 1.2, 1.4, 1.6, and 1.8 Mg m^{-3}) and five nitrogen rates (0, 50, 100, 150, and 200 mg dm^{-3}), with four replications. The variables analyzed included the chlorophyll index, dry mass of the shoot, dry mass of the head, and concentration of nitrogen accumulation in the shoots and heads. The dry mass and nitrogen accumulation in the shoot and heads of the safflower showed a 50–53% drop as the soil density increased. Nitrogen rate of 149 and 179 mg dm^{-3} produced a higher chlorophyll index and nitrogen concentration in the safflower plant heads, respectively. The concentration and shoot nitrogen accumulation revealed a 49% and 37% rise, respectively, with increased nitrogen fertilization. As the soil density and nitrogen levels influence the production and nutrition of safflower, they were isolated.

Keywords: *Carthamus tinctorius* L., soil compaction, nitrogen fertilization, soil management, oilseed crops.

Introduction

Safflower (*Carthamus tinctorius* L.) can be useful in dyes and medicines, as fodder for cattle, high quality edible oil extracted from the grain for human consumption, and potentially as a biofuel. Due to its deep root system and high drought tolerance it is a good alternative crop to grow during the off season and for crop rotation, particularly in Brazil (Peixoto, 1972, Dordas & Sioulas, 2008, Shahrokhnia & Sepaskhah, 2016).

However, some crops show greater sensitivity to soil management, as compaction induces alterations in the nutrient dynamics and decreases root development because of reduced porosity and hydraulic conductivity, as well as, greater resistance to soil penetration, which compromises the ability of the plants to absorb nutrients, thus resulting in nutritional imbalance and reduced productivity (Rosolem et al., 1994, Mossadeghi-Björklund et al., 2016). Among the nutrients having ion-root contact for mass flow, nitrogen uptake, in particular, is the most limited in these plants (Cabral et al., 2012).

In plants, nitrogen which is the chief component of proteins, enzymes, chlorophyll, and nucleic acids also plays a key role in hormone synthesis. Nitrogen thus provides the best effect as it increases the photosynthetic capacity and improves plant nutrition (Taiz & Zeiger, 2013), thus emphasizing that proper management of nitrogen fertilization is essential.

Yet, there are few studies that correlate the interaction of soil compaction with nitrogen fertilization, evaluating its influence on the production and nutrition of plants, especially with the safflower crop. From this perspective, the objective of this study was to evaluate the production and nutrition of safflower under different densities of soil and nitrogen rates in Oxisol.

Results and discussion

No significant interaction was noted between the soil densities and nitrogen rates for the variables studied.

Chlorophyll Index, dry mass of shoot, and heads

The chlorophyll index revealed the isolated significance of nitrogen rates with the quadratic regression model set at 60 and 90 days post emergence, and the highest rates (70.8 and 64.5) were observed for the nitrogen doses of 128 and 149 mg dm^{-3}, respectively (Figure 1A).

Dordas and Sioulas (2008) in their study on nitrogen fertilization in safflower culture reported a rise in the chlorophyll index with increased nitrogen fertilization. Bonfim-Silva et al. (2015) recorded the highest rate for safflower (68.19) at the nitrogen dosage of 186 mg dm^{-3}. The increased availability of soil nitrogen and its subsequent absorption by the plant increased the chlorophyll index values as nitrogen played a vital part in chlorophyll formation (Taiz & Zeiger, 2013). Identical results were reported by Barbosa Filho et al. (2008) indicating a relationship between the amount of nitrogen present in the leaves and chlorophyll in the reading of the common bean (*Phaseolus vulgaris*), whereas, Silva et al. (2010) discovered the same relationship in cowpea (*Vigna unguiculata*). Thus, the chlorophyll index is a good indicator that enables the prediction of the nutritional status of the plants with respect to nitrogen. A drop in the chlorophyll index from 60 to 90 DAE was noted, as the final assessment of the culture had been performed at

