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Granulometric fractions and physical-hydric behavior of sandy soils

Frações granulométricas e comportamento físico-hídrico de solos arenosos

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Abstract: Soils attributes such as granulometry and density determine the distribution of pore size and condition physical and differentiated hydraulic behavior. Thus, knowing the characteristics of the soils allow the use of more adequate management techniques that lead to the improvement of the performance of the use of this resource. The aim of this study was to evaluate the diameters of granulometric fractions and the physical-hydric behavior of sandy soils from semiarid region of Brazil. Trenches were excavated to collect, describe, and characterize the morphology of soil samples. The soil bulk density, particle density, granulometry, water retention curve, total porosity and pore size distribution were evaluated. The textural difference among soil studied is expressed with greater emphasis on the amount of macropores, high retention micropores and cryptopores. Fine and very fine sand are the most impacted granulometric fractions increasing macroporosity and reducing high tension microporosity and cryptoporosity. Luvisol with predominance of silt and clay fractions, presents a greater risk of densification and erosion, thus the use of lower irrigation levels is recommended. Acrisols and Luvisol, with predominance of fine and very fine sand fractions, present similar conditions of macroporosity and cryptopores with a low textural gradient. Acrisols and Luvisol do not present major problems regarding the reduction of hydraulic conductivity along the profile. Lower irrigation levels with higher application frequency are suggested due to the low water retention capacity and higher risk nutrients leaching.

Keywords: physical attributes, microporosity, pore size distribution, water dynamics

Resumo: Atributos dos solos como granulometria e densidade determinam a distribuição do tamanho dos poros e condicionam comportamentos físico hídricos. Desse modo, conhecer esses atributos dos solos permitem o emprego de técnicas mais adequadas visando o uso sustentável desse recurso. O objetivo deste estudo foi avaliação das frações granulométricas e do comportamento físico-hídrico de solos arenosos do semiárido nordestino do Brasil. Foram abertas trincheiras para descrição dos perfis, caracterização morfológica e coleta de amostras de solo. Foram avaliadas: densidade do solo, densidade de partículas, granulometria, curva de retenção de água, porosidade total e distribuição de tamanho de poros. A diferença textural entre os solos estudados se expressa com maior ênfase na quantidade de macroporos, microporos de alta retenção e cryptoros. A areia fina e muito fina são as frações granulométricas de maior impacto aumentando a macroporosidade e reduzindo a microporosidade de alta tensão e a criptoporosidade. O Luvisol, com predomínio das frações silte e argila, apresenta maior risco de adensamento e de erosão sendo recomendado o uso de menores lâminas de água. Os Acrisols e o Cambisol, com predomínio das frações areias fina e muita fina, apresentam condições semelhantes de macroporosidade e cryptoporos com pequeno gradiente textural. Os Acrisols e o Cambisol não apresentam grandes problemas quanto à redução da condutividade hidráulica ao longo do perfil. Sugere-se lâminas menores com maior frequência de aplicação em função da baixa capacidade de retenção de água e maior risco de lixiviação de nutrientes.

Palavras-chave: Atributos físicos, microporosidade, distribuição de poros, dinâmica de água

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Introduction

In recent decades, agriculture has significantly altered the configuration of the natural landscapes in several regions of Brazil through the substitution of native vegetation by agricultural crops. The expansion of agricultural activities in the Sub-middle São Francisco River Valley, especially fruits and vegetables production, has been made possible due plan relief; annual irradiation; and high-quality water (Nascimento et al., 2012). These factors allow intensive cultivation, high productivities and good cost-benefit ratios. However, the semiarid climate of the region requires irrigation use for economically viable productions, exerting strong pressure on natural resources and becoming more expressive the significance characterization of soils with purpose to prioritize agricultural and environmental sustainability.

Pedological characterization studies provide knowledge about the soil properties that support in the development of management practices and sustainable land use (Santos et al., 2012). Thus, the knowledge of the current soil characteristics assists in achieving sustainability economically, socially and environmentall, and allowing to express the genetic potential of plant species and minimizing the degradation of natural resources. Granulometry, bulk density and porosity are the predominant properties in studies of soil characterization (Mota et al., 2008). Granulometry refers to the size distribution of particles (Santos et al., 2012) and can influence other soil properties. For example, the structure refers to the arrangement of particles in aggregates, which determines the soil bulk density and porosity.

