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TECHNICAL PAPER

SOYBEAN AGRONOMIC PERFORMANCE AND SOIL PHYSICAL ATTRIBUTES UNDER TRACTOR TRAFFIC INTENSITIES

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KEYWORDS

soil compaction, yield components, shoot, soil penetration resistance, machinery traffic.

ABSTRACT

Machinery traffic intensification has been recurrent in intensive agriculture in annual crops, which may lead to structural soil degradation and, consequently, a reduction of its productive capacity. Therefore, this study aimed to assess the influence of tractor traffic intensification on soil physical attributes and soybean yield components. The study was performed in an Oxisol under no-tillage for 10 years, using a randomized block design with five tractor traffic intensities (0, 2, 4, 6, 8, and 12 passes) and five replications. Density, porosity, macroporosity, microporosity, and penetration resistance were assessed in the soil and stem diameter, number of pods per plant, number of grains per pod, grain weight per plant, thousand-grain weight, and grain yield were assessed in the soybean crop. Tractor traffic intensification changed soil physical attributes, which were not limiting factors to soybean yield under the no-tillage system, providing higher stem diameter, number of pods per plant, grain weight per plant, and grain yield after 12 passes.

INTRODUCTION

Soybean (*Glycine max*) is one of the main crops produced in different regions of Brazil. The agricultural sector has been undergoing a profound transformation over the last 40 years with the use of technologies and tools involved in rural property management, aiming to achieve satisfactory levels of yield and profitability. In this scenario, the no-till system has played an essential role in soil conservation and grain yield increase (Trentin et al., 2018).

Despite the benefits of no-tillage on resource quality, there are soil compaction problems related to increased traffic from ever larger and heavier machinery in both the topsoil (Bergamin et al., 2010; Valadão et al., 2015) and subsurface layers (Kirnak et al., 2017; Sivarajan et al., 2018).

Compaction is reported as the main problem of structural soil degradation, changing its physical properties. It changes soil pore space, reducing the macroporosity and total porosity and increasing density and soil penetration resistance (Bergamin et al., 2010; Valicheski et al., 2012; Valadão et al., 2015).

These changes limit root growth and the area explored by the roots (Secco et al., 2009), reduce water and nutrient absorption (Valadão et al., 2017), hinder gas exchange for infiltration/drainage, decrease the infiltration rate and water flow in the soil (Zambrana et al., 2010), reduce growth (Kirnak et al., 2016) and soybean yield components (Trentin et al., 2018), and may decrease grain yield (Valadão et al., 2017).

Thus, studies have reported compaction problems in the topsoil under no-tillage (Bergamin et al., 2010; Valicheski et al., 2012; Valadão et al., 2015; Arcoverde et al., 2019a). The depth of the compacted layer depends on several factors, including machine traffic intensity (Becerra et al., 2010; Valadão et al., 2015; Trentin et al., 2018), soil texture and mineralogy (Bergamin et al., 2010), organic matter content (Mujdeci et al., 2017), soil water content (Kirnak et al., 2017; Trentin et al., 2018), mass of agricultural equipment (Cortez et al., 2014; Sivarajan et al., 2018), inflation pressure, tire type, and tractor mass distribution on the axles (Cunha et al., 2009; Becerra et al., 2010; Cortez et al., 2014).

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Soil density and porosity are considered indicators of the structural soil degradation caused by compaction (Mujdeci et al., 2017; Trentin et al., 2018). Penetration resistance is related to soil density and moisture, reflecting the effects of management on the root environment (Bergamin et al., 2010; Valadão et al., 2015). Soil penetration resistance values close to 2 MPa are considered limiting to corn yield (Secco et al., 2009). However, Marasca et al. (2011) observed that higher values were not limiting to soybean yield. Kirnak et al. (2017) and Sivarajan et al. (2018) found that the intensification of machinery traffic increased soil penetration resistance and density in the subsurface soil layer, with reduced plant height and soybean stem diameter, but without an effect on grain yield. On the other hand, Valadão et al. (2017) found a decrease in soybean grain yield after four tractor passes.