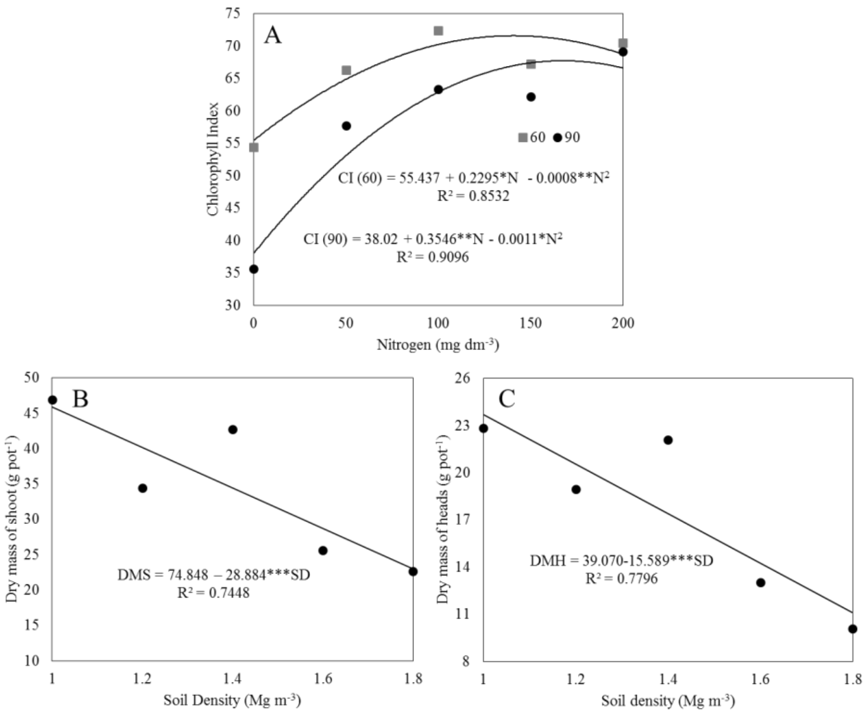

Fig 1. Chlorophyll Index (SPAD) at 60 and 90 days post emergence, based on the nitrogen rates (A), dry mass of shoot (B), and dry mass of heads (C) in safflower, as a function of soil density in Oxisol. IC - Chlorophyll index; N - Nitrogen. DMS - Dry mass of shoot; DMH - Dry mass of heads; SD - Soil density. ** and * significant at 1%and 0.1%, respectively.

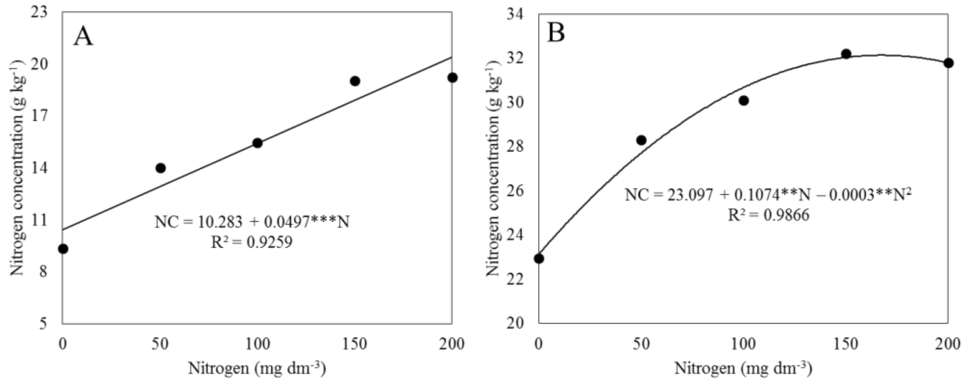

Fig 2. Nitrogen concentration in the shoot (A) and heads (B) of safflower based on the nitrogen rates. NC - Nitrogen concentration; N - nitrogen. *** Significance of 0.1%.

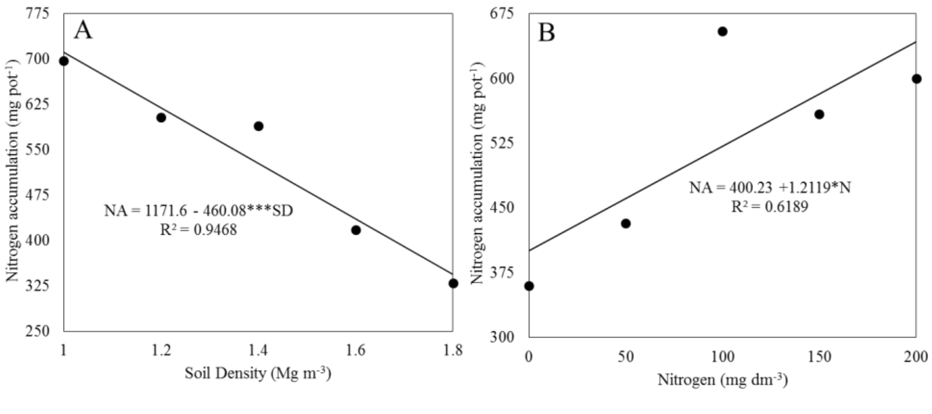

Fig 3. Nitrogen accumulation in the safflower shoot based on soil density (A) and nitrogen (B). NA - nitrogen accumulation; SD - Soil density; N - nitrogen. * and *** mean 0.1% and 5%, respectively.

