ISSN 2175-6813

Revista Engenharia na Agricultura

Viçosa, MG, DEA/UFV - DOI: 10.13083/reveng.v30i1.13469 v.30, p.97-110, 2022

# SOIL PHYSICAL ATTRIBUTES AND AGRONOMIC CHARACTERISTICS RELATIONSHIPS OF SOYBEAN IN NO-TILLAGE

Sálvio Napoleão Soares Arcoverde[1]*, Cristiano Márcio Alves de Souza[1], Egas José Armando[2] & Ana Laura Fialho de Araújo[1]

1- Federal University of Grande Dourados, Faculty of Agricultural Sciences, Dourados, Mato Grosso do Sul, Brazil

2 - Eduardo Mondlane University, Vilankulo, Mozambique

**Keywords:**
Principal components analysis
Soil compaction
Tractor traffic

**ABSTRACT**

The objective of this work was to evaluate the soil physical attributes and their relationship to soybean productivity under no-tillage system. The study was conducted in a Oxisol, based on randomized blocks design, with the treatments: no-tillage for 10 years (0 tractor traffic) and five tractor-traffic intensities (2, 4, 6, 8, and 12 passes), with five repetitions. An increase of macroporosity up to 10% under soil bulk density ranging from 1.51 to 1.56 mg.m$^{-3}$ and soil penetration resistance between 1.5 to 2.0 MPa, on the 0.00-0.10 m layer benefited the soybean productivity. The number of pods per plant, grain number per plant, stem diameter, and soybean productivity is higher in Oxisol, under intermediate compression. Soil bulk density and soil penetration resistance showed to be sensitive an indicators of soil physical quality, with more relation to soybean grain productivity.

**Palavras-chave:**
Análise de componentes principais
Compactação do solo
Tráfego de trator

**ATRIBUTOS FÍSICOS DO SOLO E RELAÇÕES COM CARACTERÍSTICAS AGRONÔMICAS DA SOJA EM PLANTIO DIRETO**

**RESUMO**

O objetivo deste trabalho foi avaliar os atributos físicos do solo e sua relação com a produtividade da soja em sistema plantio direto. O estudo foi conduzido em Latossolo, com delineamento em blocos casualizados, com os tratamentos: plantio direto por 10 anos (0 tráfego de trator) e cinco intensidades de tráfego de trator (2, 4, 6, 8 e 12 passadas), com cinco repetições. Um aumento da macroporosidade em até 10% sob densidade do solo variando de 1,51 a 1,56 mg.m$^{-3}$ e resistência à penetração do solo entre 1,5 a 2,0 MPa, na camada de 0,00-0,10 m, beneficiaram a produtividade da soja. O número de vagens por planta, número de grãos por planta, diâmetro do caule e produtividade da soja é maior no Latossolo, sob compressão intermediária. A densidade do solo e a resistência à penetração do solo mostraram-se indicadores sensíveis da qualidade física do solo, com maior relação com a produtividade de grãos de soja.



Received 23 Nov, 2021 • Accepted 11 Jan, 2022 • Published 12 May, 2022

Email (corresponding author)*: salvionapoleao@gmail.com

**SECTION EDITOR IN CHARGE**
Michael Silveira Thebaldi

## INTRODUCTION

The quality of agricultural soils is essential due to the wide range of processes associated with this trait. It is responsible, among others, for root growth, soil water movement, aeration, and heat transfer, issues that are influenced by the physical properties of the soil (LAMANDÉ *et al*., 2018).

In intensive agriculture farming systems under annual crops, the intensification of farm machinery traffic intensities has been recurrent, resulting in soil structural degradation, due to soil compaction (KIRNAK *et al.*, 2017; LAMANDÉ *et al*., 2018; SIVARAJAN *et al*., 2018) reducing its productive potential (VALADÃO *et al*., 2017).

In clayey agricultural soils, under no-tillage sytem, higher levels of compaction have been observed in the surface layers (SECCO *et al*., 2009; VALADÃO *et al.*, 2015). Trentin *et al.* (2018) pointed out that this effect has been common in soils without mobilization, once the pressures resulting from the traffic of machines are dissipated in the superficial layers. Studies have shown that, due to the increase in the mass of current agricultural equipment associated with their intensive use, severe increases of compaction occur in subsurface soil layers (KIRNAK *et al.*, 2017; LAMANDÉ *et al.*, 2018; SIVARAJAN *et al.*, 2018), which can be more harmful to grain production (LAMANDÉ *et al.*, 2018), due to less persistence of superficial compaction combined with difficulty on identifying and controlling subsurface compaction (STOESSEL *et al.*, 2018).

Soil compaction involves other factors, including the soil texture and mineralogy (STOESSEL *et al.*, 2018), the soil structure (BEUTLER *et al.*, 2004) and soil water content (LAMANDÉ *et al.*, 2018; STOESSEL *et al.*, 2018), inflation pressure, type of tires and mass distribution of the tractor on the axles (BECERRA *et al.*, 2010).

The soil compaction process promotes changes in the porous space, with a reduction of macroporosity and total porosity and, consequently, an increase in soil bulk density and soil penetration resistance (BERGAMIN *et al.*, 2015; VALADÃO *et al.*, 2015). Moreover, soil bulk density is considered as an indicator of structural degradation caused by compaction (MUJDECI *et al.*, 2017; TRENTIN *et al.*, 2018), especially when it involves machinery traffic under no-tillage systems (VALADÃO *et al.*, 2015).

Kirnak *et al*. (2017) and Sivarajan *et al*. (2018) found that the intensification of machinery traffic has increased the soil penetration resistance and soil bulk density in the subsurface layer, reducing the crop height and stem diameter of the soybean crop, however, no effect on grain yield was regarded. Despite that, Valadão *et al*. (2017) found a decrease in soybean grain yield after four tractors-traffic. Trentin *et al*. (2018), working in Oxisol, in a soybean crop under a no-tillage system, found linear reductions of the final crop density and number of pods per plant with an increase in soil bulk density from 1.16 to 1.26 $mg.m^{-3}$. Thus, it was observed that soil bulk density values ranging from 1.51 to 1.59 $mg.m^{-3}$ were considered maximum by Sá *et al*. (2016) when evaluating the soil compaction in Oxisols with clayey.

However, possible soil compaction with the intensification of farming machinery traffic intensities can increase water retention, whenever there is no water restriction, with no risk of a faster soil surface drying (VALADÃO *et al*., 2017). Moreover, in consolidated direct sowing, there may be a natural forming of bio-pores enabling crop root system growth, thus, enabling the availability of water in wetter and deeper layers of the soil, especially those more compressed and less conductive (LANDL *et al*., 2019).

Thus, the root system growth and the aerial part of the crop are influenced by several soil physical properties, involving complex interactions, with a clear interpretation when regarding them isolatedly as soil and crop attributes, in most studies, evaluating the establishment of functional relations of the soil management and crop development and production (FREDDI *et al*., 2008).

The knowledge of these relationships is essential, especially in soils that are susceptible to compaction, such as clayey Oxisols, under no-tillage system with he progress observed in the compaction process due to the non-mobilization of the soil combined with the intensification of machinery traffic. Thus, the objective of this work was to evaluate the soil physical attributes and their attributes relationship with the production of soybean, under no-tillage.

