REVISTA DE GEOCIÊNCIAS DO NORDESTE

*Northeast Geosciences Journal*

ISSN: 2447-3359

v. 9, nº 2 (2023)

https://doi.org/10.21680/2447-3359.2023v9n2ID30108

# Determination of physical soil properties by use and occupation in Caçapava do Sul – RS

## *Determinação das propriedades físicas do solo em função do uso e ocupação em Caçapava do Sul – RS*

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**Abstract:** Concern about soil quality has increased significantly, as its use and intensive mobilization reduce the ability to maintain good production. Management systems with vegetation removal, soil exposure, use of chemicals, machine traffic and animal trampling alter the soil structure, decreasing physical quality. This study aimed to determine the soil quality in the municipality of Caçapava do Sul - RS, through the characterization of physical attributes, performing a comparative analysis in different uses: soybean cultivation and livestock (native field). The physical attributes determined were: soil density, particle density, total porosity and hydraulic conductivity. The analyzes were performed in four replications performed in quadruplicate and the results analyzed by the Statistica 7.0 software. In the soybean planting area, in the layer between 0.25 and 0.35 m, the soil density showed higher values and lower porosity, evidencing the effect of soil compaction resulting from the transit of machinery. Regarding the particle density, the native field area had the lowest value in the surface layer. In hydraulic conductivity, both presented negative results. The results found demonstrate that the studied soils behaved in a similar way in relation to the evaluated parameters.

**Keywords:** Soil Density; Soil Management; Soil Porosity.

**Resumo:** A preocupação com a qualidade do solo aumentou significativamente, pois seu uso e mobilização intensa reduzem a capacidade de manter boa produção. Sistemas de manejo com remoção de vegetação, exposição do solo, uso de químicos, tráfego de máquinas e pisoteio de animais alteram a estrutura do solo, diminuindo a qualidade física. Este trabalho teve como objetivo determinar a qualidade do solo no município de Caçapava do Sul - RS, pela caracterização de atributos físicos, realizando análise comparativa em diferentes usos: cultivo de soja e pecuária (campo nativo). Os atributos físicos determinados foram: densidade do solo, densidade de partículas, porosidade total e condutividade hidráulica. As análises foram realizadas em quatro repetições realizadas em quadruplicata e os resultados analisados pelo software Statistica 7.0. Na área de plantio da soja, na camada entre 0,25 e 0,35 m, a densidade do solo apresentou valores maiores e a porosidade menores, evidenciando o efeito da compactação do solo resultante do trânsito de maquinário. Em relação à densidade de partículas, a área do campo nativo apresentou o menor valor na camada superficial. Na condutividade hidráulica, ambos apresentaram resultados negativos. Os resultados encontrados demonstram que os solos estudados se comportaram de forma semelhante em relação aos parâmetros avaliados.

**Palavras-chave:** Densidade do solo; Manejo do solo; Porosidade do solo.

Received: 25/08/2022; Accepted: 02/10/2023; Published: 13/11/2023.

## 1. Introduction

The development of plants requires appropriate physical soil conditions, and these properties are related to the flow of water, heat, and gas, which in turn directly affect the growth and productivity of crops (LOPES; GUILHERME, 2007). Currently, the concern for soil quality has significantly increased, as its use and intensive mobilization can lead to a decline in its capacity to support large-scale production (COLLARES et al., 2006; CARVALHO et al., 2004).

Soil quality refers to its ability to function within the ecosystem's limits, support biological performance, maintain environmental quality, and promote the well-being of plants and animals. This characteristic can be assessed through the monitoring of physical, chemical, and biological attributes (DE OLIVEIRA SILVA, 2021). Soil attributes commonly used as indicators of physical quality include density, porosity, hydraulic conductivity, mechanical resistance to root penetration, and infiltration rate, mainly due to their relative ease of determination and low measurement cost (SANTANA; BAHIA FILHO, 1998; MARCHÃO et al., 2007; BALBINOT JUNIOR et al., 2009). Soil physical quality degradation is manifested by low porosity, high resistance to root penetration, and reduced water retention capacity, which directly affects the fundamental functioning of the soil (AGUIAR, 2008).

The implementation of agricultural systems can lead to changes in soil physical properties, reducing its quality and often complicating recovery. What occurs is the alteration of the balance in a natural environment, as it frequently involves vegetation removal, soil exposure, application of fertilizers and pesticides, machine traffic, and changes in the hydrological regime in watersheds (ARCOVERDE, 2013).

Soil compaction caused by animal trampling is also widely cited as a cause of soil quality reduction, as it increases soil resistance to root growth (GURGEL, 2020). In compacted soil, it is also observed that the root system concentrates near the surface, reducing the plants' ability to absorb nutrients and water from sub-surface layers (LANZANOVA, et al., 2007).

