Original Research Article

Influence of Cultural Management on Compaction of a Cerrado Latosol

ABSTRACT

Soil compaction is a process that negatively affects the availability of water and nutrients to plants. Therefore, it is necessary to evaluate alternative practices of cultural management in order to reduce soil compaction. The experimental area is located in the Foundation for Research and Technological Development Rio Verde, where 13 treatments were installed with different systems of cultural management, all rotated with soy. A randomized complete block design (DBC) was used for this experiment, with three blocks (one repetition per block), thirteen treatments and two depths of soil (0-10 cm and 10-20 cm). Physical analyzes were soil resistance to penetration, soil density, and soil moisture at the time of collection. The treatment in which the soil was stirred during the fallow period was the one that presented the lowest resistance of the soil to penetration, followed by the treatment where a mixture of cover crops was used in the second harvest, and the treatment where soybean was harvested and brachiaria in the second crop, using corn with brachiaria every two years, was the one that presented lower soil density, followed by the treatment with stirring during fallow season. Planting areas with a greater diversity of rotating plants presented as a good proposal of soil management, as they provide ideal soil conditions for the crop and for the use of rainwater or irrigation.

Keywords: cultural management, compaction, soil physical analysis.

1. INTRODUCTION

Soil compaction is a process where its density increases, becoming less permeable, with reduced and discontinued pores, negatively affecting the availability of water and nutrients to the plants. Besides these, there are other problems due to soil compaction, such as nitrogen losses due to denitrification, reduction in root growth and development due to high mechanical impedance, decrease in available oxygen in the soil, increase in production costs due to increased consumption of fuel to prepare soils, and increased soil erosion by less water infiltration [1] (SOANE & OUWERKERK, 1994). "By decreasing the macroporosity, the water that is retained in the micropores is under high stresses and may be unavailable to the plants" [2].

Conventional soil preparation brings a series of benefits such as improved sowing conditions, increased water infiltration and aeration, decrease in density and reduction of soil mechanical resistance to penetration. However, when the cultivation is inadequate and intense, there is a deterioration of the soil structure due to the reduction of porosity, hydraulic conductivity and water permeability, mainly due to the increase in its resistance to penetration [3].

Cultural practices directly interfere with the natural structure of soils, and may, if not correctly implemented, lead to compaction. The intensification of erosion processes is directly related to non-conservationist management practices, such as those that soil the soil, changing the conformation of the particles, especially size and stability of aggregates. This over time compacts the soil by reducing the macroporosity, reducing the rate of infiltration of rainwater and increasing its retention in the soil, which can lead to rapid saturation and consequent erosion. According to [4], any significant changes occurring in soil structure, either by compaction or by another process, will cause changes in soil-air-water relationships, mechanical strength and soil temperature, and consequently in response of soil in terms of physical behavior to plant growth. Therefore, it is of fundamental importance to seek soil management practices that maintain or improve the structural conditions of soils.

Of the several indicators of the physical state of the soil, mainly of compaction, the most used are the mechanical resistance to the penetration and the density [5]. These are very dependent on the soil moisture condition.

Mechanical resistance to penetration, is a term that describes the physical resistance that the soil offers to a body that tries to move through it, being for example a growing root or a cultivation tool. The compaction and the reduction of soil moisture are factors that increase this resistance, which becomes a problem from the point of physical impediment to the development and growth of the roots, besides reducing the porous space, reducing the concentration of oxygen in the root zone [6]. Besides these, several other attributes and soil conditions influence the penetration resistance, such as texture, density and organic matter [7] and [8]. It can also be influenced by cohesion [9].

For the agronomic field, the analysis of mechanical resistance to penetration, besides evaluating the various physical parameters of the soil, can be used to evaluate the effect of different soil management systems [6], since it is easy and quick to obtain .

In order to evaluate soil resistance to penetration, a device called penetrometer is used. There are two main types of penetrometer, the static and the dynamic.

In the dynamic one there is a rod with a cone in the inferior end, being in the superior part a weight of constant course that causes the penetration of the rod in the ground through impacts. The penetration reading is made on the ruler beside the rod, which is graduated in millimeters [10]. Its use is verified in several studies, such as: soil resistance mapping, compaction and traffic control evaluation, spatial variability of soil properties, management of crops, pastures and forests, recovery of degraded areas, ground.