## MATERIAL AND METHODS

*Location and characterization of the experimental area*

The experiment was carried out from November 2018 to March 2019 on the Experimental Farm of Agricultural Sciences of the Federal University of Grande Dourados, Dourados, state of Mato Grosso do Sul (MS), Brazil. The Experimental Farm is located at 22º14'S latitude, longitude, and altitude 54º59'W 434 m. The climate of the region is Am type, monsoon, with dry winter, an annual average precipitation of 1500 mm, and an annual average temperature of 22ºC (ALVARES *et al*., 2013). The climatic data of temperature and precipitation from the experimental period are displayed in Figure 1. The soybean was grown in Oxisol (SANTOS *et al*., 2018), which was analyzed in the 0.00-0.20 m layer. The following parameters were analyzed: pH in the water of 6.2, contents of $Ca^{+2}$, $mg^{+2}$, $Al^{+3,}$ and $K^{+}$ of 5.2, 3.2, 0.0, respectively and 0.50 $cmol_c.dm^{-3}$ 12.8 $mg.dm^{-3}$ of P, base saturation of 75% and organic matter content 30 $g.dm^{-3}$. Moreover, the granulometric composite of the soil is composed of 60% clay, 15% silt, and 25% sand. The area has been managed for approximately 10 years with soybeancrops in the summer and maize in fall under cropped succession.

*Experimental design, equipment, and production inputs*

The experimental design was conducted in randomized blocks, with five tractor traffic intensities (2, 4, 6, 8, and 12 traffics) in an area under no-tillage for about 10 years (0 tractor traffics) with five replications, adding up 30 experimental plots. Each plot consisted of nine rows of soybeans plants of 10 m in length, spaced by 0.45 m, with a total area of 40.5 $m^2$. The useful area corresponded to the three central lines with 3.0 m each in the center of the plot.

The application of the tractor traffic intensities was carried out on soil with water content in the 0.00-0.20 m layer of 26.0 ± 1.5%, using the NH 8030 agricultural tractor with the 89 engine, 79 kW (122 hp), with diagonal tire wheels, 1.73 meters rear gauge, 1.83 m front gauge and 6.78 mg mass with ballast and 83 kPa inflation pressure in the front tires (14.9-28 R1) and 83 kPa at the rear (23.1-30 R1). The tractor was mounted with a 0.5 Mg bush-cutter at the three-point hydraulic system, which corresponded to 7.28 Mg of the total mass of the tractor-bush cutter set, whose distribution of dynamic condition was 37% on the front axle and 63% on the rear axle. The contact pressure of the front and rear tires with the soil was 113 and 109 kPa, respectively, determined according to the method proposed by O'Sullivan *et al*. (1999).

The tractor was displaced in the third reduced gear with a rotation of 2200 rpm and a speed of 5.3

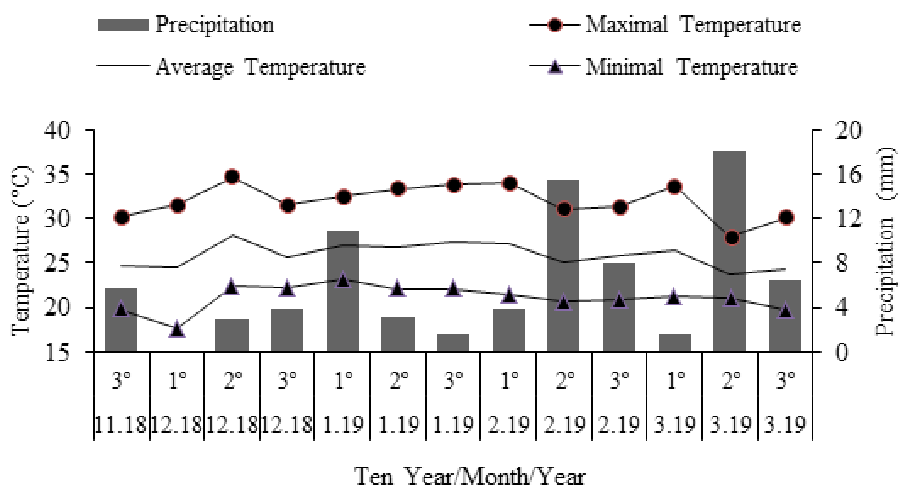



**Figure 1.** Precipitation for ten years (mm) and minimum, average, and maximum temperatures for ten years from November 2018 (sowing) to March 2019 (harvest) in Dourados, MS

km.h$^{-1}$, over the entire surface of the plot, so that the tires transited in areas parallel to each other, in such way that the number of times transited corresponded to the intensities. Traffic was superimposed on the previous one so that the entire area of each plot was trafficked an equal number of times (VALADÃO *et al*., 2015).

The soybean sowing was carried out in the opposite direction to the tractor traffic in order to ensure that the plants reached all trafficked area. On November 21, 2018, the cultivar Monsoy 6410 IPRO (maturation group 6.4, undetermined growth and cycle 105-120 days) was sown using a no-tillage seeder-fertilizer with nine rows. The seed-furrow mechanism of the sowing machine was removed so not to eliminate the possible negative effects of compaction, using only the seed doser cutting disc. The sowing density was 13 seeds per meter, spaced 0.45 m between rows. The fertilization consisted on the application of 0.4 mg.ha$^{-1}$ of the formula 05-25-06.

*Soil sampling and physical analysis*

At 85 days after sowing, when the crop was in the R5-reproductive stage (grain filling), soil samples were collected with structure preserving, with metallic cylinders sampler of 5.57 cm of diameter and 4.41 cm high (107.45 cm$^3$), between the lines in the center of the 0.00-0.10 and 0.10-0.20 m soil layers.

The soil total porosity (Pt) was obtained from the difference between the saturated soil mass and the mass of dry soil in an oven at 110 °C for 24 h; soil microporosity (Mi) was determined using the tension table method with a 0.60 m high water column (ARCOVERDE *et al*., 2019). The macroporosity was obtained from the difference between Pt and Mi. Upon reaching equilibrium in the tension corresponding to the 0.60 m high water column, the soil resistance to penetration (RP) was determined by means of an electronic penetrator with a constant penetration speed of 10 mm.min$^{-1}$, diameter of 4 mm stem base and 30º semi-angle. The soil bulk density was determined through the relationship between the dry mass at 110 ºC for 24 h of the soil sample of the volumetric ring and the volume of the same ring.

*Evaluation of soybean agronomic attributes*

Harvest was peformed at 125 days after soybean planting once physiological maturation was achived, determining in 10 plants the stem stem diameter, number of pods per plant, grain number per plant and the number of seeds per pod. The stem diameter was measured at its base with the aid of a digital caliper. The plant stand was determined by direct counting of the number of plants in the useful area of the plot,; where the plants were harvested manually and tracked in a stationary tracker to determine the mass on a digital scale. This was corrected for the moisture 13%, obtaining the grain productivity and the mass of a 1000 grains.

## RESULTS AND DISCUSSION

Figure 2 shows the dendrogram obtained by the cluster analysis, showing the formation of three groups due to the expressive variation in the values of Euclidean distance between accessions, for the set of the evaluated attributes. Thus, the variation from 160 to 350 (Figure 3) allowed an exact division of the accessions into three groups: I, II and III (Figure 2). Thus, it was possible to order the accesses according to the levels of productivity. In group I, accessions with high productivity were concentrated, in group II, accesses with medium productivity and, in group III, accessions with low productivity, according to the agronomic characteristics of the crop and soil bulk density in the 0.00-0.10 and 0.10-0.20 m layers.

