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MANAGEMENT SYSTEMS: SOIL COVER AND COMPACTION, LONGITUDINAL DISTRIBUTION, AND YIELD OF SOYBEAN CROP

Jorge W. Cortez[1*], Maiara Pusch[2], Rouverson P. da Silva[3], Mauricio V. Rufino[4], Matheus Anghinoni[4]

[1*]Corresponding author. Universidade Federal da Grande Dourados/ Dourados - MS, Brasil.
E-mail: jorgecortez@ufgd.edu.br | ORCID ID: http://orcid.org/0000-0003-1120-719X

KEYWORDS

resistance to penetration, geostatistics, soil tillage.

ABSTRACT

The way the soil is managed can influence its structuring and, consequently, crop yield. Thus, this study aimed to evaluate the effect caused by the management systems plowing followed by two intermediate harrowing operations, intermediate harrowing, chiseling, chiseling followed by intermediate harrowing, cross chiseling followed by intermediate harrowing, and non-tillage on soil and agronomic attributes of the soybean crop. A randomized block design with four replications was used. The percentage of soil cover, soil resistance to penetration, number of plants per meter, longitudinal distribution of seedlings, and soybean yield were evaluated. The data were submitted to analysis of variance by the Tukey test at 5% probability, and use of geostatistics for soil resistance to penetration. The system without soil tillage provides the best straw preservation but affects the longitudinal distribution of soybean seedlings. The use of intermediate harrowing for managing crop residues or soil tillage leads to the greatest compaction problems. Chiseling is efficient in maintaining compaction values below critical values up to a depth of 0.20 m when working at 0.35 m. Soil yield is not affected by soil management systems when the pluviometric regime is adequate to crop requirements.

INTRODUCTION

An agricultural expansion of 87% was observed in the Cerrado from 2000 to 2014, and 76% of this increase was caused by soybean (Carneiro Filho & Costa, 2016). Sustainable practices need to be established in the economic, social, and environmental spheres using new technologies and management that allow equal or greater production without increasing areas already cultivated (Borlachenco & Gonçalves, 2017).

Soil conservation and erosion reduction in soybean cultivation are associated with the adoption of management systems that do not disturb the soil, preserving plant cover (Almeida et al., 2016). Soil losses due to erosion and costs are imperceptible for producers, but considering all agriculture, the values are high and justify the importance of vegetation cover, among other factors (Delchen et al., 2015).

The way soil is managed changes the resistance to penetration, becoming an important indicator of compaction of cultivated soils (Santos et al., 2015). Soil compaction in no-tillage systems is related to the time of adoption, less aggressive management, and adoption of crop rotation, which are practices that contribute to organic matter accumulation in the soil, bring effective alternatives to minimize compaction of agricultural soils (Domit et al., 2014).

For a better understanding of soil compaction using resistance to penetration, the geostatistics, routinely used in data analysis, can be used to allow higher scientific precision in recommendations (Vieira, 2000). The widespread use of ordinary kriging for estimating non-sampled sites is due to the simplicity of the method (weighted average), which uses the structural information provided by the variogram model and provides the uncertainty associated with estimation using kriging variance (Yamamoto, 2016).

Thus, this study aimed to evaluate the effect caused by the management systems plowing followed by two intermediate harrowing operations, intermediate harrowing, chiseling, chiseling followed by intermediate harrowing, cross-chiseling followed by intermediate harrowing, and non-tillage on soil and agronomic attributes of the soybean crop.

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[2] Universidade Estadual de Campinas/ Campinas - SP, Brasil.
[3] Universidade Estadual Paulista "Julio de Mesquita Filho"/ Jaboticabal - SP, Brasil.
[4] Universidade Federal da Grande Dourados/ Dourados - MS, Brasil.

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MATERIAL AND METHODS

This study was carried out at the Experimental Farm of Agricultural Sciences – FAECA of the Federal University of Grande Dourados – UFGD, located in Dourados, MS, Brazil. The study site is located at 22°14′ S and 54°59′ W, with an altitude of 434 m. The climate is type Am, monsoon, with dry winter, average annual precipitation of 1500 mm, and an average temperature of 22 °C (Alvares et al., 2013). The soil of the area is a dystroferric Red Latosol by the Brazilian Agricultural Research Corporation (Embrapa, 2006). The area has been cultivated with soybean (*Glycine max*) in the summer and corn (*Zea mays*) in the second crop since 2013.

