

## Safflower genotypes submitted to soil density levels

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### Abstract

It is essential to have knowledge of changes in soil structure, as a result of agricultural use and its relationship with crop development, especially those with potential for use in new regions, such as the cultivation of safflower (*Carthamus tinctorius* L.) in the Cerrado. In view of this dynamics, the objective was to evaluate the phytometric components of safflower genotypes submitted to levels of soil densities in Cerrado Oxisol. Ten safflower genotypes were then submitted to compaction (five densities: 1.0, 1, 2, 1.4, and 1.8 Mg m<sup>-3</sup>) in a completely randomized design with four replications under greenhouse conditions. The plots consisted of an overlap of three rings of polyvinylidene chloride of 0.01 m height each, and the treatments were applied in the intermediate layer. The phytometric components (plant height, number of leaves and stem diameter) and shoot dry mass of the crop were evaluated at 30, 60 and 90 days after sowing. There was no significant interaction between safflower genotypes and soil densities, with the effects being isolated for genotypes and/or densities when significant. For the phytometric characteristics evaluated, the genotypes PI250196, PI301049, PI305173, and PI305205 are more stable about the variations of soil density in comparison to the others. The phytometric components and dry mass of safflower shoot are impaired from the mean density of 1.2 Mg m<sup>-3</sup>.

**Keywords:** *Carthamus tinctorius* L., soil compaction, soil physics, water availability, nutrient absorption, soil structure

### Introduction

The pressure exerted on the soil either by anthropic or natural action results in the rearrangement and compaction of soil particles. This, when in excess, causes physical-hydrological impediments to proper root development (Reichert et al., 2009), destroys the plant's sustenance, aeration, reducing the availability of water, as well as the absorption of nutrients (Lima et al., 2007; Obour et al., 2017). This recurrent dynamics in the current agricultural systems is known as soil compaction.

Soil compaction can be observed visually by observing morphological deformations in the plant root system and by analyzing soil attributes,

such as soil density, penetration resistance and optimum water interval that correlate with compaction (Lima et al., 2007; Reinert et al., 2008).

The range of soil density restrictive to plant growth and development is variable and dependent on several factors. The morphology of the root system, the plant species, and the cultivars present specific responses to changes in soil density. Thus, it is fundamental to study the response of each crop to soil compaction, especially in the highly mechanized agricultural scenario, in which the need to perform agricultural operations due to weather conditions contrasts with the ideal working moisture range, to the

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detriment of the soil physical quality (Genro Junior et al., 2004).

The compacted soil layer varies according to the condition to which it is subjected, agricultural operation and the water content during the same period. Research indicates that restrictive impediments to plant growth from 0.03 to 0.30 m depth, can be found in the general agricultural production system (Genro Junior et al., 2004; Reinert et al., 2008; Freddi et al., 2009) and the possibility of compaction increases with successive agricultural operations (Sivarajan et al., 2018).

Thus, for the incorporation of new plant species into the cropping systems, the response of the crop to the physical alterations of the soil must be considered, to ensure adaptability to the system and the best way of utilizing it. An alternative crop to the Brazilian agroecosystem is safflower (*Carthamus tinctorius* L.) (Galant et al., 2015).

Although little cultivated in Brazil, safflower is a promising crop for the Brazilian Cerrado. Oilseed has a high oil content in its seeds, with applications in industry as well as for food and feed. Due to its ecophysiology, safflower may be a viable option for second crop cultivation in the State of Mato Grosso (Bonfim-Silva et al., 2015). Therefore, an in-depth study of the response of safflower genotypes to the physical alteration of the soil for this region is necessary, aiming at a better crop recommendation to ensure that the potential of the crop is explored.

**Table 1.** Granulometric characterization and chemical analysis of the 0.0 to 0.2 m layer of the collected soil. Rondonópolis - MT, 2014

pH	Sand	Silt	Clay	P	K	Ca	Mg	H	Al	BS	CEC	V	O.M.
	g kg <sup>-1</sup>			mg dm <sup>-3</sup>		cmol <sub>c</sub> dm <sup>-3</sup>						%	g dm <sup>-3</sup>
4.0	423	133	444	1.4	23	0.4	0.2	5.4	0.8	0.7	6.8	9.7	27.1

BS - Base Sum; CEC - Cations exchange capacity; V - Base saturation; O.M. Organic Matter

Thereafter, liming was performed to increase the base saturation to 60%. After the procedure, the soil was packed in plastic bags for reaction. For plant fertilization, 200 mg dm<sup>-3</sup> of nitrogen in the form of urea, 150 mg dm<sup>-3</sup> of phosphorus (P<sub>2</sub>O<sub>5</sub>) in the form of single superphosphate and 200 mg dm<sup>-3</sup> of potassium (K<sub>2</sub>O) in the form of potassium chloride were added, according to the recommendation of Bonfim-Silva et al. (2015) for safflower cultivation.

The objective of this study was to evaluate the phytometric components and dry mass production of safflower genotypes submitted to different soil densities in Oxisol from the Cerrado.