Considering the number of groups of three, obtained in the hierarchical clustering analysis, the *k-means* clustering method was applied to confirm the ordering. The results confirmed the ordering, and all attributes were important in ordering the groups ($p<0.05$), according to the analysis of variance (Table 1). The average of each attribute in each group was compared by the test of Tukey at 5% probability (Table 2).

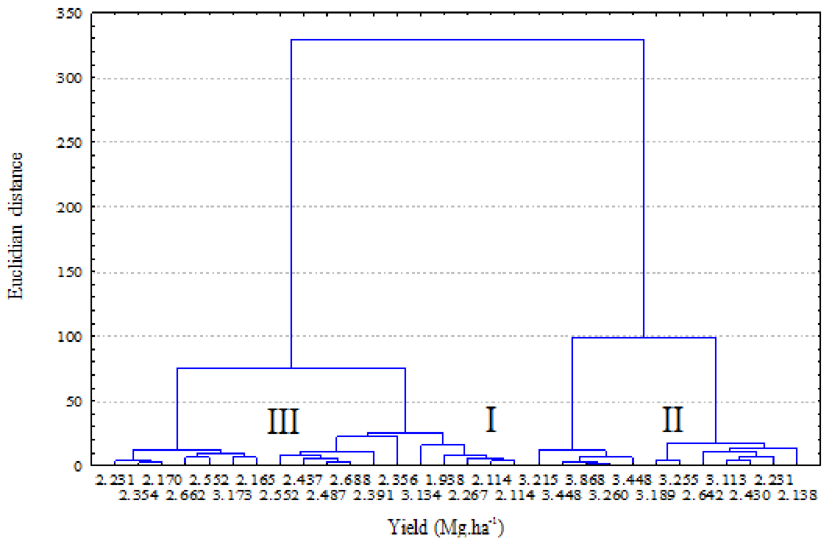



**Figure 2.** Dendrogram resulting from cluster hierarchical analysis showing the formation of groups according to the soil bulk density (SD1, 0.00-0.10 m), soil density (SD2, 0.10-0.20 m), stand, stem diameter, number of pods per plant (NPP), number of grains per plant (NGP), number of grains per pod (NSP) and mass of a thousand grains (M1000)

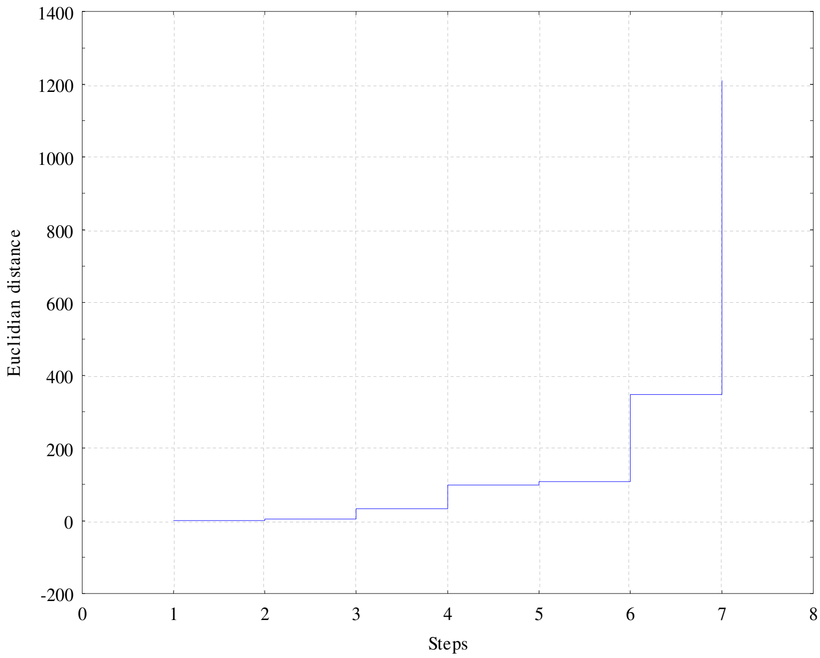



**Figure 3.** Representation of the expressive variation of the Euclidean distance between the evaluated attributes that allowed the formation of the groups

Group I (accessions with high productivity) was characterized by higher soil bulk density, which ranged from 1.49 to 1.54 mg.m$^{-3}$, in the 0.00-0.10 m layer, and from 1.35 to 1.43 mg.m$^{-3}$ in the 0.10-0.20 m layer, which increased the number of pods per plant and crop yield, as well as the mass of 1000 grains when compared to group II (with an average productivity accesses) and stem diameter in relation to group III (accessions with low productivity) (Table 2). It should be observed that, with 12 tractor traffic intensities, damaged the soybean production, due to the higher soil bulk density values (1.51 mg.m$^{-3}$), in the 0.00-0.10 m layer. However, similar values were found in this study, but were not restrictive to the crops grown in clayey soils (SECCO *et al*., 2009; ANDREOTTI *et*

**Table 1.** Analysis of variance for each attribute of the groups formed by the non-hierarchical analysis of k-means *clusters*

| Atribute(1) | SQBG | DF | SQWG | DF | F | P |
|---|---|---|---|---|---|---|
| SD1 | 0.017 | 2 | 0.059 | 27 | 3.84112 | 0.034038 |
| SD2 | 0.001 | 2 | 0.045 | 27 | 0.27434 | 0.762169 |
| M1000 | 14.698 | 2 | 231.039 | 27 | 0.85883 | 0.434909 |
| NPP | 1225.594 | 2 | 385.043 | 27 | 42.97056 | 0.000000 |
| NGP | 9543.767 | 2 | 1393.212 | 27 | 92.47757 | 0.000000 |
| NSP | 0.208 | 2 | 0.833 | 27 | 3.36642 | 0.049510 |
| Stand | 16.910 | 2 | 147.490 | 27 | 1.54780 | 0.231005 |
| STD | 10.762 | 2 | 8.363 | 27 | 17.37389 | 0.000014 |

SQBG: Sum of squares between groups; GL: Degrees of freedom; SQWD: Sum of squares within groups; F: calculated value of F; P: probability. (1): soil bulk density (SD1, 0.00-0.10 m), soil density (SD2, 0.10-0.20 m), mass of a thousand grains (M1000), number of pods per plant (NPP), number of grains per plant (NGP), number of grains per pod (NSP), stand and stem diameter (STD)

