ANALYSIS OF PENETRATION RESISTANCE OF A OXISOL UNDER ADDITIONAL COMPACTION IN NO-TILLAGE

ARCOVERDE, Sálvio Napoleão Soares[1]
SOUZA, Cristiano Márcio Alves de[2]

Recebido em: 2023.05.06 **Aprovado em:**2023.06.23 **ISSUE DOI:** 10.3738/1982.2278.4107

SUMMARY: Soil penetration resistance is an important indicator of soil compaction. Knowing the precise location of layers with increased resistance to penetration can aid in the mechanical management of soil. In this context, the objective of this study was to analyze the soil penetration resistance of a Dystroferric Red Latosol, under no-tillage system with additional compaction due to tractor traffic, using multivariate factor analysis. Compaction states were induced with tractor traffic in a no-tillage area in 0, 2, 4, 6, 8, and 12 passes of an agricultural tractor. The tractor used was the NH 8030 model, with an engine power of 89.79 kW (122 hp). It had diagonal tire wheels with an inflation pressure of 83 kPa on the front tires (14.9-28 R1) and 83 kPa on the rear tires (23.1-30 R1). Additionally, a mass of 7.28 Mg was applied to the soil with each tractor pass. An electronic penetrometer was used to evaluate the soil resistance, with 10 points being taken in each experimental plot. Simultaneously, deformed structure samples were collected to determine soil moisture. Multivariate factor analysis was used as a tool to analyze soil penetration resistance, seeking to determine its stratification up to 0.40 m depth. Factor analysis applied to the study of soil with different tractor traffic intensities allows the identification of layers of growth, transition, reduction, and stabilization of soil resistance to penetration at depth. Soil layers associated with management with furrows in previous crops were identified, as well as compacted surface soil layers induced by tractor traffic compaction, in addition to layers with stabilization at depth, possibly associated with pedogenetic factors.

Keywords: Soil layer. No-tillage. Tractor traffic.

ANÁLISE DA RESISTÊNCIA À PENETRAÇÃO DE UM LATOSSO VERMELHO DISTROFÉRRICO SOB COMPACTAÇÃO ADICIONAL EM PLANTIO DIRETO

RESUMO: A resistência do solo à penetração consiste em um indicador importante da compactação do solo. Saber com precisão a localização de camadas de crescimento de resistência à penetração pode auxiliar no manejo mecânico do solo. Nesse contexto, o objetivo desse trabalho foi analisar a resistência do solo à penetração de um Latossolo Vermelho Distroférrico, em sistema plantio direto, sob compactação adicional por tráfego de trator, utilizando-se análise multivariada do tipo fatorial. Em área com plantio direto foram induzidos estados de compactação com tráfego de trator em 0, 2, 4, 6, 8 e 12 passagens de trator agrícola, modelo NH 8030 com potência do motor de 89,79 kW (122 hp), rodados diagonais com pressão de inflação de 83 kPa nos pneus dianteiros (14.9-28 R1) e 83 kPa nos pneus traseiros (23.1-30 R1) e 7,28 Mg de massa no solo a cada passagem do trator. Utilizou-se um penetrômetro eletrônico para avaliar a resistência do solo, sendo feitos 10 pontos em cada parcela experimental. Simultaneamente, foram coletadas amostras com estrutura deformada para determinar a umidade do solo. A análise multivariada do tipo fatorial foi utilizada como ferramenta para analisar a resistência do solo à penetração, buscando determinar a estratificação da mesma até 0,40 m de profundidade. As análises de fatores aplicados ao estudo de solo com diferentes intensidades de tráfego de trator, permitem identificar camadas de crescimento, de transição, de redução e de estabilização de resistência do solo à penetração em profundidade. Identificaram-se camadas de solo associadas ao manejo com sulcadores, em culturas antecessoras; camadas compactadas de solo em superfície pela indução da compactação com tráfego de trator, além de camadas com estabilização em profundidade, possivelmente associadas a fatores pedogenéticos.

Palavras-chave: Camada de solo. Semeadura direta. Tráfego agrícola.

---

[1] ORCID- https://orcid.org/0000-0002-0453-4566 Engenheiro Agrícola e Ambiental. Msc. em Engenhara Agrícola. Dr. em Agronomia (Produção vegetal) – UFGD.

[2] ORCID- https://orcid.org/0000-0002-5347-1709 – UFGD.

INTRODUCTION

The adoption of the no-tillage system is essential for the conservation of natural resources and the increase and maintenance of high production levels. However, despite these benefits, soil compaction problems related to machine traffic have been reported (VALADÃO *et al*., 2015; TRENTIN *et al*. 2018).

Soil compaction is considered the main factor responsible for limiting agricultural production since it increases soil density values and soil resistance to penetration, as well as reduces total porosity and soil macroporosity (TORRES *et al*., 2015; VALADÃO *et al*., 2015; ARCOVERDE *et al*., 2019).

The increase in soil resistance to penetration has been attributed to greater compaction induced by tractor wheel pressure, whose effect is limited to the superficial layer of the Dystroferric Red Latosol (BERGAMIN *et al*., 2010; BAIO *et al*., 2017).

