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SPATIAL VARIABILITY OF SOIL RESISTANCE TO PENETRATION IN NO TILLAGE SYSTEM

Jorge W. Cortez[1*], Wéliton P. da S. Matos[2], Sálvio N. S. Arcoverde[2], Victor H. Cavassini[2], Igor Q. M. Valente[3]

[1*]Corresponding author. Universidade Federal da Grande Dourados/ Dourados - MS, Brasil. E-mail: jorge.cortez@yahoo.com.br

KEYWORDS

soil compaction, agricultural mechanization, geostatistics.

ABSTRACT

In areas of no tillage system where there is intense traffic of machines and minimal soil mobilization, the periodic monitoring allied on localized soil compaction represent important strategies aiming agricultural sustainability. Thus, the objective of this study was to evaluate the spatial variability of soil resistance to penetration (RP) in no tillage system. Data collection took place in an experimental area of 7.65 ha using a sample grid composed of 40 points. At each point the RP was determined by three replications from which was obtained the mean RP, the maximum RP, and the depth of the maximum RP in the 0-0.40m layer. Deformed samples were randomly collected in the area to determine the water content in the soil (θ). Then the RP data were analyzed using descriptive and geostatistical statistics techniques for spatial variability maps. The RP presents spatial variability detected by means of spherical semivariogram in all soil layers. There was spatial variability in the area with the appearance of intermediate values for RP (2.00-3.00 MPa) due to no ploughing and continuous traffic of agricultural machines. There were greater reaches and critical levels of compaction on the layers 0.10-0.20 and 0.20-0.30 m where there is predominance of the maximum RP.

INTRODUCTION

The implementation of conservation management systems, such as no tillage system and reduced tillage, brings benefits to the conservation of natural resources, prioritizing the maintenance of vegetal residues on the surface and reducing soil movement. Among the benefits are the reduction of erosion and the increase of microorganism biological activity reflecting positively on soil quality and the profitability of agricultural activity.

In spite of this, the cultivation in no tillage system by not adopting the soil rotation can result in the formation of compacted layers. In addition to the minimum ploughing which is usually carried out only in the sowing line, the intense number of mechanized operations is also responsible for formation of compacted surface layers, especially when there is continuous traffic of machines on inadequate soil water content (Streck et al., 2004) which can affect soil quality and agricultural production (Bergamin et al., 2010a; Bergamin et al., 2010b).

The soil under ideal conditions for root development is homogeneously exploited by the roots plants, and the soil volume is relatively higher than in soils with compaction problems (Valadão et al., 2015). This is due to the fact that certain compaction states cause changes in the soil structure, resulting in increased soil density and soil resistance to penetration, as well as reduction of total porosity and soil macro porosity (Freddi et al., 2007; Bergamin et al., 2010a; Bergamin et al., 2010b; Valadão et al., 2015).

One of the parameters most used to evaluate the intensity of soil compaction is soil resistance to penetration (Oliveira Filho et al., 2015). Since it is a practical and complete parameter, also related to texture, soil density and soil water content, it has been used for the periodic monitoring of soil compaction status and as an indicator in the evaluation of the effects of management systems of the soil on root environment (Bergamin et al., 2010a; Bergamin et al., 2010b; Valadão et al., 2015).

Critical values of soil resistance to penetration may vary from 1.5 MPa to 4.0 MPa (Rosolem et al., 1999); although, in general, values close to 2 MPa are accepted as impediments to root growth. It has also been observed values of soil resistance to penetration critical to root

[2] Universidade Federal da Grande Dourados/ Dourados - MS, Brasil.
[3] Universidade Estadual de Campinas/ Campinas - SP, Brasil.
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development in no tillage system from 3.0 to 4.0 MPa (Vaz et al., 2011; Betioli Júnior et al., 2012; Guimarães et al., 2013). However, Marasca et al. (2011) evaluating the spatial variability of soil resistance to penetration in soybean in no tillage system verified values from 2.9 to 4.28 MPa which were not considered restrictive to crop production.

The analysis of the spatial behavior of the soil physical attributes through geostatistics allows to detect the variability and spatial distribution of the studied attributes and, with this, to evaluate and describe in a detailed way the variability of the soil attributes (Alves et al., 2014) being important in the management and control of crop production factors, as well as in environmental monitoring (Oliveira et al., 2013).

