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Soybean development as a function of traffic of tractor with radial tires

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A B S T R A C T

This study aimed to evaluate the development of soybean as a function of traffic levels of an agricultural tractor equipped with radial tires in two collection areas. The experiment was conducted in an area located at the State University of Maringá, Campus of Umuarama-PR, Brazil, in a soil classified as Red Oxisol with sandy texture. The experiment was set in a 5 x 2 factorial arrangement, with five levels of traffic on the same track (T1 = 1, T2 = 6, T3 = 11, T4 = 16 and T5 = 21 tractor passes), two collection areas (A1 = on the track and A2 = off the track) and four replicates. Soil physical parameters and characteristics of the soybean plants were evaluated. Soybean yield on the track did not show significant difference up to 6 passes. It was concluded that the traffic levels and soil resistance to penetration interfere with soybean yield for both collection areas.

Palavras-chave:
Glycine max L.
compactação
tráfego de máquinas

Desenvolvimento da cultura da soja em função do tráfego de trator com rodado radial

R E S U M O

O presente trabalho teve como objetivo avaliar o desenvolvimento de lavoura de soja em função de níveis de tráfego de trator agrícola equipado com rodados radial em duas áreas de coleta. O experimento foi realizado em área pertencente à Universidade Estadual de Maringá, Campus de Umuarama, PR, em solo classificado como Latossolo Vermelho Distrófico típico e de textura arenosa. Foi utilizado arranjo em esquema fatorial 5 x 2, com cinco níveis de tráfego, no mesmo rastro (T1 = 1, T2 = 6, T3 = 11, T4 = 16 e T5 = 21 passadas do trator), duas áreas de avaliação (A1 = no rastro e A2 = fora do rastro) e quatro repetições. Foram avaliados os parâmetros físicos do solo e características da cultura da soja. A produtividade de soja no rastro não apresentou diferença significativa até seis passadas. Concluiu-se que os níveis de trafegabilidade interferiram na produtividade de soja e na resistência à penetração do solo, para ambas as condições das áreas de coleta.

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Introduction

The soybean crop (*Glycine max* L.) has great importance for food production in Brazil due to the demand from internal and external markets for high-quality proteins and oil (EMBRAPA, 2011). In the 2016/2017 season, Brazil was the second largest soybean producer, with approximately 107 million tons (CONAB, 2017).

Frequently, the traffic of agricultural machines and inadequate conditions of management are factors that can increase soil resistance to penetration, leading to increments in compaction.

Machado et al. (2015) demonstrated that the tractor and radial tires with radial construction, compared with those of diagonal construction, have larger contact area, higher elastic deformation, better capacity of distributing the load to minimize the effects of soil compaction, which leads to optimization of the production system and reduction in operation costs.

In modern agriculture, often the decrement of soybean yield in a certain region is not caused by soil chemical factors, but instead by physical factors, such as soil compaction.

The consequences of soil compaction are manifested in the soil and in the plant, resulting in an increase of soil density and reducing porosity and water infiltration (Roque et al., 2011; Mazurana et al., 2011), directly interfering with root system penetration, photosynthetic rate, shoot growth and, consequently, crop yield (Taylor & Brar, 1991; Materechera et al., 1992; Drescher et al., 2012). Imhoff et al. (2000) observed that values of soil mechanical resistance between 2 and 3 MPa are considered as limiting to root development.

According to Cunha et al. (2009), the effect of tractor traffic occurs on the superficial layer of 0-0.20 m, and the first pass is the one causing greater soil compaction, since the effect of subsequent passes is small.

Therefore, the present study is important to understand the influence of soil compaction due to machine traffic intensity, on and off the track, on the development of plants.

Material and Methods

The experiment was carried out in an experimental area of the State University of Maringá, Campus of Umuarama-PR, Brazil, located at latitude of 23° 47' 24" S, longitude of 53° 15' 26" W and altitude of 401 m. According to Köppen's classification, the climate of the region is Cfa, i.e., mesothermal humid subtropical, without a defined dry season, with hot summers and trend for rains concentrated in the summer months, whose mean temperature of the hottest month is higher than 25 °C and mean annual rainfall is 1500 mm (Claviglione et al., 2000).

The soil is classified according to EMBRAPA (2013) as typic dystrophic Red Latosol, with sandy texture, slope of 0.02 m, soil moisture content in the 0-0.20 m layer equal to 6% and mean density in the 0-0.20 m layer equal to 1.53 g cm^{-3}. The experiment used seeds of the soybean cultivar 'Potência RR" from the company Brasmax.

The cultivar 'Potência RR' has indeterminate growth habit, medium size, early cycle, resistance to lodging; its root system is formed by the main root (taproot) and secondary roots (adventitious roots) and is concentrated in the layer of 0.10-0.20 m. Regarding the diseases, this cultivar is resistant to Stem Canker and Phytophthora Root Rot (races 1 and 4).