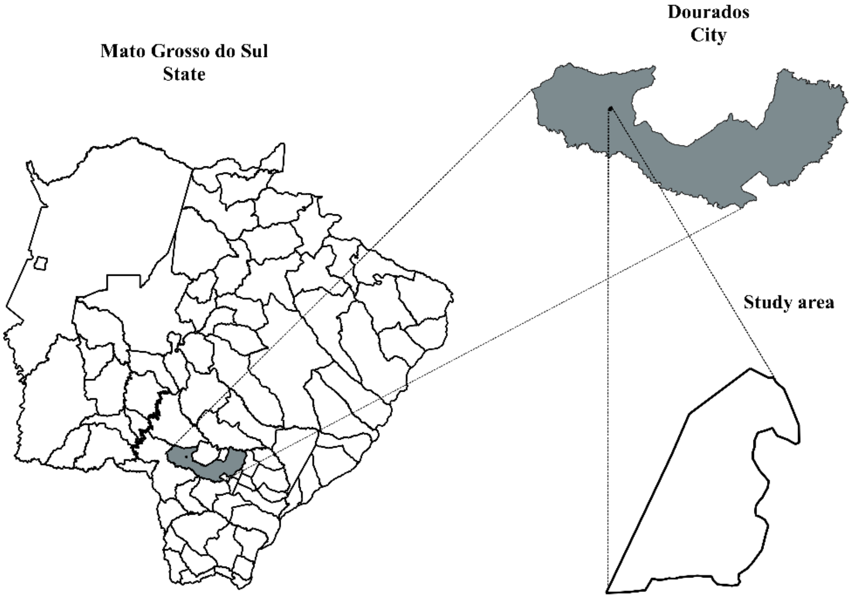
The identification of compacted layers with information on soil resistance to penetration can assist in mechanical soil management, aiming for precise decompaction with the lowest operational cost and soil conservation. Multivariate statistical techniques, such as factor analysis, have proven to be efficient in visualizing soil layers with higher or lower resistance to penetration, which may indicate compacted layers (WEIRICH NETO *et al*., 2006).

In this context, the objective of this study was to analyze soil resistance to penetration (RP) of a Oxisol under no-tillage system and additional compaction by tractor traffic, using multivariate factor analysis.

MATERIAL AND METHODS

The experiment was carried out from November 2018 to March 2019 at the Experimental Farm of Agricultural Sciences of the Federal University of Grande Dourados, Dourados, MS, Brazil (Figure 1). The location is at a latitude of 22°14'S, a longitude of 54°59'W, and an altitude of 434 m. The climate of the region is of the Am type, monsoon, with a dry winter, and an average annual precipitation of 1500 mm, and an average annual temperature of 22°C (ALVARES *et al*., 2013). The soil is classified as Oxisol (SANTOS *et al*., 2018), having in the layer from 0.00 to 0.20 m, 60% clay, 15% silt, and 25% sand. The area has been cultivated for approximately ten years with soybean (*Glycine max*) in the summer and corn (*Zea mays*) in the second crop in succession.

Figure 1. Location of experimental area in municipality of Dourados, MS, Brazil.



The experimental design was a randomized block design, with treatments consisting of no-till for ten years and additional induced states of compaction due to tractor traffic in no-till at two, four, six, eight, and twelve passes, with five repetitions, totaling 30 experimental plots. Each plot consisted of 9 rows of soybeans, 10 m long, spaced 0.45 m apart, with a total area of 40.5 m^2.

The additional compaction was performed when the soil had a water content in the layer from 0.00 to 0.20 m of 26.0 ± 1.5%, using the NH 8030 agricultural tractor model with an engine power of 89.79 kW (122 hp), with diagonal tire wheels, a rear track of 1.73 meters, a front track of 1.83 meters, and a weight of 6.78 Mg with ballast and inflation pressure of 83 kPa on the front tires (14.9-28 R1) and 83 kPa on the rear tires (23.1-30 R1), with 43% of the weight distributed on the front axle and 57% on the rear axle. To ensure the additional compaction states, a 0.5 Mg mass cutter was attached to the three-point hydraulic system of this tractor, which corresponded to 7.28 Mg of mass on the soil at each tractor pass. The contact pressure of the front and rear tires with the soil was 113 and 109 kPa.

The tractor's displacement to induce soil compaction states was performed in the 3rd reduced gear at a rotation of 2200 rpm and a speed of 5.3 km h^{-1}, over the entire surface of the plot, so that the tires compressed areas parallel to each other, with the number of passes depending on the state of compaction. The traffic was overlapped with the previous one so that the entire area of each plot was traveled an equal number of times (VALADÃO *et al*, 2015). At the time of inducing soil compaction states, the average amount of dry matter on the soil surface was 7.54 ± 1.83 t ha^{-1}, reflecting the homogeneity of the experimental area.

In the useful area of each plot, the soil's mechanical resistance to penetration (RP) test was performed, using the PenetroLOG - PLG 1020 field penetrometer, with electronic data acquisition capability. Ten sampling points were taken in the soybean crop rows. After the RP determinations, the data stored in the penetrometer CPU were extracted and analyzed to a maximum depth of 0.40 m. Simultaneously with the RP determinations, stratified deformed soil samples in the layers of 0-0.10, 0.10-0.20, 0.20-0.20-0,30 e 0.30-0.40 m Soil samples were collected at different depths to determine the soil water content using the gravimetric method.