In light of the above, this study aims to determine the physical properties of the soil based on different types of land use and occupation (livestock and soybean cultivation) in an area in the municipality of Caçapava do Sul, RS.

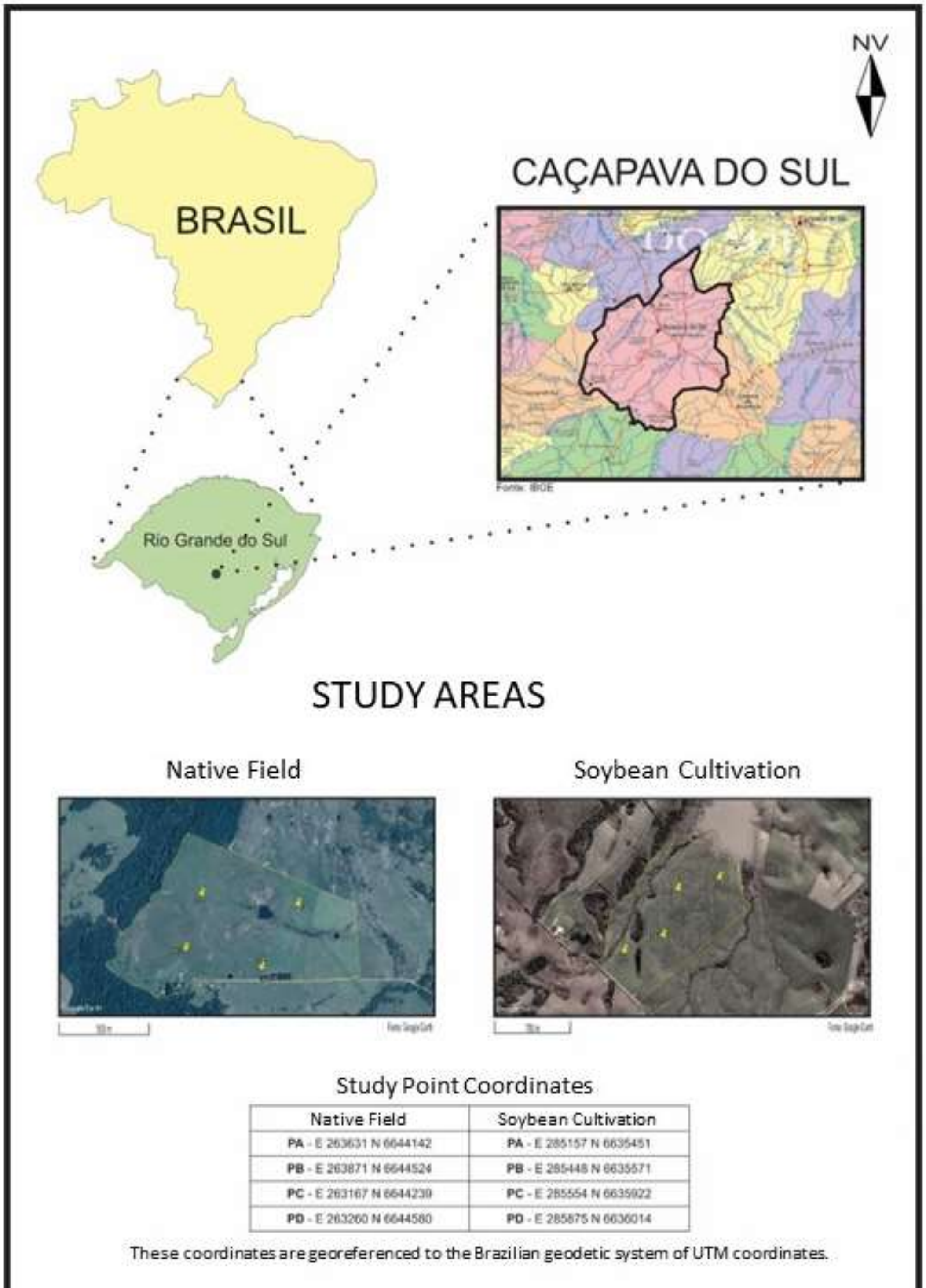
## 2. Methodology

### 2.1. Location and description of study areas

The present study was carried out on properties used for livestock and agriculture, located in the rural area of the municipality of Caçapava do Sul (localities of Passo do Souza and Dorasnal, respectively), located in the southeast of Rio Grande do Sul (Figure 1). The points analyzed in each area, as well as their respective coordinates, are also expressed in the figure.