The experimental design was a 5 x 2 factorial arrangement, with five traffic intensities (T1 = 1, T2 = 6, T3 = 11, T4 = 16 and T5 = 21 tractor passes), two collection areas (A1 = on the tractor track, A2 = off the tractor track) and four replicates, totaling 40 plots. In the last pass on the track, the tractor was attached to a seeder, distributing transgenic soybean seeds in the soil. Each plot had an area of 30 m^2 (3.00 x 10.0 m) and 20 m^2 were used for evaluations, with lateral spacings (interval between blocks) of 1 m, leaving 10 m between plots for tractor and seeder maneuvering.

In the specificity of minimum tillage, the soil must be prepared using implements with lesser mobilization of the surface soil layer, to maintain part of the cover and standardize the area, and only then observe the effect of traffic intensity. For that, the implement used in the treatments was a subsoiler, model Jumbo Matic, mounted on the 3-point hydraulic lift system, Jan brand, equipped with cutting discs and 4 shanks spaced by 0.40 m, cutting width of 2 m, weight of 800 kg and working depth of 0.40 m. The area was desiccated 20 days before soil tillage.

The experiment used a Valtra tractor, model BM125i, with nominal engine power of 91.9 kW, weight of 63 kN, front auxiliary traction turned on, L2 gear and engine rotation of 1900 rpm, forward speed of 5.45 km h^{-1}, with radial tires 480/65R28 TM 800 136 D and 600/65R38 TM 800 153 D. The inflation pressure of the tires was 69 kPa (10 psi). The experiment used a Gihal seeder, model GA 2700 S, with working width of 3.0 m.

Sowing was performed on November 8, 2014, using 300 kg ha^{-1} of the 2-20-18 (NPK) formulation as basal fertilization, sowing density of 16 seeds per meter and spacing of 0.45 m between rows.

Cultivation practices consisted of one herbicide application, two insecticide applications to control caterpillars, two fungicide applications and three insecticide applications to control bedbugs.

Harvest occurred on March 5, 2015, when plants reached their harvesting point, in the R8 stage. Grains were manually harvested and after threshing and cleaning, the moisture content was corrected to 13%.

The tractor was adjusted in order to show the ideal configuration to work in the experimental area (Table 1).

Table 1. Working configuration of the tractor used in the experiment

Machine weight - kg		kg hp^{-1}	Axle (%)	Amount of water (%)	Metal ballast	Advance (%)
Front axle	2284		35.4	60	absent	
Rear axle	4161	51.5	64.6	75	12 parts of 70 kg	1.8
Total weight	6445					

For crop development, the following variables were evaluated: plant height, stem diameter, root diameter, number of pods and yield, according to the methodology described by Souza et al. (2013).

Soil resistance to penetration was evaluated in the layers of 0-0.10, 0.10-0.20, 0.20-0.30 and 0.30-0.40 m, using a penetrometer with dynamometric ring (Contenco), according to the methodology described by Beulter & Centurion (2004).

The obtained results were subjected to analysis of variance and their significance was evaluated by F test at 0.05 probability level. Homogeneity of variances and data normality were evaluated through the Bartlett and Shapiro-Wilk tests, respectively. Means were subjected to regression analysis to determine the best models regarding the traffic and yield.

Results and Discussion

Soil resistance to penetration is directly related to the machine traffic intensity and collection area. Thus, soil resistance to penetration showed significant interaction between factors, in all evaluated layers. As traffic intensity increased, there was an increment in soil compaction both on the tire/soil interface and in subsurface. The interaction between the factors had significant effect on the soil conditions on the track, since it is a region of contact between tire and soil, where the load applied on the soil is distributed (Table 2).

In the 0-0.10 m layer, there was statistical difference from the second treatment on and, in the 0.10-0.20 m layer, the values differed statistically from the third treatment on, for the evaluations made on the tractor track (Table 3).

It is noted that, at maximum traffic intensity until the depth of 0.20 m, soil resistance to penetration was lower than that cited by Imhoff et al. (2000), who claimed that values between 2 and 3 MPa are considered as limiting to root development, proving that tire selection can interfere with crop yield (Table 3).