### Materials and Methods

Ten safflower genotypes were submitted to soil compaction (levels of soil density obtained by means of artificial compaction), cultivated in a protected environment at the Federal University of Mato Grosso - UFMT, Rondonópolis Campus, between April and July 2015. The mean temperature and relative humidity during the period were 28.4°C and 67.8%, respectively.

The study design was completely randomized, consisting of ten safflower genotypes and five soil densities (1.0, 1.2, 1.4, and 1.8 Mg m<sup>-3</sup>) with four replications, totaling 200 experimental units. Soil density levels were defined from the normal Proctor test in the laboratory so that the highest density tested (1.8 Mg m<sup>-3</sup>) is the upper limit for this soil and the optimum moisture for compaction is 16% based on mass.

Initially, the soil was collected from a Cerrado natural vegetation area in the 0.0 to 0.2 m depth layer, and this was sieved in a 4 mm mesh for the removal of vegetal material (mainly roots) and the soil was homogenized, to fill the experimental units. The soil of the area was classified as Oxisol, according to EMBRAPA (2013). Table 1 presents the results of the collected soil analysis.

For the supply of micronutrient demand, 15 mg dm<sup>-3</sup> of FTE BR 12 was applied, with a minimum guarantee of 9% Zn; 1.8% B; 0.8% Cu; 2% Mn; 3.5% Fe; and 0.1% Mo.

Each experimental unit was composed of a PVC (Polyvinyl chloride) vessel with a diameter of 200 mm and a height of 300 mm, making a volume of 9.42 dm<sup>3</sup>. They were sectioned transversely at 100 mm (Figure 1), to obtain the desired density in each layer of soil. The three rings

were fixed by means of adhesive tape and one of its ends was covered by a polyethylene screen (1 mm thick), to prevent loss of soil. After filling with soil, the experimental units were conditioned on a plastic support of 300 mm.

The treatments were applied to the central layer of each plot. The outer layers (upper and lower) maintained a density of 1.0 Mg m<sup>-3</sup>. Soil compression to the desired density was carried out with the aid of a hydraulic press

Bovenau mark - model P15ST. The soil volume required to fill each ring at its respective densities was obtained using Eq. 1:

$$\rho_s = \frac{M_{DS}}{V_T} \quad (1)$$

where:

$\rho_s$  – soil density (kg dm<sup>-3</sup>);  $M_{DS}$  – Mass of dry soil (kg) and  $V_T$  – Total ring volume (3.14 dm<sup>-3</sup>).

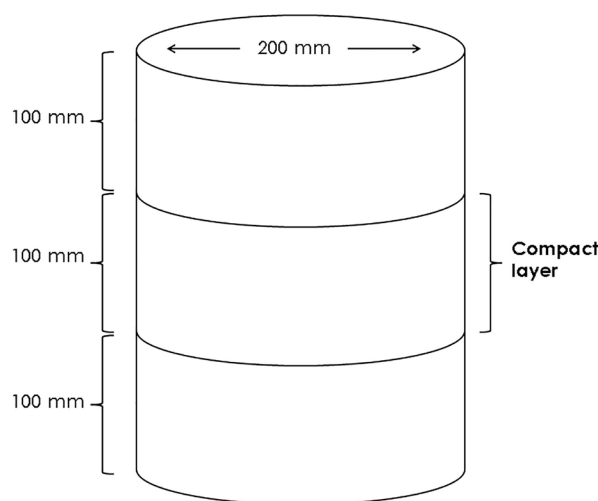


Figure 1. Representation of an experimental unit and its three layers of soil.

Ten safflower genotypes (PI237538; PI248385; PI250196; PI301049; PI305173; PI305205; PI306596; PI306603; PI560202 and PI613366) were provided by the Mato Grosso Cotton Institute - IMA. Twenty (20) seeds were seeded per pot to ensure emergence in all plots. The soil was irrigated through the surface until the establishment of the plants (15 days). From this moment, the water was provided by capillarity to provoke the need in the plants to deepen the roots against the compacted layer (Silva et al., 2006). Soil moisture was maintained below the 25 kPa soil moisture tension and was measured using Irrigas (Calbo and Silva, 2005), a device widely used for irrigation management mainly in vegetables. When tension was reached, water was applied freely via capillarity, so that water was not a limiting factor for the growth and development of safflower plants. After the emergence of the plants, three thinnings were performed at 5, 7 and 15 days after emergence, in which ten, six and two plants were left in each pot at the end of the third thinning, respectively.

As a phytosanitary treatment for the prevention and control of fungal diseases (mainly of the genus *Alternaria*), fungicide/bactericide was used with contact action of the inorganic chemical group based on Copper Oxychloride at a dose of 1.68 g i. a. L<sup>-1</sup> at 15 days after sowing with new application every 15 days. Systemic fungicide was also applied to the chemical groups of Strobilurin and Triazol, at a dose of 2.0 and 0.8 g i. a. L<sup>-1</sup>, respectively, at 45 days after emergence with reapplication at 15-day intervals.