For the RP data for each cm of depth (0-40 cm), a multivariate analysis was performed using the factor analysis method through Statistica 7.0 software. Each depth interval was considered as an independent variable, and the execution of the multivariate factor analysis aimed to group depth intervals (independent variables) whose RP values presented similar variability. For this purpose, the analysis determined the correlation between the RP values in each depth interval and one of the factors. When this correlation showed high values, it was interpreted that the layers varied together, i.e., there is a tendency to form a layer (WEIRICH NETO *et al*., 2006).

When the correlation coefficients of the factors between the studied values were above 0.5 and they were similar, it was interpreted as the formation of a layer. Only factors with relative variance above 10% were analyzed, avoiding low values of little practical explanation. To obtain a simpler and more easily interpretable factor structure (FIGUEIREDO FILHO; SILVA JUNIOR, 2010), the orthogonal rotation method of the data, called Varimax (ARCOVERDE *et al*., 2015; SALVIANO *et al*., 2018), was used to redistribute the variances.

To facilitate data interpretation, the communality and eigenvalue were determined along with the Factor. The communality is the total amount of variance that an original variable shares with all other variables included in the analysis. A communality value below 0.50 identifies variables with insufficient explanation (FIGUEIREDO FILHO; SILVA JUNIOR, 2010). The eigenvalue represents the amount of variance given by a Factor, according to Kaiser's rule. Thus, the number of factors with eigenvalues above 1.0 was determined (SILVA *et al*., 2016). The correlation coefficient of the factors linearly represents the original variables generated from the RP data, with values above 0.50 interpreted as having practical significance.

RESULTS AND DISCUSSION

It can be observed in the 0-40 cm soil layer that the average values of soil water content are similar, except for the treatment with 6 tractor passes which obtained a lower value, which may explain the higher values of mean RP and maximum RP (Table 1). However, when the soil water content was higher (0 and 12 tractor passes), lower values of mean RP and maximum RP were observed.

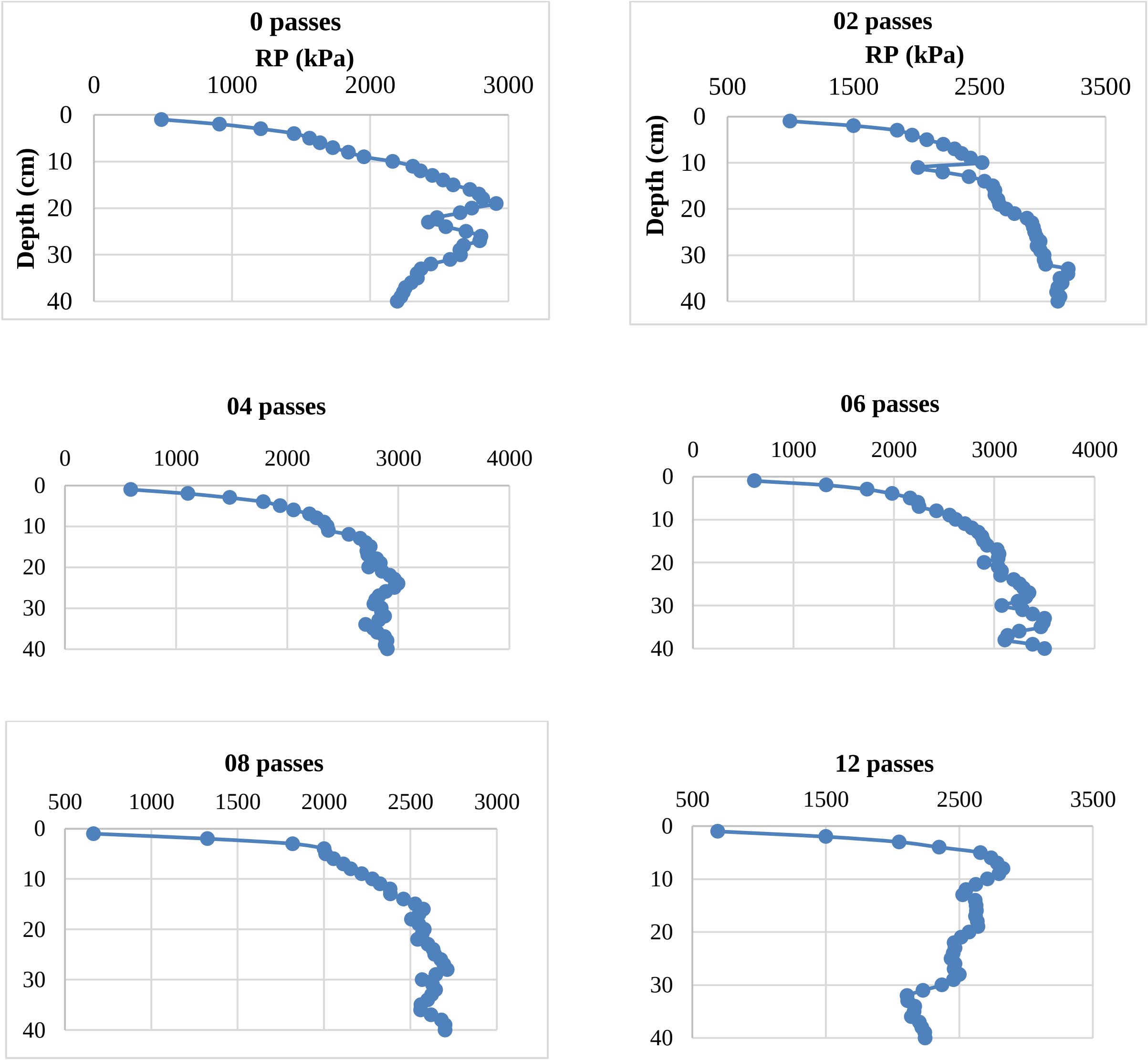
Furthermore, when analyzing Table 1, it can be observed that only the treatment with 12 passes obtained the maximum RP in the first 10 cm of soil, while in the other tractor traffic intensity treatments, it was observed between 19 and 33 cm.