In view of the above, the objective of this study was to evaluate the spatial variability of soil resistance to penetration (RP) in no tillage system.

MATERIAL AND METHODS

The study was developed at the Experimental Farm of Agricultural Sciences at Federal University of Grande Dourados (UFGD) located in the municipality of Dourados – MS, Brazil between the geographic coordinates of 22º14' South latitude and 54º59' West longitude with an average altitude of 434 m. The climate is type AW, according to the classification of Köppen. The soil of the area is a Distroferric Red Latosol, which granulometric composition, according to the classification proposed by the United States Department of Agriculture (USDA) is presented in Table 1.

TABLE 1. Granulometry composition of the Dystrophic Red Latosol at Experimental Farm in UFGD.

Layers	Clay	Silte	Sand
(m)		g kg^{-1}	
0.00-0.10	597.8	217.3	184.9
0.10-0.20	592.6	222.4	185.0
0.20-0.30	623.1	197.9	179.1
0.30-0.40	628.3	202.3	169.4

In the experimental area it is cultivated as summer crop soybean (*Glycine max*) and as winter crop corn (*Zea mays*) in a system of succession of crops without ploughing in which the no tillage system on the straw has been adopted for more than 20 years. The area has 7.65 ha and was divided into a mesh with 40 sample points, using a navigation system that contoured the area and generated a sample mesh with a difference between points of 0.20 ha (approximately 45 m between points).

The determination of soil resistance to penetration (RP) was carried out by means of a digital penetrometer, model PenetroLOG® PLG1020, with electronic capability for data acquisition, according to ASAE S 313.3 (ASABE, 2006). The penetrometer is operated manually and depends on the strength of the rod operator; it is an equipment that has a sonar type sensor which indicates the depth and composes the calculation on the speed penetration and, on the other hand, also warns the user if the speed is out of the standard, canceling the measurement. This penetrometer has a CPU that stores the collected data and has a direct interface to computers, besides a display that allows the user to make settings and view the measurements made for penetration (Molin et al., 2012). The speed penetration of the rod was maintained close to 30 mm s^{-1}, according to instrumentation of the apparatus. A cone was used with a diameter of 12.83 mm and a penetration angle of 30°. The resolution of the equipment is 7.7 kPa and the maximum RP allowed is 7700 kPa (Cunha et al., 2009).

Data on the penetrometer were extracted from the digital memory and analyzed at a maximum depth of 0.40 m. With these data were obtained the mean and maximum stratified values in the layers 0-0.10; 0.10-0.20; 0.20-0.30 and 0.30-0.40 m, as well as the mean RP of the evaluated profile, the maximum RP of the profile 0-0.40 m and the depth of maximum RP.

The determination of RP was carried out at each sampling point where three measurements were made, in the culture interlayer, within a radius of up to 5 m from the marked point by the navigation system.

Deformed soil samples were collected in the experimental area randomly in the layers 0-0.10; 0.10-0.20; 0.20-0.30 and 0.30-0.40 m for determination of soil water content (θ) obtained by the thermogravimetric method. The mean data of θ were used for general characterization of the area in soil layers.

The RP data were analyzed through descriptive statistics, to allow a general visualization of the data behavior, as well as the normality of the data using the Ryan-Joiner test (Coelho et al., 2012). Then, the geostatistics analysis was performed to verify the spatial dependence of RP by the calculation of the semi variance and data adjustment to the semivariogram. The semivariograms were adjusted by the GS $^{+}$ program from which the models were selected based on the best coefficient of determination (r^2) and the smallest sum of squared residual being tested the spherical, exponential, Gaussian, linear models and linear without baseline and pure nugget effect. In the adjusted semivariograms the following parameters were defined: nugget effect (C_0); baseline (C_0 + C1) and range (A) (Marasca et al., 2011; Coelho et al., 2012; Bottega et al., 2013; Oliveira Filho et al., 2015; Nagahama et al., 2016).

Subsequently, interpolation was performed by ordinary kriging, which is an interpolation technique to estimate values on property in non-sampled locations. By means of kriging interpolation, the (two-dimensional) isoline maps were constructed for spatial detailing of the collected data using a 20 m interpolation grid.