The meteorological data during the experimental period were obtained at the Embrapa Western Agriculture weather station (temperatures) and an analog crystal rain gauge installed at the UFGD experimental farm collected precipitation data (Figure 1).

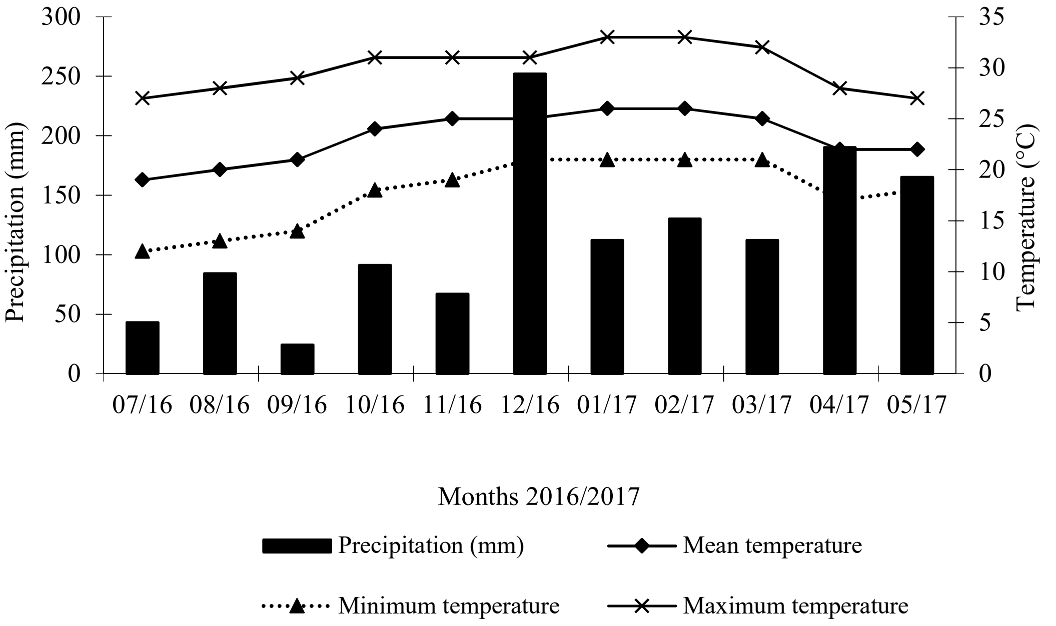

FIGURE 1. Monthly meteorological data (precipitation and temperature) from 2016 to 2017 obtained at the experimental farm.

A randomized block design with four replications was used. Treatments consisted of six management systems: plowing followed by two intermediate harrowing operations (T1), intermediate harrowing (T2), chiseling (T3), chiseling followed by intermediate harrowing (T4), cross chiseling followed by intermediate harrowing (T5), and non-tillage (T6). These operations were performed before the summer crop in October 2016. Each experimental plot occupied an area of 15 × 20 m (300 m^2).

Plots were tilled using a five-shank chisel plow with points of 0.08 m wide and working depth of 0.35 m (chiseling treatments); a disc plow with four 28” discs, with a working depth of 0.30 m (conventional tillage); and an intermediate drag type offset disc harrow, with 20 discs with a diameter of 20” at each section (notched in the front section and plain in the rear section) and working depth of 0.15 m (conventional tillage, chiseling, cross chiseling, and harrowing).

Sowing was performed by a pneumatic seed drill at 5 km h^{-1}, with a fertilizer furrow shank, seven rows of soybeans spaced at 0.45 m set to distribute thirteen seeds per linear meter at a depth of 0.05 m, and a helical fertilizer metering mechanism set to distribute 300 kg ha^{-1} of the 8–20–20 N–P–K formulation. The cultivar was Monsoy 6410 IPRO with 99% purity and 80% germination, as manufacturer’s information.

The percentage of soil cover by straw and soybean after sowing was obtained using a 7.5 m long copper wire and with equidistant markings of 0.15 m, totaling 50 reading points, as methodology adapted by Laflen et al. (1981). An x-shaped reading was carried out at plots, resulting in one hundred points.