Table 1. Mean (kPa), standard deviation (SD), maximum soil resistance to penetration (RP Max.; kPa), depth of maximum soil resistance to penetration (Prof. Max.; cm), and water content in the 40 cm soil layer (U, g g^{-1}), under tractor traffic intensities.

	Number of tractor passes					
	0	2	4	6	8	12
Média	2271.29	2647.17	2555.05	2858.86	2402.05	2389.82
DP	544.64	500.012	529.50	619.47	404.57	378.99
RP Max.	2912.56	3205.27	2998.20	3503.00	2713.13	2829.13
Prof.	19	33	24	33	28	8
U	0.27	0.26	0.26	0.24	0.26	0.27

The RP along the depth in the six tractor traffic intensities indicates differentiated behavior in general between the treatment without additional compaction (0 passes) and the other treatments (Figure 2). It was observed, in the layer (0-10 cm), RP values above 2000 kPa in the treatments with additional compaction and lower values in the treatment with 0 passes. In the treatments with a higher number of tractor passes (8 and 12), there was a greater variation in RP values in the layer (0-10 cm), followed by stabilization, especially with 12 passes.

Figure 2. Soil penetration resistance in Oxisol cultivated with soybean under no-till system and different tractor traffic intensities.



In Table 2, the five factors and their attributed variance, as well as the comminality of the studied depth for the RP values sampled between the rows of the culture without additional compaction (0 tractor pass), are presented. Two soil layers can be identified according to the first three factors. The first factor (Factor 1), which represents 53.78% of the total variance, clearly demonstrates the existence of a layer from 7 to 22 cm, which, according to Weirich Neto *et al.* (2006), is characterized by the contact between the furrow opening system and the soil, with the latter serving as support for the system.

With 21.6% of the variance, the second factor characterizes the existence of a layer from 30 to 40 cm, depth where the previously used soil preparation tends not to interfere, that is, where pedogenetic phenomena are responsible for the characterization of such layer.

The third factor, which represents a variance of 11.60% of the total, defines a layer from 0 to 5 cm, which is a reflection of the soil disorganization in this layer by the furrow opening mechanism for seed deposition in previous years.

Table 2. Correlation coefficients of soil penetration resistance at depths and factors (Factor 1, Factor 2, etc.) and communalities, between the seed rows without additional tractor passes (0 pass) in an orthogonal rotation under no-till system. **(Continua)**

			0 pass			
Depth(cm)	F1	F2	F3	F4	F5	Commonalities
0-1	-0.354	0.15	**-0.79**	0.051	-0.037	0.776
1-2	-0.150	0.055	**-0.949**	0.011	0.059	0.928
2-3	-0.086	0.009	**-0.937**	-0.047	0.025	0.887
3-4	0.026	-0.121	**-0.902**	-0.002	-0.236	0.883
4-5	-0.088	-0.029	**-0.711**	-0.157	-0.592	0.888
5-6	0.061	0.079	-0.45	-0.23	-0.769	0.856
6-7	0.226	-0.075	-0.111	-0.053	-0.927	0.93
7-8	**0.511**	-0.1	0.177	0.193	-0.723	0.863
8-9	**0.670**	0.001	0.204	0.389	-0.394	0.797
9-10	**0.770**	0.159	0.215	0.379	-0.3	0.898
10-11	**0.875**	0.251	0.117	0.209	-0.237	0.942
11-12	**0.897**	0.254	0.025	0.16	-0.221	0.945
12-13	**0.831**	0.224	0.005	0.301	-0.211	0.876
13-14	**0.835**	0.194	0	0.333	-0.176	0.877
14-15	**0.908**	0.22	0	0.255	-0.118	0.951
15-16	**0.931**	0.188	0.047	0.274	-0.047	0.98
16-17	**0.916**	0.211	0.1	0.256	0.011	0.959
17-18	**0.885**	0.175	0.119	0.325	0.052	0.936
18-19	**0.843**	0.162	0.126	0.368	0.057	0.892
19-20	**0.766**	0.445	0.084	0.189	0.128	0.844
20-21	**0.742**	**0.5**	0.116	0.133	0.123	0.846
21-22	**0.508**	**0.715**	0.217	-0.081	0.106	0.834
22-23	0.433	**0.782**	0.224	0.127	0.054	0.868
23-24	0.485	**0.669**	0.091	0.435	0.012	0.88
24-25	0.462	0.422	-0.012	0.742	0.004	0.942
25-26	0.430	0.275	-0.044	0.844	0.007	0.974
26-27	0.378	0.227	-0.007	0.889	0.042	0.986
27-28	0.332	0.464	0	0.792	0.074	0.957
28-29	0.326	0.396	0.028	0.848	0.037	0.983
29-30	0.351	0.333	0.084	0.852	0.008	0.967
30-31	0.338	**0.513**	0.108	0.761	-0.013	0.967
31-32	0.135	**0.859**	0.065	0.432	0.016	0.946
32-33	0.05	**0.934**	0.054	0.3	0.027	0.967
33-34	0.034	**0.955**	0.053	0.238	0.066	0.977
34-35	0.102	**0.923**	0.001	0.255	0.048	0.929
35-36	0.16	**0.9**	-0.08	0.303	0.04	0.936
36-37	0.205	**0.894**	-0.06	0.274	0.006	0.92
37-38	0.258	**0.905**	-0.136	0.179	-0.031	0.936
38-39	0.343	**0.889**	-0.1	0.167	-0.084	0.953