Due to multiple factors involved in soil compaction under the no-tillage system, researches on the subject should be carried out to understand better its relationship with heavy machinery traffic under different soil and climate conditions and assist in carrying out appropriate management practices. For this reason, this study aimed to assess the influence of tractor traffic intensification on soil physical attributes and soybean yield components.

MATERIAL AND METHODS

The experiment was conducted from November 2018 to March 2019 at the Experimental Farm of Agricultural Sciences of the Federal University of Grande Dourados, Dourados, MS, Brazil. The site is located at latitude 22°14′ S, longitude 54°59′ W, and altitude of 434 m. The regional climate is type Am, i.e., a monsoon climate with dry winter, annual mean precipitation of 1500 mm, and annual mean temperature of 22 °C (Alvares et al., 2013). The climate data of temperature and precipitation during the experiment period are shown in Figure 1. Soybean was cultivated in a dystroferric Red Latosol (Embrapa, 2013), with the following chemical characteristics in the layer from 0.00 to 0.20 m: pH in water of 6.2, Ca^{2+}, Mg^{2+}, Al^{3+}, and K^{+} of 5.2, 3.2, 0.0, and 0.50 $cmol_c$ dm^{-3}, respectively, P of 12.8 mg dm^{-3}, base saturation of 75%, and organic matter of 30 g dm^{-3}. The particle size analysis showed 60% of clay, 15% of silt, and 25% of sand. The area has been cultivated with soybean in the summer and corn in the second crop in succession for approximately 10 years.

The experimental design consisted of randomized blocks, with five tractor traffic intensities (0, 2, 4, 6, 8, and 12 passes) on a 10-year no-tillage area and five replications, totaling 30 experimental plots. Each plot consisted of 9 soybean rows of 10 m in length, spaced 0.45 m, with a total area of 40.5 m^2. The usable area corresponded to the three central rows, with 3.0 m each, in the center of the plot.

The implementation of traffic intensities was carried out in soil with mean water content in the 0.00 to 0.20 m layer of 26.0±1.5% using an NH 8030 tractor, with 89.79 kW (122 hp) engine power, diagonal tire wheels, 1.73 meter rear gauge, 1.83 meter front gauge, and 6.78 Mg mass with ballast and 83 kPa inflation pressure on front tires (14.9-28 R1) and 83 kPa on rear tires (23.1-30 R1). A grass cutter with a 0.5 Mg mass was coupled to the three-point hitch system, which corresponded to 7.28 Mg total mass of the tractor-grass cutter set, whose dynamic distribution was 37% on the front axle and 63% on the rear axle. The front and rear tire contact pressure with the soil was 113 and 109 kPa, respectively, determined according to the method proposed by O'Sullivan et al. (1999).