According to the Köppen climate classification, the region's climate can be classified as humid subtropical (Cfa), characterized by good water availability and an even distribution of rainfall throughout the year, without a well-defined dry season (ROSSATO, 2020). Caçapava do Sul has a total annual rainfall of 1727.4 mm, with April being the month with the highest average rainfall (177.6 mm) and August the month with the lowest rainfall (104.3 mm) (WREGE et al., 2012). In the locality of Passo do Souza, a study was carried out in an area destined to beef cattle ranching (native field), in which its entire size measures approximately 100 hectares. At the time of the experiment, the stocking was 80 animals with calves, in an area that had been used exclusively for grazing activities for approximately 30 years.

The second locality, known as Dorasnal, corresponds to the soybean crop (summer planting), an area that during the winter is used for the planting of ryegrass. Aiming at soil correction, this area is treated with 3 tons of limestone per hectare.




| Native Field | Soybean Cultivation |
|---|---|
| **PA** - E 263631 N 6644142 | **PA** - E 285157 N 6635451 |
| **PB** - E 263871 N 6644524 | **PB** - E 285448 N 6635571 |
| **PC** - E 263167 N 6644239 | **PC** - E 285554 N 6635922 |
| **PD** - E 263260 N 6644580 | **PD** - E 285875 N 6636014 |

*Figure 1 – Location scheme including maps of the study areas (repetitions performed in the native field and soybean fild and their respective coordinates).*
*Source: Authors (2022).*

### 2.2. Soil sampling

To characterize the physical attributes and consequent evaluation of the soil quality, soil samples were collected in each use system (soybean and livestock). In each of these areas, four sub-areas (considered repetitions) of approximately 30 m2 were randomly delimited. For the analysis of density (Ds) and particle density (Dp), three different depths were considered, named Points 1, 2 and 3 (0.15 cm to 0.25 cm; 0.25 cm to 0.35 cm and 0.35 cm to 0.45 cm, respectively), following the methodology proposed by Aguiar (2008) with modifications. Then, the samples were sent for laboratory analysis.

### 2.3. Determination of Physical Attributes

#### Soil Density (Ds) and Particle Density (Dp)

To determine the bulk density (Ds) the volumetric ring method was used, and to determine the particle density (Dp) the method used the volumetric flask and alcohol as a penetrating liquid. Both methodologies are described in the Manual of Soil Analysis Methods of the Brazilian Agricultural Research Corporation (EMBRAPA, 2017).

#### Total porosity (Pt)

The total porosity (Pt) was determined by the relationship between soil density (Ds) and soil particle density (Dp) according to Equation 1 (AGUIAR, 2001):

$$Pt(\%) = \frac{(D_p - D_s)}{D_p}\ (X100) \qquad \text{Equation (1)}$$

Where:
Pt – total porosity;
Dp – density of solid soil particles;
Ds – soil density.

#### Hydraulic conductivity (K)

The determination of hydraulic conductivity (K) was based on the use of the Guelph Permeameter, using two pressure loads (H1=5cm and H2=10cm), as described by Aguiar (2001). To this end, the following steps were carried out: the hole was drilled and the depth reached was measured with the help of a ruler, and it was necessary to level the base and regularize the walls of the hole. The Guelph Permeameter was assembled, connecting the acrylic tube to the Mariotte bottle through malleable plastic hoses. The Permeameter was placed over the hole, adjusting the tripod legs so that the device was level. The solution was placed inside the acrylic tube, allowing the water to completely fill the hoses. The Mariotte tube was adjusted by means of the graduated ruler to establish the pressure height maintained inside the hole. Thus, the readings began to be taken at constant intervals of time, through the graduated ruler of the acrylic tube. When the differences in measurements between the readings became constant, the trial was stopped.

The calculation of the hydraulic conductivity (K) was obtained by knowing the value of the infiltration rate and its association with the dimensions of the borehole and the height of the water column inside it, using the following equation (CELLIGOI et al., 2006):

$$K = [(0{,}0041)(X)(R_2) - (0{,}0054)(X)(R_1) \qquad \text{Equation (2)}$$

Where:
K: Hydraulic conductivity (cm/s);
R1 and R2: Stabilized infiltration rates corresponding to H1 (5 cm) and H2 (10 cm) respectively (cm/s);
X: constant corresponding to the area of the pipe used (in this case 35.36 cm2).