RESULTS AND DISCUSSION

The values of soil water content (θ) in the layers 0.10-0.20; 0.20-0.30 and 0.30-0.40 m (Table 2) are above the range, according to Bottega et al. (2013), higher than that recommended for mechanized operations. It can be observed that there was an increase from θ to the layer of 0.20-0.30 m with higher average variation (13.0%) of its surface layer values (0.00 -0.10 and 0.10-0.20 m) for the layers of 0.20-0.30 and 0.30-0.40 m.

These results disagree with those found by Bottega et al. (2013) who working on dystroferric Red Latosol under no tillage system verified greater variation of θ values in the superficial layer, however it should be noted that other factors such as sampling time and organic matter content may influence this variation, as well as RP values.

TABLE 2. Water content in soil (θ) at the moment of the mechanical resistance of the soil to penetration (RP).

Layer (m)	Water content in soil (%)
0.00-0.10	23.37
0.10-0.20	23.94
0.20-0.30	27.11
0.30-0.40	26.50

In the summary of the descriptive statistical analysis for soil resistance to penetration (RP) in the different studied layers (Table 3), there is an increase in RP with depth up to the layer of 0.20-0.30 m, in which we found maximum levels of compaction. Cortez et al. (2014) point out that the lower RP found in the 0.0-0.10 m layer in relation to the underlying layers can be attributed to the deposition of organic matter that contributes to soil density reduction.

TABLE 3. Descriptive statistics of soil resistance to penetration (kPa).

Parameters	Layers (m)						
	0-0.10	0.10-0.20	0.20-0.30	0.30-0.40	General average	RP maximum	Depth of maximum RP
				Average layer value			
Average	1322.6	2658.6	2668.4	2397.4	2238.9	3526.9	21.38
SD	451.0	345.2	488.8	597.5	344.6	594.7	6.43
Variance	203400.3	119161.7	238959.0	357037.9	118751.0	353672.0	41.37
CV	34.10	12.98	18.32	24.92	15.39	16.86	30.09
Minimum	598.3	2163.7	2006.7	1594.0	1762.3	2657.3	11.00
Maximum	2316.7	3634.0	4209.7	4196.0	3346.0	4856.7	36.00
Asymmetry	0.49	0.81	1.38	1.16	1.36	0.71	0.46
Curtose	-0.65	0.19	1.79	1.35	2.10	-0.38	-0.19
Prob	>0.10	0.05	<0.01	<0.01	<0.01	0.03	>0.10
				Maximum Layer Value			
Average	2637.0	3117.5	3022.6	2725.0	2875.5	--	--
SD	764.0	449.2	495.8	647.0	427.6	--	--
Variance	583482.0	201805.6	245785.1	419103.0	182834.3	--	--
CV	28.96	14.41	16.40	23.76	14.87	--	--
Minimum	1585.0	2397.3	2190.7	1812.0	2245.0	--	--
Maximum	4496.0	4361.7	4539.7	4406.0	4042.7	--	--
Asymmetry	0.83	0.59	1.22	0.79	1.13	--	--
Curtose	-0.22	0.05	1.69	0.05	1.13	--	--
Prob	0.015	>0.10	<0.01	0.05	<0.01	--	--

*p≥0.05 normal, non-significant - symmetric data; ** p <0.05 non - normal, significant - asymmetric data. SD: standard deviation; CV: coefficient of variation; Prob: probability.

In general, the mean RP is low (<2.00 MPa), in the 0-0.10 m layer, the intermediate layer (2.00-3.00 MPa) in the other layers, below the critical levels (3.00-4.00 MPa) reported in research projects (Vaz et al., 2011; Betioli Júnior et al., 2012; Guimarães et al., 2013); although, according to Rossolem et al. (1999) restrictive values may range from 1.5 to 4.0 MPa as a function of culture. However, Secco et al. (2009) found that RP values close to 2 MPa are limiting to grain yield in maize in Dystrophic Red Latosol and Dystroferric Red Latosol; while Marasca et al. (2011) observed that critical RP levels in the order of 2.9 to 4.28 MPa in dystroferric Red Latosol did not prove to be limiting to soy production.