**Table 2.** Mean values of the agronomic characteristics of corn and soil densities in each group by analyzing *k-means* clusters

| Grupo | Acess | SD1 | SD2 | M1000 | NPP | NGP | NGPP | Stand | STD |
|---|---|---|---|---|---|---|---|---|---|
| | $mg.ha^{-1}$ | $mg.m^{-3}$ | | g | | | | $plant.m^{-1}$ | mm |
| | 3.448 | 1.49 | 1.43 | 98.561 | 59.8 | 126.5 | 2.12 | 15 | 7.39 |
| | 3.260 | 1.54 | 1.39 | 97.103 | 57.8 | 129.7 | 2.24 | 16 | 7.11 |
| I | 3.216 | 1.51 | 1.35 | 95.021 | 52.7 | 134.1 | 2.54 | 12 | 7.00 |
| | 3.448 | 1.52 | 1.40 | 96.728 | 56.8 | 130.1 | 2.29 | 18 | 6.84 |
| | 3.868 | 1.49 | 1.37 | 96.226 | 56.8 | 130.1 | 2.29 | 15 | 6.68 |
| Aver.(1) | 3.448a | 1.51a | 1.39a | 96.728a | 56.8a | 130.1a | 2.30a | 15a | 7.00a |
| | 2.138 | 1.4 | 1.43 | 101.149 | 47.6 | 101.7 | 2.14 | 12 | 5.32 |
| | 2.115 | 1.42 | 1.42 | 100.351 | 35.8 | 78.0 | 2.18 | 12 | 4.40 |
| | 1.938 | 1.43 | 1.40 | 103.200 | 41.2 | 84.8 | 2.06 | 11 | 5.58 |
| | 2.115 | 1.44 | 1.47 | 100.351 | 38.9 | 80.3 | 2.06 | 12 | 4.20 |
| | 2.267 | 1.46 | 1.41 | 101.263 | 42.6 | 79.0 | 1.85 | 12 | 4.47 |
| | 2.166 | 1.47 | 1.41 | 91.947 | 43.6 | 90.8 | 2.08 | 15 | 5.55 |
| | 2.170 | 1.41 | 1.38 | 94.660 | 42.4 | 94.7 | 2.23 | 17 | 5.55 |
| | 2.231 | 1.43 | 1.41 | 93.250 | 52.9 | 109.0 | 2.06 | 15 | 5.20 |
| | 2.231 | 1.38 | 1.44 | 95.218 | 45.3 | 95.7 | 2.11 | 15 | 6.04 |
| III | 2.356 | 1.42 | 1.43 | 98.225 | 33.7 | 63.9 | 1.90 | 15 | 5.42 |
| | 2.391 | 1.55 | 1.38 | 92.846 | 33.1 | 74.5 | 2.25 | 14 | 5.92 |
| | 2.688 | 1.53 | 1.40 | 93.003 | 40.0 | 80.0 | 2.00 | 15 | 5.87 |
| | 2.437 | 1.53 | 1.42 | 94.353 | 36.5 | 83.5 | 2.29 | 14 | 5.03 |
| | 2.430 | 1.5 | 1.41 | 94.400 | 38.3 | 78.6 | 2.05 | 14 | 5.64 |
| | 2.487 | 1.44 | 1.38 | 95.579 | 48.7 | 84.1 | 1.73 | 14 | 5.39 |
| | 3.134 | 1.44 | 1.38 | 94.417 | 41.5 | 89.9 | 2.17 | 10 | 6.09 |
| | 3.255 | 1.42 | 1.33 | 96.311 | 44.2 | 95.4 | 2.16 | 18 | 5.67 |
| | 3.173 | 1.46 | 1.29 | 95.225 | 41.0 | 76.1 | 1.86 | 18 | 5.28 |
| | 3.114 | 1.38 | 1.33 | 97.624 | 41.0 | 92.0 | 1.99 | 19 | 6.00 |
| Aver. | 2.465c | 1.45 b | 1.40a | 96.493a | 41.5b | 85.9c | 2.06a | 14a | 5.40b |
| | 3.189 | 1.53 | 1.4 | 93.651 | 46.6 | 109.3 | 2.35 | 15 | 5.26 |
| | 2.642 | 1.53 | 1.38 | 94.540 | 50.6 | 113.7 | 2.25 | 12 | 6.55 |
| | 2.354 | 1.48 | 1.33 | 94.364 | 48.7 | 106.5 | 2.19 | 12 | 6.20 |
| II | 2.553 | 1.47 | 1.43 | 93.185 | 53.9 | 115.9 | 2.15 | 14 | 6.77 |
| | 2.553 | 1.39 | 1.37 | 93.472 | 41.7 | 106.6 | 2.56 | 18 | 6.83 |
| | 2.662 | 1.45 | 1.33 | 93.492 | 37.0 | 89.9 | 2.43 | 17 | 6.21 |
| Aver. | 2.659b | 1.48ab | 1.37b | 93.784b | 46.4b | 107.0b | 2.32a | 15a | 6.30ab |

(1) Aver.: Average

*al*., 2010; SÁ *et al*., 2016).

When analyzing group II (accessions with medium productivity), an intermediate soil density was observed in the 0.00-0.10 m layer, which varied between 1.39 to 1.53 mg.m$^{-3}$, not differing among other groups; however, a lower soil bulk density was observed in the 0.10-0.20 m layer, ranging from 1.33 to 1.43 mg.m$^{-3}$, therefore reducing the weight of a thousand grains due to increased number of grains per plant (Table 2).

Group III (accessions with low productivity) presented the lowest soil bulk density in the 0.00-0.10 m layer, in relation to group I, varying from 1.38 to 1.55 mg.m$^{-3}$, in the 0.00-0.10 m layer, and greater soil bulk density in the 0.10-0.20 m layer in relation to the group II, ranging from 1.29 to 1.47 mg.m$^{-3}$, increasing the weight of the one-thousand grain, however, with a reduction in the number of grains per plant and stem diameter.

Figure 4 shows the averages of agronomic characteristics of soybeans and soil bulk densities for each group, according to cluster analysis by the *k-means* method. In addition, it is observed that, in the condition of higher soil bulk density in the 0.00-0.20 m layer, the highest number of pods per plant (NPP), number of grains per plant (NGP) and stem diameter (STD) occurred, resulting in higher grain productivity, confirming the results shown in Table 2.

The principal component analysis allowed a single distribution of the accessesion variables (first main component x second main component). The two main components together enabled a bi-dimensional ordering of the accesses variables, allowing a plotation of a bi-plot graph (Figure 5). The amount of total information on the original variables retained by the two principal components (Figure 5A) was 60.71% (42.24% from the first principal component + 18.47% from the second).

The order of accessed variables, according to the first two principal components analysis, confirms the ordering of accessions into three groups obtained by cluster analysis, hierarchical and non-hierarchical (Figure 5B).

The graphical representation and the correlation of the attributes in the principal components (Figure 5 and Table 3) permitted to identify the attributes that were more discriminated in formation of the groups I, II and III. The characteristics number of grains per plant (-0.90), stem diameter (-0.89) and