Periodic evaluations were performed at 30-day intervals. Thus, the data were collected at 30, 60 and 90 days after the emergence of the following variables: Plant Height (PH) - measured between the soil level and the apex of the plants (cm); Number of leaves (NL) - count of the total number of leaves of each plant; Stem diameter (STD) - measured at 2 cm from the soil surface by means of a digital caliper (mm) and Shoot dry mass (SDM) - obtained by the mass of the whole aerial part except for the determined portions

after drying in an oven at 65°C until constant mass.

The collected data were submitted to ANOVA and, if significant, submitted to polynomial regression analysis for soil density levels and Scott-Knott test for the genotypes. The analyses were performed using the Sisvar program (Ferreira et al., 2011), considering the 5% probability level.

**Table 2.** Plant height of safflower genotypes as a function of density levels at 30, 60 and 90 days after emergence. Rondonópolis - MT, 2014

Safflower genotypes	Plant height (cm)		
	30 DAE	60 DAE	90 DAE
PI237538	32.22 a	83.15 a	93.75 b
PI248385	28.08 b	69.83 b	71.68 c
PI250196	26.05 b	69.65 b	112.28 a
PI301049	28.28 b	87.13 a	103.73 a
PI305173	25.83 b	80.25 a	105.50 a
PI305205	30.33 b	83.65 a	87.35 b
PI306596	29.83 b	78.91 a	91.50 b
PI306603	26.48 b	70.80 b	94.18 b
PI560202	28.49 b	78.03 a	94.13 b
PI613366	25.93 b	66.08 b	113.55 a
Mean	28.45	76.78	96.76
Significance	***	**	**
CV (%)	20.85	21.43	19.44

Means followed by the same letter in the column belongs to the same group according to Scott-Knott test at 5% of probability \*\*\*, \*\*Significant at 0.1 % and 1 % probability, respectively. Rondonópolis - MT, 2014. CV - coefficient of variation.

At the beginning of the growth of some safflower genotypes, at 60 DAE, it was possible to observe two groups that presented higher heights (PI237538, PI301049, PI305173, PI305205, PI306596, and PI560202) followed by the second group with lower heights (PI248385, PI250196, PI306603 and PI613366).

In the evaluation performed at 90 DAE, 90% of the experimental units were flowered, and three distinct groups were formed. The first group with an average height of 108.77 cm, was formed by the highest plants (PI250196, PI301049, PI305173, and PI613366). The second group (PI237538, PI305205, PI306596, PI306603, PI560202) in which the height averages ranged from 87.35 to 94.18 cm, followed by the third group, formed only by the genotype PI248385 with a mean height of 78 cm. It should be noted that genotype PI613366 presented only 40% of its flowering experimental units, due to the fungal attack, which occurred with greater severity in this genotype, even with the application of fungicides in all treatments and genotypes.

These results show a significant difference

## Results and discussion

### Plants height

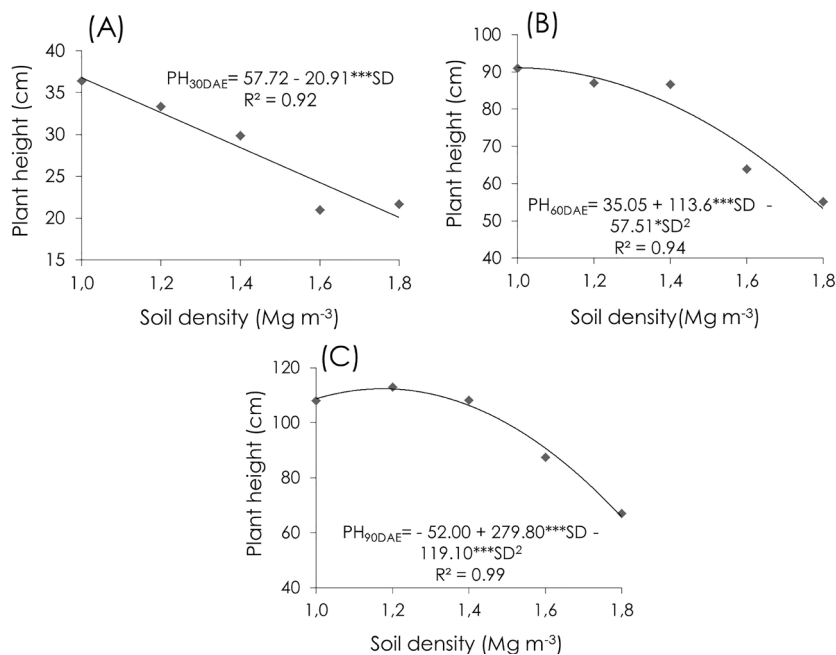
There was a statistical difference between the genotypes as a function of the evaluation days (Table 2). This fact reveals differences in the genetic characteristics of safflower genotypes from the initial phase of their development. At 30 DAE, the genotype PI237538 stood alone with the highest plant height (32.22 cm).

in the plant height of safflower genotypes, which is closely related to the genetic characteristics of safflower (Figure 2). The height of safflower plants was influenced by soil density levels alone. It was observed that this variable adjusted to the linear regression model for the evaluation performed at 30 DAE, with a reduction in plant height equivalent to 45.44%, between the lowest and highest density levels (Figure 2A).