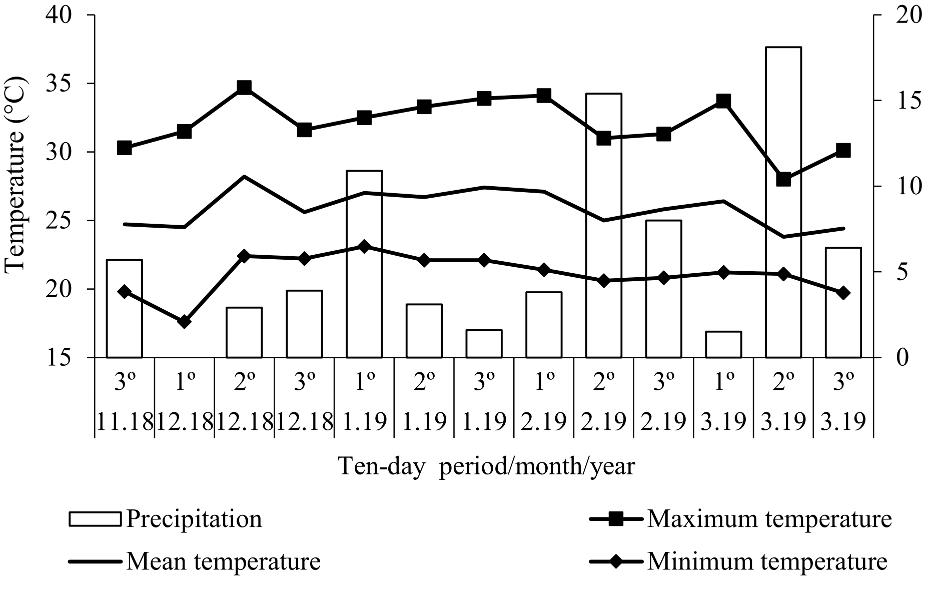

FIGURE 1. Precipitation (mm) and minimum, mean, and maximum temperatures per ten-day period from November 2018 (sowing) to March 2019 (harvest) in Dourados, MS, Brazil.

The tractor was shifted in 3rd low gear, with a rotation of 2,200 rpm and a speed of 5.3 km h^{-1}, across the plot area so that the tires compressed areas parallel to each other, with the number of times trafficked as a function of intensity. Traffic was superimposed over the previous one, and every area of each plot was trafficked with equal number of times (Valadão et al., 2015).

Soybean sowing was carried out in the opposite direction to tractor traffic to ensure that plants reached the entire traffic area. The cultivar Monsoy 6410 IPRO (maturity group 6.4, indeterminate growth, and cycle of 105–120 days) was sown on November 21, 2018, using a nine-row no-till seed-cum-fertilizer drill. The ridger mechanism was removed from the drill not to eliminate the possible negative effects of compaction, using only the cutting disc of the seed metering (Bergamin et al., 2010). The sowing density was 13 seeds per meter, with a 0.45 m row spacing. Fertilization consisted of the application of 0.4 Mg ha^{-1} of the formula 05–25–06.

Undisturbed soil samples were collected at the interrows in the 0.00–0.10 and 0.10–0.20 m soil layers at 85 days after sowing, when the crop was at reproductive stage R5 (beginning of grain filling), using metal cylinders of 5.57 cm in diameter and 4.41 cm in height (107.45 cm^3) for the determination of soil density, total porosity, macroporosity, and microporosity. These samples were saturated by capillarity to obtain macroporosity, microporosity, and total porosity using a tension table calibrated at 0.006 MPa (Donagema et al., 2011).

Soil penetration resistance was measured at the useful area of each plot using a PenetroLOG PLG 1020 field penetrometer, with an electronic aptitude for data acquisition. Five sampling points were made at the soybean interrows. After soil penetration resistance determinations, the data stored in the penetrometer were extracted and analyzed to a maximum depth of 0.20 m, where there may be higher effect of agricultural management. Mean values stratified in the 0.00–0.10 and 0.10–0.20 m soil layers were obtained from these data. A deformed soil sample was taken simultaneously to soil penetration resistance determinations from each treatment and assessment layer to determine the water content (Table 1) by the gravimetric method (Donagema et al., 2011).

TABLE 1. Soil water content (g g^{-1}) when determining soil penetration resistance at the tractor traffic intensities.

	Passes					
Layer (m)	0	2	4	6	8	12
0.00–0.10	0.27	0.27	0.27	0.25	0.23	0.26
0.10–0.20	0.27	0.26	0.27	0.25	0.26	0.26

No-tillage for 10 years ago (no pass) and tractor traffic intensities of 2, 4, 6, 8, and 12 passes.

Deformed soil samples were collected at a depth of 0.00–0.20 m using a Dutch auger from 93 to 125 days after sowing (soybean harvest), every two days, to determine the water content after oven drying by the gravimetric method (Donagema et al., 2011). The mean water content in the soil under no-tillage for 10 years (no pass) ranged from 0.26 to 0.34 kg kg^{-1} (Figure 2), which characterized a good soil water condition during the grain filling period.