The data from soil mechanical resistance to penetration (RP) were collected three and a half months after soil tillage using an IAA/Planalsucar-Stolf impact penetrometer (Stolf et al., 2011). RP determinations at plots were carried out every 0.225 m width × 0.10 m depth within the traffic band (five rows of the seed drill), totaling twenty-eight sample points. RP data were collected at depths of 0.00–0.10, 0.10–0.20, 0.20–0.30, and 0.30–0.40 m, transformed into MPa (Stolf, 1991), and analyzed per treatment at depth and considering the individual mean per depth, in addition to the spatialization of soil profiles.

Random disturbed soil samples were taken from the same depths sampled for RP to determine soil water content after oven-drying by gravimetric method, according to Kiehl (1979) and Claessen (1997) (Table 1).

TABLE 1. Soil water content at the time of collecting the data of resistance to penetration.

Depth (m)	Average water content in the soil profile (%)
0.00–0.10	19.32
0.10–0.20	19.15
0.20–0.30	19.15
0.30–0.40	19.25

The number of plants per meter was evaluated in eight rows of each plot in two meters in length each using a measuring tape.

A measuring tape was also used in the evaluation of longitudinal distribution or uniformity of spacings between seedlings, and readings were performed in eight rows of each plot in two meters in length. The percentage of normal, flawed, and double spacings was obtained according to ABNT (1984) and Kurachi et al. (1989), considering double spacings (D) $< 0.5\times Xref$, normal spacings (A) $0.5 < Xref < 1.5$, and flawed spacings (F) $> 1.5\times Xref$, where Xref is the reference spacing. The mean reference spacing was 10.33 m, i.e., values lower than 0.051 m were considered as double, and spacing values above 0.154 m were considered as flawed.

The yield was obtained after collecting plants from four meters in length and two rows per plot, being later threshed (stationary thresher), with masses measured separately by the plot and values corrected for 13% moisture.

An analysis of variance was carried out and subsequently, when significant, the Tukey test at 5% probability was used for comparing the means of soil (percentage of soil cover and resistance to point penetration) and plant data (stand, distribution, and yield).

Geostatistics was used to analyze the spatial dependence of resistance to penetration in the soil profile of each plot. The adjustment of the mathematical model for semivariograms of each variable provided the parameters nugget effect (C0), sill (C0+C), and range (A). The nugget effect is the value of semivariance for distance zero and represents the component of random variation, sill is the value of semivariance at which the curve stabilizes over a constant value, and range is the distance from the origin to where sill reaches stable values, expressing the distance beyond which the samples are not correlated (Vieira et al., 1983). The degree of spatial dependence (DSD) classification was based on the ratio between the nugget effect and sill (C0/C0+C1), being considered strong for a DSD higher than 75%, moderate for a DSD between 25 and 75%, and week for a DSD lower than 25% (Cambardella et al., 1994). Model selection was performed based on the lowest sum of squared residuals (SSR) and the best coefficient of determination (R^2).

MATERIAL AND METHODS

The data of soil cover (Table 2) differed according to the management. The non-tillage system presented a higher amount of straw on the soil and lower amount of soil exposed because tillage is carried out only in the sowing row, thus maintaining the amount of straw on the soil surface.

The systems with higher soil mobilization resulted in lower straw values on the soil, with a higher development of soybean plants (Table 2). Deperon Júnior et al. (2016) verified that the increased soil resistance to penetration leads to a decrease in the dry matter value of corn plants. Considering the soybean/corn succession system in the experimental area, values below 80% could be related to possible high values of resistance to penetration.

TABLE 2. Summary of the values of analysis of variance and test of means for the percentage of vegetation cover by straw, soil, and soybean plants.

	Vegetation cover (%)		
Treatment	Straw	Soil	Plant
T1	33.00 d	55.25 a	11.75 a
T2	61.5 b	31.25 cd	7.25 ab
T3	56.75 bc	35.75 c	7.50 ab
T4	48.75 c	41.00 bc	10.25 ab
T5	34.50 d	54.00 ab	11.25 a
T6	75.75 a	19.75 d	4.50 b
F-test	36.36**	20.45**	4.02*
CV (%)	10.56	15.30	31.99

^{NS}: not significant (p>0.05); *: significant (p<0.05); **: significant (p<0.01); CV: coefficient of variation. Means followed by the same lowercase letters in the column do not differ from each other by Tukey test at 5% probability. Plowing followed by two intermediate harrowing operations (T1), intermediate harrowing (T2), chiseling (T3), chiseling followed by intermediate harrowing (T4), cross chiseling followed by intermediate harrowing (T5), and non-tillage (T6).