Although it is easier to use and more widespread in agriculture, the dynamic impact penetrometer has some characteristics that hinder its use. In the use of impact penetrometers, the operator has no control over the thickness of the penetrated layer caused by the impact. Therefore, it is not possible to generate resistance results at constant depth intervals, as in the 0-5 layers; 5-10; and 10-15 cm, for example. This aspect makes it difficult to analyze resistance results, of several profiles, in layers at the same depth, and studies of spatial variability [11].

Already [11] explains that with the constant or static velocity penetrometer, a rod with conical tip is slowly introduced into the soil, concomitantly registering the reaction force that is equal to the resistance of the soil. When a data storage system is added to the penetrometer, it says there is a penetrograph.

There are a wide variety of constant speed penetrographs available in the market, but the main constituent parts and their purposes are the same: 1) the penetrograph rod, usually made of round stainless steel profile; 2) the stainless steel conical tip attached to the lower end of the penetration rod, the geometry of which is known; 3) the penetration system rod attached to the penetrograph rod by a load cell; 4) the load cell (force transducer), which is the constituent of the system, whose purpose is to measure the force applied to the cone, transmitting electrical signals in mV (millivolts) to a data acquisition system; 5) the system of acquisition, calculation and storage of data, consisting of main board, interface card, monitor, external memory card; 6) the electromechanical system with electric motor, powered by battery, that drives a set of gears, responsible for transmitting the vertical movement to the penetration rod; 7) manual selector switch, allowing the operator to control the movement of the penetration rod in three different directions, namely: off, up and down; 8) sensor element (transducer), to obtain the penetration depth [12].

The penetrograph may still be field, in which the efficiency and the capacity to obtain and store data are smaller, or bench, used mainly in laboratories, obtaining more information by the greater capacity of obtaining and storing data.

Penetrometers and penetrographs, although there are several makes and models, work in the same way. A source of electrical energy (a battery, for example) drives the electromechanical system motor, which transfers a theoretically constant velocity by means of motion transmission mechanisms, to the penetration rod, consequently to the penetrograph rod and the tip, in the vertical direction. Upon initiation of penetration into the ground, the load cell connected to the rod begins to measure the force exerted on it by means of electrical stimuli under electric voltage (electric potential difference). Simultaneously, the sensor element (transducer), at each displacement (pre-defined) interval penetrated by the rod, also emits an electrical stimulus so that the data acquisition system records which force value was measured by the load cell in that die range. When the required depth is reached, the user switches the equipment off using the selector switch. At the end of the penetration test, a series of data is stored in the data acquisition, calculation and storage system, which converts the electrical voltage values into penetration pressure or penetration resistance data [12].

As already mentioned, the physical properties of a soil have a direct influence on the root development of the crop and, consequently, its productivity. Among these properties, soil density (ds) is a parameter that serves as soil compaction index [13], and is widely used in assessing soil structural status [14].

In general, it can be stated that the higher the soil density, the greater its compaction and the degraded structure, the lower its total porosity and, consequently, the greater the restrictions for root system growth and plant development [15].

There are basically two types of density when talking about soils: soil density and particle density. Soil density is defined as the ratio between the mass of a soil sample dried at 105 ° C and the sum of the volumes occupied by the particles and the pores. In other words, soil density takes into account the soil sample mass and the total soil volume collected in the sample (particle volume plus pore volume). This density is given by the following formula:

$$d_s = \frac{m_s}{V_T}$$

At where: ms= soil mass

Vt= Total volume

ds= soil density

The particle density differs from the first because it considers only the volume occupied by the soil particles, not admitting the volume occupied by the pores. The following formula is used to express this density in:

$$\rho_s = \frac{m_s}{V_s}$$

At where: ms= soil mass

Vs= volume of solids

ps= particle density

There are several methods of density determination. The volumetric ring method (MAV) is considered as the standard method of sampling for the evaluation of soil density, which consists of sampling the soil with an undisturbed structure in a ring (metallic cylinder) of known volume [16].

To extract an undisturbed soil sample, the Kopeck volumetric ring can be used, with sharp edges and known internal capacity, generally 100 cm³; the ring is screwed into the profile wall or the soil surface by removing it; then the excess soil is removed, which will be abraded with the aid of a cutting knife until it matches with both surfaces of the ring. Soon after the thinning, the faces of the sample in the ring are identified, indicating which side represents the surface of the soil and which represents the lower part. The ring is capped on both sides and taken to the laboratory with care.