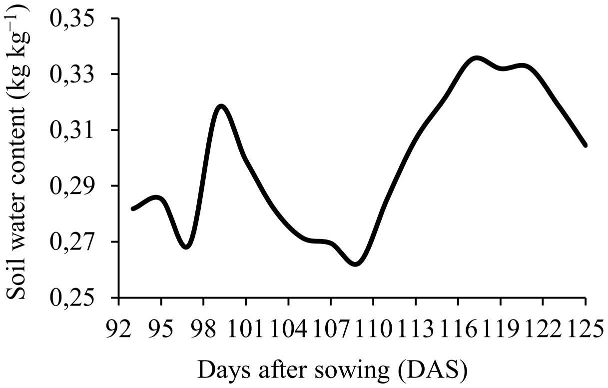

FIGURE 2. Mean soil water content under no-tillage for 10 years (no pass) in the 0.00-0.20 m layer, from 93 to 125 days after sowing (DAS) of the soybean crop.

Soybean was harvested at 125 days after sowing, i.e., after physiological maturation, and stem diameter, number of pods per plant, number of grains per pod, and grain weight per plant (GMP, g) were obtained at that time. Stem diameter was measured at its base using a digital caliper. Grain yield (kg ha^{-1}) and thousand-grain weight (TGW, g) were determined by sampling the useful area of each plot, and the plants were threshed on a stationary threshing machine to determine the weight on a digital scale. The variables yield, TGW, and GMP were corrected to a moisture of 13%.

The data of soil physical attributes were subjected to analysis of variance for each soil layer individually. Polynomial regression analysis as a function of tractor traffic intensities was carried out when statistical significance of at least 5% probability was observed. The same analysis procedure was performed for soybean yield components, with regression models selected based on the values of the coefficient of determination and significance ($p \leq 0.01$) of the equation parameters. The analyses were performed using the statistical software AGROESTAT (Barbosa & Maldonado Junior, 2015).

RESULTS AND DISCUSSION

Regarding soil physical attributes, after the induction of tractor traffic intensities in the 0.00–0.10 and 0.10–0.20 m layer, a significant effect was observed for macroporosity (Ma), microporosity (Mi), total porosity (Pt), soil density (Ds), and soil penetration resistance (PR) only in the 0.00–0.10 m layer (Table 2).

TABLE 2. F-values, significance, coefficient of variation (CV, %), and mean of physical attributes in the soil layers as a function of tractor traffic intensity.

Attribute	Layer (m)					
	0.00–0.10			0.10–0.20		
	F	CV	Mean	F	CV	Mean
Ma	13.17^{**}	12.32	0.09	4.45^{**}	14.63	0.11
Mi	2.81^{*}	3.80	0.43	7.60^{**}	2.71	0.43
Pt	4.02^{*}	4.75	0.52	4.23^{**}	2.07	0.54
Ds	12.19^{**}	2.06	1.46	7.54^{**}	1.98	1.39
PR	13.96^{**}	8.73	1.86	2.14^{NS}	15.81	2.60

*Significant (p<0.05); **significant (p<0.01); Ma: macroporosity; Mi: microporosity; Pt: total porosity; Ds: soil density; PR: soil penetration resistance.

The 0.00–0.10 m layer showed low mean values of macroporosity with 6 and 12 passes (0.07 and 0.08 $m^3\ m^{-3}$), which is lower than the minimum adequate for liquid and gas exchange between the external environment and soil (0.10 $m^3\ m^{-3}$) and considered critical for root growth in most crops. In this sense, Rossetti & Centurion (2013), Valadão et al. (2015), and Valadão et al. (2017), in studies carried out on clayey dystrophic Red Latosol, and Bergamin et al. (2010), with a clayey dystroferric Red Latosol, found macroporosity values of 0.08 and 0.09 $m^3\ m^{-3}$, respectively, after 6 tractor passes in the 0.00–0.10 m layer.