The least efficient systems for the preservation of straw are the treatments plowing followed by two intermediate harrowing operations and cross chiseling followed by intermediate harrowing (Table 2), in which there is higher soil mobilization, incorporating the vegetation cover and reducing the amount of straw on the soil. These systems presented higher levels of exposed soil because they incorporate crop residues.

The system intermediate harrowing presented the highest resistance to penetration at depths of 0–0.10, 0.10–0.20, and 0.20–0.30 m (Table 3). Resistance values can be compared as proposed by Moraes et al. (2014), who stated that 2.0, 3.0, and 3.5 MPa should be adopted for the conventional tillage system, chiseled soil, and no-tillage system, respectively, as limits to root development. Resistance values are very high in the intermediate harrowing system due to the effect of successive disc harrow strides over the years at the same depth. However, treatment without tillage showed the highest resistance to penetration at a depth of 0.30–0.40 m, which is probably due to the lack of soil disturbance and, consequently, higher compaction at depths below the development of roots.

TABLE 3. Summary of the values of the analysis of variance and test of means for soil resistance to penetration (MPa).

	Depth (m)				
Management	0.0–0.10	0.10–0.20	0.20–0.30	0.30–0.40	Mean
T1	3.25 ab	5.88 ab	6.16 ab	6.01 ab	5.33 ab
T2	4.11 a	6.79 a	6.64 a	5.55 ab	5.77 a
T3	1.92 b	3.98 bc	4.74 bc	5.46 ab	4.03 c
T4	2.06 b	4.03 bc	5.25 abc	5.40 ab	4.19 bc
T5	1.85 b	3.48 c	3.92 c	5.29 b	3.64 c
T6	3.48 ab	6.18 ab	6.18 ab	6.18 a	5.5 a
F-test	5.20**	7.17**	8.35**	3.74*	10.99**
CV (%)	30.20	20.5	13.00	6.57	11.40

^{NS}: not significant (p>0.05); *: significant (p<0.05); **: significant (p<0.01); CV: coefficient of variation. Means followed by the same lowercase letters in the column do not differ from each other by Tukey test at 5% probability. Plowing followed by two intermediate harrowing operations (T1), intermediate harrowing (T2), chiseling (T3), chiseling followed by intermediate harrowing (T4), cross chiseling followed by intermediate harrowing (T5), and non-tillage (T6).

The highest overall means of resistance to penetration were found in the intermediate harrowing and non-tillage (Table 3). On the other hand, the treatment with the lowest values at all depths was cross chiseling followed by intermediate harrowing (Table 3). Cross chiseling provides several cracks in the soil profile and, together with harrowing, leads to a more aerated and less compacted soil when compared to the harrowing alone, maintaining the benefits caused by the used implements. Chiseling promotes the improvement of soil structure, with a residual effect of up to two and a half years through mechanical intervention in soil managed under no-tillage (Drescher et al., 2012). Toigo et al. (2015) found that mechanical chiseling improved soil physical properties in the surface layer thirteen months after the intervention, surpassing the no-tillage system. However, Nicoloso et al. (2008) observed that the effect of mechanical chiseling on a very clayey Oxisol at a high precipitation period is temporary, with no improvement regarding physical conditions after nine months.

The mean values of each treatment at each depth showed that the treatments plowing followed by two intermediate harrowing operations and non-tillage presented increasing values of resistance to penetration from 4.0 MPa up to approximately a depth of 0.10–0.20 m to 6.0 MPa at the following depths (Figure 2). In this case, the unprepared soil has been under the no-tillage system for three years, and plowing followed by two intermediate harrowing operations was performed four months before RP determinations. Thus, the system under non-tillage preserved soil physical structure.