Table 2. Correlation coefficients of soil penetration resistance at depths and factors (Factor 1, Factor 2, etc.) and communalities, between the seed rows without additional tractor passes (0 pass) in an orthogonal rotation under no-till system. **(Conclusão)**

	0 pass					
Depth(cm)	F1	F2	F3	F4	F5	Commonalities
39-40	0.418	**0.836**	-0.15	0.1	-0.156	0.93
Eigenvalues	21.514	6.051	4.642	2.765	1.655	
%Variance	53.784	15.127	11.605	6.911	4.137	

The first factor (Factor 1), which represents 43.71% of the total variance, demonstrates the existence of a layer between 22 and 40 cm (Table 3), possibly originating from pedogenic processes, as in no-till planting, there is only superficial soil mobilization by the furrow openers, and soil preparation does not usually reach deeper layers.

With 33.93% of the variance, the second factor characterizes the existence of a layer from 0 to 15 cm, whose increase in RP up to 10 cm can be explained by external forces resulting from management practices. The decrease in RP possibly occurs due to the dissipation of pressure from tractor wheel traffic being more prominent in the soil surface layer (BERGAMIN *et al*., 2010).

Factor 3, with 12.12% of the variance, demonstrates the existence of an intermediate layer from 10 to 22 cm, which may be a reflection of previous management practices or, as reported by Weirich Neto *et al*. (2006), a residual effect, as well as the influence of a transition zone between the A and B horizons of the soil, which is characteristic of deep and well-formed Oxisols.

Table 3. Correlation coefficients of soil penetration resistance at depths and factors (Factor 1, Factor 2, etc.) and communalities, between sowing rows with two additional passes (2 passes) and (4 passes) of agricultural tractor, with orthogonal rotation, under no-tillage. **(Continua)**

	---------------------- 02 passes --------------------				---------------------- 04 passes ----------------------		
Depth (cm)	F1	F2	F3	Commonalities	F1	F2	Commonalities
0-1	0.051	**0.924**	-0.261	0.943	-0.137	0.502	0.816
1-2	0.087	**0.924**	-0.268	0.935	-0.152	0.296	0.836
2-3	0.016	**0.96**	-0.173	0.951	0.043	0.124	0.926
3-4	-0.004	**0.972**	-0.154	0.972	0.18	0.115	0.939
4-5	0.064	**0.957**	-0.163	0.95	0.12	0.419	0.924
5-6	0.108	**0.963**	-0.117	0.957	0.093	**0.669**	0.838
6-7	0.141	**0.96**	-0.049	0.952	0.088	**0.791**	0.891
7-8	0.156	**0.958**	0.099	0.97	0.052	**0.891**	0.918
8-9	0.173	**0.953**	0.106	0.962	0.31	**0.851**	0.884
9-10	0.058	**0.935**	0.135	0.899	0.264	**0.913**	0.947
10-11	-0.025	**-0.698**	**0.603**	0.881	0.217	**0.903**	0.873
11-12	-0.048	**-0.702**	**0.614**	0.901	**0.515**	**0.69**	0.951
12-13	0.024	**-0.654**	**0.676**	0.895	**0.627**	**0.501**	0.907

Table 3. Correlation coefficients of soil penetration resistance at depths and factors (Factor 1, Factor 2, etc.) and communalities, between sowing rows with two additional passes (2 passes) and (4 passes) of agricultural tractor, with orthogonal rotation, under no-tillage. **(Conclusão)**

	----------------------- 02 passes ---------------------				----------------------- 04 passes -----------------------		
Depth (cm)	F1	F2	F3	Commonalities	F1	F2	Commonalities
13-14	0.071	**-0.633**	**0.67**	0.865	**0.681**	0.401	0.882
14-15	0.175	**-0.557**	**0.745**	0.9	**0.734**	0.469	0.947
15-16	0.175	-0.431	**0.852**	0.953	**0.861**	0.358	0.945
16-17	0.081	-0.304	**0.92**	0.959	**0.895**	0.277	0.929
17-18	0.196	-0.105	**0.936**	0.941	**0.93**	0.213	0.933
18-19	0.254	0.041	**0.905**	0.904	**0.94**	0.099	0.963
19-20	0.33	0.037	**0.882**	0.965	**0.663**	-0.128	0.555
20-21	0.225	0.086	**0.842**	0.909	**0.838**	-0.042	0.957
21-22	0.463	0.093	**0.668**	0.936	**0.8**	0.057	0.94
22-23	**0.671**	0.139	0.329	0.974	**0.761**	0.143	0.919
23-24	**0.764**	0.2	0.165	0.982	**0.709**	0.136	0.868
24-25	**0.801**	0.128	0.175	0.992	**0.595**	0.126	0.87
25-26	**0.851**	0.035	0.142	0.989	0.464	0.152	0.858
26-27	**0.895**	-0.019	0.082	0.987	0.424	0.164	0.892
27-28	**0.919**	-0.021	0.08	0.983	0.376	0.165	0.965
28-29	**0.944**	0	0.02	0.988	0.365	0.184	0.965
29-30	**0.96**	0.094	0.023	0.989	0.346	0.2	0.952
30-31	**0.781**	-0.282	-0.056	0.742	0.392	0.204	0.938
31-32	**0.986**	-0.096	0.057	0.986	0.357	0.208	0.939
32-33	**0.952**	0.132	0.024	0.954	0.321	0.109	0.968
33-34	**0.971**	0.076	0.082	0.978	0.366	-0.163	0.826
34-35	**0.973**	0.079	0.164	0.979	0.343	0.102	0.963
35-36	**0.962**	0.129	0.172	0.973	0.252	0.196	0.993
36-37	**0.947**	0.122	0.249	0.974	0.203	0.18	0.993
37-38	**0.924**	0.163	0.235	0.939	0.243	0.142	0.984
38-39	**0.911**	0.139	0.253	0.915	0.249	0.148	0.982
39-40	**0.898**	0.079	0.262	0.885	0.229	0.159	0.974
Eigenvalues	17.485	13.573	4.85		23.891	5.678	
%Variance	43.714	33.933	12.125		57.827	14.056	