#### Statistical analysis

The analyses were performed in four replications, which were conducted in quadruple. The results are expressed as mean ± standard deviation and submitted to analysis of variance (ANOVA). The means were compared with each other using Tukey's test, considering a significance level of 95% (p<0.05). The results were analyzed using *the Statistica 7.0 software.*

## 3. Results and discussion

### 3.1. Soil density

According to Aguiar (2001), soil density is influenced by the structure, degree of compaction and the characteristics of soil expansion and contraction. Reichert and Reinert (2006) describe that if there is a change in the pore space, there will be a consequent change in the density of the soil, and its main use is as an indicator of compaction. The results of soil density (Ds) found in this study can be seen in Figure 2, presented below:

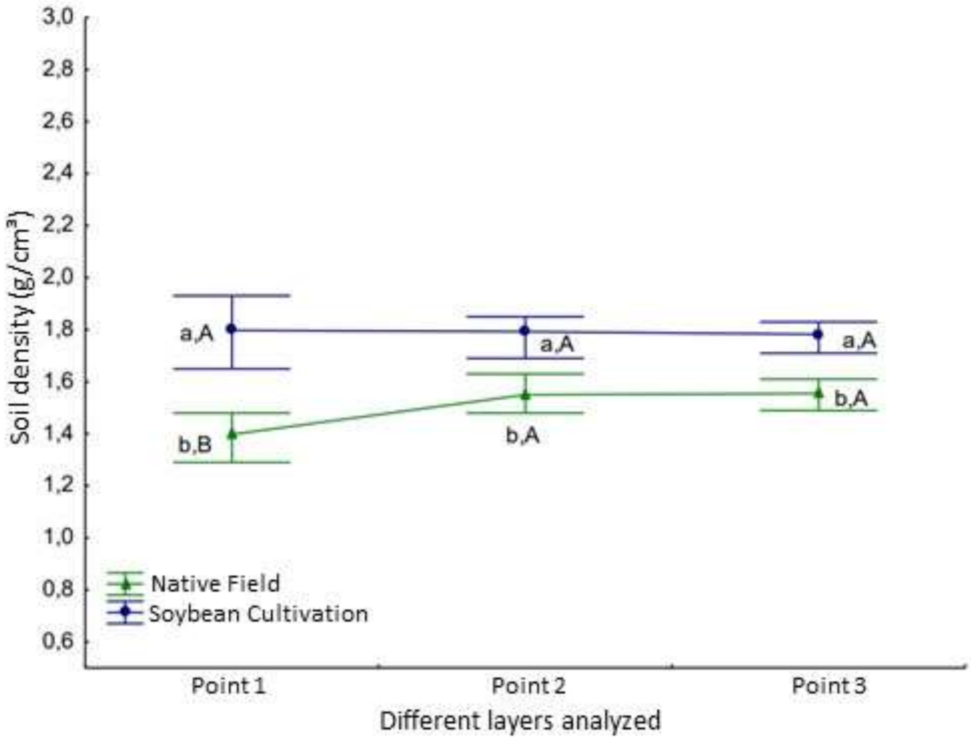



*Figure 2 – Mean values of soil density (Ds), expressed in g/cm3, found for the native field and for the area used for soybean planting, considering the three depths analyzed.*
Source: Authors (2022).

Point 1 covers depths from 0.15 to 0.25m, Point 2 from 0.25 to 0.35m and Point 3 from 0.35 to 0.45m. The values are presented as an average of four repetitions, means followed by lowercase letters compare density levels in the different soils analyzed, while uppercase letters compare values found for the different layers in the same soil at the level of 5% probability by Tukey's test (p<0.05).

From the results presented in Figure 2, it can be seen that for the three depths analyzed, the area used for soybean planting presented significantly higher density values (P<0.05) when compared to the native field, used for livestock. Similar results were found by Seron et al. (2013) when evaluating the soil density of livestock and crop systems at a depth of 0 to 0.20m. The authors state that even though there is no significant difference between the treatments, there is evidence of higher values in the tillage system and justify this behavior by the greater traffic of machines and implements that occurs in the tillage system when compared to pasture. However, the results presented do not agree with the theory cited by Kunz et al. (2013), who report that the pressure exerted by animals on the soil is greater than the pressure exerted by tractors. The authors point out that the high pressure exerted by the animals is due to the fact that their weight is concentrated in a small area – the hoof, while agricultural machinery, despite having a greater weight, exerts less pressure on the soil surface, since its weight is distributed in a larger area (tires). causing less compaction and consequently decreased density.

Regarding the three different layers analyzed, the area used for soybean planting did not show significant difference ($p<0.05$), i.e., the depth of sampling did not influence the density of the soil studied. However, for the native grassland, the most superficial layer (Point 1), which encompasses the depth of 0.15 to 0.25 m, presented a significantly lower result when compared to the other layers analyzed. Azevedo and Dalmolin (2004) found similar results, with soil density values between 0.95 and 1.80 g/cm3, with an increase in these results with increasing depth. According to the authors, this occurs naturally due to the weight exerted by the upper horizons.