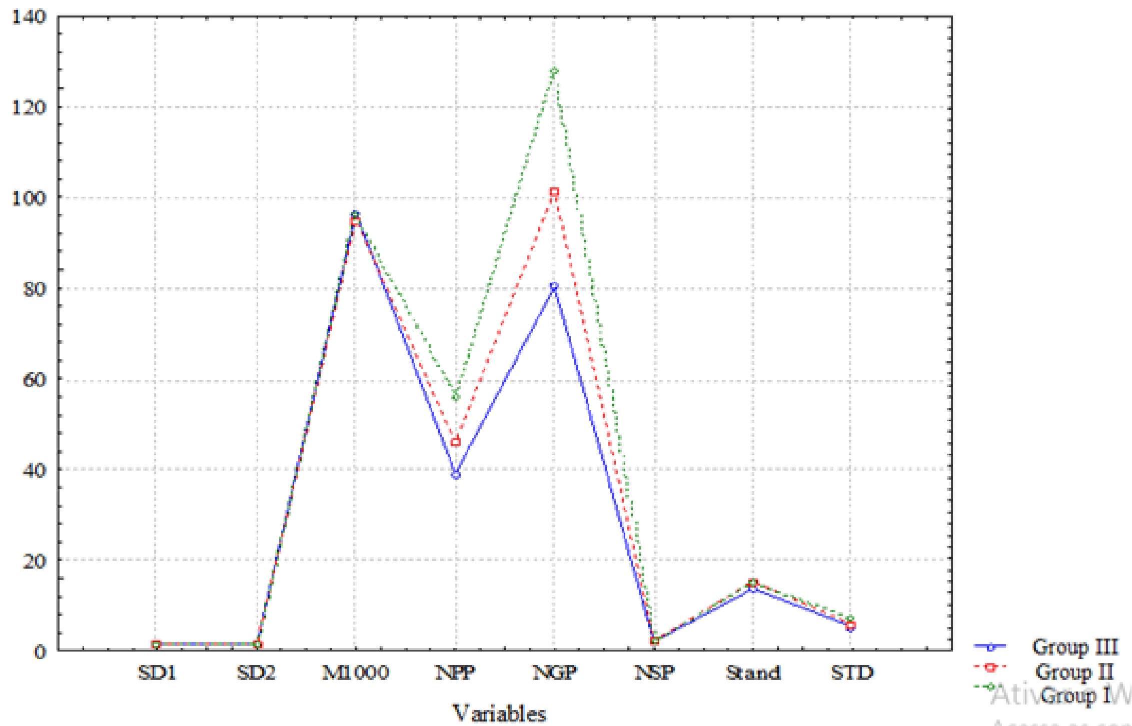



**Figure 4.** Standardized means of the agronomic characteristics of soybean and soil bulk density for each group as cluster analysis to non-hierarchical *k-means*

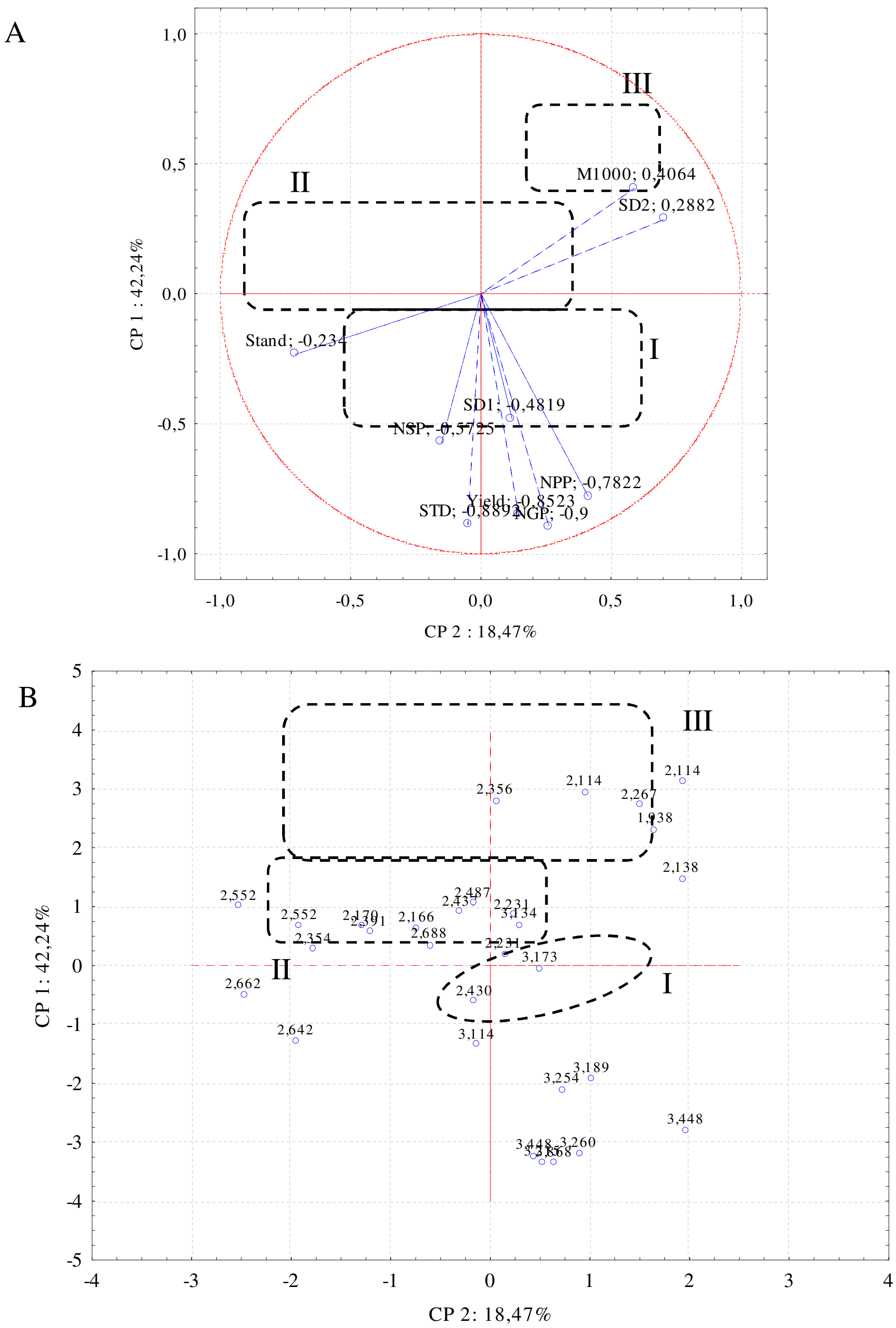



**Figure 5.** Dispersion (biplot chart) of the evaluated attributes (A) with soybean productivity (B, mg.ha$^{-1}$) under different levels of in Clayey Oxisol

number of pods per plant (-0.78) were responsible for the discrimination of group I, located at the right quadrant of CP2 (negative correlations), while the stand (-0.72) and soil density (0.71), in the 0.10-0.20 m layer, were responsible for the discrimination of group II, mostly located at the left quadrant of CP2 (positive correlations). Thus, Groups I and II (greater productivity) were characterized by more developed plants with larger number of pods per plant, more grain number per plant, number of seeds per pod and stem diameter, while the group III (low productivity) it is characterized by a greater mass of a thousand grains, but with a few number of grains per plant, which explains the lower productivity in this group.

The presented relations of grain productivity and agronomic characteristics of soybean through the principal component analysis was highlighted by means of the *Pearson's* correlation (Table 4).

An increase in grain productivity was observed with the increase of stem diameter, which reflected on greater development of the plant (Figure 6). It is noteworthy that the stem diameter of the soybean may be related to the density of plants and, consequently, with height and branches per plant. Thus, a smaller plant stand can be favored, besides increasing the stem diameter, increasing the number of pods and seeds per plant, possibly due to the larger branches (SOUZA *et al*., 2010).

Macroporosity linearly decreased with the increase in soil bulk density, in which, starting from 1.45 mg.m$^{-3}$, macroporosity with values less than 10% were observed (Figure 7), indicating as the minimum suitable for gas exchange in the root system, once this parameter is considered critical for the root growth of most crops, therefore, reducing the crop productivity (REICHERT *et al*., 2009). Andreotti *et al*. (2010) and Bergamin *et al*. (2015) also reported low macroporosity values (5 and 9%, respectively), in the 0.0-0.10 m layer for clayey Red oxisol and Valadão *et al*. (2015) in the same layer (8%) of a clayey Red-Yellow Latosol.