According to [17], the most modern methods of determining soil density are based on nuclear techniques. Among these techniques, computed tomography (CTM) has been used for more than two decades mainly in studies of soil compaction and its effects on agricultural production and soil degradation.

Linked to the analyzes of density and resistance to penetration, is the soil moisture. Several methods and techniques are used to determine the water content in the soil, some delayed, other faces and some quite imprecise depending on the soil condition, according to [18].

The standard method is the extraction of water from a soil sample by means of heat, using electric greenhouses, thus determining the gravimetric moisture of the soil by the relation between the water mass and the dry soil mass [18]. According to [19] it is a destructive, direct and very precise method.

After obtaining the sample in the field, it is placed in an aluminum cap, closing well, so that there is no water vapor. After this, the assembly is weighed, obtaining the wet weight. The soil samples are oven dried at 105-110 ° C for 24 hours. After drying the samples should be placed in a desiccator to cool without moisture absorption and subsequently weighed. These samples are weighed before and after drying and it is possible to calculate the percentage of dry soil moisture [20].

$$Ug = \frac{(Mu - Ms)}{Ms} \times 100$$

Where: Ug is the gravimetric content of water in the soil (% of mass), Mu is the wet mass of the sample (g), and Ms is the dry mass of the sample (g).

Therefore, the objective of this work was to evaluate the influence of cultural practices on compaction of a cerrado latosol.

2. MATERIAL AND METHODS

The long - term experiment was implemented in the 2015/2016 crop, at the dependencies of the Rio Verde Technological Research and Development Foundation, at Km 8, Zona Rural, MT 449, located between the geographic coordinates 13 ° 00'27 "S - 55 ° 58'07 "W and 12 ° 59'34" S - 55 ° 57'50 "W, with average altitude of 387 meters, in the municipality of Lucas do Rio Verde - MT. The predominant climate is Am (tropical climate with mean annual rainfall> 1500 mm and rainfall of the driest month <60 mm), according to Köppen-Geiger classification, showing two well defined seasons (rainy, October to April and dry, from May to September), the soil is classified as RED LATOSOLO Dystrophic yellow with a clayey texture.

Three blocks were used in full sun, each one with the 13 treatments, with each plot being 15m wide and 30m long. A randomized complete block design (DBC) was used for this experiment, with three blocks (one repetition per block), thirteen treatments and two depths of soil (0-10 cm and 10-20 cm). It was not possible to carry out the soil collection in a stratified form up to 300mm deep, since there were no materials needed for the work. The field-based penetrometer test was performed, but data are still being processed.

The implanted treatments related to the 13 different cultural management, conducted uninterrupted from the 2015/2016 harvest. They are: 1) Harvest - Soy (Fertilization in the planting line). Offsetting - area remained fallow; 2) Harvest - Soy (Fertilization in the planting line). Offsetting - area remained fallow, but the soil was stirred at each off-season; 3) Harvest - Soybean (Fertilization in the planting line). Second harvest - Maize (Fertilization in the Planting Line). Offsetting - fallow; 4) Harvest - Soya (Fertilization to haul). Second harvest - Maize (Fertilization with haul). Offsetting - fallow; 5) Crop - Soya (Fertilization in the planting line). Second harvest - Maize (Fertilization in the Planting Line) + Crotalaria. Cross-harvesting - Crotalaria; 6) Harvest - Soya (Fertilization in the planting line). Second crop - Maize (Fertilization in the Planting Line) + Brachiaria. Offsetting - Brachiaria; 7) Harvest - Soya (Fertilization in the planting line). Offsetting - Brachiaria; 8) Crop - Soya (Fertilization in the planting line). Cross-harvesting - Crotalaria; 9) Crop - Soya (Fertilization on the planting line). Second crop - Brachiaria + Crotalaria. Offsetting - Brachiaria; 10) Harvest - Soybean (Fertilization in the planting line). Offshoring - Brachiaria + Crotalaria; 11) Harvest - Soya (Fertilization on the planting line). Entressafra - Milheto; 12) Crop - Soya (Fertilization in the planting line). Entressafra-Brachiaria + Crotalaria + Millet + Forage Turnip; 13) Harvest - Soybean (Fertilization in the planting line). Inter-harvesting, each crop will receive a different coverage culture each year, namely: 1st) Brachiaria Year; 2º) Year Crotalaria Spectabilis; 3rd) Millet Year (adopted for this work); 4º) Year Turnip; 5º) Year Crotalaria Ochroleuca 6º) Year Wheat Morisco; 7º) Year Oat Black; 8º) Year Guandu Beans.