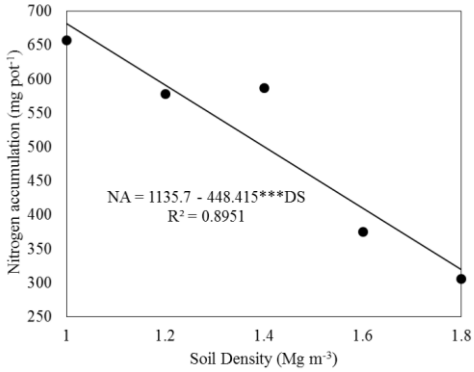

Fig 4. Nitrogen accumulation in the safflower heads based on soil density. NA - nitrogen accumulation; SD - Soil density. *** Significance of 0.1%.

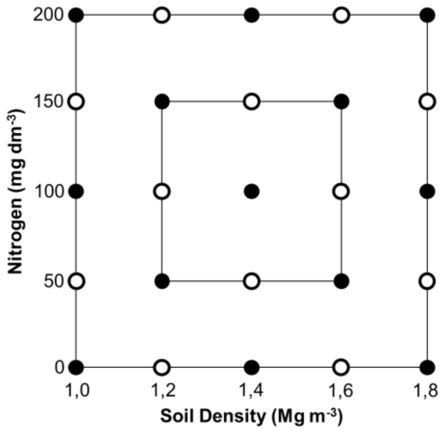

Fig 5. Experimental factorial design with 5x5 split, using five soil densities and five nitrogen doses, adapted from Littel and Mott (1975). ● - Existing combinations; ○ - Combinations to be estimated.

the culmination of the flowering season. It had dominated the filling process of the grains during which the nutrients and reserves for heads were translocated. Similar results were also reported by Dordas & Sioulas (2008), in their study on the safflower culture, with respect to the chlorophyll index.

Normally, an interaction between the chlorophyll index and crop yield components is observed. However, unlike these results, Zhang et al. (2008) in their study, reported that the increase in the chlorophyll index was not accompanied by a increase in the production of dry mass, the "luxury product" of chlorophyll.

An isolated significance of soil density on the dry mass of shoots was observed, which had set the linear regression model. At the density of 1.0 Mg m^{-3} a higher mass (45.96 g pot^{-1}) and a 50.3% reduction were obtained, when compared with the higher bulk density (1.8 Mg m^{-3}) (Figure 1B).

As the soil density increased, the porosity decreased causing greater resistance to penetration, limiting the soil volume that could be exploited and the water and nutrients available from the roots. This resulted in an increase in the energy expenditure of the root system to overcome the physical barrier caused by the subsurface compaction (Gao et al., 2016, Nunes et al., 2016). Under such conditions, the roots may act as drains during the vegetative growth, because the plants can be directed to assimilate from the root system, resulting in a lesser accumulation of carbohydrates in the dry mass of shoots, with increased soil density (Bonelli et al., 2011).

For dry mass heads, a fit was observed in the linear regression model. Greater dry mass heads (23.48 g pot^{-1}) were seen at a density of 1.0 Mg m^{-3}. Thus, as soil compaction increased, a decrease of 53.15% was noted in the dry mass heads, as compared to the bulk density of 1.0 mg dm^{-3} with 1.8 mg dm^{-3} (Figure 1C).

The heads corresponded directly to the grain production and oil yield in the safflower crop (Dordas & Sioulas, 2008). The dry mass of the heads presented a similar adjustment in the dry mass of shoots, showing reduced production as soil density increased. This occurred due to a lower nutrient accumulation and reserve carbohydrates in the stem and a decreased production of assimilates by the leaves, which are translocated by the heads as and when they are formed (Taiz & Zeiger, 2013).

