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EFEITO DO TRÁFEGO AGRÍCOLA NA INFILTRAÇÃO DE ÁGUA NO SOLO

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1 RESUMO

As modificações causadas por atividades antrópicas como o tráfego de máquinas afetam diretamente a infiltração de água no solo. O trabalho teve por objetivo avaliar a infiltração de água no perfil do solo submetido a diferentes intensidades de tráfego agrícola. O experimento foi realizado na Fazenda Lageado da UNESP/FCA, Botucatu/SP, em duas classes de solo, Nitossolo Vermelho distroférrico (NVd) e Latossolo Vermelho distroférrico (LVd). O delineamento experimental foi completamente casualizado, com os respectivos tratamentos de compactação: T0 = 0; T1 = 1; T2 = 2; T3 = 3; T4=5 e T5 = 10 passadas consecutivas de um trator agrícola. Foram determinados os seguintes atributos: infiltração de água no solo, porosidade e água disponível no solo. Constatou-se que a velocidade de infiltração básica do solo foi baixa para ambos os solos em todos os tratamentos que houve o tráfego. Para as duas classes de solo houve a redução da macro porosidade e não interferência na microporosidade. O teor de água disponível às plantas no solo argiloso teve maior variação do que no solo de textura média. Há efeito da compactação do solo na dinâmica da lâmina de água no perfil do solo.

Palavras-chave: compactação do solo, tráfego de máquinas, infiltração de água no solo.

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EFFECT OF TRAFFIC IN AGRICULTURAL SOIL WATER INFILTRATION AND THE PHYSICAL ATTRIBUTES OF THE SOIL

2 ABSTRACT

Modifications caused by human activities such as machine traffic directly affect water infiltration into the soil. The objective of this work was to evaluate the water infiltration in the soil profile submitted to different intensities of agricultural traffic. The experiment was carried out at the Lageado Farm at UNESP/FCA, Botucatu/SP, in two soil classes, Dystroferric Red

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Nitosol (NVd) and Dystroferric Red Oxisol (LVd). The experimental design was completely randomized, with the respective compaction treatments: T0 = 0; T1 = 1; T2 = 2; T3 = 3; T4=5 and T5 = 10 consecutive passes of an agricultural tractor. The following attributes were determined: soil water infiltration, porosity, and available soil water. It was found that the basic soil infiltration speed was low for both soils in all treatments that had traffic. For both classes of soil there was a reduction in macro porosity and no interference in microporosity. The water content available to plants in clayey soil had greater variation than in medium textured soil. There is an effect of soil compaction on the water depth dynamics in the soil profile.

Keywords: soil compaction, machinery traffic, water infiltration into the soil.

3 INTRODUCTION

Scientific studies have shown that the greatest degree of soil compaction occurs immediately after the first passes of machines, and subsequent traffic adds less compaction, unless there is an increase in the applied load compared with the previous load or a change in the water content of the soil. Other studies note that compaction occurs differently in the surface horizon of the soil and is generated by the contact between the wheel and the soil, whereas with respect to depth, the axle load becomes the most important factor.

It has been suggested that compaction can be identified by evaluating physical soil attributes, such as soil resistance to penetration, soil density, total porosity, pore size and continuity, aggregate stability, water infiltration, hydraulic conductivity, and water retention characteristic curves, among other attributes.

According to Libardi (2005), water infiltration is defined as the process by which water penetrates the soil profile downward through its surface. The amount of water that passes through the soil profile per unit time is called the infiltration rate or soil water infiltration velocity (VI), expressed in cm h^{-1} or mm h^{-1}. This parameter indicates the behavior of a layer of water over the soil in relation to the time it takes to infiltrate.

This infiltration rate decreases over time, tending toward a constant rate. This constant over time is called the basic infiltration rate (BIV), a value that should correspond to the average saturated or nearly saturated hydraulic conductivity of the soil surface profile (BOUWER, 1978; REICHARDT; TIMM, 2004).

In irrigation, VIB is as important as VI, as it indicates whether the soil supports the intensity of water application imposed by a certain type of emitter.