For 4 passes of tractor, the first factor (Factor 1), which represents 57.82% of the total variance, demonstrates the existence of a layer between 11 and 25 cm (Table 3), which may be a reflection of the previous management adopted over the years with no-till farming. The second factor, with 14.05%, demonstrates the formation of a layer between 6 and 13 cm, which may be attributed to the action of soil furrowing mechanisms on the surface in previous crops, which aim to obtain a more cohesive seedbed in the superficial layer of the soil, where there is a tendency for an increase in RP values in no-till farming (SECCO *et al.*, 2009).

The layers formed according to the factor analysis in the treatments with 6 and 8 passes of the tractor (Table 4), where their respective factor 1 showed the formation of a layer below 17 cm depth, possibly attributed to pedogenetic processes; while factor 2 showed the formation of a layer growing between 5 and 12 cm, related to the lower slope of RP due to surface soil compaction (Figure 2), which also occurred with 4 tractor passes.

Table 4. Correlation coefficients of soil penetration resistance at depths and factors (Factor 1, Factor 2, etc.) and communalities, between sowing rows with six additional passes (6 passes) and (8 passes) of agricultural tractor, with orthogonal rotation, under no-tillage.

	----------------------- 6 passes ---------------------			----------------------- 8 passes -----------------------		
Depth (cm)	F1	F2	Commonalities	F1	F2	Commonalities
0-1	-0.079	-0.526	0.576	-0.140	-0.08	0.811
1-2	-0.103	0.014	0.942	-0.140	-0.11	0.811
2-3	0.012	0.205	0.966	-0.051	0.23	0.707
3-4	0.079	0.316	0.927	-0.024	**0.651**	0.81
4-5	0.061	0.487	0.918	-0.021	**0.924**	0.922
5-6	0.161	**0.621**	0.763	-0.007	**0.954**	0.926
6-7	0.468	**0.559**	0.836	0.105	**0.963**	0.979
7-8	0.109	**0.916**	0.927	0.204	**0.933**	0.934
8-9	-0.08	**0.942**	0.915	0.253	**0.923**	0.95
9-10	0.002	**0.881**	0.924	0.264	**0.897**	0.967
10-11	0.028	**0.74**	0.914	0.266	**0.809**	0.961
11-12	0.185	**0.543**	0.821	0.324	**0.614**	0.929
12-13	0.205	0.319	0.911	0.288	0.253	0.94
13-14	0.308	0.1	0.956	0.225	0.132	0.96
14-15	0.351	-0.15	0.941	0.188	0.114	0.963
15-16	0.441	-0.147	0.913	0.237	0.107	0.97
16-17	**0.555**	-0.046	0.94	0.278	0.168	0.966
17-18	**0.568**	0.035	0.909	0.414	0.312	0.969
18-19	**0.53**	0.052	0.926	**0.527**	0.219	0.968
19-20	**0.316**	-0.213	0.8	**0.633**	0.223	0.971
20-21	**0.554**	-0.234	0.902	**0.712**	0.203	0.985
21-22	**0.672**	-0.329	0.794	**0.787**	0.209	0.969
22-23	**0.593**	-0.329	0.636	**0.783**	0.22	0.966
23-24	**0.755**	-0.074	0.772	**0.809**	0.213	0.943
24-25	**0.837**	-0.056	0.832	**0.8**	0.252	0.923
25-26	**0.907**	-0.052	0.948	**0.817**	0.277	0.937
26-27	**0.919**	0.008	0.951	**0.878**	0.224	0.97
27-28	**0.978**	0.033	0.977	**0.905**	0.222	0.972
28-29	**0.82**	0.167	0.959	**0.847**	0.325	0.954
29-30	0.04	0.253	0.903	0.353	0.369	0.649
30-31	**0.818**	0.104	0.915	**0.848**	0.168	0.871
31-32	**0.905**	0.087	0.955	**0.906**	0.124	0.916
32-33	**0.946**	0.075	0.964	**0.926**	0.043	0.951
33-34	**0.902**	0.083	0.945	**0.929**	0.067	0.939
34-35	**0.893**	0.043	0.948	**0.93**	0.05	0.923
35-36	**0.745**	0.114	0.909	**0.922**	-0.007	0.931
36-37	0.246	0.156	0.835	**0.895**	-0.008	0.919
37-38	-0.071	0.174	0.864	**0.898**	0.05	0.955
38-39	0.761	0.117	0.712	**0.894**	0.073	0.972
39-40	0.852	0.066	0.812	**0.914**	0.05	0.979
Eigenvalues	18.648	7.218		22.79	6.385	
%Variance	46.619	18.045		56.976	15.963	