The experimental area was not irrigated at any time, counting only rainwater for the maintenance of water availability. The management carried out throughout the year in the area varied according to the treatment adopted and the month of the year, but they were fallow, fallow with stirring, and desiccation. The objective of this work was to evaluate the influence of the aforementioned maneuvers on soil compaction of the experimental area, using physical indicators of soil mechanical resistance to penetration, soil density and gravimetric moisture.

Soil sampling was carried out in a rainy month (April), aiming at a moisture condition closer to the recommended one, and a visual evaluation of moisture was made, and good conditions for sampling on the day of work were found. Sampling points were randomly defined within each plot, avoiding sites close to anthills, trail of passage of the agricultural machinery wheel among other impediments. Two samples of each plot were also collected and the mean values of these values were then performed for each depth. The undeformed samples were collected with a Kopecky sampler with a previously identified ring, noting in the field book the identification of the ring and the location of the sampling point. It was necessary to surface cleaning the collection site, removing the remains of culture, but without scraping the soil, then nail the sampler vertically and strike it until its body is completely inserted into the soil. Making constant circular movements, the sampler of the soil and the ring of the sampler was taken very carefully and using tools like spatula and stylet to facilitate the extraction. Then the two faces of the ring were thinned and both are capped, always identifying the upper and lower faces of the ring. Finally, it is necessary to place the samples in suitable containers, so that there is no damage to their characteristics.

The test to evaluate soil penetration resistance (RSP) was done with laboratory bench penetrograph. All the samples had their high humidity up to the field capacity, because the interest was to evaluate the RSP in the field capacity, for that each ring with soil when arriving in the laboratory had its covers removed and in the lower face of each one was placed a blade thin fabric (perflex) secured by rubber elastics (money elastic). The rings were then placed in a plastic tray and water was slowly added (24h) in the bottom until the water level reached near ground level height in the rings. Then the tray was inclined to drain the free water, with an average duration of 48 hours. In the workbench (Figure 5), the Quantum X Assistant V2 0 R1 (57) programs were used in the computer that controls the penetrograph (PEAB), making it necessary to calibrate the equipment for the type of test to be performed, of the type of tip and rod adopted. With the penetrograph instruction manual and the POP (Standard Operating Procedure) in hand, it was possible to operate the equipment, carry out the tests for all the available proofs, obtain and store the data in Excel file, interpret the information, perform conversions of units, and use mathematical formulas to obtain the values of depth in millimeters and soil resistance to penetration in Mega Pascal.

The soil density of the samples was obtained with the same specimens from the previous RSP test; the rings with soil samples had already been identified in the field. The precision balance used (400g capacity, and 0.001g resolution) was turned on to heat it, then a watch glass was placed on the scale and the tare was made. The rings with the samples, individually, were weighed in the scale and the weight obtained was recorded in a specific worksheet. The rings were then placed in a metal tray, placed in a controlled oven at 105 ± 2 ° C, remaining there for 24 hours; then transferred from the oven to a desiccator with a crucible tweezer and allowed to stand for one hour. Again the scale was switched on, cleared with a watch glass, and each dry sample ring was individually weighed, this weight being recorded on a specific spreadsheet. The soil was then discarded, the rings rinsed and left to dry in the environment, after which, heavy and the value of the same recorded in a specific worksheet. Soil density was determined by the volumetric ring method (MAV), where the density is equal to the division of the mass of dry soil in greenhouse by the volume of the ring used (100 cm^3).