Among the many variables that influence soil water infiltration, wheel displacement is one of the most important, as it causes a significant increase in soil density during machine–soil interactions. The decrease in larger-diameter pores due to compaction occurs because, among other factors, aggregate fragmentation caused by the action of soil preparation equipment or the weight of machines traveling on the soil exceeds the maximum internal resistance of the aggregates, destroying the larger interaggregate spaces (HORN et al., 1995). Consequently, a dense rearrangement of smaller soil aggregates and the formation of smaller-diameter pores occur (HORN et al., 1995), which alters water retention and redistribution in the soil profile (TARAWALLY et al., 2004). Therefore, air flow and water movement in the soil are severely impaired (BEUTLER et al., 2001).

Plant-available water corresponds to a moisture range that ranges from an upper limit, the field capacity (FC), to a lower limit, the permanent wilting point (PWP). Considering that the FC and PWP limits depend on the soil's physical properties, which are altered by the management system, the degree to which they are affected may reflect reduced water availability to plants if the additional amount of stored water is retained at lower potentials than those the plants can extract. (GONÇALVES, 2011).

The water content at field capacity can be defined by the soil water content at a matric potential of –0.01 MPa (HAISE; HASS; JENSEN, 1955), and the permanent wilting point can be defined by the soil water content at a potential of –1.5 MPa (RICHARDS, 1965).

This work aimed to evaluate the occurrence and distribution of water along the soil profile and the physical attributes of the soil according to different intensities of agricultural traffic.

4 MATERIALS AND METHODS

The present study was conducted at the Lageado Experimental Farm belonging to the São Paulo State University "Júlio de Mesquita Filho", Faculty of Agricultural Sciences, located in the municipality of Botucatu, in the state of São Paulo.

The experiment was carried out in two areas: the first, "Area 1", which is geographically located at 22° 50' 24" South Latitude, 48° 25' 23" West Longitude and an altitude of 791 m, and the second, "Area 2", which is located at 22° 51' 17" South Latitude, 48° 26' 10" West Longitude and an altitude of 822 m.

The soil of Area 1 is classified by Carvalho, Espíndola and Paccola (1983) as Terra Rocha Estruturada, adapted to the classification of Embrapa (2013), as Dystroferric Red Nitosol (NVd) with flat relief and clayey texture, with 50% clay content. The study area was 3,670 m² in area; before its preparation, it was covered with vegetation and brachiaria, and a compacted layer with flat relief was present.

The granulometric composition was determined in the Soil Physics Laboratory of the same Department, according to the methods of Teixeira et al. (2017). The results of the physical characterization of the soil in area 1 are presented in Table 1.

Table 1. Granulometric characterization of experimental area 1.

	Granulometric fractions			
Layers (mm)	**Sand**	**Silt g kg¹**	**Clay**	**Texture**
0-200	348	156	496	Clayey
200-400	345	153	502	Clayey

Source: Fernandes et al. (2019).

In the second experimental area, designated Area 2, the soil was classified as Red Latosol (LV) (EMBRAPA, 2013), with a medium texture, a clay content between 15% and 35%, and a high degree of weathering. The predominant relief is gently undulating, occupying the highest parts of the Lageado Experimental Farm. The study area was 4,239 m² and was covered by spontaneous vegetation. This area has not been cultivated for several years. The results of the soil physical characterization of Area 2 are presented in Table 2.

Table 2. Granulometric characterization of experimental area 2.

Layers (mm)	Granulometric fractions			
	Sand	Silt	Clay	Texture
		g kg $^{-1}$		
0-200	706	38	256	Average
200-400	696	41	263	Average

Source: Fernandes et al. (2019).

The region's climate is Cfa, a warm temperate (mesothermal) humid climate, according to the Köppen classification (ALVARES et al., 2013), with a dry season, which runs from April to August according to the Thornthwaite classification (CUNHA; MARTINS, 2009).

The experimental design was completely randomized. Treatments were constituted according to traffic intensity: T0 = 0 control (no tractor passes); T1 = 1; T2 = 2; T3 = 3; T4 = 5 and T5 = 10 consecutive tractor passes, which is similar to sugarcane harvesting with harvesters, transshipment, tractors with living areas, and other agricultural operations, all with unidirectional movement, in the same location. The compaction treatments were performed after soil preparation in 150 m² (5x30 m) plots when the soil water content was close to field capacity. There was a discrepancy in the evaluations of the T2 treatment in Area 2; therefore, it was not included in the statistical analysis.