Nitrogen concentration in plants

The nitrogen concentration in the shoot was set in the linear regression model for the nitrogen levels. The highest concentration observed (20.22 g kg^{-1}) was for a nitrogen dose of 200 mg dm^{-3}, indicating a 49% increase when compared with the absence of nitrogen fertilization (Figure 2A). These results of nitrogen concentration in the shoot agreed with the studies of Dordas and Sioulas (2008) and Anicésio et al. (2015). They reported the linear behavior of the nitrogen concentration in safflower, wherein, the increase in the nitrogen doses induced concentrations in the range of 9 to 18.5 g kg^{-1} of nitrogen in the shoot. A suitable nitrogen concentration level in the shoot is relevant because of the chlorophyll formation and it participates in the gas exchange processes, exerting a direct bearing on the assimilation and carbohydrate accumulation (Taiz & Zeiger, 2013). The nitrogen concentration in the safflower heads revealed an isolated significant difference in the nitrogen levels, with the setting of the quadratic regression model. The highest nitrogen concentration (32.71 g kg^{-1}) was observed at a nitrogen rate of 179 mg dm^{-3}, showing a 29% increase, when compared with the complete absence of nitrogen fertilization (Figure 2B). The higher nitrogen concentration observed in the heads when compared with the shoot, is a result of this nutrient being exported for grain filling. Abbadi et al. (2008) in their study of achenes, observed that any increase in the nitrogen concentration triggered an increase in the oil income, thereby supporting the significance of the nutritional status of plants and their reproductive structures. Anicésio et al. (2015) reported a higher nitrogen concentration in the heads, up to 33.4 g kg^{-1}, for a nitrogen dose of 240 mg dm^{-3}.

Nitrogen accumulation by plants

Nitrogen accumulation in the shoot revealed isolated significant differences for soil density and nitrogen (Figure 3). The soil density was adjusted to the linear regression model, in which, at the density of 1.0 M g m^{-3} a higher nitrogen accumulation was achieved in the shoots (711,52 mg pot^{-1}), showing a 52% decrease in relation to the higher bulk density (1.8 Mg m^{-3}) (Figure 3A).

However, the nitrogen accumulation in the shoot caused an adjustment in the linear regression model to nitrogen fertilization, with the highest accumulation (643 mg pot^{-1}) reported for a nitrogen dose of 200 mg dm^{-3}. This was a 37% increase considering the lack of nitrogen fertilization (Figure 3B).

As the soil density increased, a correpsonding drop in nitrogen accumulation by the plant was observed. The soil density increase caused a reduction in the total porosity; while the irrigation experiment was predominantly subsurface in nature, it could have decreased the water availability in the surface layer (Nunes et al., 2016). These conditions induced those nutrients with an ion-root contact for mass flow, like nitrogen, for instance, to become more limited in plant uptake (Cabral et al., 2012). Anicésio et al. (2015) recorded a nitrogen accumulation in safflower plants ranging from 280–400 mg pot^{-1} in the safflower shoot.

The heads, in turn, showed nitrogen accumulation as isolated, with significant differences in soil density, adjusting the linear regression model, with a density of 1.0 Mg m^{-3} higher nitrogen accumulation in the heads of 687, 3 mg pot^{-1}. Thus, by increasing the density, the nitrogen accumulation decreased by 52.2%, as shown in Figure 4.

Nitrogen accumulation in the safflower heads dropped when the soil density increased, due to the lower degree of accumulation of this nutrient in the shoot. This occurred due to a reduction in the nitrogen accumulation in the dry mass and heads, which is directly related to the lower translocation of this nutrient, which assimilates in the shoots and heads in their training as source-sink ratio (Taiz & Zeiger, 2013).

Materials and methods

Localization, design of experiments, and plant material

The experiment was conducted in a greenhouse at the Federal University of Mato Grosso, Rondonópolis - MT, Brazil, located at latitude 16º27'49" S, longitude 50º34'47" W, and a height of 284 m. The experiment was conducted between April and July 2015. A randomized block design was adopted for the experiment with four blocks, in a factorial 5x5 fractionated scheme (5^2), adapted from Littell and Mott (1975), using five soil densities (1.0, 1.2, 1.4; 1.6, 1.8 mg m^{-3}) and five nitrogen levels (0; 50; 100; 150; 200 mg dm^{-3}), with a total of 13 treatments (1.0 - 0; 1.0 - 100; 1.0 - 200; 1.2 - 50; 1.2 - 150; 1.4 - 0; 1.4 - 100; 1.4 - 200; 1.6 - 50; 1.6 - 150; 1.8 - 0; 1.8 - 100; 1.8 - 200) (Mg m^{-3} - mg dm^{-3}) (Figure 5). The plant material was safflower (*Carthamus tinctorius* L.) cultivar IMA 0213.