The higher productivity observed with the reduction of soil macroporosity (Figure 8) disagrees with the values obtained by Andreotti *et al*. (2010), for soybean, and by Bergamin *et al*. (2015), for the maize crop, who observed in less compacted areas of clayey Oxisol, the higher productivity of the crop. Thus, in this study, macroporosity values slightly 10% less than this may have been beneficial due to the intermediate compaction in the 0.00-0.10 m layer, which in very porous soils is likely to have increased the volume of pores responsible for storing water in a voltage available for the plants.

The relationship between the soil physical attributes in 0.00-0.10 m layer performed by Pearson's correlation (Table 5) shows a positive correlation between soil bulk density and soil

**Table 3.** Correlation between principal components and soil bulk density in Clayey Oxisol and agronomic traits of soybean crop

| Attribute | PC1 | PC2 | PC3 |
|---|---|---|---|
| SD1 | -0.48 | 0.12 | <u>-0.70</u> |
| SD2 | 0.29 | <u>0.71</u> | -0.19 |
| M1000 | 0.41 | 0.59 | 0.47 |
| NPP | <u>-0.78</u> | 0.41 | 0.32 |
| NGP | <u>-0.90</u> | 0.26 | 0.19 |
| NSP | -0.57 | -0.15 | -0.27 |
| Stand | -0.23 | <u>-0.72</u> | 0.40 |
| STD | <u>-0.89</u> | -0.05 | 0.11 |
| Productivity | <u>-0.85</u> | 0.14 | 0.01 |

**Table 4.** Correlation between some agronomic traits of soybean

| | M1000 | NPP | NSP | STD |
|---|---|---|---|---|
| M1000 | 1 | | | |
| NPP | -0.019 | 1 | | |
| NSP | -0.13 | 0.90$^{**}$ | 1 | |
| STD | -0.33$^{*}$ | 0.62$^{**}$ | 0.74$^{**}$ | 1 |
| Stand | -0.20 | -0.30$^{*}$ | -0.22$^{*}$ | 0.015 |
| Yield | -0.24$^{*}$ | 0.69$^{**}$ | 0.69$^{**}$ | 0.76$^{**}$ |

**(p≤0.01); *(p≤0.05)

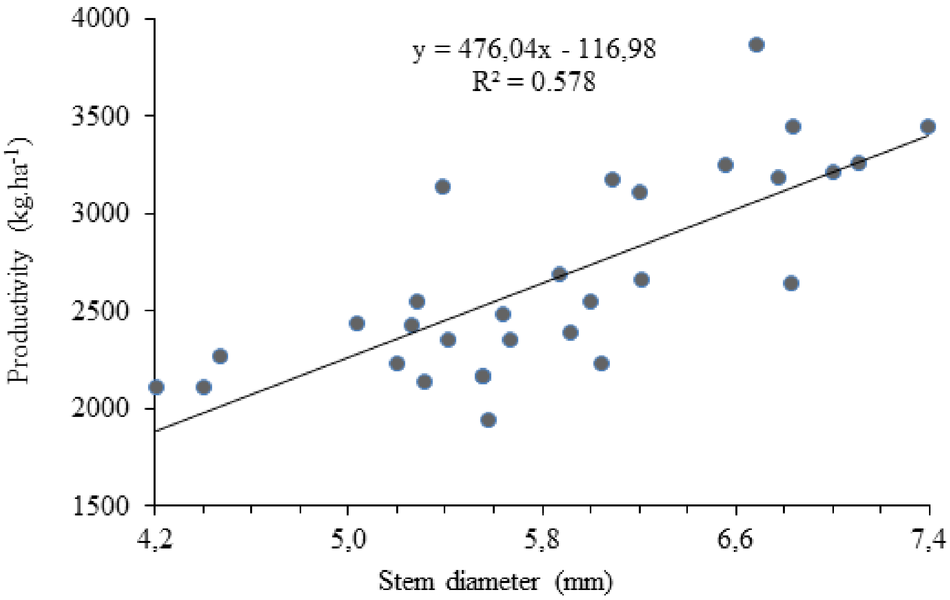



**Figure 6.** Productivity of the grains estimation under stem diameter of the crop

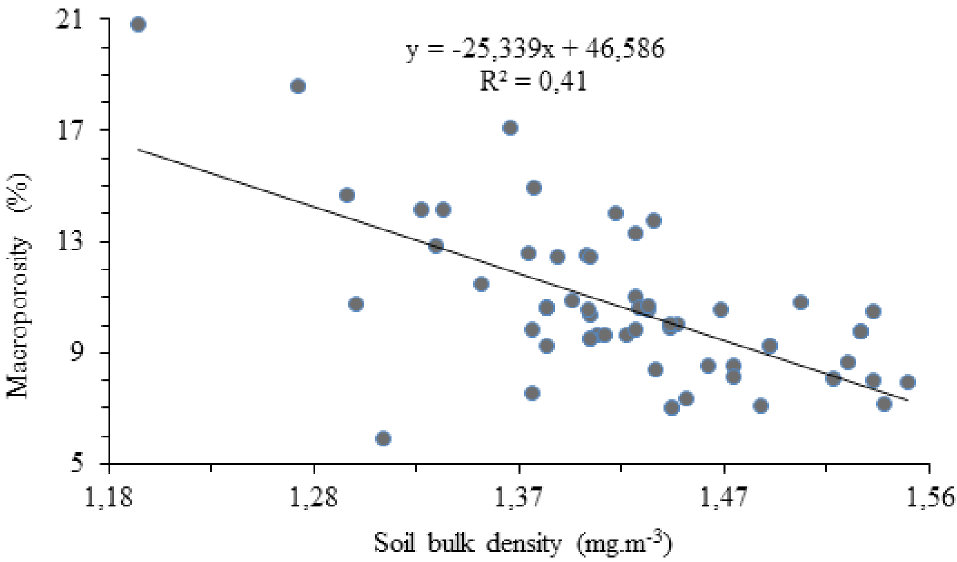



**Figure 7.** Macroporosity estimation under soil bulk density in the layer 0.00-0.20 m

resistance to penetration (0.61) and a negative correlation between soil bulk density and macroporosity and soil total porosity, agreeing with Beutler *et al*. (2004) and Bergamin *et al*. (2015).