The soil gravimetric moisture was determined in a standard way, through the extraction of water from the samples by means of heat, using an electric stove. Soil samples were collected in the field, between the depths of 0-10 cm and 10-20 cm, stored in aluminum cans with a lid, and identified with a permanent brush. The precision balance used (400g capacity, and resolution of 0.001g) was turned on about 10 minutes before to warm it up, so a watch glass was placed on the scale and the tare was performed. Individual weighing of the wet soil samples contained in each aluminum capsule, with its respective cover, using the watch glass as a bulkhead was used, so that the soil did not come in direct contact with the scale, and the weight was recorded in a spreadsheet proper. The capsules were placed on the caps themselves, facing upward, and accommodated in a metal tray, then brought to the oven set at 105 ± 2 ° C for 24 hours. The capsules were transferred from the oven to a desiccator with a crucible tong, capped immediately and allowed to stand for one hour. Again the scale was switched on, cleared with a watch glass, and each capsule with its lid and the dry sample was weighed individually, and this weight was noted in a suitable spreadsheet. The soil contained in the capsules was discarded, the capsules and lids were washed (without removing the markings) and allowed to air dry, then weighed with their respective cap, and the values were recorded in a suitable spreadsheet. With the mass data of wet soil plus capsule and cap, dry soil mass plus capsule and lid and mass of capsules plus lid, it was possible to obtain by difference the mass of dry soil and the mass of moist soil contained in each capsule. The percentage of moisture of each sample was obtained by subtracting the wet mass value from the dry mass value, divided by the dry mass value and multiplied by one hundred.

3. RESULTS AND DISCUSSION

3.1. Ground penetration resistance (RSP)

The analysis of variance showed that there is a statistical difference between the treatments studied and the differences between averages were compared by the Tukey test, at a 5% probability level (Table 1). The coefficient of variation for the means test was 27.37%.

The treatment that was superior, that is, the one in which the soil offered the lowest resistance to penetration, independent of the block and the observed depth, was the treatment of number 2 (crop with soybean, fertilization in the planting line, fallow and off), with 1.29 MPa of resistance to penetration resistance offered by the soil. The treatments of number 12,6,9,4,7,11 and 1, did not differ statistically among them, presenting RSP values between 1.75 and 2.54 MPa. The treatments that showed to be more compacted, offering greater resistance to penetration, were those of number 8,10,5,3 and 13 (presenting average values between 2.5743 and 2.8836 MPa), being: 8) Crop - Soybean (Fertilization on the planting line). Cross-harvesting - Crotalaria; 10) Harvest - Soybean (Fertilization in the planting line). Offshoring - Brachiaria + Crotalaria; 5) Crop - Soya (Fertilization in the planting line). Second harvest - Maize (Fertilization in the Planting Line) + Crotalaria. Cross-harvesting - Crotalaria; 3) Harvest - Soybean (Fertilization in the planting line). Second harvest - Maize (Fertilization in the Planting Line). Offsetting - fallow; 13) Harvest - Soybean (Fertilization in the planting line). Crossroads - Millet.

Table 1 - Soil Resistance to Mega Pascal Penetration (MPa)

Treatments	Averages	Results
2	1.29	A
12	1.75	AB
6	1.89	AB
9	2.02	AB
4	2.25	AB
7	2.39	AB
11	2.50	AB
1	2.54	AB
8	2.57	B
10	2.59	B
5	2.63	B
3	2.79	B
13	2.88	B

**Averages followed by the same letter in the column do not differ from each other by the Tukey test, at a 5% probability level.*

The lowest value of soil resistance to penetration (where the lowest compaction was observed) was in treatment 2, where each time the soil underwent a stirring. This suggests that this management promotes greater disaggregation of soil particles, an increase in macroporosity, and a disturbance in the natural accommodation of particles. An inverse proportional relation is observed by [21], in which soil compaction is caused by soil surface pressures due to machine traffic and the movement of fine particles to subsurface horizons, which clog the pores and decrease the macroporosity of the soil. soil, a condition that is present with less intensity in revolving soils. The same author suggests that the causes of soil disaggregation can be natural or anthropic, and among them is the mechanical disaggregation, with rotating hoe and grids [21]. The treatments that presented the highest values of RSP, received crotalaria at some point, making it evident that this crop is not the most suitable for the decompression of the soil in depth of 0-20 cm. This is probably due to the fact that its pivoting root system is not so efficient for this depth range, compared to brachiaria, whose root system is fasciculate and shallower. [22] argue that pivotal roots offer greater constraint on development and penetration in denser soils. According to [23], in order to establish a good system of biological decomposition of the soil it is necessary that there be plants capable of developing in compacted soils, forming biopores and improving the physical conditions of this soil.

The overall mean of the two depths used for soil sampling (0-10 cm and 10-20 cm) differed statistically from RSP (Tukey, at a 5% probability level), regardless of the treatment and the observed block. The sample depth of 10-20 cm was less compacted according to the test, with a mean value of 2.01 MPa, while the depth of 0-10 cm showed an average RSP value of 2.62 MPa. The possible explanation for the behavior of this result is the fact that the traffic of agricultural machines and implements causes a compactation in the most superficial layer of the soil in the system of direct sowing [24]. According to [25], cropping and harvesting are also contributing factors for compaction at the soil surface.