Soil characteristicsand fertilizations

The soil, Oxisol (Embrapa, 2013), was collected from the region supporting Cerrado vegetation, to a depth of 0–0.2 m. The chemical and textural analysis (Embrapa, 1997) revealed the following characteristics: pH ($CaCl_2$) = 4.0; Q = 1.4 mg dm^{-3}; K = 23 mg dm^{-3}; Ca = 0.4 cmolc dm^{-3}; Mg = 0.2 cmolc dm^{-3}; H = 5.4 cmolc dm^{-3}; Al = 0.8 cmolc dm^{-3}; CTC = 6.8 cmolc dm^{-3}; V = 10.3%; O. M. = 27.1 g dm^{-3}; sand: 423 g kg^{-1}; silt: 133 g kg^{-1}, and clay: 444 g kg^{-1}. Soil acidity was corrected by using dolomitic limestone (PRNT = 80.3%) and increasing the saturation of the bases to 60% (Anicésio et al., 2015). After sieving the soil through a 4 mm mesh it was transferred to the experimental units and fertilized with the micronutrient, at a rate of 30 mg dm^{-3} FTE BR12 (9% Zn - 1.8% B - 0.8% Cu - 2% Mn - Fe 3.5% - 0.1% Mo), phosphorus (P_2O_5), and potassium (K_2O), both at a rate of 300 mg dm^{-3}, just prior to compression, to ensure homogeneous fertility throughout all the layers. Nitrogen was applied in two steps, first at sowing and next 30 days post emergence.

Pots composed and soil compaction

The pots composed of PVC tubing (polyvinyl chloride) were 0.2 m in diameter, having three superimposed rings 0.1 cm each, with each pot being 0.30 m in height. The rings were joined using silver duct tape. Plastic dishes were placed at the base of the pot to facilitate subsurface irrigation and prevent soil loss from the experimental unit. Soil compaction was done using a hydraulic press P15 ST Bovenau® mark. The upper and lower rings were filled with soil, with a density of 1.0 Mg m^{-3} (soil without being compressed), while the central ring was filled with the compacted soil at different ground densities (1.0, 1, 2; 1.4; 1.6; 1.8 Mg m^{-3}) to simulate the subsurface compaction. To assess the dry mass of the compacted soil layer, the density was considered as a ratio between the dry soil mass and the total ring volume (Equation 1) (Nunes et al., 2016).

$$SD = \frac{DSM}{TV} \quad (1)$$

Where;
SD - Soil density
DSM - dry soil mass,
TV - total ring volume.

Traits measured

The variables analyzed included the chlorophyll index, dry mass of shoot and heads, and concentration and accumulation of nitrogen in the shoot and heads. The chlorophyll index was checked using a Minolta SPAD-502 leaf chlorophyll meter with evaluations being done 60 and 90 days post emergence. At 90 days post emergence, the neck of the plants was cut, to separate the shoot portion of heads and oven dried with forced air circulating at 65°C temperature, until constant mass. The dry masses were determined using a Semi-Analytical balance. The dry mass of the shoot and heads were ground in the Wiley mill, to determine the nitrogen concentration using the sulfuric acid digestion process, adopted from the Kjeldahl method, as described by Malavolta et al. (1997). The nitrogen accumulation was assessed by relating the concentration of the dry mass of the shoot and heads.

Data analysis

The results were then submitted to the analysis of variance, and when found significant they were subjected to regression through the "Statistical Analysis System" (SAS. 2002). Analysis of variance was performed using a combination of soil densities and nitrogen, based on the significance level of the F test for these combinations. The Response Surface Regression procedure, which employs the method of least squares to fit the quadratic response surface regression models, was used to study the response surface. In cases where the significance between the bulk density and the nitrogen rate was isolated, the first and second regression study degrees were studied using the generalized linear model command. We used the maximum statistical significance of 5% probability error in all the tests.

Conclusions

The soil density and nitrogen doses affect the production and nutrition of safflower plants in isolation. The dry mass and nitrogen accumulation in shoots and safflower heads revealed 50–53% decrease when the bulk density was inreased to 1.8 Mg m^{-3}. Nitrogen doses of 149 mg dm^{-3} and 179 mg dm^{-3} resulted in a higher chlorophyll index and nitrogen concentration in the safflower plant heads, respectively. Nitrogen concentration and shoot nitrogen accumulation showed a rise of 49% and 37%, respectively, when nitrogen fertilization was increased by utilizing a nitrogen dose of 200 mg dm^{-3}.

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