According to Gerhardt (2014), reported that plant height is a very important characteristic to be analyzed in the selection of genotypes, because very short plants make mechanized harvesting difficult, and very tall plants are more prone to bedding in the field.

For the evaluations performed at 60 and 90 DAE, there was an adjustment to the quadratic regression model, with higher heights (91.14 and 112.33 cm) at soil densities of 1.0 and 1.17 Mg m<sup>-3</sup> (Figure 2B and 2C). These results show that the plant height of safflower genotypes is influenced by different soil densities.

Silva et al. (2006) when evaluating the growth of the aerial part of cotton plants



**Figure 2.** Plant height of safflower as a function of soil density at 30 (A), 60 (B) and 90 (C) days after emergence. PH - Plant height; SD - Soil density. \*\*\* Significant at 0.1% probability. Rondonópolis - MT, 2014.

(*Gossypium hirsutum* L.), Marandu grass (*Brachiaria brizantha*), maize (*Zea mays*) and soybean (*Glycine max* L.) cultivated in pot, submitted to compaction levels of Oxisol, found an increase in height near soil density of 1.2 Mg m<sup>-3</sup>.

Larger densities provided a decrease in the height of the studied plants. Freddi et al. (2009), also verified a reduction in the height of maize plants, cultivated in Oxisol of medium texture and Oxisol of clay texture with the increase of soil density.

Compacted soils generally show serious reductions in root growth and total soil volume, so that shoot growth and development is significantly affected by this fact. Recent research has indicated a reduction of up to 94.1% of root length in safflower plants in soil with high resistance to penetration (4 MPa) after 10 days of growth (Gao et al., 2016).

Thus, the sustenance, absorption of water and nutrients are compromised, also there is increased susceptibility to water deficits, due to the concentration of roots in the soil surface layer and the low volume of soil that reduces the availability of water, in periods of drought.

#### Number of leaves

For the number of leaves, there was no significant interaction between safflower genotypes and soil densities in the evaluations performed at 30 and 60 days after plant emergence (DAE) (Table 3). These results show that, for the evaluated genotypes, the soil density exerts a significant influence on the number of leaves until the beginning of the flowering of safflower plants.

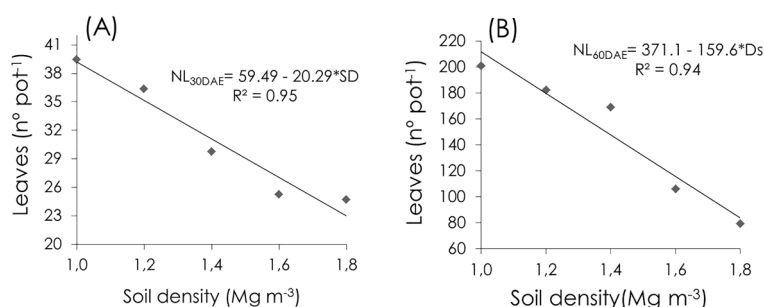
It can be observed that in the safflower genotypes there was a reduction in the number of leaves with increased levels of soil density, and for the evaluations performed at 30 and 60 DAE, the number of leaves was described by the linear regression model (Figure 3A and 3B).

These results demonstrate that the increase in soil density influences the reduction in the number of safflower leaves. In a study by Bonfim-Silva et al. (2011) in wheat plants (*Triticum aestivum* L.), the authors concluded that the densities of an Oxisol from the same area of the present study may interfere with the availability of nutrients to the roots, contributing negatively to the absorption of nutrients by reducing leaf production. Higher soil densities also lead to a reduction in the volume of soil explored by the roots and, consequently, result in decreased availability of water and nutrients in the soil solution.

**Table 3.** Number of leaves of safflower genotypes as a function of density levels at 30 and 60 days after emergence. Rondonópolis - MT, 2014.

Safflower genotypes	Leaves (n° pot <sup>-1</sup> )	
	30 DAE	60 DAE
PI237538	29.55 b	162.20 a
PI248385	34.35 a	190.25 a
PI250196	26.90 b	116.25 b
PI301049	32.45 a	165.40 a
PI305173	26.25 b	152.25 a
PI305205	29.80 b	179.75 a
PI306596	34.30 a	126.60 b
PI306603	37.20 a	143.70 b
PI560202	29.65 b	115.05 b
PI613366	30.40 b	125.40 b
Mean	31.09	147.69
Significance	***	***
CV (%)	23.09	32.22

Means followed by the same letter in the column belongs to the same group according to Scott-Knott test at 5% of probability \*\*\*Significant at 0.1 % probability, respectively. Rondonópolis - MT, 2014. CV - coefficient of variation



**Figure 3.** Number of safflower leaves as a function of soil density levels at 30 (A) and 60 (B) DAE. NL - Number of Leaves; SD - Soil Density. \* Significant at 5% probability. Rondonópolis - MT, 2014.

Ohland et al. (2014), also observed that the increase in density levels in Oxisol, influenced the number of safflower and jatropha leaves, with quadratic effect as a function of soil density levels, up to a density of 1.26 Mg m<sup>-3</sup>.

In the evaluation performed at 90 days after emergence, the number of leaves showed significant interaction between safflower genotypes and soil densities (Table 4).