According to Silva (2008) and Pequeno (2011), the study of soil density is important, as this parameter is recognized as a fundamental factor regarding the characteristics related to land use. Soils with a high degree of compaction (high density) are marked by resistance to root penetration, significantly hindering the absorption of water and nutrients by plants, due to the limitation of the area explored by the roots.

### 3.2. Particle Density (Dp)

Particle density, also called real density, is the ratio between the mass and volume of solids in a soil, without taking into account porosity (GUBIANI; REINERT; REICHERT, 2006). The particle density results found in this study are shown in Table 1.

*Table 1 – Mean values of particle density (Dp), expressed in g/cm3, found for the native field and for the field used for soybean planting, for the three depths analyzed.*

| Particle Density (Dp) | | |
|---|---|---|
| | **Native Field** | **Soybean Field** |
| Point 1 | $2,28 \pm 0,14^{a,A}$ | $2,53 \pm 0,24^{a,A}$ |
| Point 2 | $2,45 \pm 0,01^{a,A}$ | $2,60 \pm 0,24^{a,A}$ |
| Point 3 | $2,45 \pm 0,22^{a,A}$ | $2,59 \pm 0,24^{a,A}$ |

*Source: Authors (2022).*

The values are presented as mean ± standard deviation. Averages followed by equal lowercase letters in the row and uppercase letters in the column did not differ statistically from each other by Tukey's test at the 5% probability level ($p<0.05$).

Through the results shown in Table 3, it can be seen that, taking into account the different layers studied, there was no significant difference between the two soils evaluated, and the difference in depth during sampling also did not influence the result of the analysis for each particular treatment ($p<0.05$). Soil particle density is a unique quality that is hardly altered by the way the soil is treated. Therefore, the result obtained was already expected.

According to Gubiani; According to Reinert and Reichert (2006), the determination of soil particle density (Dp) is of renowned importance as an indicator of mineralogical composition, and can be used to calculate the sedimentation rate of particles in liquids and also for indirect determination of porosity. Studies developed by Kiehl (1979), Mello (2002) and Scherer et al., (2013) point out that particle density can be influenced by the density of minerals present in the soil and by the amount of organic matter, which has the ability to increase or reduce this parameter as the carbon content increases or decreases. Following this context, Kiehl (1979) also presented in his studies values of particle density that indicate the presence of some minerals in the soil. Among the minerals pointed out by the author, those that present values close to the results found in this study are montmorillonite ($2.20 < Dp < 2.70$) for the native field and orthoclase ($2.50 < Dp < 2.60$), haloisite ($2.55 < Dp < 2.56$) and microcline ($2.54 < Dp < 2.57$) for the soybean area. In this way, it is possible to induce the presence of these minerals in the respective soils and perhaps also corroborate their influence on the results found for this parameter.

### 3.3. Total Porosity

According to Aguiar (2001), soil porosity is the ratio between the volume of voids and the total volume of soil. Lorenzo (2010) states that the total porosity is reflected by the state of density of the soil, and these characteristics are changeable depending on the management used. Table 2 shows the mean values of total porosity found in this study for the two types of soil analyzed.

*Table 2 – Mean porosity values expressed as percentages, found for the native field and for the field used for soybean planting, for the three depths analyzed.*

| **Particle Density (Dp)** | | |
|---|---|---|
| | **Native Field** | **Soybean Field** |
| Point 1 | 38,59±2,41[a,A] | 37,74±1,74[a,A] |
| Point 2 | 36,72±2,87[a,A] | 34,55±2,49[a,A] |
| Point 3 | 36,27±3,26[a,A] | 34,98±1,51[a,A] |

*Source: Authors (2022).*

The values are presented as mean ± standard deviation. Averages followed by equal lowercase letters in the row and uppercase letters in the column did not differ statistically from each other by Tukey's test at the 5% probability level ($p<0.05$).

Through the mean values expressed in Table 4, it can be seen that the different sampling layers did not influence the results of the analysis, since there was no significant difference ($p<0.05$) for both the native field and the area with soybean plantation when taking into account the three layers analyzed (point 1, point 2 and point 3). This was expected, since porosity is strongly influenced by soil density, and in this parameter the vast majority of the results, which took into account the difference in sampling in the same soil, did not differ statistically from each other (item 6.1). Similar results were found by Wendling et al., (2012) when they analyzed the porosity of the soil under no-tillage at two different depths (0 to 0.10 m and 0.10 to 0.20 m) and by Pignataro Netto et al., (2009) when they studied pastures with different use histories, they also did not observe differences in the total porosity values regarding the sampling depth.