Also in Table 3 high amplitude is observed between the minimum and maximum RP values, 598.3 and 4209.7 kPa, in the layers 0-0.10 and 0.20-0.30 m, respectively, demonstrating that the inadequate traffic possibly influences the variability of the attribute which shows that there are critical points in the area which should receive differentiated management. Despite this large amplitude the coefficient of variation was low with the data following a normal distribution.

When analyzing the maximum value, it is possible to notice that the layers' values 0.10-0.20 and 0.20-0.30 m are just above 3 MPa, considered critical and limiting for both root development and maize crop production (Freddi et al., 2007). This can be explained by the increased traffic of the mechanized assemblies in the area in question. According to Valadão et al. (2015) there is positive correlation between RP and intensification of the traffic to the depth of 0.20 m in no tillage area.

According to Nogueira (2007), coefficient of variation greater than 35% reveals that the series is heterogeneous and the mean has little meaning; if it is greater than 65%, the series is very heterogeneous and the mean has no meaning, but if it is less than 35% the series is homogeneous and the mean has significance. In this case, this can be used as representative of the series in which it was obtained. Considering these data, the RP in the soil layers presented a homogeneous series (Table 3).

It should be noted that the values of standard deviation and variance (Table 3) were higher in the layers 0.20-0.30 and 0.30-0.40 m, showing that in these layers the variability of compaction degree is higher showing that the compaction effect by machine traffic is reflected in these regions; unlike that found by Bottega et al. (2013) which under similar condition to those on the present study, observed a decrease in these parameters with depth increase; that is, the highest RP values were found in the superficial layer.

The normality test indicated a normal distribution for the analyzed variables, even though this is not an assumption for the application of geostatistics. All variables presented values of asymmetry and kurtosis within the range of -2 and 2 (Table 3), which indicates that the data respect a normal distribution (Albiero et al., 2012; Melo et al., 2013; Silva et al., 2013).

From the semivariogram analysis for RP (Table 4) we observed the adjustment of the spherical model for the evaluated layers and for the analysis of the maximum resistances and the occurrence depths of maximum resistances throughout the evaluated area, agreeing with Cortez et al. (2014) when analyzing RP in Yellow Argisol under different intensities of tractor traffic. Similarly, Marasca et al. (2011), Oliveira Filho et al., (2015) and Nagahama et al. (2016) when evaluating spatial variability of RP verified a greater adjustment of the spherical model for soil physical attributes.

TABLE 4. Semivariogram adjusted data and cross-validation for soil resistance to penetration in the studied layers.

	Layers (m)						
	0.00-0.10	0.10-0.20	0.20-0.30	0.30-0.40	General average	RP max profile	Depth of the maximum RP
				Average layer value			
Model	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co+C	260788.98	194424.61	387278.52	551158.09	205236	528428.7	47.39
A (m)	443.96	584.01	469.96	422.92	475.28	477.72	432.40
				Maximum Layer Value			
Model	Spherical	Spherical	Spherical	Spherical	Spherical	--	--
Co	0.00	0.00	0.00	0.00	0.00	--	--
Co+C	774631.28	328269.36	425708.27	634859.60	317424	--	--
A (m)	472.26	578.61	512.18	441.09	501.16	--	--

Co: nugget effect; Co+C: baseline; A: range.

It is observed that the nugget effect presented zero value for all the attributes in the studied layers. Values of nugget effect close to zero were found by Bottega et al. (2013) and Nagahama et al. (2016) who pointed out that the occurrence of such values increases the accuracy of estimates through kriging. This is because the lower the proportion of the nugget effect in relation to the variogram baseline, the greater the continuity of the phenomenon and the variance of the estimate, and the greater the confidence that can be had in the estimation (Bottega et al., 2013).

As for the results obtained for the average RP in the layers there is variation of 422.92 m and 584.01 m which shows that the sample mesh could be at least 422.92 m of horizontal distance since it was used the distance of 45 m; that is, to obtain the same precision of data sampled, the meshes could have been of at least 422.92 m and maximum of 584.01m.

It should be noted that the highest reaches were obtained in the 0.10-0.20 and 0.20-0.30 m layers, demonstrating continuity of RP in these layers of the profile along the area, probably due to the traffic effect of machines that contributed to the formation of compacted layers in a more comprehensive way by the distribution of the exerted pressures on the surface of the soil (Freddi et al., 2007; Bergamin et al., 2010a; Bottega et al., 2013; Valadão et al., 2015).