As soil depth increased, despite the increasing values, the data became statistically similar, as explained by Cunha et al. (2009) and Reichert et al. (2009), who claimed that the effect of traffic is concentrated in the most superficial layers of the soil, in general between 0 and 0.20 m. From this depth on, soil

Table 2. Summary of the ANOVA with statistical values of the F test for soil resistance to penetration in four layers

SV	DF	Layer (m)			
		0-0.10	0.10-0.20	0.20-0.30	0.30-0.40
Traffic (F1)	4	12.5185 **	4.223 **	1.5424 ns	4.9694 **
Collection area (F2)	1	216.144 **	198.7481 **	61.0542 **	63.7473 **
F1 x F2	4	18.7964 **	14.75 **	3.6175 *	6.8711 **
CV%		16.8	19.92	24.98	17.97

**Significant at 0.01 probability level *Significant at 0.05 probability level; ns - Not significant; DF - Degrees of freedom; SV - Source of variation

Table 3. Values of soil mechanical resistance (RP) on the track (A1) and off the track (A2) of the tractor in four layers, as a function of the traffic levels (T1 = 1, T2 = 6, T3 = 11, T4 = 16 and T5 = 21 passes)

Layer (m)		RP (MPa)				
		T1	T2	T3	T4	T5
0-0.10	A1	0.87 c A	1.16 bc A	1.37 b A	1.92 a A	1.79 a A
	A2	0.55 ab B	0.71 a B	0.79 a B	0.31 b B	0.76 a B
0.10-0.20	A1	1.30 c A	1.51 c A	1.66 bc A	2.28 a A	2.05 ab A
	A2	0.83 a B	0.86 a B	1.04 a B	0.38 b B	0.88 a B
0.20-0.30	A1	1.66 b A	2.23 a b A	2.26 ab A	2.36 ab A	2.56 a A
	A2	1.35 a b A	1.24 a b B	1.52 a B	0.62 b B	1.11 ab B
0.30-0.40	A1	1.99 b A	2.55 ab A	2.58 ab A	2.55 ab A	3.01 a A
	A2	1.85 a A	1.89 a B	1.98 a B	0.69 b B	1.59 a B

Means followed by the same letter, lowercase in the row and uppercase in the column for same depth, do not differ by Tukey test ($p < 0.05$)

compaction is related to other factors, such as the formation of compacted layers called "hard pan" (Table 3).

According to Figure 1, it is possible to calculate the maximum point, using the equation, and obtain yield of 6.02 t ha^{-1}, which corresponds to RP of 1.2 MPa. Therefore, yield increases up to the resistance of 1.2 MPa and, from this point on, it decreases. Hence, it is demonstrated that the increase in traffic intensity leads to increment in soil resistance to penetration, contributing to the reduction of yield, as observed in the studies of Taylor & Brar (1991), Silva et al. (2003), Drescher et al. (2012) and Machado et al. (2015).

The values of soil mechanical resistance until the depth of 0.20 m affected plant development and yield, since the studies reported that most of the soybean root system is between the soil depths of 0 and 0.20 m (Beulter & Centurion, 2004; Borém, 2005).

As observed in Table 4, the mean values of the variables related to crop development were not significant in the interaction between factors, which occurs because radial tires have greater elastic deformation and, consequently, larger

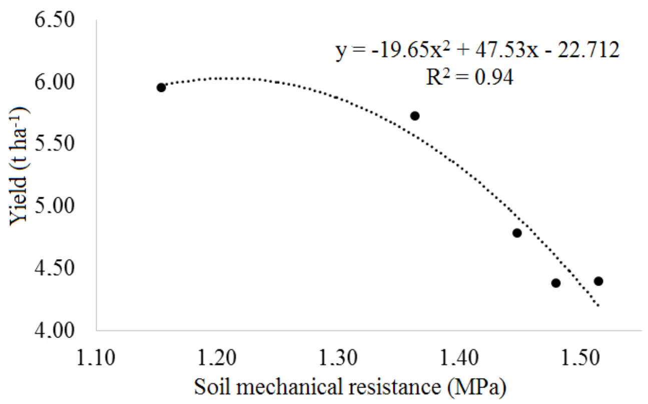

Figure 1. Soybean yield as a function of soil resistance to penetration in the 0-0.20 m layer

Table 4. Summary of the ANOVA with statistical values of the F test for soybean development features

SV	DF	Calculated F				
		PH	NP	RD	SD	Y
Traffic (F1)	4	5.2591 **	2.0259 ns	0.22188 ns	1.383 ns	35.551 **
Collection area (F2)	1	6.9369 **	0.3226 ns	6.6553 *	1.076 ns	28.609 **
F1 x F2	4	0.1450 ns	0.0926 ns	0.4496 ns	1.228 ns	0.6217 ns
CV (%)		7.34	22.68	14.39	20.66	6.20

**Significant at 0.01 probability level *Significant at 0.05 probability level; ns - Not significant; DF - Degrees of freedom; SV - Source of variation; PH - Plant height; NP - Number of pods; RD - Root diameter; SD - Stem diameter; Y – Yield; CV - Coefficient of variation