Soil compaction process lead to changes in the porous space, with a reduction in macroporosity and total porosity and, consequently, an increase in the soil bulk density and resistance of the soil to penetration under no-tillage system (BERGAMIN *et al*., 2015; VALADÃO *et al*., 2015). The positive relationship between soil bulk density and soil resistance to penetration can be associated to the fact that soil compaction causes a greater friction or cohesion between solid particles, while the inverse relationship between soil bulk density and macroporosity, besides the management effect already mentioned, can be attributed to the kaolinite mineralogy of these oxisols which, due to the face-to-face adjustment of the plates of the soil aggregates, develop a dense plasma, resulting

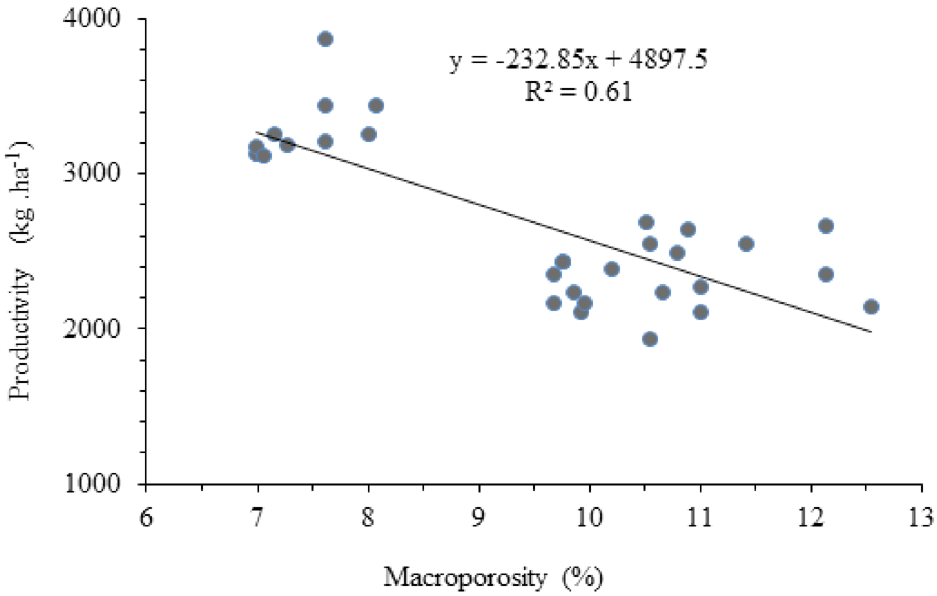



**Figure 8.** Grain productivity estimation under soil Macroporosity in the soil layer 0.00-0.10 m

**Table 5.** Correlation between soil physical attributes

| | RP | Ma | Mi | TP |
|---|---|---|---|---|
| RP | 1 | | | |
| Ma | -0.024 | 1 | | |
| Mi | 0.14 | 0.21 | 1 | |
| TP | 0.09 | 0.75** | 0.40** | 1 |
| SD | 0.61** | -0.53** | -0.097 | -0.46** |

**(p≤0.01)

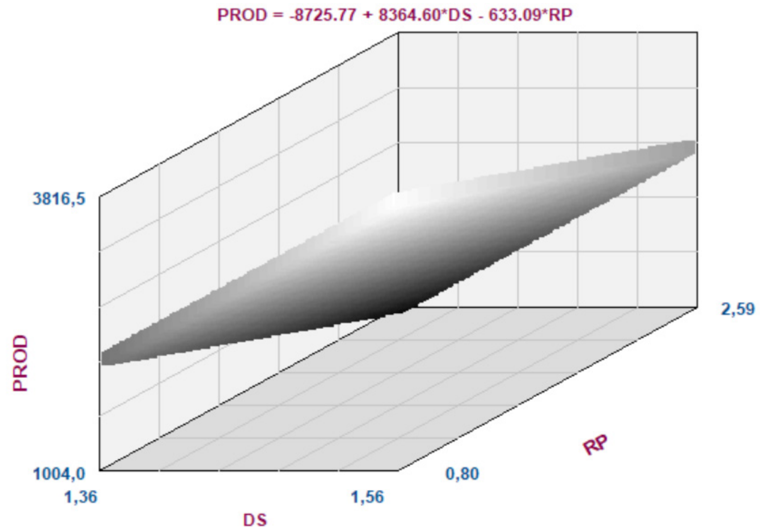
in a rise in the values of soil bulk density and lower macroporosity soil (FERREIRA *et al*., 1999).

Through the multiple regression analysis between two physical attributes and soybean productivity attributes (Figure 9), an increasing linear model of productivity was observed with the increase of soil bulk density and reduction in the soil resistance to penetration, in the 0.00-0.10 m layer.

Bergamin *et al*. (2015) also found an inverse linear relationship between soil resistance to penetration and corn productivity, when studying a Oxisol under different levels of compaction. It was observed that soil bulk density values from 1.51 to 1.56 mg.m$^{-3}$ associated with soil resistance to penetration between 1.5 to 2.0 MPa keep productivity above 3000 kg.ha$^{-1}$ (Figure 9), contributing for the formation of the group with the highest grain productivity (Figure 2 and Table 2). Secco *et al*. (2009) also observed no obstacles in soybean production in Oxisol under tillage system, at soil bulk density of 1.54 mg.m$^{-3}$.

Regarding the largest soil resistance to penetration values from 2.0 MPa, they were influenced by soil compaction caused by not revolving it at the till, and may have limited the strip of water available in higher densities of the soil combined with the restrictions imposed on the system root plants by the higher mechanical impedance (MOREIRA *et al*., 2014).

The highest values of productivity are in agreement with Andreotti *et al*. (2010), when studying a clayey Oxisol under no-tillage and observed a productivity of 3.270 kg ha$^{-1}$, even with average soil bulk density values of 1.52 Mg m$^{-3}$ and macroporosity of 5%. Soil bulk density values from which the crop yield is reduced vary with the type of soil and management adopted (MOREIRA




Productivity** = -8725.77 + 8364.60xDs – 633.09xRP R² = 0.42** **(p<0.01)

**Figure 9.** Multiple Regression of the Productivity (Productivity, kg.ha$^{-1}$) estimation under soil bulk density (Ds, mg.m$^{-3}$) and soil penetration resistence (RP, MPa) in the 0.00-0.10 m layer

*et al*., 2014). However, in this study, it is possible that the highest values of soil bulk density allowed the stability of the microstructure and maintenance of sufficient porous space for gas exchange in the soil, which enabled the development of plants and resulted in satisfactory productivity. In other words, the compaction induced by tractor traffic caused intermediate values of soil density and resistance to penetration, did not limit the growth and the crop yield.

This can also be explained by the management applied in the area as consolidated no-tillage causes bioporosity that resulted from reduction in mechanical movement of the soil that can offer alternative paths for root growth, compensating for the greater soil resistance to penetration of the soil matrix (BETIOLI JÚNIOR *et al*., 2012) and, consequently, water acesss in more humid and deeper layers of soil, especially in more compacted and less conductive soils (LANDL *et al*., 2019). In addition, an increase in the resistance of the soil to penetration in the superficial layer could stimulate the proliferation of lateral roots, which are thinner and capable of growing in soil pores of reduced diameter, reaching greater depths.

## CONCLUSIONS

- An increase in the macroporosity values up to 10%, soil bulk density between 1.51 to 1.56 mg.m$^{-3}$ and soil resistance to penetration between 1.5 to 2.0 MPa, in the 0.00-0.10 m layer, benefits the soybean productivity.
- The number of pods per plant, grain number per plant, stem diameter, and soybean productivity are higher in Oxisol, under intermediate compression.
- The soil bulk density and penetration resistance are sensitive, regarding them as soil physical quality indicators, and they are more related to grain productivity.

## AUTHORSHIP CONTRIBUTION STATEMENT

**ARCOVERDE, S.N.S.:** Conceptualization, Formal Analysis, Software, Supervision, Writing – original draft; **SOUZA, C.M.A.:** Funding acquisition, Methodology, Project administration, Validation, Visualization; **ARMANDO, E.J.:** Investigation, Resources, Writing – original draft, Writing – review & editing; **ARAÚJO, A.L.F.:** Data curation, Validation.

## DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## REFERENCES

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

ANDREOTTI, M.; CARVALHO, M. P.; MONTANARI, F.; BASSO, F. C.; PARIZI, C. M.; AZENHA, M.V.; VERCESE, F. Produtividade da soja correlacionada com a porosidade e a densidade de um Latossolo Vermelho do cerrado brasileiro. **Ciência Rural**, Santa Maria, v.40, n.3, p.520-526, 2010.

ARCOVERDE, S. N. S.; CORTEZ, J. W.; OLSZEVSKI, N.; SALVIANO, A. M.; GIONGO, V. Multivariate analysis of chemical and physical attributes of quartzipsamments under different agricultural uses. **Engenharia Agrícola**, Jaboticabal, v.39, n.4, p.457-465, 2019.

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

BECERRA, A. T.; BOTTA, G. F.; BRAVO, X. L.; TOURN, M.; MELCON, F. B.; VASQUEZ, J.; RIVERO, D.; LINARES, P.; NARDON, G. Soil compaction distribution under tractor traffic in almond (*Prunus amigdalus* L.) orchad in Alméria España. **Soil and Tillage Research**, Amsterdam, v.107, n.1, p.49-56, 2010.

BEUTLER, A. N.; CENTURION, J. F.; ROQUE, C. G. Relação entre alguns atributos físicos e a produção de grãos de soja e arroz de sequeiro em latossolos. **Ciência rural**, Santa Maria, v.34, n.2, p.365-371, 2004.

BERGAMIN, A. C.; VITORINO, A. C. T.; SOUZA, F. R.; VENTUROSO, L.R.; BERGAMIN, L.P.P.; CAMPOS, M.C.C. Relationship of soil physical quality parameters and maize yield in a Brazilian Oxisol. **Chilean Journal of Agricultural Research**, Santiago, v.75, n.3, p.357-365, 2015.

BETIOLI JÚNIOR, E.; MOREIRA, W. H.; TORMENA, C. A.; FERREIRA, C. J. B.; SILVA, A.P.; GIAROLA, N.F.B. Intervalo hídrico ótimo e grau de compactação de um Latossolo Vermelho após 30 anos sob plantio direto. **Revista Brasileira de Ciência do Solo**, Viçosa, v.36, n.3, p.971-982, 2012.

FERREIRA, M. M.; FERNANDES, B.; CURI, N. Influência da mineralogia da fração argila nas propriedades físicas de latossolos da região sudeste do Brasil. **Revista Brasileira de Ciência do Solo**, Viçosa, v.23, n.3, p.515-524, 1999.

FREDDI, O. S.; FERRAUDO, A. S.; CENTURION, F. Análise multivariada na compactação de um latossolo vermelho cultivado com milho. **Revista Brasileira de Ciência do solo**, Viçosa, v.32, n.3, p.953-961, 2008.

KIRNAK, H.; GOKALP, Z.; DOGAN, E.; ÇOPUR, O. Soil characteristics of soybean fields as effected by compaction, irrigation and fertilization. **Legume Research**, Karnal, v.40, n.4, p.691-697, 2017.

LAMANDÉ, M.; GREVE, M. H.; SCHJONNING. Risk assessment of soil compaction in Europe – Rubber tracks or wheels on machinery. **Catena**, Cremlingen, v.167, p.353-362, 2018.

LANDL, M.; SCHNEPF, A.; UTEAU, D.; PETH, S.; ATHMANN, M.; KAUTZ, T.; PERKONS, U.; VEREECKEN, H.; VANDERBORGHT, J. Modeling the Impact of Biopores on Root Growth and Root Water Uptake. **Vadose Zone Journal**, Madison, v.18, n.1, p.0-20, 2019.

MOREIRA, F. R.; DECHEN, C. F.; SILVA, A. P.; FIGUEIREDO, G. C.; DE MARIA, I. C.; PESSONI, P. T. Intervalo hídrico ótimo em um latossolo vermelho cultivado em sistema semeadura direta por 25 anos. **Revista Brasileira de Ciência do Solo**, Viçosa, v.38, n.1, p.118-127, 2014.

MUJDECI, M.; ISILDAR, A. A.; UYGUR, V.; ALABOZ, P.; UNLU, H.; SENOL, H. Cooperative effects of field traffic and organic matter treatments on some compaction-related soil properties. **Solid Earth**, Guangzhou, v.8, n.1, p.189-198, 2017.

O'SULLIVAN, M. F.; HANSHALL, J. K.; DICKSON, J. W. A. A. Simplified method for estimating soil compaction. **Soil and Tillage Research**, Amsterdam, v.49, n.4, p.325-335, 1999.

REICHERT, J. M.; SUZUKI, L. E. A. S.; HORN, R.; HÅKANSSON, I. Reference bulk density and critical degreeof-compactness for no-till crop production in subtropical highly weathered soils. **Soil and Tillage Research**, Amsterdam, v.102, n.2, p.242-254, 2009.

SÁ, M. A. C.; SANTOS JUNIOR, J. D. G.; FRANZ, C. A. B.; REIN, T. A. Qualidade física do solo e produtividade da cana-de-açúcar com uso da escarificação entre linhas de plantio. **Pesquisa Agropecuária Brasileira**, Brasília, v.51, n.9, p.1610-1622, 2016.

SANTOS, H. G.; JACOMINE, P. K. T.; ANJOS, L. H. C.; OLIVEIRA, V. A.; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A.; ARAUJO FILHO, J. C.; OLIVEIRA, J. B.; CUNHA, T. J. **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**, Santa Maria, v.39, n.1, p.58-64, 2009.

SIVARAJAN, S.; MAHARLOOEIA, M.; BAJWAA, S. G.; NOWATZKIA, J. Impact of soil compaction due to wheel trac on corn and soybean growth, development and yield. **Soil and Tillage Research**, Amsterdam, v.175, p.234-243, 2018.

SOUZA, C. A.; GAVA, F.; CASA, R. T.; BOLZAN, J. M.; KUHNEM JUNIOR, P. R. Relação entre densidade de plantas e genótipos de soja roundup readyTM. **Planta Daninha**, Viçosa, v.28, n.4, p.887-896, 2010.

STOESSEL, F.; SONDEREGGER, T.; BAYER, P.; HELLWEG, S. Assessing the environmental impacts of soil compaction in Life Cycle Assessment. **Science of The Total Environment**, Amsterdam, v.630, p.913-921, 2018.

TRENTIN, R. G.; MODOLO, A. J.; VARGAS, T. O.; CAMPOS, J. R. R.; ADAMI, P. F.; BAESSO, M. M. Soybean productivity in Rhodic Hapludox compacted by the action of furrow openers. **Acta Scientiarum Agronomy**, Maringá, v.40, n.35015, p.1-9, 2018.

VALADÃO, F. C. A.; WEBER, O. L.; VALADÃO JÚNIOR, D. D.; SANTIN, M. F. M.; SCARPINELLI, A. Teor de macronutrientes e produtividade da soja influenciados pela compactação do solo e adubação fosfatada. **Revista de Ciências Agrárias**, Lisboa, v.40, n.1, p.183-195, 2017.

VALADÃO, F. C. A.; WEBER, O. L.; VALADÃO JÚNIOR, D. D.; SCARPINELLI, 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**, Viçosa, v.39, n.1, p.243-255, 2015.