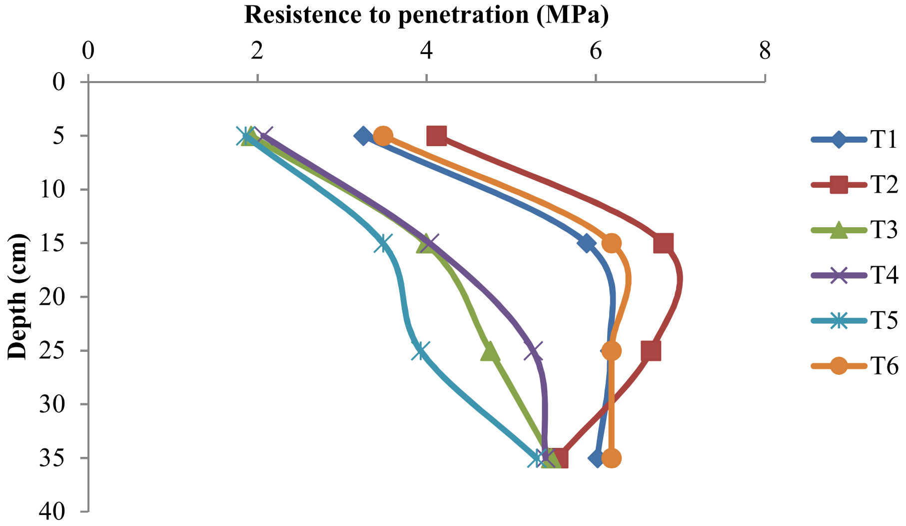

FIGURE 2. Resistance to penetration as a function of depth and treatment. Plowing followed by two intermediate harrowing operations (T1), intermediate harrowing (T2), chiseling (T3), chiseling followed by intermediate harrowing (T4), cross chiseling followed by intermediate harrowing (T5), and non-tillage (T6).

Soil resistance to penetration was increased gradually until the last depth in the management chiseling plow, chiseling followed by intermediate harrowing, and cross chiseling followed by intermediate harrowing, with values higher than 4.0 MPa only at deeper layers, but with a lower value than the previous ones (Figure 2). Therefore, chisel plow leads to lower soil compaction when compared to systems that do not use chiseling. However, the treatment with intermediate harrowing showed increasing RP values up to a depth of 0.10–0.20 m (> 6.0 MPa), decreasing in depth although they were still high. This high value obtained for resistance to penetration may be due to a possible mirroring caused by the working depth in which the management with disc harrow (0.15 m) was carried out.

The spatial dependence of RP showed that the treatment with intermediate harrowing (Table 4) had no adjustment, i.e., it presented a pure nugget effect, not being possible to generate spatialization. The spherical model predominated in the other treatments. Campos et al. (2014) studied the spatial variability in an agroforestry system and found dependence at all evaluated layers, with a predominance of the spherical model and a moderate degree. The spatial dependence range is an important parameter in the semivariogram study, defining the maximum distance that a variable is spatially correlated (Silva et al., 2017). Treatments with plowing followed by two intermediate harrowing operations, chiseling, chiseling followed by intermediate harrowing, and cross chiseling followed by intermediate harrowing obtained a strong spatial dependence, but T6 showed a moderate spatial dependence, a result also found by Cortez et al. (2017).

The profile with variability of resistance to penetration in the treatment with plowing followed by two intermediate harrowing operations presented values lower than 4.0 MPa only superficially, with most of the profile showing values of resistance to penetration between 4.0 and 6.0 MPa. Also, some random points had values between 6.0 and 8.0 MPa, not showing a continuous soil profile (Figure 3).

TABLE 4. Semivariogram of resistance to penetration for the management systems.

	Treatment					
	T1	T2	T3	T4	T5	T6
			Semivariogram			
Model	Sph	–	Sph	Sph	Sph	Sph
C0	0.001	–	0.001	0.20	0.01	0.29
C0+C	2.83	–	2.913	3.06	3.42	4.76
Range	0.10	–	0.40	0.39	0.42	0.83
			Degree of spatial dependence (DSD)			
DSD	1	–	1	0.93	0.99	0.75
Class	Strong	–	Strong	Strong	Strong	Moderate
			Cross-validation (CV)			
CV	0.99	–	1.19	1.31	1.01	0.81
Straight line	F	–	F	F	F	F

C0: nugget effect; C0+C: sill. Range (m). Plowing followed by two intermediate harrowing operations (T1), intermediate harrowing (T2), chiseling (T3), chiseling followed by intermediate harrowing (T4), cross chiseling followed by intermediate harrowing (T5), and non-tillage (T6).