The first factor (Factor 1), which represents 49.48% of the total variance, demonstrates the existence of a layer between 26 and 35 cm (Table 5), which can be attributed to the transition from the A to B horizon typical of Latosols. The factor 2, with 15.96%, demonstrates the formation of a more compacted layer between 3 and 9 cm, and according to factor 3, with 11.68% of variance, the formation of the layer between 9 and 20 cm evidences the influence of the contact between the furrow opening system and the soil, with the latter serving as support (WEIRICH NETO *et al.*, 2006). It should be noted that this fact also occurred in the other treatments, which evidences the strong influence of the agricultural management employed in previous crops.

Table 5. Correlation coefficients of soil resistance to penetration at depths and factors (Factor 1, Factor 2, etc.) and communalities, between sowing rows with twelve additional tractor passes (12 passes), with orthogonal rotation, under no-tillage. **(Continua)**

			12 passes			
Depth (cm)	F1	F2	F3	F4	F5	Commonalities
0-1	0.134	-0.376	0.449	0.503	-0.19	0.65
1-2	0.121	-0.183	0.259	0.866	-0.074	0.871
2-3	0.098	0.387	-0.067	0.864	-0.027	0.911
3-4	0.071	**0.771**	-0.135	0.532	-0.092	0.91
4-5	0.168	**0.889**	-0.036	0.288	-0.219	0.95
5-6	0.032	**0.931**	-0.009	0.118	-0.082	0.889
6-7	-0.057	**0.971**	-0.073	-0.051	-0.057	0.957
7-8	0.166	**0.87**	-0.019	-0.19	-0.131	0.837
8-9	0.149	**0.79**	0.226	-0.47	0.043	0.92
9-10	0.286	0.483	**0.645**	-0.448	0.187	0.968
10-11	0.513	0.079	**0.761**	-0.251	0.137	0.93
11-12	0.354	-0.007	**0.833**	-0.235	0.31	0.97
12-13	0.243	-0.111	**0.896**	-0.172	0.272	0.978
13-14	0.214	-0.07	**0.93**	-0.081	0.198	0.962
14-15	0.155	0.091	**0.946**	0.007	0.188	0.963
15-16	0.132	0.088	**0.922**	0.111	0.185	0.922
16-17	0.107	-0.054	**0.919**	0.239	0.184	0.95
17-18	0.187	-0.066	**0.879**	0.262	0.18	0.913
18-19	0.247	-0.123	**0.851**	0.194	0.323	0.942
19-20	0.282	-0.138	**0.629**	0.099	0.605	0.869
20-21	0.187	-0.233	0.495	0.053	0.748	0.896
21-22	0.117	-0.282	0.321	-0.006	0.81	0.853
22-23	0.114	-0.291	0.234	-0.015	0.836	0.851
23-24	0.142	-0.194	0.212	-0.118	0.873	0.879
24-25	0.19	-0.202	0.123	-0.248	0.87	0.91
25-26	0.4	-0.15	0.081	-0.282	0.8	0.909
26-27	**0.558**	-0.128	0.04	-0.291	0.674	0.867
27-28	**0.723**	-0.09	0.079	-0.284	0.556	0.928

Table 5. Correlation coefficients of soil resistance to penetration at depths and factors (Factor 1, Factor 2, etc.) and communalities, between sowing rows with twelve additional tractor passes (12 passes), with orthogonal rotation, under no-tillage. **(Conclusão)**

12 passes						
Depth (cm)	F1	F2	F3	F4	F5	Commonalities
28-29	**0.791**	0.035	0.241	-0.156	0.479	0.938
29-30	**0.865**	0.118	0.308	-0.019	0.269	0.929
30-31	**0.928**	0.125	0.15	0.027	0.116	0.914
31-32	**0.888**	0.125	0.232	0.14	0.158	0.903
32-33	**0.856**	0.089	0.36	0.17	0.253	0.963
33-34	**0.805**	0.027	0.401	0.181	0.366	0.976
34-35	**0.711**	0.059	0.408	0.201	0.493	0.959
35-36	0.39	0.049	0.262	0.245	0.755	0.854
36-37	0.478	0.178	0.425	0.105	0.687	0.923
37-38	0.487	0.209	0.413	0.101	0.686	0.933
38-39	0.364	0.226	0.339	0.06	0.774	0.901
39-40	0.329	0.256	0.321	0.043	0.787	0.898
Eigenvalues	19.794	6.385	4.673	3.283	2.31	
%Variance	49.484	15.963	11.683	8.207	5.776	

The soil layers in no-tillage systems with and without additional compaction were better highlighted in this study using the multivariate factor analysis technique, which helped to explain soil stratification through soil resistance to penetration. This makes it clear the possible effects of soil surface compaction by machinery traffic, the effects of management in previous crops using soil furrowers, as well as pedogenetic factors acting at greater depths. These facts were observed by Secco *et al*. (2009) studying levels of compaction in Oxisols under no-tillage, who observed a trend of compaction in the subsurface layer, where dependence of RSP on soil density was verified, as well as an inverse relationship between RSP and soil moisture. Also, Baio *et al*. (2017), evaluating RP in a Oxisol cultivated with cotton, did not observe changes in this attribute according to sampling position below 0.20 m depth, which demonstrates that changes or not in RSP in underlying layers are more related to intrinsic factors of the soil (pedogenetic) than to a possible effect of agricultural management, such as the action of the soil furrowers evaluated in this study.