Soil density values are below the range of 1.51 to 1.59 Mg m^{-3} considered maximum by Sá et al. (2016) and Oliveira et al. (2012) when evaluating the compaction in clayey to very clayey Oxisols, and 1.55 Mg m^{-3}, considered critical by Camargo & Alleoni (1997) in clay loam to clay soils.

According to Bergamin et al. (2010), clay soils usually present surface compaction up to 0.10 m, with increased density and reduced macroporosity, which are attributes significantly influenced by machinery traffic (Valadão et al., 2015; Arcoverde et al., 2019a). It is caused by the first tractor passes, promoting higher breakage of soil aggregates and favoring particle approximation (Valicheski et al., 2012).

Soil microporosity presented a reduction in the 0.00–0.10 m layer with 8 passes when compared to zero passes (Figure 3). However, these treatments did not differ from the others, which suggests a higher effect of intrinsic soil factors, agreeing with Bergamin et al. (2010), Arcoverde et al. (2019a), and Arcoverde et al. (2019b), who attributed it to the mineralogy of the clay fraction in a dystroferric Red Latosol.

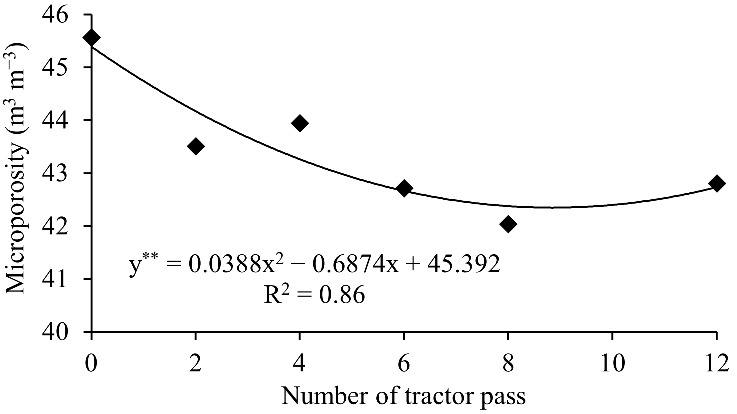

FIGURE 3. Soil microporosity in the 0.00–0.10 m layer as a function of the number of tractor passes. **Significant ($p \leq 0.01$).

A higher increase in soil penetration resistance was observed with 12 passes (2.31 MPa) in the 0.00–0.10 m layer when compared to 6 (2.0 MPa), 8 (1.86 MPa), 4 passes (1.81 MPa), and 0 passes (1.51 MPa) (Figure 4). Increases in soil penetration resistance of 52.90, 27.62, 24.19, and 15.50% were observed when comparing 12 with 0, 4, 8, and 6 passes, respectively, which is possibly related to the high density (1.51 Mg m^{-3}) and low macroporosity values (0.08 $m^3\ m^{-3}$).

Significant changes in density and total porosity, caused after 4 passes, resulted in a significant increase in soil penetration resistance in the topsoil, similar to that found by Valicheski et al. (2012) and Bergamin et al. (2010), who verified increased soil penetration resistance up to 0.10 m depth after 4 tractor passes.

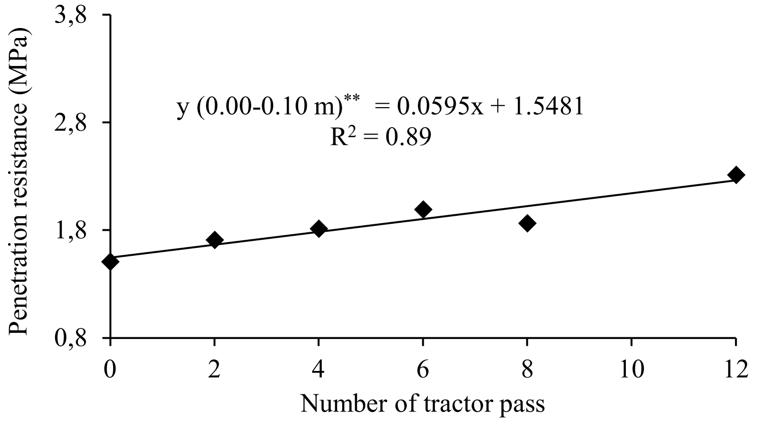

FIGURE 4. Soil penetration resistance in the 0.00–0.10 m layer as a function of the number of tractor passes. **Significant ($p \leq 0.01$).