The soils in both areas were covered with Brachiaria grass before preparation, so subsoiling and harrowing were performed for leveling and breaking the soil. The average working depth reached was 350 mm. A tractor with a maximum power of 89 kW (121 hp) was used for these soil preparation operations. The subsoiler used was a trailed subsoiler with five subsoiling shanks, which was equipped with depth control wheels driven by hydraulic actuators and adjusted to reach a maximum working depth of 400 mm. The harrow used after subsoiling was an offset grader with 32 180 mm diameter discs and an average working depth of 120 mm.

To simulate soil compaction, a tractor with a maximum power of 121 kW (165 hp) and an auxiliary front wheel drive (4x2 TDA) mounted on 16.9–28” R1 tires with 22 psi and 20.8–38” R1 with 24 psi, all with 75% liquid ballast, was used. The total weight of the tractor, 91,300 N (9,310 kg), was determined by means of a floor scale with a load cell and weighing receiver, with a load distribution of approximately 40% on the front axle and 60% on the rear axle.

The evaluation of water infiltration in the soil was carried out via the constant load concentric ring infiltrometer method (COELHO; MIRANDA; DUARTE, 2000). This method consists of two rings positioned concentrically in the soil (top view). The inner ring has a diameter of 150 mm, and the outer ring is 300 mm; both rings are buried approximately 100 mm in the soil and level with a hand level.

Water was added to both rings simultaneously. Infiltration measurements were taken in the inner ring, as the outer ring serves as a boundary, preventing infiltration from flowing laterally into the soil.

After the rings were installed, water was added to the inner ring via a graduated cylinder to determine the volume of water applied to the cylinder. Water was added to maintain a water depth of approximately 100 mm. Once infiltration began, the water was replenished, allowing a maximum variation of 2 cm in the water level in the inner ring and creating a constant hydraulic load. The time and volume of water used were recorded every 10 minutes. Three consecutive replicates were performed for each treatment; data collection ended when the infiltration rate observed in the inner ring became constant over time (Figure 1). To calculate the VIB, the infiltration rate was considered constant when the infiltration depth reading in the inner ring remained constant for at least three measurements.

Figure 1. The basic infiltration rate of water in the soil (VIB) was determined via the concentric ring method.

Source: Fernandes et al. (2019).

The microporosity was determined via undisturbed samples collected from 5 cm diameter by 5 cm height cylinders, which were the same as those used to determine the soil bulk density. A tension table at -0.006 MPa was used. The total soil porosity was calculated from the soil bulk density and particle density measurements. The soil macroporosity was calculated as the difference between the total porosity and microporosity via the method described by Teixeira et al. (2017). Plant-available water limits were obtained by extracting water from disturbed soil samples in Richards chambers (TEIXEIRA et al., 2017). The results were tabulated and subjected to analysis of variance via the MINITAB® statistical program, version 16.0 (MINITAB, 2010). The treatment means were compared via the Tukey test at a 5% probability of error.

5 RESULTS AND DISCUSSION

The basic infiltration rate of water in the soil for Dystroferric Red Nitosol (NVd) was influenced by the different treatments. The treatment that promoted the highest VIB value was T0 at 39.3 mm h^{-1}, which was classified as a soil with very high VIB, according to Bernardo, Soares and Mantovani (2006). The highest VIB values obtained were verified in the soil where there was no agricultural traffic due to the type of microstructure present in this soil and the resulting porosity. The number of macropores in this treatment was greater than that in the other treatments, which favored greater water movement along the profile.

Owing to the discrepancy in the VIB values of T0, treatments T1, T2, T3, T4 and T5 were statistically analyzed without T0 (Table 3).

Table 3. Average values of VIB (basic infiltration rate) for treatments T0, T1, T2, T3, T4 and T5.

Basic infiltration rate (BIV)	
Treatments	**mm h $^{-1}$**
T0	39.3 *
T1	4.3 a
T2	3.6 ab
T3	1.8 bc
T4	1.1 c
T5	1.1 c

Means followed by the same lowercase letters do not differ according to Tukey's test. *T0 was not included in the statistical analysis. **Source:** Fernandes et al. (2019).

There was a difference between treatments T1, T2, T3, T4 and T5 ($p<0.01$), as T1 presented the highest VIB value (4.3 mm h $^{-1}$), which did not differ from that of T2 (3.6 mm h $^{-1}$), and treatments T3, T4 and T5 presented the lowest values. In general, all the treatments had VIB values below 5 mm h $^{-1}$, which is characteristic of low-VIB soil, according to the classification of Bernardo, Soares and Mantovani (2006).