Although there was no statistical difference in relation to Tukey's test, the area used for soybean planting showed lower average values of total porosity when compared to the native grassland in the three layers studied, with the layer from 0.25 to 0.35 m (point 2) being the one with the lowest value. This result may show the phenomenon known as "plough foot" or "harrow foot", related to the formation of subsurface soil compaction just below the upturned soil layer by the implements, associated with the use of agricultural machinery for several consecutive years for soil preparation (LANÇAS, 2002). According to Andreolla (2010), for the same soil, the higher its density, the greater the resistance to penetration and the lower the porosity, which confirms the result found since in the analysis of soil density (Ds) the field with soybean planting presented higher values.

According to Pauletto et al., (2005) and Camargo and Alleoni (1997), an ideal soil should have 50% of total pore volume, which, in field capacity, would have 33.5% occupied by water and 16.5% occupied by air. Therefore, in general, it can be stated that for all treatments, low values of total porosity were found when compared to the ideal values cited in the literature (Table 4), i.e., values below 40%.

### 3.4. Hydraulic conductivity (K)

According to Carvalho (2002), the hydraulic conductivity of the soil is a parameter that translates the ease with which water moves along the soil profile and its determination, especially in the field, becomes essential, since the movement of water in the soil is directly related to the production of agricultural crops. The results found for hydraulic conductivity (K) are shown in Table 3.

*Table 3 – Mean values of hydraulic conductivity (K) found for the native field and for the field used for soybean planting.*

| **Hydraulic conductivity (K)** | |
|---|---|
| Native Field | -4,0x10-4±0,0000187[a] |
| Soybean Field | -3,7x10-4±0,0000345[a] |

*Source: Authors (2022).*

The values are presented as mean ± standard deviation. Means followed by identical letters did not differ statistically from each other by Tukey's test at the level of 5% probability ($p<0.05$).

It can be seen from the results shown in Table 5 that, both for the native field (livestock) and for the area used for soybean planting, the results of the hydraulic conductivity analysis originated negative values. Studies developed by Sousa and Celligoi (2011) showed similar results when evaluating hydraulic conductivity in agricultural and forested areas in the city of Londrina – PR using the Guelph permeameter and the technique of two load heights, the same method used in this work.

Studies developed by Reynolds et al., (1985) justify the occurrence of negative results in the determination of hydraulic conductivity through the technique of two load heights by the following factors: presence of air trapped in the soil, errors in flow measurement due to the presence of air bubbles, small spatial variation in scale of the hydraulic properties of the soil or due to the disturbance of soil characteristics, resulting in different measurement conditions.

Although the results were negative, it can be seen that there was no significant difference between the values found for the two land uses analyzed, which was expected, since, according to Mesquita and Moraes (2004), hydraulic conductivity is strongly dependent on attributes such as total porosity, size and distribution of soil particles. It is noteworthy that in this study, the porosity parameter did not present results that differed statistically when comparing the different land uses (item 6.3).

The hydraulic conductivity of the soil (K) is a property that expresses the ease with which water moves in it, and its determination is important for soil management, crop production, and the preservation of the soil and the environment (GONÇALVES; LIBARDI, 2013).

## 4. Final thoughts

The area used for soybean planting showed higher values of soil density (Ds) when compared to the native field, used for livestock. For the area with soybean planting, the difference in sampling depth did not influence the density, and for the native grassland, only the most superficial layer (0.10 to 0.25 m) presented a lower value.

Regarding particle density, both the two soils analyzed and the different layers sampled did not significantly influence this parameter. Although there was no statistical difference, the native field had the lowest value in the most superficial layer (0.10 to 0.25 m) while the soybean field obtained the highest result in the intermediate layer (0.25 to 0.35 m).

Taking into account the total porosity, all treatments presented low values when compared to the values mentioned in the literature for ideal soils. The different soil types evaluated, as well as the different layers analyzed, did not show statistical difference in relation to this parameter, although the soybean field showed lower results in the 0.25 to 0.35 m layer (Point 2).

The hydraulic conductivity (K), which represents the level of soil permeability, was also no different for the native field and for the soybean field, which presented negative results for this factor, showing that the technique used was not compatible for this determination.

According to the results found, it is possible to affirm that the two different land uses (native field and area with soybean plantation) analyzed behaved in a similar way in relation to the parameters evaluated, and for the determination of hydraulic conductivity, it is necessary to use other techniques that possibly respond better to the determination. Therefore, the work developed may contribute to the elaboration and execution of other academic research aimed at evaluating the soil in relation to different uses.