As for the block, the mean values of the RSP values did not differ statistically (Tukey, at a 5% probability level), indicating that the behavior of the means was similar in the three blocks, with no difference between them under the resistance penetration.

3.2. Soil Density (Ds)

The analysis of variance showed that there is a statistical difference between the treatments studied and the differences between averages were compared by Tukey test, at a 5% probability level (Table 2), independent of depth and block. The coefficient of variation for the means test was 3.06%.

Table 2 - Soil Density

Treatments	Averages	Results
9	1,36	A
2	1,38	A B
7	1,41	A B
8	1,42	A B
6	1,43	A B
10	1,43	A B
4	1,44	A B
13	1,44	A B
5	1,44	A B
12	1,45	A B
3	1,45	B
11	1,46	B
1	1,46	B

**Averages followed by the same letter in the column do not differ from each other by the Tukey test, at a 5% probability level*

The treatment that showed superiority, that is, the one that presented lower density, independent of the block and the observed depth, was the treatment of number 9 [Safra - Soja (Fertilization in the planting line). Second crop - Brachiaria + Crotalaria. , With an average soil density of 1.3608 g / cm³. The treatments of number 2,7,8,6,10,4,13,5 and 12, did not differ statically among themselves, presenting mean values of density between 1.38 and 1.45 g / cm³. The worst results were from treatments 3,11 and 1, with respective mean values of 1.45, 1.45 and 1.46 g / cm³. These treatments were: 3) Harvest - Soybean (Fertilization in the planting line). Second harvest - Maize (Fertilization in the Planting Line). Offsetting - fallow; 11) Harvest - Soya (Fertilization on the planting line). Entressafra - Milheto; 1) Harvest - Soybean (Fertilization in the planting line). Offsetting - area remained fallow.

The superior result of the treatment 9 (soybean in the crop and brachiaria in the second harvest and off-season) in relation to the others in terms of density, is based on the characteristics of rusticity and the aggressiveness of the brachiaria grass, as well as its tolerance to compaction, making it a very interesting forage crop to rotational planting systems. According to [26], "brachiaria constitutes a prominent option among species with potential to promote improvements in soil structure, due to the quantity, quality and distribution of root biomass that it adds to the soil, and the satisfactory tolerance to soil compaction, besides of not significantly interfering with maize productivity ". In a study carried out with brachiaria in the crop-livestock system and the soybean monoculture system, the lowest values of density were observed in the first case, because the brachiaria has a well developed root system, thus contributing to a greater contribution of MOS [27].

The worst results shown in treatments 3,11 and 1 indicate that they are more compacted due to lack of crop diversification (monoculture) and fallow cycles, being cultivated only with soybean, maize and millet in the main crop and second crop , and left fallow the rest of the year. [28] point out that the duration of fallow has an influence on environmental sustainability and a very short period results in an accelerated local degradation of cultivated soils. A study developed by [29] showed that areas of no-tillage system presented higher Ds, which can be explained as a consequence of the management carried out in these areas with the use of agricultural machinery for planting and harvesting.

The general mean of the two depths adopted for sampling (0-10 cm and 10-20 cm) did not show statistical differences in soil density (Tukey, at a 5% probability level), regardless of the treatment and the block observed . This indicates that the behavior of the averages was similar for the two depths observed, with no difference between them in soil density. What may explain this result is that both depths, though different, are located superficially, very close to each other.

The averages of soil density values in the blocks differed statistically (Tukey, at a 5% probability level), regardless of treatments and depths. The block that showed to be superior, with average density of 1.40 g / cm³, was block 2. Block 3 and block 1 did not differ among them, presenting values of 1.439 and 1.442 g / cm³, respectively. The blocks located on the edges of the experimental area were slightly more susceptible to the action of external agents such as people, machines and animals, which may explain the higher values of Ds for these blocks.

3.3. Soil moisture (Ug)

The moisture content of the samples that were stored in the aluminum cans (preserving soil moisture at the time of collection) was collected in the laboratory (table 3). The coefficient of variation of the test was 7.56%.