A highly significant effect of soil compaction was observed on soybean agronomic traits, except for the number of grains per pod (NGP) (Table 3).

TABLE 3. F values, significance, coefficient of variation (CV, %) for growth and yield variables of the soybean crop.

Variable	F	CV (%)	Mean
Diameter (mm)	11.61^{**}	8.36	5.85
NPP	9.28^{**}	10.86	45.0
NGP	1.03^{NS}	9.38	2.0
GWP (g)	28.11^{**}	8.16	7.68
TGW (g)	15.24^{**}	1.66	95.99
Yield (kg ha^{-1})	89.26^{**}	4.70	2667.51

^{NS}Not significant; **significant ($p<0.01$); NPP: number of pods per plant; NGP: number of grains per pod; GWP: grain weight per plant; TGW: thousand-grain weight.

Stem diameter showed an increase with 6 (6.20 mm), 8 (6.00 mm), and 12 passes (7.00 mm) compared to 0 passes (4.79 mm), which corresponded to an increase of 29.44, 25.11, and 46.14%, respectively (Figure 5). However, 2 (5.55 mm) and 4 (5.54 mm) passes showed a similar effect when compared to those of 0, 6, and 8 passes, but lower only than with 12 passes.

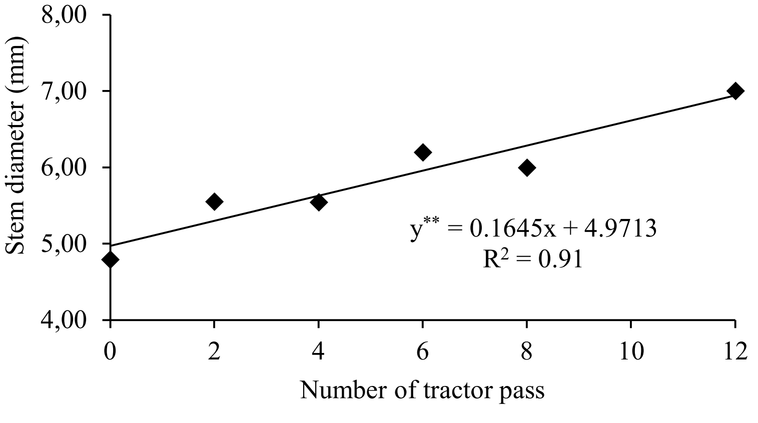

FIGURE 5. Stem diameter of soybean plants as a function of the number of tractor passes. **Significant ($p \leq 0.01$).

The highest values of the number of pods per plant, grain weight per plant, and grain yield were obtained with 12 passes, reaching values of 57.0, 9.73 g, and 3,448.0 kg ha^{-1}, respectively, followed by 6 passes, with values of 49.0, 9.34 g, and 3,173.0 kg ha^{-1}, respectively (Figures 6, 7, and 9).

Thousand-grain weight showed lower values with intermediate tractor passes (2, 4, 6, and 8) than 0 and 12 passes (Figure 8). In addition, no water deficit was observed in the soil under no-tillage during the final stage of soybean filling (Figure 2).

This increase in stem diameter and agronomic performance of soybean with 12 passes suggest that a possible compaction with traffic intensification could increase water retention, especially under water restriction, without risk of faster drying of the soil surface, preventing seedlings from deepening the roots and absorbing water in the soil profile (Valadão et al., 2017).

