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AGRICULTURAL ENGINEERING

Soybean productivity in Rhodic Hapludox compacted by the action of furrow openers

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ABSTRACT. The heavy traffic of machines in no-tillage systems causes problems as soil compaction and loss of crops productivity. The objective of this paper is to evaluate the productivity of soybeans in reference to furrow openers and the levels of soil compaction in two crops. The experiment was conducted on Rhodic Hapludox by tracing random blocks with subdivided parcels. The soil bulk density levels were laid out in the parcels (1.16, 1.20, 1.22, and 1.26 Mg m^{-3}) and the furrowers in the sub-parcels (double disc and shanks). The resistance to penetration, depth of the furrow, mobilized soil area, final plant stands, height of plants, mean number of beans by pod, 1,000 bean mass, number of pods per plant and productivity of the culture were evaluated. The resistance to penetration increased with the levels of soil compaction regardless of the farming year and up to a depth of 0.20 m. In the first crop, higher productivity with the use of the shank was observed. In the second crop, the use of the shank resulted in an increase in depth of the furrow, mobilized soil, height of the plants and final stand of the plants, but this did not indicate an increase in productivity.

Keywords: no-tillage, seeder-fertilizer, soil density.

Produtividade de soja em Latossolo compactado em função de mecanismos sulcadores

RESUMO. O intenso tráfego de máquinas no sistema plantio direto tem acarretado problemas de compactação do solo, ocasionando queda de rendimento das culturas. O objetivo deste trabalho foi avaliar a produtividade de soja em razão de mecanismos sulcadores e níveis de compactação do solo, em duas safras agrícolas. O experimento foi conduzido em Latossolo Vermelho distroférrico típico, em delineamento de blocos ao caso com parcelas subdivididas, onde nas parcelas foram dispostos os níveis de densidade (1,16; 1,20; 1,22 e 1,26 Mg m^{-3}) e nas subparcelas os sulcadores (disco duplo e haste sulcadora). Foram avaliados a resistência à penetração, profundidade de sulco, área de solo mobilizada, estande final de plantas, altura de plantas, número médio de grãos por vagem, massa de 1.000 grãos, número de vagens por planta e produtividade da cultura. Independente do ano agrícola, a resistência à penetração aumentou com os níveis de compactação do solo até em torno de 0,20 m de profundidade. Na primeira safra, foi observado maior produtividade com o uso da haste. Na segunda safra, a haste proporcionou, aumento na profundidade de sulco, área mobilizada, altura de plantas e estande final de plantas, mas isso não se refletiu em ganhos de produtividade.

Palavras-chave: plantio direto, semeadora-adubadora, densidade do solo.

Introduction

Over the last 40 years, there have been important technological improvements that have brought about an expressive evolution in agriculture, particularly in the amounts produced by a large segment of the culture. Among these, the culturing of soybean stands out due to its high productive capacity accompanied by good profitability. In addition, soybeans are the chief crop in Brazil.

The no-tillage system played an important role in the establishment of the production levels and became one of the chief soil management systems used in Brazil and one of the best options to reduce soil and water losses. This system consists of stirring up the soil only in the sowing furrow (Palma et al., 2010; Botta, Tolon-Becerra, Lastra-Bravo, & Tourn, 2010). It is also marked by the intense traffic of machines and equipments, which results in serious problems with soil compacting that may cause a loss in production (Moraes et al., 2016; Naderi-Boldaji & Keller, 2016; Botta et al., 2016).

In the Southwest of Paraná State, a region of family agriculture that is based on the production of milk, the land must be intensively used by bringing in animals in the winter to where soybean and corn cultures are grown in the summer in an integrated farming-livestock system.

Intensive exploitation, together with inappropriate conditions and equipment, is an aggravating element in the compaction process that results in the degradation of the soil and a consequent loss in productivity. To solve this problem, a large number of farmers have adopted the use of the shank to replace the disc at the time of sowing (Modolo et al., 2013; Trogello, Modolo, Scarsi, & Dallacort, 2013). However, the use of the bar has become common, even in areas where the levels of soil compaction are not high, which favours soil erosion and increases weeds in the sowing line (Siczek, Horn, Lipiec, Usowicz, & Łukowski, 2015), as well as increases fuel consumption (Santos, Volpato, & Tourino, 2008).