Table 3 - Gravimetric Humidity

Treatment	Soil moisture (%)
1	24.2
2	22.2
3	24.3
4	20.5
5	24.5
6	20.9

7	24.7
8	23.7
9	26.6
10	24.5
11	25.2
12	22.3
13	26.8

The soil moisture range was ideal for the soil sampling process with Kopecky sampler for RSP evaluation and soil density, ranging from 20.50 to 26.85%, such conditions preserve the soil sample undeformed at the moment of collection, as well as providing a more reliable RSP value. A study by [30] evaluated that in the wet months of the year the RSP is smaller when compared to the dry months, and the coefficient of variation is also lower. The same author is justified in the affirmation that the humidity changes the cohesion between the soil particles, which in the driest months are closer and difficult to be separated by any external force, justifying the higher values of RSP.

4. CONCLUSION

The annual soybean cultivation system, fertilized in the planting line, sown in October and harvested in February, with fallow and tillage in the off season, obtained the best result when the soil resistance to penetration was evaluated, indicating that this management was what the less compacted the soil in an interval of three years of study.

The annual management system in which the crop was cultivated with soybean fertilized in the planting line, the second crop cultivated with brachiaria + crotalaria, and the off - season cultivated with brachiaria presented the lowest value of density, evidencing the importance of a decompressive forage crop in the area.

It is also concluded that soil moisture is an important parameter to consider at the time of sampling, since several other soil physical analyzes are dependent on it.

REFERENCES

1. SOANE, B.D., OUWERKERK, C. van. Soil compaction problems in world agriculture. In: SOANE, B.D., OUWERKERK, C. van, (eds). Soil compaction in crop production. Netherlands: Elsevier, 1994. p.1-21.

2. KERTZMANN, F.F. Modifications in the structure and behavior of a Purple Latosol caused by compaction. São Paulo, SP, 1996. 153p. Thesis (PhD in Physical Geography) - Faculty of Philosophy, Letters and Human Sciences, University of São Paulo, 1996.

3. PEDROTTI, A .; PAULETTO, E.A .; GOMES, A.S .; TURATTI, A.L. & CRESTANA, S. Systems of irrigated rice cultivation and the compaction of a Planosol. Pesq. Agropec. Bras., 36: 709-715, 2001.

4. PEDROTTI, A. & DIAS Jr., M.S. Soil compaction: how to avoid it. Agropec. Catarinense, 9: 50-52, 1996.

5. BORTOLON, Leandro. EQUIPMENT FOR COLLECTION OF UNDERNEOUS SOIL SAMPLES FOR STUDIES IN CONTROLLED CONDITIONS. Brazilian Journal of Soil Science, Porto Alegre, v. 5, n. 8, p.1929-1934, set. 2009.

6. BENGHOUGH, A.G. & MULLINS, C.E. Mechanical impedance to root growth responses: a review of experimental techniques and root growth responses. J. Soil Sci., 41:341-358, 1990.

7. STOLF, R .; FERNANDES, J. & URLANI NETO, V.L. Recommendation for the use of the impact penetrometer - model IAA / Planalsucar - Stolf. São PauloMIC / IAA / PNMCA-Planalsucar, 1983. 8p. (Bulletin, 1).

8. BUSSCHER, W.J .; BAUER, P.J .; CAMP, C.R. & SOJKA, R.E. Correction of cone index for soil water content differences in a coastal plain soil. Soil Till. Res., 43: 205-217, 1997.

9. GIAROLA, N.F.B .; SILVA, A.P .; TORMENA, C .; SOUZA, L.S. & RIBEIRO, L.P. Similarities between cohesive soil character and Hardsetting behavior: Case study. R. Bras. Ci. Solo, 25: 239-247, 2001.

10. KAMAQ. Impact Penetrometer. 2013. Available at: <http://www.kamaq.com.br/instrumentos_penetrometro.php>. Accessed on: 22 Oct. 2017.

11. STOLF, Rubismar et al. Stolf impact penetrometer - computational data program in EXCEL-VBA. Brazilian Journal of Soil Science, [s.l.], v. 38, n. 3, p.774-782, jun. 2014.

12. REINERT, Dalvan J .; COLLARES, Gilberto L .; REICHERT, José M .. Cone penetrometer with constant rate of penetration in the soil: development and functional testing. Agricultural Engineering, [s.l.], v. 27, n. 1, p.304-316, apr. 2007. Fapunifesp (SciELO).