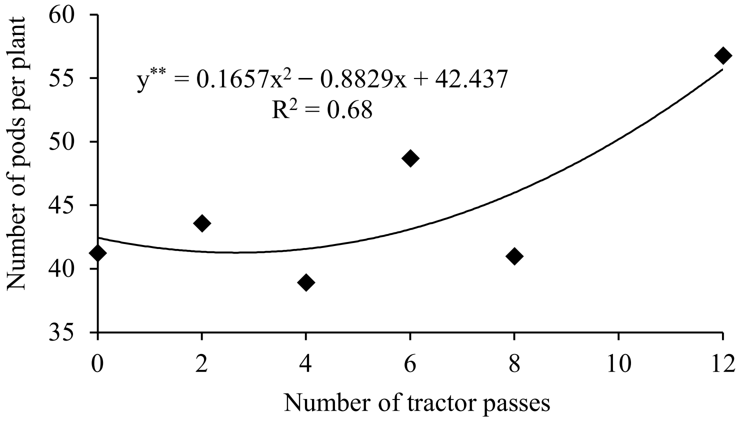

FIGURE 6. Number of pods per soybean plant as a function of the number of tractor passes. **Significant ($p \leq 0.01$).

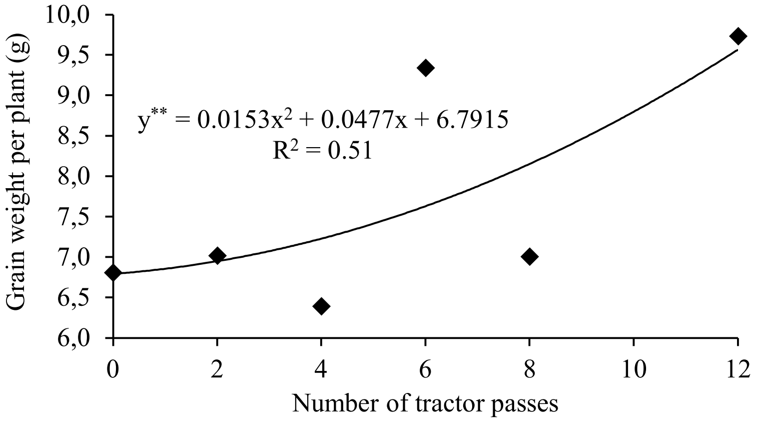

FIGURE 7. Grain weight per soybean plant as a function of the number of tractor passes. **Significant ($p \leq 0.01$).

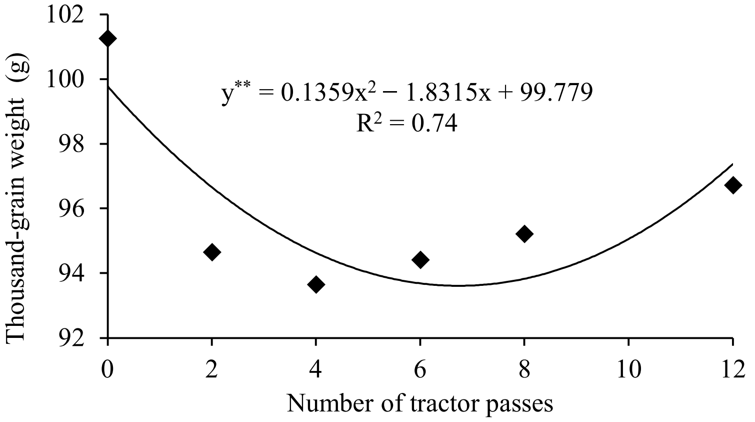

FIGURE 8. Thousand-grain weight of soybean as a function of the number of tractor passes. **Significant ($p \leq 0.01$).

Twelve 12 passes led to increases of 63.05, 54.55, 38.65, 35.07, and 8.57% in the yield when compared to 0, 2, 4, 8, and 6 passes, respectively (Figure 9). Yields related to 6 and 12 passes are in agreement with Valicheski et al. (2012), while the other passes ranged from 2114.53 (0 passes) to 2552.5280 kg ha^{-1} (8 passes).