The average soil water content values (%) at the time of the soil water infiltration assessment for calculating the VIB were 17.69% for the 0–200 mm layer and 18.26% for the 200–400 mm layer of the NVd.

Similar results were reported by Blanco-Canqui, Claassen, and Stone (2010), who reported greater water infiltration in untrafficked lines, demonstrating that greater rainfall volumes can infiltrate and that more water can become available in soils where traffic is controlled. Reduced water infiltration due to agricultural traffic can have adverse implications for water conservation and plant growth, potentially leading to increased water losses through runoff and evaporation and thus significantly reducing the capture and storage of water from precipitation.

In clayey soil, Li, Tulberg, and Freebairn (2001) reported that the infiltration rate was reduced four to five times with wheel traffic. Tomasini et al. (2010) evaluated the effect of agricultural traffic on soil water infiltration in sugarcane crops and reported that traffic caused a 72–83% reduction in soil water infiltration.

In this evaluation, the reduction in the basic soil infiltration rate was approximately nine times greater in T1, which was related to the intensity of the wheel passes, and the basic infiltration rate was 35 times greater (10%) in T5 than in the treatment without traffic.

The basic infiltration rate of water in the soil for Red Latosol (LV) was not influenced by the different treatments. The treatment that promoted the highest VIB value was T0 at 23.6 mm h $^{-1}$ (Table 4), which was classified as high VIB soil, according to Bernardo, Soares and Mantovani (2006).

The average soil water content values (%) at the time of the soil water infiltration assessment for calculating the VIB were 10.29% in the 0–200 mm layer and 11.19% in the 200–400 mm layer for the LV.

The highest VIB values were obtained in soil without agricultural traffic because of the type of microstructure present in this soil and the resulting porosity. The number of macropores in this treatment was greater than that in the other treatments, which favored greater water movement throughout the profile.

Table 4. Average values of VIB (basic infiltration rate) for treatments T0, T1, T3, T4 and T5.

Basic infiltration rate (BIV)	
Treatments	**mm h -1**
T0	23.6*
T1	2.3 a
T3	1.7 to
T4	1.2 to
T5	1.4 to

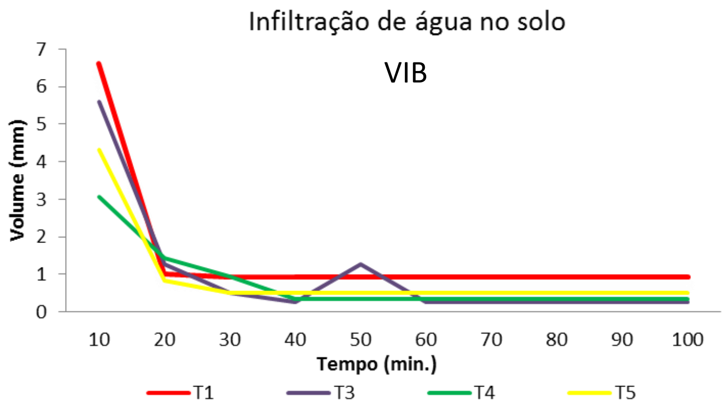
Means followed by the same lowercase letters do not differ according to the Tukey test. *T0 was not included in the statistical analysis. **Source**: Fernandes et al. (2019).

There was no difference between treatments T1, T3, T4 and T5 (p>0.01), which presented VIB values below 5 mm h $^{-1}$, a characteristic of low-VIB soil, according to Bernardo, Soares and Mantovani (2006).

In this evaluation, the reduction in the basic soil infiltration rate was approximately 10% for T1, reaching a reduction in basic infiltration of approximately 6% for T5 in relation to the treatment without traffic.

In the treatments where traffic occurred, less water infiltration into the soil was observed, probably due to the decrease in the percentage of pores with a relatively large diameter, which negatively influences water infiltration into the soil, since these pores are typically for water drainage (Figure 2).