Safflower genotypes PI237538 and PI301049, fit the quadratic regression model as a function of soil density (Figure 4A and 4C). Thus, they demonstrate that the soil densities interfere negatively with the number of leaves of the safflower genotypes studied.

In the genotype PI301049, it was observed that at a soil density of 1.22 Mg m<sup>-3</sup>, 453 leaves were produced, for the genotype PI237538 the best yield was found at 1.25 Mg m<sup>-3</sup> soil density with 389 leaves (Figure 4).

Fagundes et al. (2014), when studying soil compaction by means of density, in the

Oxisol (clay texture) of the Cerrado with three sugarcane cultivars, found that the highest number of leaves was recorded at 93 DAE, in soil density of 1.30 Mg m<sup>-3</sup>.

The genotypes PI248385, PI305173, PI305205, PI306596, PI306603 and PI613366 were adjusted to the linear regression model with a mean reduction of 70.42% between the lowest soil density (1.0 Mg m<sup>-3</sup>) and the highest soil density (1.8 Mg m<sup>-3</sup>) (Figure 4B, 4D, 4E, 4F, 4G and 4H). The genotypes PI248382 and PI560202 did not present a significant difference in the number of leaves and soil density in the evaluation performed at 90 DAE.

#### Stem diameter

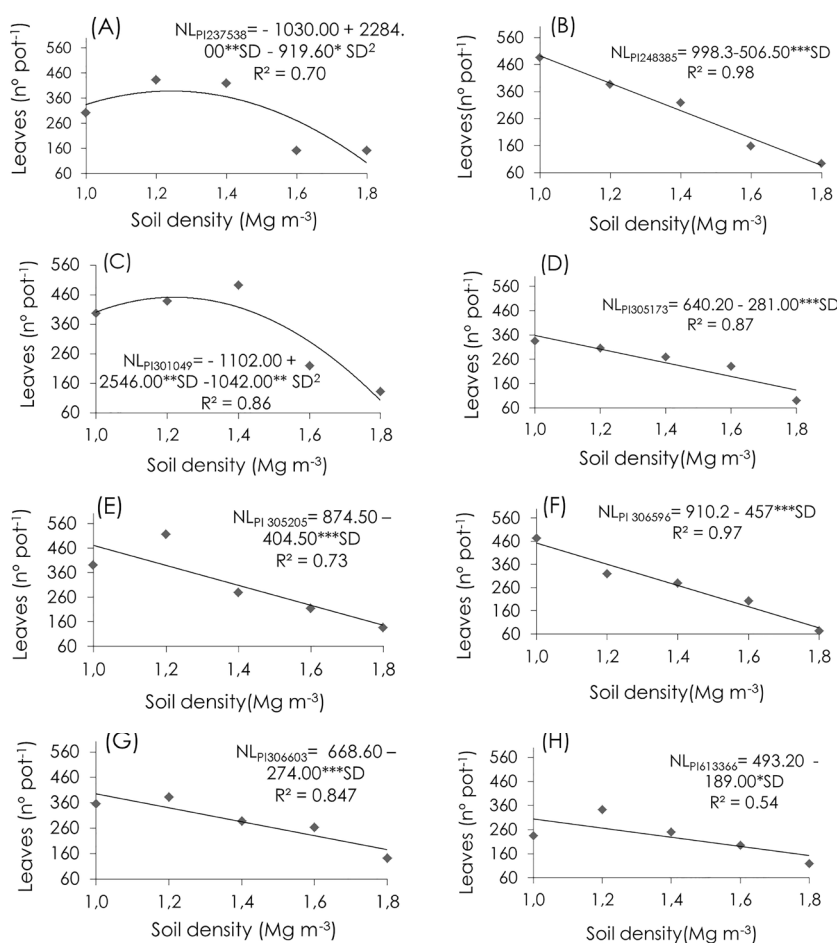
For stem diameter, there was no significant interaction between genotypes and soil density levels. At 30, 60 and 90 DAE, genotypes PI250196 and PI613366 presented the best results for stem diameter (Table 5).

At 30 DAE, the stem diameter variable

**Table 4.** Number of leaves of safflower genotypes as a function of soil density levels at 90 days after emergence. Rondonópolis - MT, 2014.

Soil density	Safflower genotypes Leaves (n° pot <sup>-1</sup> )									
Mg m <sup>-3</sup>	PI237538	PI248385	PI250196	PI301049	PI305173	PI305205	PI306596	PI306603	PI560202	PI613366
1.0	302 B	486 A	175 B	396 A	335 A	391 A	473 A	355 A	250 B	235 B
1.2	433 A	388 A	169 C	437 A	306 B	516 A	321 B	381 A	224 C	343 B
1.4	419 A	319 B	185 B	491 A	170 B	280 B	280 B	287 B	192 B	250 B
1.6	152 A	159 A	135 A	219 A	232 A	216 A	203 A	261 A	197 A	195 A
1.8	151 A	94 A	64 A	131 A	92 A	137 A	75 A	142 A	132 A	121 A
Significance	**									
CV (%)	37.7									

Means followed by the same letter in the column belongs to the same group according to Scott-Knott test at 5% of probability. \*\*Significant at 1% probability. Rondonópolis - MT, 2014. CV - coefficient of variation.