13. BOWEN, H.D. Alleviating mechanical impedance. In: ARKIN, G.F., TAYLOR, H.M., (eds). Modifying the root environment to reduce crop stress. St. Joseph: American Society of Agricultural Engineers, 1981. p.21-57.

14. HAKANSSON, I., VOORHEES, W.B. Soil compaction. In: LAL, R., BLUM, W.H., VALENTIN, C., et al. (eds). Methods for assessment of soil degradation. Boca Raton: Lewis, 1997. p.167-179.

15. COOPER, Miguel; MAZZA, Jairo Antonio. Soil density and particle density. . Available in: <https://edisciplinas.usp.br/pluginfile.php/300387/mod_resource/content/0/Theoretical Lecture 3 - Soil Density and Particle Density.pdf>. Accessed on: 27 Oct. 2017.

16. EMBRAPA. National Soil Research Center. Manual of soil analysis methods. 2. ed. Brasília, 1997. 212p.

17. PIRES, Luiz Fernando. Comparison of methods of measuring soil density. Acta Scientiarum., Maringá, v. 33, n. 1, p.161-170, out. 2011.

18. KLEIN, V. A. Soil Physics - Passo Fundo: Ed. Universidade de Passo Fundo, 2008. 212p;

19. SANTOS, R. M. et al. Mounting and accuracy of an experimental weighing system for calibration of soil moisture sensors. Science and agro-technology, Lavras, v. 30, n. 6, p. 1162-1169, nov./dez. 2006.

20. Taise Cristine. HUMIDITY BEHAVIOR OF SOIL DETERMINED BY EXPEDITED METHODS.2011. 68 f. Dissertation (Master degree) - Agricultural Engineering Course, Federal University of Santa Maria, Santa Maria, 2013.

21. CARVALHO JÚNIOR, I.A., FONTES, L.E.F., COSTA, L.M. Modifications caused by the use and formation of compacted layers and, or, densified in a Latossolo VermelhoEscuro medio texture, in the Cerrado region. Brazilian Journal of Soil Science, Viçosa, v.22, p.505-514, 1998.

22. BORGES, E. N. et al. Responses of soybean varieties to compaction of soil layers. Journal of Ceres, v. 35, n. 202, p. 553-568, 1988.

23. CARDOSO, E. G .; ZOTARELLI, L .; PICCININ, J .; TORRES, J. Distribution of the root system of soybean crop as a function of soil management. In: Brazilian Congress of Soil Science, 29, 2003, Ribeirão Preto. Anais ... SBCS, 2003. CD Rom.

24. WOORHEES, W.B. & LINDSTORM, M.J. Soil compaction constraints on conservation tillage in the Northern Corn Belt. J. Soil Water Conserv., 38: 307-311, 1983.

25. FLOWERS, M.D. & LAL, R. Axle load and tillage effects on soil physical properties and soybean yield on a Molic Ochraqualf in Northwest Ohio. Soil Till. Res., 48: 21-35, 1998.

26. CALONEGO, J.C .; BORGHI, E. & CRUSCIOL, C.A. C. Optimum water interval and soil compaction with intercropping of maize and brachiaria. Brazilian Journal of Soil Science, 35: 2183-2190, 2011.

27. LOSS, A. Dynamics of organic matter, soil fertility and aggregation in areas under different systems of use in the Cerrado of Goiás. 2011. 134 f. Thesis (Doctorate in Agronomy - Soil Science) - Federal Rural University of Rio de Janeiro, Seropédica, 2011.

28. CASTAGNARA, Deise Dalazen et al. PHYSICAL ATTRIBUTES OF RED LATOSOLO UNDER POUSIO OR CULTIVATED WITH TROPICAL FORRAGEIRES UNDER PASTEJO. Biosci. J., Uberlândia, v. 28, n. 1, p.150-158, mar. 2012.

29. LOSS, Arcângelo et al. Density and soil fertility under no-tillage systems and crop-livestock integration in the Cerrado. Rev. Cienc. Agrar., Rio Verde, v. 55, n. 4, p.260-268, out. /ten. 2012.

30. SILVEIRA, Dreid de Cerqueira et al. HUMIDITY VERSUS VERSUS RESISTANCE TO PENETRATION FOR A DISTROCOUS YELLOW ARGISSOL IN THE RECHARGE OF BAHIA. R. Bras. Ci. Solo, Cruz das Almas, v. 55, n. 4, p.659-667, mar. 2010.