In the isolines maps (Figure 1) with the mean and maximum RP values grouped into 6 color classes, we can verify the variability of RP within each layer along the area. It is observed a discrepancy in the maximum values of each layer, which indicates that in many cases, the average masks the results obtained within the study area. Thus, a higher concentration of areas in the map with values above 4,000 kPa is observed when the maximum value of the layer is used, and this will increase the area to be scarified / subsoiled. And since the aim of precision agriculture is to make the correct management, the use of maximum layer value allows better expression of compaction areas.

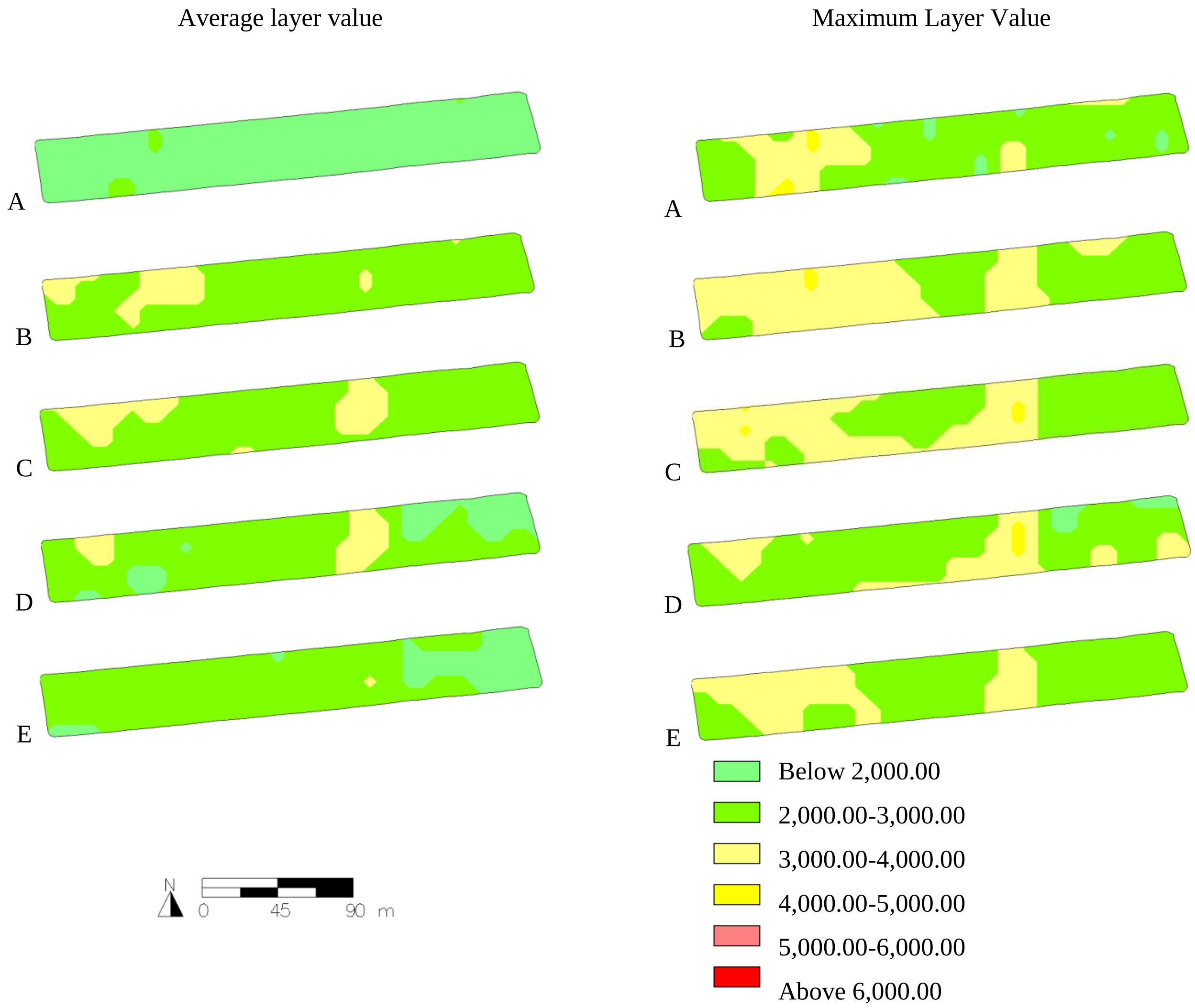

FIGURE 1. Penetration resistance (RP) maps using the average value of the layer and the maximum value. A - 0.00-0.10 m. B = 0.10-0.20 m. C = 0.20-0.30 m; D = 0.30-0.40 m; E - 0.00-0.40 m.