Several studies have examined the effects of soil compaction in the development of plants in several types of soil, but they are not conclusive with regard to the values of soil density and resistance to penetration that are considered limiting factors since good moisture conditions may supplement the lower volume of soil used by the roots to supply the plant with water and nutrients (Oliveira et al., 2012; Gao, Whalley, Tian, Liu, & Ren, 2016; Moraes et al., 2016).

In their studies of the effect of soil density on root growth of several plants in a Rhodic Hapludox, Reinert, Albuquerque, Reichert, Aita, and Andrada (2008) observed that direct planting resulted in an increase in soil density and that restrictions to root development occurred at levels above 1.75 Mg m^{-3}, which resulted in morphological deformities in the roots. Secco, Reinert, Reichert, and Ros (2004) determined that in Rhodic Hapludox with a 42.7% clay content, there was no reduction in the yield of soybeans. Lima, Reinert, Reichert, and Suzuki (2010) studied the productivity of soybeans and bean cultures in Rhodic Hapludox and found that resistance to the penetration of approximately 1.9 MPa is considered critical to the growth and productivity of grains.

In this context, the present paper aims to evaluate the productivity of soybeans in reference to furrow openers and levels of soil compaction over the period of two agricultural crops.

Material and methods

The experiment was conducted in a Rhodic Hapludox (Soil Survey Staff, 2014) with a high clay content (77.40% clay, 20.31% sand and 2.29% silt) whose chemical characteristics are shown in Table 1. The area is defined by the coordinates 26°16’36”S and 52°41’20” W with an average altitude of 750 m and a maximum slope of 3%.

Treatments combined double disc split furrowers and shank in a direct planting sowing-fertilizer, and four levels of soil compaction were obtained using a tractor moving over the entire parcel so that the tires could compress parallel areas. The number of passages of the tractor varied in accordance with the treatment, as follows: Level 0 – no additional compaction, Level 1 – additional compaction using two passages by the tractor, Level 2 – additional compaction using four passages of the tractor, and Level 3 – additional compaction using six passages of the tractor, corresponding to soil densities of 1.16, 1.20, 1.22, and 1.26 Mg m^{-3}, respectively.

A New Holland® tractor model TL75E 4 x 2 TDA (Front Auxiliary Traction) with a maximum allowed weight (4,630 kg) and standard front tires 12.4 x 24, rear tires 18.4 x 30, and a mounted Jacto® sprayer (250 kg) with 600 L of water, which made a total mass of 5,480 kg, was used. The compaction was conducted in November 2013 (2013/2014 crop) immediately after the rainy season with a soil humidity of approximately 38.1%. This procedure was repeated in October 2014 (2014/2015 crop) with the same experimental equipment and a soil moisture of approximately 37.5%.

The climate is a humid subtropical type Cfa according to Köppen’s classification. During the culture cycle from 2013/2014, the crop monthly precipitation was over 150 mm in February 2014 and 329 mm in March 2014 with average temperatures between 21 and 27°C. In 2015, the crop precipitation varied from 117 mm in October 2014 to 279 mm in January 2015 with average temperatures between 21 and 25°C (Figure 1).

Table 1. Chemical features of the soil in layers 0.0-0.10 and 0.10-0.20 m deep before the start of the experiment.

Prof.	pH	M.O	P	H+Al	K	Ca	Mg	SB	CTC	V
(m)	CaCl$_2$			g dm^{-3}	mg dm^{-3}		cmol$_c$ dm^{-3}		%	
0.0-0.10	4.85	52.27	13.08	5.30	0.21	4.33	1.52	6.06	11.36	53.26
0.10-0.20	4.85	45.91	8.09	5.28	0.16	4.54	1.27	5.86	11.14	52.55

MO extracted by humid digestion; P and K extracted by Mehlich – 1, pH in $CaCl_2$; Ca, Mg and Al exchangeably extracted in KCL 1 mol L^{-1}.