The soil physical-hydric behavior is controlled by pore size distribution. That means influence in the water storage, nutrient availability and transport of soil solution and soil air. Larger pores are responsible for the aeration and movement of water, while smaller pores are responsible for storage being classified as macropores, micropores and cryptopores. Micropores are responsible for water retention in the range of 6 to 1,500 kPa, and cryptopores retain water at pressures higher than 1,500 kPa. Klein and Libardi (2002) subclassified micropores as low-retention micropores (between 6 and 100 kPa) and high-retention micropores (between 100 and 1,500 kPa). The low-retention micropores hold the water that is readily available to the majority of plants.

Whereas the characteristics such as particle size and bulk density can control the pore size distribution and lead to different physical and hydric behavior in soils, the aim of this study was to evaluate the diameters of granulometric fractions and the physical-hydric behavior of sandy soils from semiarid region of Brazil.

Materials and Methods

The study was performed between the parallels 09º 27 '19 "S of latitude and 40º 49' 24" of longitude west in the semiarid region of Brazil. The climate is Bswh' according to the Köppen classification (semiarid), very hot and with low annual precipitation (<500 mm). The rainfalls are irregularly distributed in time and space, and are concentrated in three or four months of the year (Silva et al., 2010). The average annual temperatures vary from 23º to 27º C, and evaporation is approximately 2,000 mm yr^{-1}. These climatic characteristics result in high evapotranspiration rates and, consequently, negative water balance (Silva et al., 2010).

Four rural properties located surrounding Sobradinho Lake were selected. The soil classes are the most representatives and important for agriculture in the region. Four trenches were dug in non-agricultural areas of secondary vegetation of the Caatinga Biome. The profiles were morphologically described according to Santos et al. (2013a), based on samples collected from horizons of Cambisol (Tb Haplic Cambisol) (9° 27' 42.1" S; 40° 52' 34.9" W), Acrisol (dystrophic Yellow Argisol) (9° 29' 51.5" S; 40° 51' 22.5" W), Luvisol (orthic Chromic Luvisols) (9° 26' 46.4" S; 40° 53' 19.8" W) and Acrisol (dystrophic Yellow Argisol) (9° 30' 20.8" S; 40° 51' 0.5" W). The samples were dried and sieved (2 mm mesh) to obtain air-dried fine soil.

The samples collected from horizons were characterized physically according Donagema et al (2011). Undisturbed soil from the profiles was sampled with a volumetric ring (73.5 cm-3) to determine soil bulk density (BD); the particle size (granulometry) was determined by dispersion, using 0.1 mol L-1 sodium hydroxide; the particle density (PD) was determined by the volumetric

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flask method and soil porosity (TP) was determinate using equation 1

$$TP = 100 (PD-BD)/PD \quad \text{Eq. 1}$$

The granulometry classified by USDA classification and the fractioning of sand particles were divided into classes: very coarse sand (VCS; 2.00-1.00 mm), coarse sand (CS; 1.00-0.50 mm), medium sand (MS; 0.50-0.25 mm), fine sand (FS; 0.25-0.10 mm) and very fine sand (VFS; 0.10-0.05 mm).

To obtain the soil water characteristic curves (SWC), the undisturbed samples were saturated for 24 hours. The excess water was drained before weighing. The samples were subjected to pressures from 6, 10, 30, 60, 100 and 1,500 kPa by centrifugation (Silva and Azevedo, 2002). The water retention values were adjusted by the van Genuchten model (1980) using equation 2 and minimizing the sum of squares deviations using the SWRC software (Dourado Neto et al., 2000). This allowed the acquisition of the empirical adjustment parameters α, m and n as well as fixing θs (saturation moisture) at the value that corresponded to the total porosity.

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{\left[1 + (\alpha \Psi m)^n\right]^m} \quad \text{Eq. 2}$$

where θ is the soil water content (m^3 m^{-3}), θs is the soil water content in the saturated condition (m^3 m^{-3}), θr is the soil water content at 1,500 kPa (m^3 m^{-3}), Ψm is the soil matrix potential and α, m and n are empirical parameters of the equation.