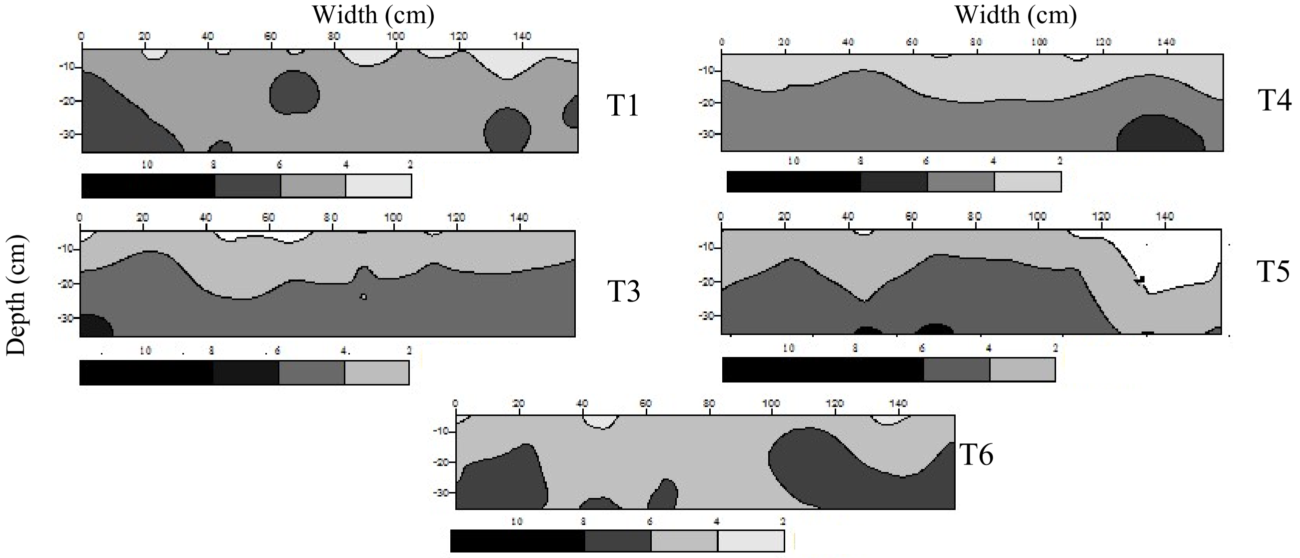

FIGURE 3. Spatialization of soil profile compaction (MPa) for the management systems. Plowing + two intermediate harrowing operations (T1), chiseling (T3), chiseling + intermediate harrowing (T4), cross chiseling + intermediate harrowing (T5), and non-tillage (T6).

The system plowing followed by two intermediate harrowing operations disrupted the soil, not being possible to identify a continuous profile, as in the system without tillage (Figure 3). However, Cortez et al. (2017) observed a continuous layer for RP in the no-tillage system (>10 years) up to a depth of 0.30 m because the values were cumulative over time in this tillage. The treatments chiseling, chiseling followed by intermediate harrowing, and cross chiseling followed by intermediate harrowing showed a continuous soil profile for RP, with values up to 4.0 MPa for surface layers and higher than 4.0 MPa below 0.20 m, evidencing a compaction in depth according to values stipulated by Moraes et al. (2014). Moreover, the chiseling system was effective in maintaining compaction below the critical limit up to 0.20 m, with a working depth of 0.35 m.

The highest number of plants per meter was observed in the treatment intermediate harrowing, with the lowest values for the treatment non-tillage (Table 5). It may be correlated to the fact that the intermediate harrowing had the highest incidence of double spacing, which was lower in the cross chiseling followed by intermediate harrowing.

TABLE 5. Summary of the values of analysis of variance and test of means for plants per meter and longitudinal distribution.