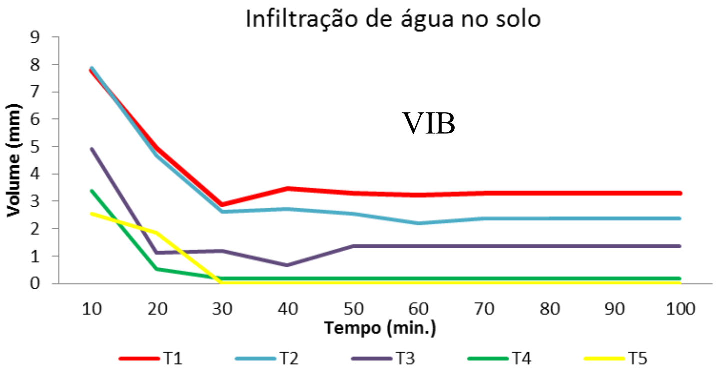
Figure 2. Soil water infiltration capacity for the treatments studied in the NVd.



Source: Fernandes et al., (2019).

The infiltration capacity is one of the most important soil characteristics, as it affects the potential of the soil to allow water to enter the profile. In other words, precipitation can exceed the infiltration capacity. When infiltration is significantly reduced, surface runoff increases, transporting soil sediments and fostering erosion (Figure 3).

Figure 3. Soil water infiltration capacity for the treatments studied in LVd.



Source: Fernandes et al. (2019).

The results regarding the total porosity, macroporosity, and microporosity of the samples collected from the two layers in the soil profile for NVd in the different treatments are presented in Table 5. The macropore volume of 0.119 m³ m $^{-3}$ in the 0--200 mm layer for the T0 treatment was provided by the soil preparation operations. Thus, it exceeded the limit of 0.10 m³ m $^{-3}$ established by Grable and Siemer (1968) as the critical aeration porosity limit for optimal plant development. These results corroborate those of Calonego (2007), who reported that mechanical management provides the best effect on soil decompaction, taking into account the effect on increasing macroporosity.

According to Torres and Saraiva (1999), in clayey textured soils, it is common to find reduced macroporosity, that is, below 0.10 m³ m $^{-3}$, due to the smaller specific surface area of the particles.

Little influence on microporosity due to compaction was observed, corroborating the findings of Silva and Kay (1997), who highlighted that soil microporosity is strongly influenced by texture and organic carbon content and is little influenced by soil compaction. Silva and Kay (1996) reported that as the level of compaction increased, the microporosity increased due to a decrease in the macroporosity.

Table 5. Results of the macroporosity, microporosity and total porosity of the soil, referring to the different treatments.

Treatments	Porosity (m³ m -3)		
	Total	Micro	Macro
	0-200 mm		
T0	0.505 to	0.385 to	0.119 a
T1	0.411 b	0.381 a	0.030 bc
T2	0.400 bc	0.397 a	0.003 c
T3	0.410 b	0.394 a	0.016 c
T4	0.395 bc	0.384 a	0.011 c
T5	0.367 c	0.351 a	0.016 c
	200- 400 mm		
T0	0.488 a	0.416 a	0.072 a
T1	0.431 b	0.407 a	0.024 b
T2	0.429 b	0.412 a	0.016 b
T3	0.398 bc	0.39 a	0.000 b
T4	0.408 bc	0.395 to	0.013 b
T5	0.384 c	0.374 a	0.011 b

Means followed by the same letters do not differ according to the Tukey test. **Source:** Fernandes et al. (2019).

In general, in both layers (0–200 mm and 200–400 mm), a greater proportion of macropores was observed in the T0 treatment than in the T1 treatment. For the other treatments, this was not a relatively sensitive measurement of the effects of the intensity (different levels of compaction) of agricultural traffic on the soil; however, it was evident, owing to the reduced proportion of macropores for treatments T1, T2, T3, T4 and T5, that there was accommodation of soil particles by forces exerted on the soil surface due to agricultural traffic.

The results regarding the total porosity, macroporosity and microporosity of the samples collected from the two layers in the soil profile under the different LV treatments are presented in Table 6.

Table 6. Results of the macroporosity, microporosity and total porosity of the soil, referring to the different treatments.

Treatments	Porosity (m^3 m^{-3})		
	Total	Micro	Macro
	0-200 mm		
T0	0.387 a	0.276 a	0.111 a
T1	0.306 b	0.293 a	0.013 b
T3	0.303 b	0.278 a	0.024 b
T4	0.299 b	0.266 a	0.033 b
T5	0.306 b	0.279 a	0.027 b
	200-400 mm		
T0	0.392 a	0.277 a	0.115 to
T1	0.303 b	0.284 a	0.020 b
T3	0.320 b	0.284 a	0.037 b
T4	0.303 b	0.289 a	0.014 b
T5	0.274 b	0.256 a	0.017 b

Means followed by the same letters do not differ according to the Tukey test. **Source:** Fernandes et al. (2019).