The evaluation based on the mean values of RP in the layers can lead to erroneous results regarding soil management procedures in the studied area. In this case, it overestimates the area with intermediate RP regions (2.00-3.00 MPa) which may compromise crop yield, since, according to Secco et al. (2009), corn suffers reduction of production when RP values are close to 3 MPa.

In the evaluated profiles it was observed that up to 0.30 m depth occurred critical RP levels (Figure 2), and in a punctual way up to the depth of 0.40 m, which indicates that there will be difficulty in root growth in the profile, mainly in corn crop as observed by Freddi et al. (2007), Bergamin et al. (2010a) and Bergamin et al. (2010b); since most of the area presented RP values close to 3 MPa.

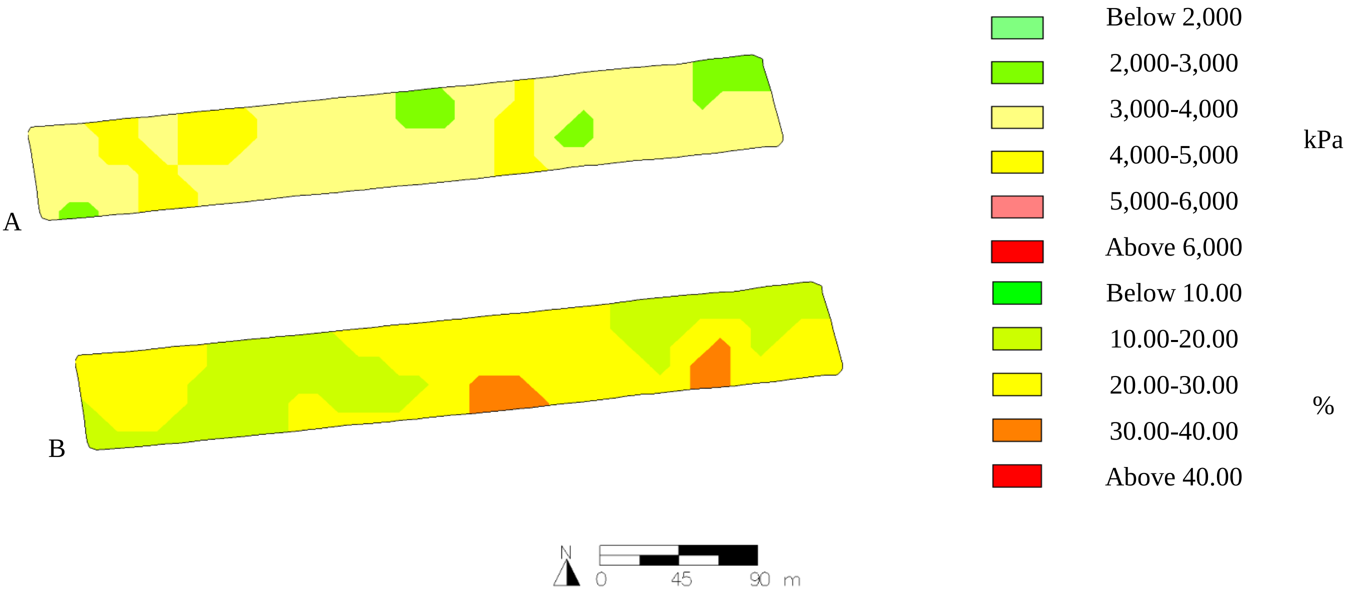

FIGURE 2. Maximum profile resistance (A) and depth (cm) of the maximum resistance in the soil profile (B).