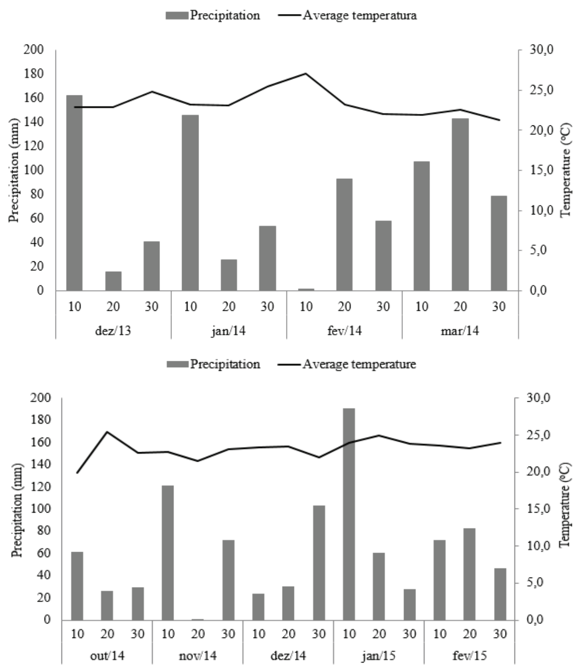

Figure 1. Meteorological data observed during the period of the experiment.
Source: Agronomy Institute of Paraná.

Random blocks encompassing eight treatments and four repetitions were utilized in subdivided parcels with the chief parcels formed by four levels of soil density and the sub-parcels by two furrow openers. The area was divided into four random blocks making up a total of 32 experimental units, each with an area of 75 m^2 (3.75 x 20 m) and with 10-m spacing between the blocks, which was used for the manoeuvring and stabilization of the velocity of the tractor.

The sowing of the soybeans took place on December 12, 2013 (2013/2014 crop), and October 22, 2014 (2014/2015 crop), under the black oats straw (*Avena strigosa*). The Don Mario 5.8i (BMX Apolo) variety was used with a density of 13.5 seeds per linear metre and with a final stand of approximately 265,000 plants ha^{-1}. The average depth of the sowing was 0.05 m. In the moment of sowing, 390 kg ha^{-1} of 02-20-18 compound was used.

A seeder-fertilizer, Vence Tudo brand, was used with a mechanic seed dispenser that contained five sowing rows with inter rows spaced 0.45 m apart. The average sowing speed was 5.0 km h^{-1}.

The furrowers used for laying the fertilizer were shanks with a width point (cone) of 17.76 mm, an angle of attack of 20° and a height of 0.45 m, or a split double disc type furrower with a diameter of 381 mm (15”), according to the treatment.

The mechanical resistance of the soil to penetration was obtained using a Falker penetrometer model PLG1020 with a cone of 1.0 cm^2 and 10 randomly distributed measuring points at each experimental unit. The values of resistance to penetration were obtained for depths between 0 and 0.4 m.

The transversal area of the mobilized soil was determined by a wooden profilometer with vertical rulers graded in centimetres and placed every 0.02 m in the transversal direction with regard to the sowing line. At each experimental unit, the outlines of the natural surface and the final surface of the soil were found. A collection was made along two sowing lines with two repetitions for each line.

The depth of the fertilizer furrow was obtained considering the highest difference between the profiles of the original and internal surface of the soil in the sowing furrow (Araújo, Casão Júnior, Ralisch, & Siqueira, 1999). The evaluation of the final stand of the plants was determined in the physiological maturation of the culture and by counting the plants at 5 m in each of the three central sowing lines in each experimental unit. The result was extrapolated to the number of plants per hectare.

The final height of the plants was measured by the distance between the neck of the plant and the apex of the main stem. The total number of pods per plant was determined by counting all of the pods inserted in the plant including those deemed empty. The mean number of grains per pod was obtained by the relation between the number of pods per plant and the number of grains per plant. The mass of 1,000 grains was defined on the basis of the total mass of the grains per plant and the number of grains per plant.

The harvest was done manually and the threshing by a stationary combine harvester. To calculate the yield, the humidity of the grains was corrected to 13%. The productivity in kg ha^{-1} was calculated through the total mass of grains produced per parcel.

The data obtained were tabulated and underwent a variance analysis. When significant differences occurred ($p \leq 0.05$), the furrower’s means were compared to the Tukey test ($p \leq 0.05$), whereas for the soil compaction factor, which was represented by the variable soil density, a polynomial regression analysis was adopted. Models were selected by the criteria of higher R^2 and significance ($p \leq 0.05$) of the parameters of the equation. All of the data were submitted to the Cocharan test ($p \leq 0.05$) to verify the homogeneity of the variances. For non-homogeneous variables, the normality of the data was verified through the Lilliefors test ($p \leq 0.05$), and the variables that did not comply with the homogeneity and normality assumptions were transformed into the square root.

For the analysis of the data, SAEG 9.1 software was used.