**Figure 4.** Number of safflower leaves as a function of soil density levels at 90 days post-emergence, PI237538 (A), PI248385 (B), PI301049 (C), PI305173 (D), PI305205 (E), PI306596 (F), PI306603 (G) and PI613366 (H). NL - Number of leaves; SD - Soil Density. \*\*\*, \*\*, \* Significant at 0.1%, 1% and 5% probability, respectively. Rondonópolis - MT, 2014

fitted to the linear regression model (Figure 5A). Thus, it can be observed that with increased soil density, there is a decrease in stem diameter of 5.96 mm between the lowest and the highest density levels, a reduction of 51.73%. For the evaluations performed at 60 and 90 DAE, the variable was adjusted to the quadratic regression model with the largest diameter (12.08 and 11.85 mm) at densities of 1.17 and 1.18 Mg m<sup>-3</sup>,

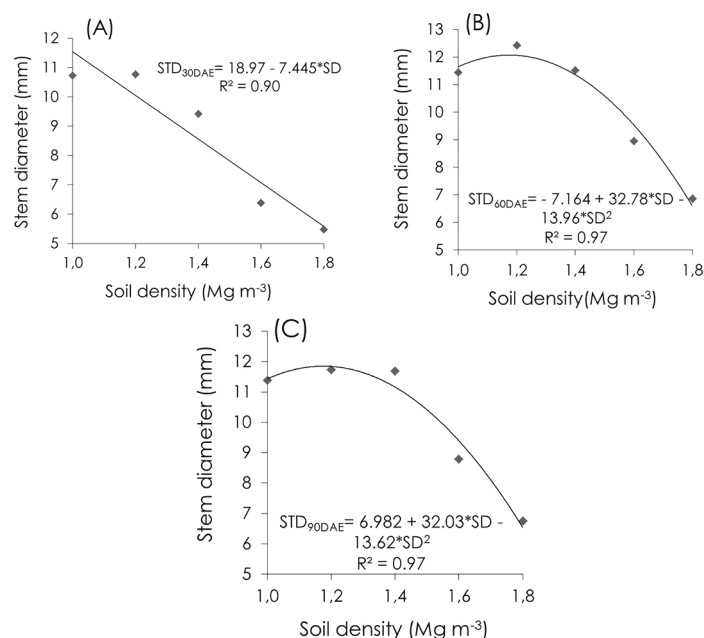
respectively (Figure 5B and 5C).

The genotypes showed a significant reduction in stem diameter with increasing soil density, suggesting that the crop is sensitive to soil compaction for this variable. Plants with a thick stem may result in lodging during the fruiting phase since larger diameter stems offer better support, as well as a probable reduction in the height of the plants, which may affect harvesting.

**Table 5.** Stem diameter of safflower genotypes as a function of density levels at 30, 60 and 90 days after emergence. Rondonópolis - MT, 2014

Safflower genotypes	Stem diameter (mm)		
	30 DAE	60 DAE	90 DAE
PI237538	6.92 b	8.84 b	9.21 c
PI248385	7.47 b	8.15 b	7.95 c
PI250196	12.07 a	12.76 a	12.12 a
PI301049	7.42 b	8.84 b	9.54 c
PI305173	8.88 b	10.56 b	10.62 b
PI305205	7.62 b	9.75 b	9.35 c
PI306596	8.09 b	9.33 b	9.35 c
PI306603	8.52 b	10.30 b	10.43 b
PI560202	7.84 b	9.54 b	9.28 c
PI613366	10.77 a	13.40 a	12.86 a
Mean	8.56	10.25	10.07
Significance	***	***	***
CV (%)	25.82	22.83	20.58

Means followed by the same letter in the column belongs to the same group according to Scott-Knott test at 5% of probability \*\*\*Significant at 0.1 % probability. Rondonópolis - MT, 2014. CV - coefficient of variation.



**Figure 5.** Safflower stem diameter as a function of soil density levels at 30 (A), 60 (B) and 90 (C) DAE. STD - stem diameter; SD - Soil Density. \* Significant at 5% probability. Rondonópolis - MT, 2014

The results observed by Silva et al. (2012) corroborate those found in this study. When evaluating the stem diameter of crambe plants, they observed a reduction in stem growth when a physical impediment was found in the soil. Therefore, interferences in the root system directly influence the aerial part (shoot) of the plant.

From the physical point of view, increased soil density, besides being an impediment to root growth, causes changes in plant water availability, aeration, and soil heat flux. These changes are predominant for proper root development of any species, some of which

are more adaptable to these alterations (Lima et al., 2007). However, the negative influence on water availability results in a decrease in the absorption of water and nutrients by plants, since they are absorbed via soil solution, resulting in lower growth and development (Taiz et al., 2017).

Soils with reduced aeration can cause serious damage to plant metabolism. In soil oxygen deficiency situations (anoxia or hypoxia), the absorption and transport of water and nutrients can be impeded, due to the closure of the aquaporins of root cells, so that the permeability of the root to water is reduced



and the absorption and transportation are compromised (Buchanan et al., 2015).