## References

AGUIAR, Adriana Briggs. *O emprego do permeâmetro de guelph na determinação da permeabilidade do solo, de camadas de lixo e sua cobertura***.** DISSERTAÇÃO (Mestrado em Engenharia Civil) – Universidade Federal do Rio de Janeiro, 2001.

AGUIAR, Maria Ivanilda. *Qualidade física do solo em sistemas agroflorestais***.** 2008. 79p. Dissertação (Mestrado em solos e Nutrição de Plantas) – Universidade Federal de Viçosa, 2008.

ANDREOLLA, Veruschka Rocha Medeiros. *Integração lavoura-pecuária: atributos físicos do solo e produtividade das culturas do feijão e milho***.** 2010. 120p. TESE (Doutorado em Agronomia) – Universidade Federal do Paraná, 2010.

ARCOVERDE, Sálvio Napoleão de Soares. *Qualidade de solos sob diferentes usos agrícolas na região do entorno do lago de Sobradinho – BA*. 2013. 71p. Dissertação (Mestrado em Engenharia Agrícola) – Universidade Federal do Vale do São Francisco, 2013.

AZEVEDO, Antônio Carlos. De; DALMOLIN, Ricardo Simão Diniz. *Solos e ambiente: uma introdução***.** Santa Maria: Editora Palotti, 100 p. 2004.

BALBINOT JUNIOR, Alvadi Antonio et al. Integração lavoura-pecuária: intensificação de uso de áreas agrícolas. *Revista Ciência Rural*, Santa Maria, v. 39, n. 6, p.192-193, março 2009.

CAMARGO, O. A.; ALLEONI, L. R. F. *Compactação do solo e o desenvolvimento das plantas***.** São Paulo: Divisão de biblioteca e documentação - ESALQ/USP. 132 p. 1997.

CARVALHO, Laercio Alves. *Condutividade hidráulica do solo no campo: As simplicações do método do perfil instantâneo***.** 2002. 86p. DISSERTAÇÃO (Mestrado em Agronomia) – Escola superior de agricultura Luiz de Queiroz, 2002.

CARVALHO, Rodrigo; GOEDERT, Wenceslau; ARMANDO, Marcio Silveira. Notas Científicas Atributos físicos da qualidade de um solo sob sistema agroflorestal. *Pesq. Agropec. Bras. Brasília*, v.39, n.11, p.1153-1155, nov. 2004.

CELLIGOI, André. et al. Utilização do permeâmetro Guelph na determinação da condutividade hidráulica da zona não-saturada do aquifero freático nas imediações do lixão de londrina – Pr. *Anais do XIV Congresso Brasileiro de águas subterrâneas*, 2006.

COLLARES, Gilberto Loguércio et al. Qualidade física do solo na produtividade da cultura do feijoeiro num Argissolo. *Pesq. agropec. bras*., Brasília, v.41, n.11, p.1663-1674, nov. 2006.

DE OLIVEIRA SILVA, Michelangelo et al. Qualidade do solo: indicadores biológicos para um manejo sustentável. Brazilian Journal of Development, v. 7, n. 1, p. 6853-6875, 2021.

EMBRAPA. Centro Nacional de Pesquisa de Solos ( Rio de Janeiro, RJ). *Manual de métodos de análise de solo*. 3. edição. Brasília, DF: Embrapa, 2017. 574 p.

GONÇALVES, Adriano Dicesar Martins de Araújo; LIBARDI, Paulo Leonel. Análise da determinação da condutividade hidráulica do solo pelo método do perfil instantâneo. *Revista Brasileira de Ciência do Solo***,** v. 37, p. 1174-1184, 2013.

GUBIANI, Paulo Ivonir; REINERT, Dalvan José; REICHERT, José Miguel. Método alternativo para a determinação da densidade de partículas do solo: exatidão, precisão e tempo de processamento. *Ciência Rural*, v. 36, p. 664-668, 2006.

GURGEL, Antonio Leandro Chaves et al. Compactação do solo: Efeitos na nutrição mineral e produtividade de plantas forrageiras. *Revista Científica Rural*, v. 22, n. 1, p. 13-29, 2020.

KIEHL, E.J. *Manual de edafologia: Relações solo-planta*. São Paulo: Ceres, 1979. 262p.

KUNZ, Marcelo. et al. Compactação do solo na integração soja-pecuária de leite em Latossolo argiloso com semeadura direta e escarificação. *Revista Brasileira de Ciência do Solo*, v.37, p.1699-1708, 2013.

LANÇAS, K.P. *Subsolagem ou escarificação*. Revista Cultivar Máquinas. Setembro-Outubro, 2002, p. 34-37.