Results and discussion

The highest values of resistance to penetration were observed in the treatment with the highest number of passages and up to the depth of approximately 0.20 m, followed by the treatments with four and two passages, respectively. Between the depths of 0.20 and 0.40 m, the values of resistance to penetration were not influenced by the tested density levels, which indicates that the traffic imposed by the tractor increased resistance to penetration in the superficial layers only up to a depth of 0.20 m (Figure 2). This behaviour with higher values of resistance to penetration in the superficial layers is characteristic of soils under no-tillage system, whereas the cumulative effect of the tensions generated by the traffic of machines and equipment is dissipated in the superficial layers (Beutler, Centurion, Centurion, & Silva, 2006; Bonini, Gabriel Filho, Secco, Souza, & Tavares, 2008; Gao et al., 2016; Botta et al., 2016).

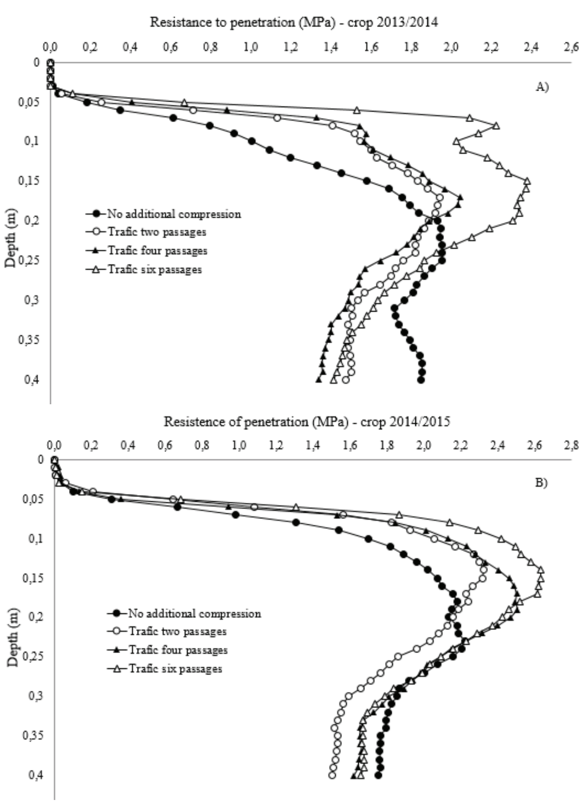

Figure 2. Resistance of the soil to penetration (MPa) in reference to the number of passages of the tractor. A) 2013/2014 crop; B) 2014/2015 crop.

In the 2013/2014 crop, the values of resistance to penetration reached 2.1 MPa when the soil presented 37.7% moisture; in the 2014/2015 crop, resistance reached 2.6 MPa with 36.7% soil moisture. Similar results were obtained by Bonini et al. (2008) in Hapludox under four levels of soil compaction with densities varying between 1.23 and 1.35 Mg m^{-3} and with observed values of resistance of the soil to penetration in the 0.10 to 0.20 m layer of 2.50 and 2.21 MPa, respectively.

Several studies determined the critical values of resistance to penetration with results varying between 1.5 and 4.0 MPa, which are influenced by the type of soil and vegetal species; however, the value of 2.0 MPa is considered to prevent root growth (Botta et al., 2010; Valicheski, Grossklaus, Stürmer, Tramontin, & Baade, 2012). In the present paper, it was observed in the first year of the experiment that only the six passages with the traffic presented values of resistance to penetration higher than 2.0 MPa, unlike the results obtained in the 2014/2015 crop where only areas without additional compaction showed results below that value in the layers up to a depth of 0.2 m. This was probably influenced by the lesser amount of humidity presented at the time of the test and by the cumulative effect of the compacting levels imposed in two consecutive years in spite of the similarity in observed values of soil density in the two years of the experiment.

In the first year of the experiment, the depth of the furrow was not influenced by the density of the soil and by the furrow openers with a mean value of 5.9 cm. However, in the second year, the shank resulted in a furrow depth that was 79% higher than the double disc (Table 2). This result verifies the higher ability of the shank to burst through the compacted layer, thus positioning the fertilizer below the seed. The positioning becomes important since in some cultures, direct contact between the seed and the fertilizer may harm germination and the development of the seedlings as observed by Souza, Farinelli, and Rosolem (2007) when evaluating the depths of fertilizer deposition in the culturing of cotton.

Table 2. Depth of the fertilizer furrow (m) and mobilized soil area (m^2) with reference to the furrow openers.