Factor	Plants per meter	Longitudinal distribution		
		Normal (%)	Flawed (%)	Double (%)
Management (M)				
T1	10.28 ab	82.25 ab	7.52 ab	10.21 ab
T2	10.96 a	81.88 ab	5.79 b	12.31 a
T3	9.20 bc	83.48 ab	8.68 ab	7.82 ab
T4	9.65 bc	82.08 ab	8.59 ab	9.31 ab
T5	9.03 bc	85.13 a	9.34 ab	5.51 b
T6	8.95 c	79.24 b	11.36 a	9.39 ab
F-test	8.17**	2.38 ^{ns}	3.05*	3.58*
CV (%)	5.78	24.83	26.56	3.06

^{NS}: not significant ($p>0.05$); *: significant ($p<0.05$); **: significant ($p<0.01$); CV: coefficient of variation. Means followed by the same lowercase letters in the column do not differ from each other by Tukey test at 5% probability. Plowing followed by two intermediate harrowing operations (T1), intermediate harrowing (T2), chiseling (T3), chiseling followed by intermediate harrowing (T4), cross chiseling followed by intermediate harrowing (T5), and non-tillage (T6).

The longitudinal distribution presented a significant effect on normal, flawed, and double spacings. The treatment cross chiseling followed by intermediate harrowing showed the highest index of normal spacings, which may be due to the lower amount of double spacings. On the other hand, the treatment non-tillage presented the lowest value of normal spacings, which may be due to a higher incidence of flawed spacings. Systems without soil tillage impaired the longitudinal distribution due to a smaller normal spacing and higher flawed spacing, which may be due to the presence of straw on the surface without any management.

Despite the significant effect on the number of plants per meter and longitudinal distribution, soybean yield did not show a significant effect on the management systems (Figure 4). The coefficient of variation was 11.65% for soybean yield, which is considered medium according to Carvalho et al. (2003), who classified as medium CV values higher than 8.2% and lower than or equal to 14.9% for soybean yield.

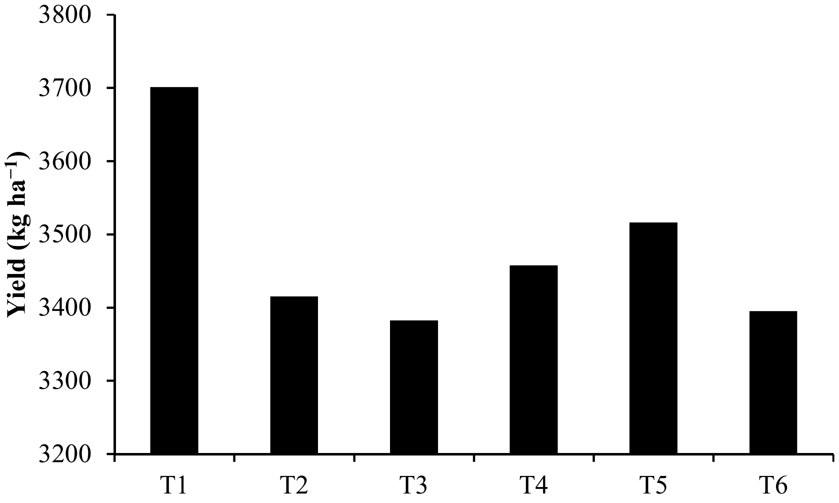

FIGURE 4. Soybean yield as a function of soil tillage systems. Plowing + two intermediate harrowing operations (T1), intermediate harrowing (T2), chiseling (T3), chiseling + intermediate harrowing (T4), cross chiseling + intermediate harrowing (T5), and non-tillage (T6). CV = 11.65%.

Restrictive values of resistance to penetration may not affect soybean development in years with adequate precipitation volumes, i.e., without water deficit. Marasca et al. (2011) found that although resistance to penetration presented values considered restrictive to root development, no negative influence on yield was observed. However, Cortez et al. (2017) found that the use of chisel plow in a no-tillage area for more than 10 years led to an increase of 25.64% in soybean yield due to a reduction in soil compaction.

CONCLUSIONS

The system without soil tillage provides the best straw preservation but affects the longitudinal distribution of soybean plants.

The use of intermediate harrowing for managing crop residues or soil tillage leads to the greatest compaction problems.

Chiseling is efficient in maintaining compaction below critical values up to a depth of 0.20 m when working at 0.35 m.

Soil yield is not affected by soil management systems when the pluviometric regime is adequate to crop requirements.

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