LANZANOVA, Mastrângello Enívar et al. Atributos físicos do solo em sistema de integração lavoura-pecuária sob plantio direto. *Revista Brasileira Ciência do Solo*, v. 31, p. 1131-1140, 2007.

LOPES, Alfredo Scheide; GUILHERME, Luiz Roberto Guimarães. Fertilidade do solo e produtividade agrícola. *Fertilidade do solo*, p. 2-64, 2007.

LORENZO, Mariana. *PEDOLOGIA – Morfologia: Densidade do Solo***.** Disponível em: <https://marianaplorenzo.com/2010/10/18/pedologia-morfologia- densidade-do-solo>. Acesso em 23 mai. 2016.

MARCHÃO, R. L. et al. Qualidade física de um Latossolo Vermelho sob sistemas de integração lavoura-pecuária no Cerrado. *Pesq. agropec. bras*., Brasília, v.42, n.6, p.873-882, jun. 2007

MELLO, N. A. Degradação física dos solos sob integração lavoura pecuária. In: ENCONTRO DE INTEGRACAO LAVOURA PECUARIA NO SUL DO BRASIL, 2002**,** Pato Branco. Anais. Pato Branco: CEFET – PR, p.43-60, 2002.

MESQUITA, M. G. B. F; MORAES, S. O. A dependência entre a condutividade hidráulica saturada e atributos físicos do solo. *Revista Ciência Rural*, v.34, n.3, p. 963-969, 2004.

PAULETTO, Eloy A. et al. Avaliação da densidade e da porosidade de um gleissolo submetido a diferentes sistemas de cultivo e diferentes culturas. *Revista Brasileira de Agrociências***.** V.11, n.2, p. 207-210, 2005.

PEQUENO, Petrus Luiz de Luna, et al. Avaliação da densidade do solo em áreas com cafeeiro robusta arborizado em Rondônia**.** Anais. *XXXIII congresso brasileiro de ciência do solo*, 2011.

PIGNATARO, Netto, et al. Atributos físicos e químicos de um latossolo Vermelho- amarelo sob pastagens com diferentes históricos de uso. *Revista Brasileira de Ciência do Solo*, Viçosa, v. 3, p. 1441-1448, 2009.

REICHERT, José Miguel; REINERT, José Dalvan. *Manual das propriedades físicas do solo*. Universidade Federal de Santa Maria – UFSM, maio 2006.

REYNOLDS, W. D. et al. The constand head well permeameter: effects of unsaturated flow. *Soil Science*, v.139, n.2, p.172-180, 1985.

ROSSATO, Maíra Suertegaray. Os climas do Rio Grande do Sul: uma proposta de classificação climática. *Revista Entre-Lugar*, v. 11, n. 22, p. 57-85, 2020.

SANTANA, Derli Prudente; BAHIA FILHO, Antonio. Soil quality and agricultural sustainability in the Brazilian Cerrado. In: WORLD CONGRESS OF SOIL SCIENCE, 16. 1998, Montpellier. Anais. Montpellier: ISSS, 1998. CD-ROM.

SCHERER, Vinícius Saldanha, et al. Densidade de partículas de sedimentos depositados no arroio pelotas e relação com textura e mineralogia. Anais**.** XXI *Congresso de Iniciação Científica da Universidade Federal de Pelotas*. 2013.

SERON, Cássio de Castro et al. Densidade e porosidade do solo em área de implantação do sistema integração lavoura-pecuária. Anais do VIII EPCC – *Encontro Internacional de Produção Científica Cesumar*, UNICESUMAR – Centro Universitário Cesumar Editora CESUMAR Maringá – Paraná – Brasil, 2013.

SILVA, D. I. *Influência de forrageiras e leguminosas na densidade e porosidade do solo na região de Rolim De Moura – RO***.** Rolim de Moura, 2008. 35 p. Trabalho de Conclusão do Curso de Agronomia – Departamento de Agronomia. Unir - Campus de Rolim de Moura, 2008.

SOUSA, Rodrigo Vitor Barbosa; CELLIGOI, André. Avaliação da condutividade hidráulica do solo em área agrícola e florestada na cidade de londrina (pr) através do permeâmetro Guelph. *Boletim de geografia*, Maringá, v.29, n.2, p. 123-133, 2011.

WENDLING, Beno. et al. Densidade, agregação e porosidade do solo em áreas de conversão do cerrado em floresta de pinus, pastagem e plantio direto. *Journal Biosci*. V.28, n.1, p.256-265, 2012.

WREGE, Marcos Silveira et al. *Atlas climático da região sul do Brasil: estados do Paraná, Santa Catarina e Rio Grande do Sul.* Pelotas: Embrapa Clima Temperado; Colombo: Embrapa Florestas, 2012. 333 p.