Furrows	Depth of the fertilizer furrow (m)	Mobilized soil area (m^2)
	Crop 2014/2015	
Disc	0.048 b	0.0031 b
Shank	0.086 a	0.0064 a

Means followed by different lower case letters differ ($p \leq 0.05$) by the Tukey test.

The mobilized soil area in the 2013/2014 crop did not show differences between the treatments with a mean value of 0.0051 m^2. In the 2014/2015 crop, the mobilized area showed a linear relation with soil density (Figure 3).

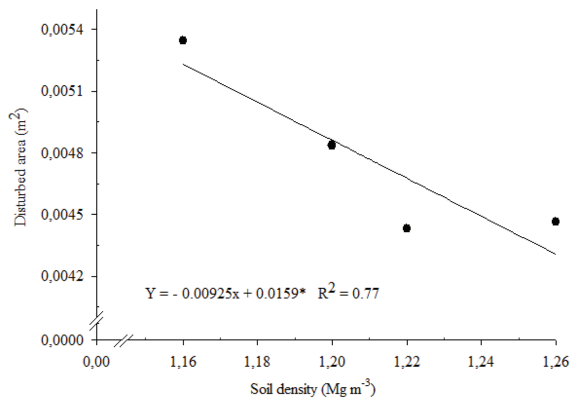

Figure 3. Mobilized soil area (m^2) with reference to soil density in the 2014/2015 crop.

In the second year of the experiment, the shank mobilized twice the soil area in comparison with the double disc (Table 2), which could be explained by the deeper furrow obtained with the shank and the lower soil humidity, which directly influences the cohesive force among the particles and keeps the aggregates more stable and thus brings a greater volume of mobilized material. These results corroborate those obtained by Levien, Furlani, Gamero, Conte, and Cavichioli (2011), who observed a 52% greater soil mobilization when utilizing the shank in comparison with the double disc on a Hapludox in the sowing of a corn culture.

In a study conducted by Mion, Benez, Viliotti, Moreira, and Salvador (2009) on a Hapludox, no difference was observed between the shank and the double disc for the mobilized area on a soil with an average density of 1.42 Mg m^{-3} and in the layer up to 0.15 m and managed through direct planting. The homogeneity in the mobilized soil area observed in the above-mentioned study may be related to the low clay content in the soil (6 g kg^{-1}). In this condition, the lack of a more expressive amount of the colloidal fraction renders the formation of more stable aggregates more difficult as it reduces the cohesion among the soil particles, which facilitates its pulverization and reduces the mobilized volume in the line of planting.

Trogello et al. (2013) did not find a significant difference in the mobilized area of the soil between the same furrowing mechanisms when they studied the speed of operation and cover managements on the same soil and utilized the same sowing as in the present study.

However, Modolo et al. (2013), when studying the action of furrowing mechanisms under different intensities of grazing, obtained a larger area of mobilized soil by utilizing the shank in comparison with the double disc, but did not observe any influence of the grazing intensities on the mobilized soil area. Mion and Benez (2008) evaluated the effects of different furrowing tools on Hapludox and also found a larger area of mobilized soil when utilizing the shank.

In the 2013/2014 crop, a greater stand of plants (260,000 plants ha^{-1}) was observed in the highest soil density (1.26 Mg m^{-3}) when the double disc was utilized (Figure 4). The smallest final stand presented by the smallest soil density may be related to the greater sowing depth obtained at this density (5.1 cm), which makes the still fragile seedling require more vigour to emerge at the surface. However, when the shank was utilized, no influence of the soil density on the final plant stand was noted; the average value was 233,888 plants ha^{-1}.

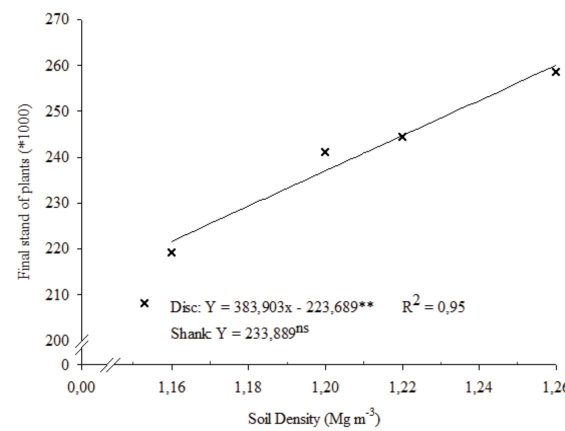

Figure 4. The final stand of soy plants (plants ha^{-1}) in the 2013/2014 crop in reference to the soil density and furrow openers.