Table 5. Plant height (PH) and yield (Y) of soybean on the track (A1) and off the track (A2) of the tractor, as a function of the traffic levels (T1 = 1, T2 = 6, T3 = 11, T4 = 16 and T5 = 21 passes)

		T1	T2	T3	T4	T5
PH	A1	85.41 b	86.81 b	94.60 ab	94.60 ab	101.61 a
(cm)	A2	83.87 a	81.07 a	90.20 a	90.20 a	93.05 a
Y	A1	5995.97 a	5655.87 a	4790.83 b	4371.06 b	4425.0 b
(kg ha^{-1})	A2	6500.92 a	5923.33 ab	5377.68 bc	5128.14 c	5016.6 c

Means followed by the same lowercase letter in the row do not differ by Tukey test ($p < 0.05$)

contact area, thus minimizing the effects of soil compaction, which is consistent with the study of Machado et al. (2015).

It is noted in Table 5 that plants on the tractor track showed increasing heights, due to the increment in traffic intensity. The treatment in which the tractor passed only once (T1) differed only from the treatment with 21 passes (T5). Thus, soil compaction caused modifications in plant development, particularly in plant height.

This characteristic of plant growth as a function of soil compaction is related to the possibility of cell elongation, but this process is limited with respect to the growth potential of the plant compared with the degree of soil compaction (Materechera et al., 1992; Drescher et al., 2009).

It can be observed that, although the results show statistical differences between soil conditions and traffic intensity, for both compaction and crop yield, in the treatment of 21 passes the yield obtained in the present study was above the national mean relative to the 2014/2015 agricultural year, equal to 2,882 kg ha^{-1}, according to data of CONAB (2017) (Table 5).

For crop yield, there was a significant decrease from the treatment with six passes on. As traffic intensity increased, crop yield decreased (Table 5), which is consistent with Drescher et al. (2012), who observed that the increment in soil compaction directly affect the structural physical quality of the soil, causing increase in resistance to penetration.

The increase in traffic intensity can consequently lead to yield losses, because when the level of soil compaction is higher there is a reduction in the growth of main roots, besides an increment in the accumulation of lateral roots in more superficial soil layers (Table 5).

It is known that soils with higher mechanical resistance cause thickening of plant roots. Thus, it can be claimed that mean plant height as a function of the collection area (A1 - on the track A2 - off the track) and root diameter were significantly higher in plants in the track area, a result similar to that found by Materechera et al. (1992) (Table 6).

On the other hand, the yield of plants on the track had a significant reduction of 10% in comparison to the condition off the track. These results are equivalent to those observed by Taylor & Brar (1991), who found that soil compaction may cause alterations in the physical and chemical conditions of this environment, reducing the availability of water and nutrients to plants, which explains the fact that plants off the track showed higher yield (Table 6).

According to Figure 2, the compaction caused by the traffic of heavy machines and equipment tend to reduce crop yield, both on the track and off the track. However, it is observed that the yield of plants that were off the track was higher for all treatments, corroborating with the results of Beulter & Centurion (2004) and Reichert et al. (2012).

Table 6. Plant height (PH), root diameter (RD) and yield (Y) of soybean as a function of the collection area: A1 - on the track and A2 - off the track

	PH (cm)	RD (mm)	Y (kg ha^{-1})
A1	93.21 a	1.42 a	5047.76 b
A2	87.68 b	1.26 b	5589.35 a
LSD	4.28	0.125	206.92

Means followed by the same letter do not differ by Tukey test ($p < 0.05$)

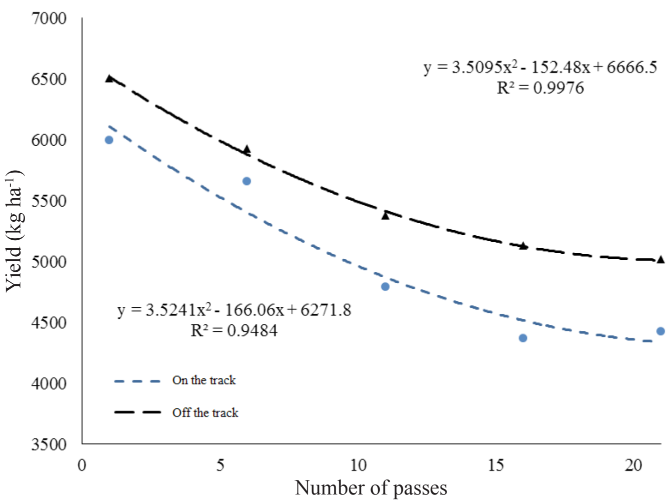

Figure 2. Soybean yield as a function of traffic intensity

Conclusions

1. Traffic intensity influences crop yield after the sixth pass with the tractor.

2. The increase in soil resistance to penetration leads to decrease in soybean yield. Plants located in the area off the track were less influenced by the traffic levels.

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