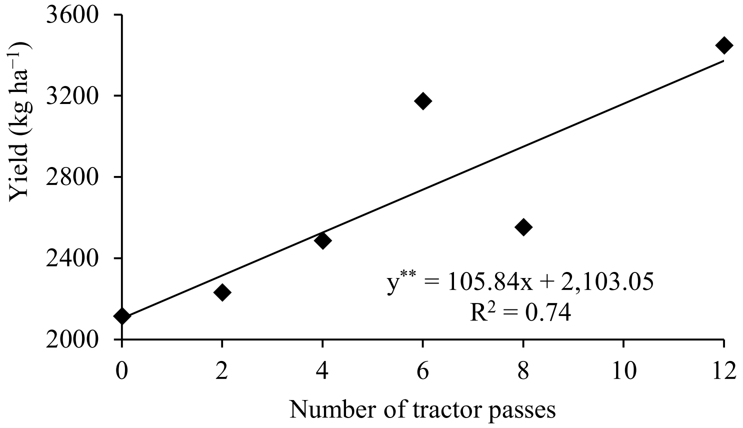

FIGURE 9. Yield of soybean grains as a function of the number of tractor passes. **Significant ($p \leq 0.01$).

Losses to soybean yield were expected with 12 tractor passes, as there were low mean values of macroporosity (0.08 m^3 m^{-3}) and high values of density (1.51 Mg m^{-3}) and penetration resistance (2.31 MPa) in the 0.00–0.10 m layer. However, density values have not been considered limiting to crop development in clay soils (Camargo & Alleoni, 1997; Oliveira et al., 2012; Sá et al., 2016). Moreover, density was very close to 1.48 Mg m^{-3} after 12 passes, which is the value that maximizes soybean grain yield in the 0.00–0.10 m layer (Figure 10). The optimum density for yield was 1.37 Mg m^{-3} in the 0.10–0.20 m layer, suggesting that soil compaction not restrictive to root growth may be beneficial for soybean yield.

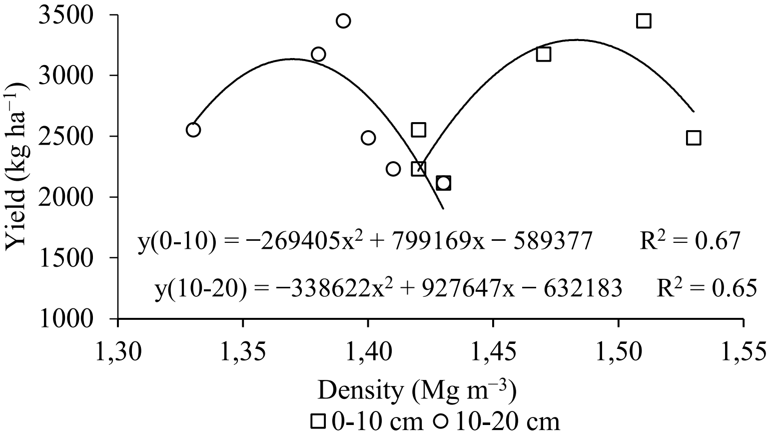

FIGURE 10. Yield of soybean grains as a function of soil density in the 0.00–0.10 and 0.10–0.20 m layers.

These results are in accordance with Foloni et al. (2006), who concluded that an increase in soil penetration resistance in the surface layer could stimulate lateral root proliferation, which is thinner and capable of growing in small diameter soil pores, reaching higher depths. It occurs especially in consolidated no-tillage areas, where there is the natural formation of biopores that allows for higher root growth and, consequently, access to water in deeper and wetter soil layers, mainly in those more compact and less conductive (Landl et al., 2019).

Under this condition, tractor traffic intensification caused soil compaction states not harmful to soybean plants, maintaining satisfactory physical and hydraulic conditions to the crop performance (Moraes et al., 2018).

CONCLUSIONS

Tractor traffic intensification changed soil physical attributes, which were not limiting factors to soybean yield under the no-tillage system, providing higher stem diameter, number of pods per plant, grain weight per plant, and grain yield after 12 passes.

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