In the 2014/2015 crop, the final plant stand was influenced only by the furrowers and there was no effect of soil density on this variable. In Table 3, it is possible to observe that when the shank was utilized, the final stand was 20% greater than that shown by the double disc because the bar presented a greater soil mobilization, thus improving the burying of the seeds and providing better germinating conditions.

Table 3. The final stand of soy plants (plants ha^{-1}) and final height of plants (m) in relation to furrow openers.

Furrows	Final stand of plants (*1000)	Final height of plants (m)
	Corn 2014/2015	
Disc	205.5 b	0.72 b
Shank	247.5 a	0.75 a

Means followed by different lower case letters in a column differ ($p \leq 0.05$) by the Tukey test.

Studies in Rhodic Hapludox comparing the effects of the furrowing systems by bar and disc are conflicting. Trogello et al. (2013) did not find a difference in the final stand for the two mechanisms. However, Arf, Afonso, Romanini Junior, Silva, and Buzetti (2008) and Kaneko et al. (2010) observed two consecutive years where the shank mechanism significantly increased this variable in relation to the double disc. The fact that the above-mentioned authors found conflicting results may not be related to the tools in question, but rather, to the characteristics of the soils utilized in the experiments. In spite of the fact that the soils presented the same classification, they may present considerable differences regarding their physical features and management. Specifically, regarding the Oxisol class, the clay content may range from 20 to 100% without a change in the classification, which renders extrapolation and comparison of the results more difficult.

In the 2013/2014 crop, no influence of the furrow opener mechanisms and soil density on the final height of the plants was observed. The mean height observed was 77.83 cm. In the second year of the experiment, the furrowing bar provided greater aerial development (Table 3), which for its part, may be related to a greater mobilization and rupture of compacted layers caused by the shank in comparison with the double disc (Table 2); this allowed the roots to more efficiently explore the volume of the soil (Giarola, Brachtvogel, Fontaniva, Pereira, & Fioreze, 2009). This result was not observed in the 2013/2014 crop because the mobilized area did not differ between the furrowing tools and thus afforded a similar condition for the growth of the roots.

Corroborating the results observed in the present study, Giarola et al. (2009) obtained the same plant height when evaluating two levels of compaction of a Rhodic Hapludox with densities of 1.38 and 1.45 Mg m^{-3} (at a depth of 0.0 to 0.10 m). However, a study by Oliveira et al. (2012) working on irrigated Rhodic Hapludox and under compacting levels with soil densities ranging between 1.20 and 1.36 Mg m^{-3} in the 0.0 to 0.10 layer, obtained smaller plant heights with an increase in soil compaction. A similar result was also observed by Beutler et al. (2006) in Rhodic Hapludox under compacting levels, and soil densities ranged from 1.31 to 1.71 Mg m^{-3} (at a depth of 0.08 to 0.11 m). It is important to highlight that despite presenting the same classification, the soils used in the three studies mentioned above present differences that may strongly influence vegetal development. Giarola et al. (2009) worked with a soil similar to the present study, which showed a clay content of much higher than 65% (very argillaceous). Oliveira et al. (2012) worked with an argillaceous soil, that is, a clay content between 35 and 65%. However, Beutler et al. (2006) used a medium texture soil in their experiment (a clay content between 15 and 35%). These differences with regard to the content of clay have a strong influence on the hydraulic conductivity of the soil, which may influence the absorption of water and consequently its development (Moraes et al., 2016; Nadei-Boldaji & Keller, 2016).

The mean number of grains per pod was not influenced by the variation in the density of the soil or by the furrowers in the two evaluated crops with average values of 1.9 and 2.3 grains per pod in the 2013/2014 and 2014/2015 crops, respectively. The lack of response for this variable is probably because the number of grains per pod is typically a genetic characteristic and hence did not influence the treatments (Centurion et al., 2006).

For the 2013/2024 crop, the use of the bar provided an increase in the number of pods per plant with an increase in the soil density (Figure 5). However, when utilizing the double disc, the number of pods per plant does not depend on the soil density: an average value of 42.02 pods per plant was observed.