In a research on the effect of compacting a dystrophic Red Latosol (clay texture) on dwarf pigeon pea, adjustment to the linear regression model was observed at 33 days after emergence of the plants, for stem diameter, with a reduction of 38.49% due to the increase in soil density levels (Farias et al., 2013).

Evaluating the optimum water range in Oxisol (very clayey) in the no-tillage systems in the State of Paraná, Tormena et al. (2007) found that densities above 1.25 Mg m<sup>-3</sup> significantly decrease aeration porosity and increase penetration resistance. For Valichesi et al. (2012), significant reductions in the dry matter yield of turnip and black oat were observed at soil density above 1.34 Mg m<sup>-3</sup>.

Thus, it is evident that soil densities above 1.2 to 1.3 Mg m<sup>-3</sup> cause physical impediments to

root growth and development of various crops. It is also assumed that, besides the physical impediment to growth, densities above the above-mentioned range, especially in clay soils, cause detriment to the aeration of the root system and water availability, which will compromise the growth and development of vegetative and reproductive structures of the safflower plant.

Research evidenced a greater susceptibility to compaction of a clayey Oxisol than a clay-sandy loam at humidity close to the field capacity in response to agricultural traffic. They also verified a reduction in the pore volume and pore diameter, altering the water retention energy in the soil (Lima et al., 2017).

#### Shoot dry mass

For the shoot dry mass, there was a significant interaction between the genotypes and soil densities (Table 6 and Figure 6).

**Table 6.** Shoot dry mass of safflower genotypes as a function of soil density levels at 90 days after emergence. Rondonópolis - MT, 2014.

SD (Mg m <sup>-3</sup> )	Shoot dry mass of safflower genotypes (g vaso <sup>-1</sup> )									
	PI237538	PI248385	PI250196	PI301049	PI305173	PI305205	PI306596	PI306603	PI560202	PI613366
1.0	68 C	50 C	83 B	63 C	63 C	66 C	66 C	59 C	52 C	111 A
1.2	65 B	48 B	85 A	77 A	74 A	67 B	66 B	59 B	60 B	92 A
1.4	59 B	37 B	85 A	71 A	72 A	65 B	66 B	55 B	60 B	83 A
1.6	18 B	14 B	61 A	34 B	69 A	22 B	28 B	38 B	32 B	60 A
1.8	13 A	12 A	23 A	22 A	12 A	15 A	9 A	23 A	15 A	14 A
Significance *										
CV (%)	34.04									

Means followed by the same letter in the column belongs to the same group according to Scott-Knott test at 5% of probability \*Significant at 5% probability, Rondonópolis - MT, 2014. CV - coefficient of variation.

At soil density of 1.0 Mg m<sup>-3</sup>, the genotype PI613366 showed the highest shoot dry mass (111 g pot<sup>-1</sup>), followed by genotype PI250196 (83 g pot<sup>-1</sup>), being the third group formed by the other genotypes that did not differ statistically from each other, presenting a mean shoot dry mass of 60.88 g pot<sup>-1</sup>.