A macropore volume of 0.111 m^3 m^{-3} in the 0–200 mm layer and 0.115 m^3 m^{-3} in the 200--400 mm layer for the T0 treatment was probably provided by soil preparation operations and was above the limit of 0.10 m^3 m^{-3} established by Grable and Siemer (1968) as the critical aeration porosity limit for optimal plant development and corroborated with Calonego (2007), who reported that mechanical management provides the best effect on soil decompaction, taking into account the effect on increasing macroporosity.

No influence of traffic on soil microporosity was observed. In general, in both layers (0–200 mm and 200–400 mm), a greater proportion of total porosity and macropores was observed in the T0 treatment. For the other treatments, this measurement was not relatively sensitive to the effects of the intensity (different levels of compaction) of agricultural traffic on the soil.

For NVd, the average soil water content at 0.01 MPa stress (CC) was 0.2801 m^3 m^{-3} in the 0–200 mm layer and 0.2852 m^3 m^{-3} in the 200–400 mm layer. At 1.5 MPa, the stress (PMP) was 0.1659 m^3 m^{-3} in the 0–200 mm layer and 0.1750 m^3 m^{-3} in the 200–400 mm layer. The soil water content between tensions of 0.01 and 1.5 MPa varied from 0.1142 m^3 m^{-3} for the 0–200 mm layer to 0.1102 m^3 m^{-3} for the 200–400 mm layer (Table 7).

Table 7. Average values of the soil water content ($m^3 m^{-3}$) at tensions of 0.01 and 1.5 MPa for the layers studied.

Layer	MPa voltages	
	0.01	**1.5**
mm	$m^3 m^{-3}$	
0-200	0.2801	0.165
200-400	0.2852	0.1750

Source: Fernandes et al. (2019).

In LV, the average soil water content for the 0.01 MPa stress (CC) treatment was 0.1740 $m^3 m^{-3}$ in the 0–200 mm layer and 0.1639 $m^3 m^{-3}$ in the 200–400 mm layer. The 1.5 MPa stress (PMP) was 0.0743 $m^3 m^{-3}$ in the 0–200 mm layer and 0.0772 $m^3 m^{-3}$ in the 200–400 mm layer. There was little variation in the water content with depth. The soil water content between stresses of 0.01 and 1.5 MPa varied from 0.1005 $m^3 m^{-3}$ for the 0–200 mm layer to 0.0867 $m^3 m^{-3}$ for the 200–400 mm layer (Table 8).

Table 8. Average values of the soil water content ($m^3 m^{-3}$) at tensions of 0.01 and 1.5 MPa for the layers studied.

Layer	MPa voltages	
	0.01	**1.5**
mm	$m^3 m^{-3}$	
0-200	0.1748	0.0743
200-400	0.1639	0.0772

Source: Fernandes et al. (2019).

6 CONCLUSIONS

In the treatments in which there was traffic, the VIB in the clay soil was considered low, with a reduction in infiltration speed of 10% for T1 (one pass) and 6% for T5 (10 passes) consecutive passes of the wheel in relation to the treatment without traffic (39.3 mm $^{-1}$).

In the medium-textured soil, there was no difference between the treatments in which there was traffic, all of which were considered to have low VIB, with a nineteen-fold reduction in water infiltration in the treatment with ten consecutive wheel passes compared with the treatment without traffic (23.6 mm $^{-1}$).

In the treatments where there was traffic, a reduction in the macroporosity (<0.030 $m^3 m^{-3}$) was observed in the clayey soil, and there was no interference in the microporosity. In the medium-textured soil, a reduction in macroporosity and an increase in microporosity were observed.

Clay soils have smaller grain sizes than medium-textured soils do, with smaller pore spaces, thus retaining more water. Thus, the plant-available water content in the clay soil ranged from 0.285 to 0.1659 $m^3 m^{-3}$, whereas in the medium-textured soil, the water content ranged from 0.1748 to 0.0743 $m^3 m^{-3}$.

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