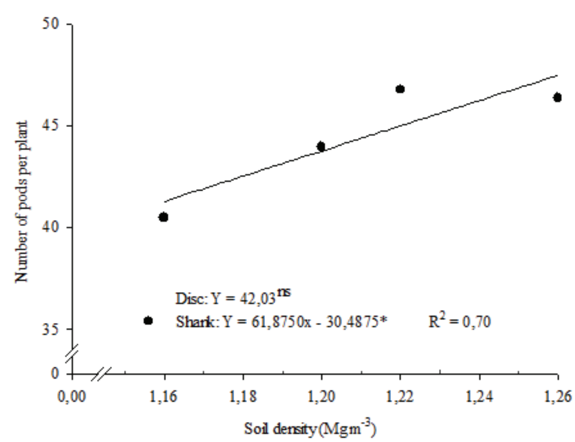

Figure 5. Means number of pods per plant in the 2013/2014 crop in reference to the soil density and furrow openers.

In the 2014/2015 crop, only the furrowing tools had a significant influence (Table 4). The number of pods per plant obtained by the use of the double disc was 15% greater than that presented by the shanks. This result is related to the smaller final stands of the plant obtained by this furrowing tool (Table 3).

Several studies indicate that the increase in the density of the plants reduces the number of pods per plant in the soybean culture. This behaviour occurs because in the largest sowing densities, there is greater competition for light, water and nutrients and less availability of photo-assimilated elements, which reduces the number of pods (Mauad, Silva, Almeida Neto, & Abreu, 2010).

Table 4. Mean number of pods per plant and soy productivity (t ha^{-1}) in reference to the furrow openers.

Furrows	Number of pods per plant	Productivity (t ha^{-1})
	Crop 2014/2015	Crop 2013/2014
Disc	63.8 a	2.10 b
Shanks	55.3 b	2.33 a

Means followed by different lower case letters in a column significantly differ ($p \leq 0.05$) by the Tukey test.

The thousand grain mass was not influenced by the variables of soil density and furrowers in the two agricultural crops. The average observed values were 125.67 and 120.05 in the first and second crops, respectively. Centurion et al. (2006) and Arf et al. (2008) observed that both the number of grains per pod and the thousand grain mass are more related to the genetic characteristics of the variety.

In the two evaluated crops, no influence of the soil density on the grain yield was observed. There was a significant difference only with regard to the furrowing mechanism, with the shank producing approximately 11% more than the double disc in the experiment conducted in the 2013/2014 crop. Taking into consideration that the components of the yield (number of grains per pod and thousand grain mass) did not differ significantly between the furrows, this result was only influenced by the variable number of pods per plant, which on average was 6% greater when using the shank. The average yield observed in the second year of the experiment was 3.57 t ha^{-1}.

The good water supply during the crops (Figure 1) may also have contributed to the lack of response of the tested density levels on productivity. Several authors indicate that soil compacting reduces the root growth of soybean plants. However, it is possible that the reduction of the volume of soil explored by the roots may not be sufficient to restrict the supply of water and nutrients to the aerial parts of the plants, thus maintaining the production of the culture (Centurion et al., 2006; Giarola et al., 2009; Oliveira et al., 2012).

Soy beans are sensitive to temperature and the photo-period, and premature flowering may occur as a result of higher temperatures and fewer sunlight hours. Thus, late sowing may reduce the productivity both of the varieties with a premature cycle and those with a later cycle (Botta et al., 2010; Amorim, Hamawaki, Sousa, Lana, & Hamawaki, 2011). This situation may have generated the greater productivity observed in the 2014/2015 crop in comparison with the 2013/2014 crop.

Working with Rhodic Hapludox under the compacting levels, Beutler et al. (2006) and Oliveira et al. (2012) obtained a reduction in productivity with an increase in the compacting level for soil densities ranging between 1.31 to 1.71 Mg m^{-3} and 1.20 to 1.36 Mg m^{-3}, respectively. However, Secco, Reinert, Reichert, and Silva (2009), working with Rhodic Hapludox, did not verify a significant difference between the compacting levels evaluated with soil densities ranging between 1.38 and 155 Mg m^{-3}.

Conclusion

The application of traffic on the soil increased the resistance to penetration up to a depth of approximately 0.20 m with higher values in the treatment with a greater number of passages.

The use of as hank proved advantageous only in the 2013/2014 crop because it provided greater productivity in comparison with the double disc. In the 2014/2015 crop, the use of the shank resulted in an increase in the depth of the furrow, the mobilized soil area, height of the plants and their final stand, but this was not reflected in productivity gains.

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