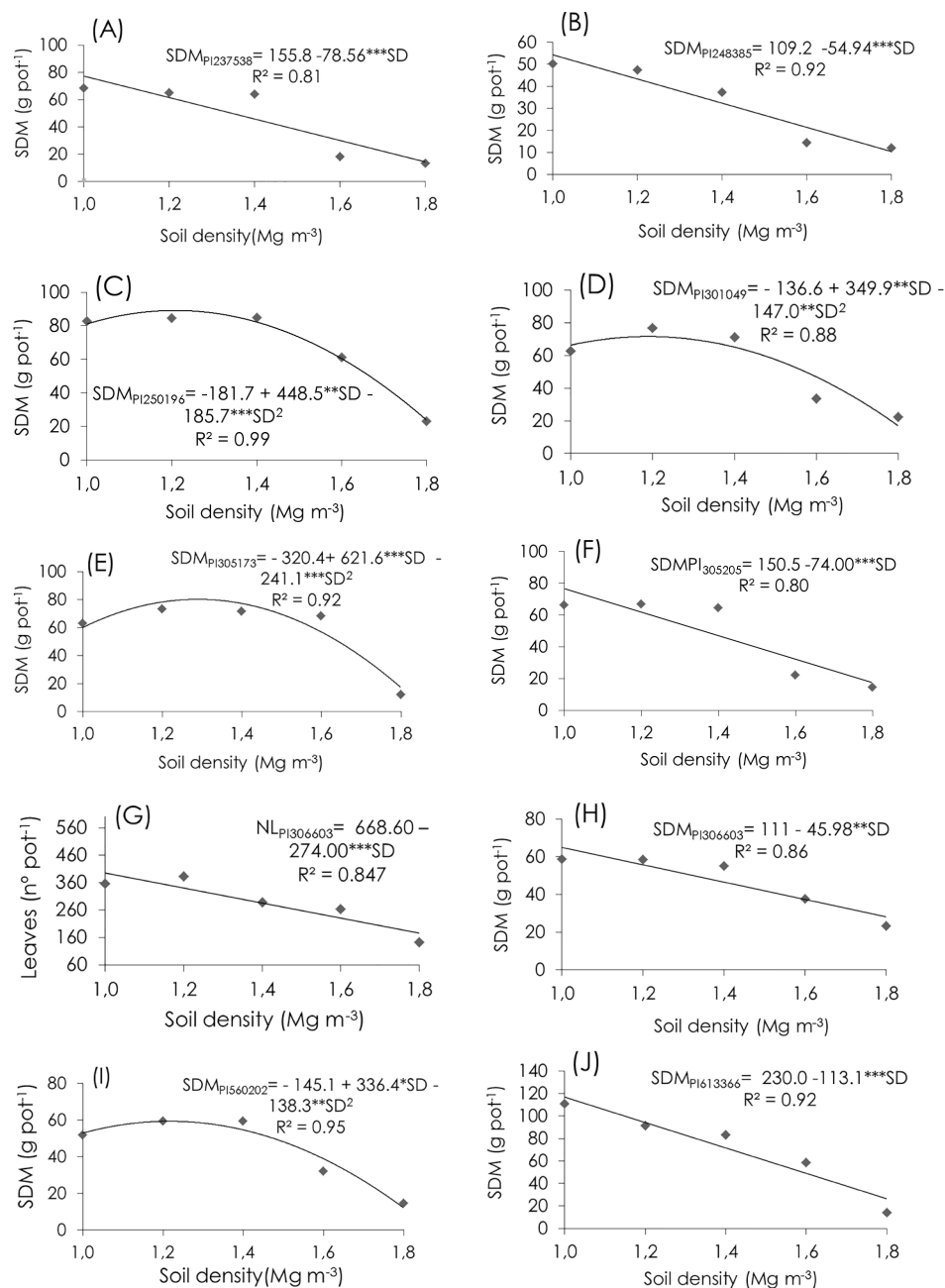
For the density 1.2 Mg m<sup>-3</sup>, two groups were formed, the ones that produced the greatest quantity of dry mass PI250196, PI301049, PI305173 and PI613366 and the one with lower dry mass production genotypes PI237538, PI248385, PI305205, PI306596, PI306603, and PI560202.

In the soil density 1.4 Mg m<sup>-3</sup>, significant differences were observed among the genotypes, evidencing that the genotypes PI250196, PI301049, PI305173, and PI613366 are less sensitive to this level of soil density when

compared to the second group formed by the genotypes PI237538, PI248385, PI305205, PI306596, PI306603 and PI560202.

For the density 1.6 Mg m<sup>-3</sup>, three genotypes PI250196, PI305173 and PI613366 stood out with an average of 63.33 g pot<sup>-1</sup> of shoot dry mass. In the other genotypes, PI237538, PI248385, PI301049, PI305205, PI306596, PI306603 and PI560202 a mean of 26.57 g pot<sup>-1</sup> was observed. This corresponds to a difference of 58.05% between the two groups, showing that some of the studied genotypes present a better developmental adaptation in the density of 1.6 Mg m<sup>-3</sup>. However, for soil density of 1.8 Mg m<sup>-3</sup>, there was no significant difference between the genotypes.

The genotypes PI237538, PI248385, PI305205, PI306603 and PI613366 presented an



**Figure 6.** Shoot dry mass of safflower as a function of the levels of soil density, PI237538 (A), PI248385 (B), PI250196 (C), PI301049 (D), PI305173 (E), PI305205 (F), PI306596 (G), PI306603 (H), PI560202 (I) e PI613366 (J). SDM - Shoot dry mass; SD - Soil Density. \*\*\*, \*\*, \* Significant at 0.1%, 1% and 5% probability, respectively. Rondonópolis - MT, 2014.

adjustment to the linear regression model with increasing soil density (Figure 6A, 6B, 6F, 6H, and 6J). It can be observed that there was a reduction in shoot dry mass, with an increase in soil density.

The genotypes PI250196, PI301049, PI305173, PI306596, and PI560202 conformed to the quadratic regression model, showing that they are more tolerant to increasing soil density (Figure 6C, 6D, 6E, 6G and 6I). The genotypes developed better at densities of 1.20; 1.19; 1.28; 1.12 and 1.22  $Mg\ m^{-3}$ , respectively.

Bonfim-Silva et al. (2012), when studying two cultivars of *Brachiaria brizantha* (cvs. Xaraés and Marandu) under four soil densities (1.0; 1.2; 1.4 and 1.6  $Mg\ m^{-3}$ ), found the highest shoot dry matter yield in soil density of 1.23  $Mg\ m^{-3}$ , corroborating the results found in the present study.

## Conclusions

Safflower genotypes presented different responses to soil density levels, with a mean

reduction of 56.30% in all evaluated components. The number of leaves was the most affected, with a reduction of 70.42%.

The safflower genotypes evaluated showed high sensitivity to growth in soil with physical impediments, except for PI250196, PI301049, PI305173 and PI305205 which are more stable about soil density variations.

The phytometric components of plant height, number of leaves and stem diameter, as well as the dry mass of safflower shoot are impaired from the mean density of 1.2 Mg m<sup>-3</sup>.

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