CONCLUSION

Multivariate factor analysis was applied to study soil layers under different tractor traffic intensities, allowing the identification of layers of growth, transition, reduction, and stabilization of soil resistance to penetration in depth.

Soil layers associated with the use of soil openers in previous crops were identified, as well as surface compacted soil layers induced by tractor traffic, in addition to layers with depth stabilization, possibly associated with pedogenetic factors.

ACKNOWLEDGEMENTS

The authors would like to thank the Coordination of Improvement of Higher Education Personnel (CAPES) for the postdoctoral scholarship awarded to the first author, and the Experimental Farm of the Federal University of Grande Dourados for providing the study area and supporting the agricultural operations.

REFERENCES

ALVARES, C.A.; STAPE, J.L.; SENTELHAS, P.C.; GONÇALVES, J.L.M.; SPAVOREK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v.22, n.6, p.711-728, 2013.

ARCOVERDE, S. N. S.; SOUZA, C. M. A. de; SUAREZ, A. H. T.; COLMAN, B. A.; NAGAHAMA, H. J. Atributos físicos do solo cultivado com cana-de-açúcar em função do preparo e época de amostragem. **Revista de Agricultura Neotropical**, v.6, n.1, p.41-47, 2019.

ARCOVERDE, S.N.S.; SALVIANO, A.M.; OLSZEVSKI, N.; MELO, S.B. de.; CUNHA, T.J.F.; SOUZA, J.P. de. Qualidade física de solos em uso agrícola na Região Semiárida do Estado da Bahia. **Revista Brasileira de Ciência do Solo**, v.39, n.5, p.1473-1482, 2015.

BAIO, F.H.R.; SCARPIN, I.M.; ROQUE, C.G.; NEVES, D.C. Soil Resistence to penetration in cotton rows and interows. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.21, n.6, p.433-439, 2017.

BERGAMIN, A.C.; VITORINO, A.C.T.; FRANCHINI, J.C.; SOUZA, C.M.A.A. de.; SOUZA, F.R. de. Compactação de um Latossolo Vermelho Distroférrico e suas relações com o crescimento radicular do milho. **Revista Brasileira de Ciência do Solo**, v.34, n.3, p.681-691, 2010.

FIGUEIREDO FILHO, D.B.; SILVA JUNIOR, J.A. Visão além do alcance: uma introdução à análise fatorial. **Opinião Pública**, v.16, n.1, p.160-185, 2010.

LOPES, A.P.; COSTA, M.J.S. Comparação entre métodos de aproximação numérica utilizando o programa Matlab. **Revista Margens Interdisciplinar**, v.11, n.17, p.245-258, 2017.

SALVIANO, A.M.; OLSZEVSKI, N.; ARCOVERDE, S.N.S.; MELO, S.B.; GIONGO, V.; CUNHA, T.J.F.; PEREIRA, J.S. Soil chemical quality in agricultural land uses in the semiarid of Bahia. **Revista Agrarian**, v.11, n.42, p.328-336, 2018.

SANTOS, H.G.; JACOMINE, P.K.T.; ANJOS, L.H.C.; OLIVEIRA, V.A.; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.Á.; ARAÚJO, J.C.; OLIVEIRA, J.B.; CUNHA, T.J.F. **Sistema Brasileiro de Classificação de Solos**.5 ed.Brasília: Embrapa, 2018.

SECCO, D.; REINERT, D.J.; REICHERT, J.M.; SILVA, V.R. Atributos físicos e rendimento de grãos de trigo, soja e milho em dois Latossolos compactados e escarificados. **Ciência Rural**, v.39, n.1, p.58-64, 2009.

TORRES, J.L.R.; PEREIRA, M.G.; ASSIS, R.L.; SOUZA, Z.M. Atributos físicos de um Latossolo Vermelho cultivado com plantas de cobertura, em semeadura direta. **Revista Brasileira de Ciência do Solo**, v.39, n.2, p.428-437, 2015.

TRENTIN, R.G.; PEREIRA, M.G.; ASSIS, R.L.; SOUZA, Z.M. Soybean productivity in Rhodic Hapludox compacted by the action of furrow openers. **Acta Scientiarum. Agronomy**, v.40, n.35015, p.1-9, 2018.

VALADÃO, F.C.A.; WEBBER, O.L.S.; VALADÃO JÚNIOR, D.D.; SCAPINELLI, A.; DEINA, F.R.; BIANCHINI, A. Adubação fosfatada e compactação do solo: sistema radicular da soja e do milho e atributos físicos do solo. **Revista Brasileira de Ciência do Solo**, v.39, n.1, p.243-255, 2015

WEIRICH NETO, P.H.; BORGHI, E.; SVERZUT, C.B.; MANTOVANI, E.C.; GOMIDE, R.L.; NEWES, W.L.C. Análise multivariada da resistência do solo à penetração sob plantio direto. **Ciência Rural**, v.36, n.4, p.1186-1192, 2006.