Starting from the premise that a differentiated management must be carried out within the study area when analyzing Table 5 it is verified that in the layer 0.00-0.10 m high percentage of the occupied area (<2000 kPa), that is, in this first layer, the compaction level is low, but when using the maximum RP there is a displacement of the values, indicating that most of the area in the 0-0.10 m layer presents intermediate values of maximum RP (2,000-3,000 kPa), followed by critical RP values (3,000-4,000 kPa). The other layers presented most part of the area at intermediate RP levels (2,000-3,000 kPa), mainly in the layers 0.10-0.20 m, 0.20-0.30 and 0.30-0.40 m; the same occurred with maximum RP, except in the layer 0.10-0.20 m which presented higher percentage of value above 3,000 kPa.

TABLE 5. Percentage of occupied area in each class of penetration resistance.

RP (kPa)	Layers (m) 0.00-0.10	0.10-0.20	0.20-0.30	0.30-0.40	General average	RP maximum
			Average layer value			
<2,000	97.40	0.00	0.00	18.23	21.88	0.00
2,000 to 3,000	2.60	86.46	81.77	69.79	77.60	10.42
3,000 to 4,000	0.00	13.54	18.23	11.98	0.52	72.92
4,000 to 5,000	0.00	0.00	0.00	0.00	0.00	16.67
5,000 to 6,000	0.00	0.00	0.00	0.00	0.00	0.00
>6,000	0.00	0.00	0.00	0.00	0.00	0.00
			Maximum Layer Value			
<2,000	4.69	0.00	0.00	4.17	0.00	--
2,000 to 3,000	72.92	45.31	56.25	70.31	66.15	--
3,000 to 4,000	20.31	53.65	42.19	23.96	33.85	--
4,000 to 5,000	2.08	1.04	1.56	1.56	0.00	--
5,000 to 6,000	0.00	0.00	0.00	0.00	0.00	--
>6,000	0.00	0.00	0.00	0.00	0.00	--

Therefore, greater control over the area and on compacted layers allow to make exact decisions on the management to be adopted, as well as the implement to be used, aiming to reduce ploughing and avoiding possible compaction. However, in spite of being reported in researches that soybean does not suffer reduction on productivity in no tillage system with critical RP values on surface (Marasca et al., 2011; Valadão et al., 2015), that is, ranging from 3.0 to 4.0 MPa it is necessary differentiated management for the removal of the compacted layers, since this condition can restrict the root development of the corn (Freddi et al., 2007; Bergamin et al., 2010a; Bergamin et al., 2010b; Valadão et al., 2015) when doing succession with soybean.

Evaluating the percentage of occupied area by the maximum values of RP (Table 6) we found that in the layer <10 cm and > 40 cm, it had 0.0% occupied, that is, it had no evidence of compaction. However, in the other layers, compaction indexes were obtained, being layer 0.20-0.30 m comprising maximum RP values in 54.17% of the area, followed by the layer 0.10-0.20 m with 39.58% of the area and, finally, the layer 0.30-0.40 m with only 6.25%. Therefore, for the maximum RP in 100.00% of the area it is necessary to use the management in order to decompress the soil in layer 0.10-0.40 m.

TABLE 6. Percentage of area occupied by maximum RP values in each soil layer.

Depth of maximum RP	Percentage (%)
< 10 cm	0.00
10 to 20 cm	39.58
20 to 30 cm	54.17
30 to 40 cm	6.25
> 40 cm	0.00

The results of this study allow the identification and differentiation of regions with critical compaction levels which require localized soil management procedures aiming the decompaction of the soil at the most adequate depth and only where it is really necessary.

CONCLUSIONS

The soil resistance to penetration presents spatial variability detected by means of the spherical semivariogram in all the evaluated soil layers.

The resistance to penetration present spatial dependence in all layers within the sampling grid with the highest reaches in layers 0.10-0.20 and 0.20-0.30 m, in which critical levels have been verified, probably due to the continuous traffic of machines / implements.

The adoption of no tillage system and constant traffic of machines favors the appearance of intermediate values of soil resistance to penetration (2.00-3.00 MPa), in most of the area.

In most of the area, soil resistance to maximum penetration is in the layers 0.20-0.30 and 0.10-0.20 m, respectively.

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