The porosity was classified based on the pore diameters. Pores larger than 0.048 mm and that lose water at pressures less than 6 kPa were classified as macropores (Ma). The micropores were subclassified as low-retention micropores (Mil), diameters between 0.003 and 0.048 mm and lose water at pressures between 6 and 100 kPa, and high-retention micropores (Mih), diameters between 0.0002 and 0.003 mm and lose water at pressures between 100 and 1,500 kPa (Klein and Libardi, 2002). Pores smaller than 0.0002 mm that loses water at pressures higher than 1,500 kPa were classified as cryptopores. The available water capacity is the range of available water stored in soil between field capacity and wilting point.

Results and Discussion

The soils were classified as Cambisol (Tb Haplic Cambisol) (P1), Luvisol (orthic Chromic Luvisols) (P3) and Acrisol (dystrophic Yellow Argisol) (P2 and P4) (Figure 1). The physical attributes was described in Table 1.

The Cambisol (P1) contained horizons sequence A-BA-Bi1 (Table 1), with effective depth of the 0.40 m. The Acrisol (P2) presents thickness more than 1.0 m and presence of plinthite (approximately 20 % of the volume) beginning at soil depth of 0.80 m. The Luvisol (P3) has low depth and textural horizons with higher clay contents in profile. This soil class presents, characteristically, clay of high activity that has high plasticity and stickiness. In addition, it may exhibit low hydraulic conductivity, especially when there is accumulation of sodium. The profile P4 (Acrisol) presents thickness less than 0.75 m and it is very gravelly starting at 0.35 m depth. In general, the soils are shallow, to difficult irrigation management and reduce the volume of soil explored by the roots. These soils require higher frequency of irrigation because they are more susceptible to salinization and erosion processes. These characteristics can be accentuated in the Bt horizon presence, as in Acrisols and Luvisol. In this case, the hydraulic conductivity is reduced in the soil profile and there is possibility of soil waterlogging due to the elevation of the water table level. The presence of plintite in the acrisol profile (P2) corroborates the hypothesis of the occurrence of drainage restriction

Furthermore, this would reduce water and nutrients absorption, and would affect the plant fixation in the soil, mainly in perennial crops. However, these characteristics are not important for crops commonly produced in the region. These plants presents effective root system not very deep (less than 0.30 m depth), not requiring deep tillage.

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Figure 1. Morphological aspects of the four soils from Northeast semiarido region of Brazil.

Table 1. Physical attributes of the four soils from Northeast semiarid region of Brazil.

Hor	Depth	Sand						Silt	Clay	BD	TC
		VCS	CS	MS	FS	VFS	Total				
	m	---g kg^{-1}---								Mg m^{-3}	
P1 – Cambisol											
A	0.00-0.10	12	27	115	414	257	823	72	105	1.50	LS
BA	0.10-0.20	6	34	139	399	219	796	92	112	1.53	LS
Bi1	0.20-0.40	59	31	125	333	211	759	95	146	1.55	SL
P2 – Acrisol											
A	0.00-0.20	15	29	118	412	253	826	69	105	1.53	LS
Bt1	0.20-0.40	15	28	164	389	208	803	125	72	1.47	LS
Bt2	0.40-0.80	14	30	129	342	221	736	131	133	1.46	SL
Btf3	0.80-0.120	14	25	108	264	192	603	222	175	1.41	SL
Btf4	$0.120\text{-}0.150^{+}$	10	20	103	283	223	639	170	191	1.39	SL
P3 – Luvisol											
A	0.00-0.17	8	8	13	51	104	183	594	223	1.55	SiL
Bt1	0.17-0.35	9	9	16	53	101	187	464	349	1.47	SiCL
Bt2	0.35-0.50	10	13	19	64	270	376	191	433	1.48	C
BC	0.50-0.70	10	7	19	75	210	321	550	129	1.38	SiL
Cr	0.70-1.00+	6	19	116	145	179	466	430	104	1.59	ML
P4 – Acrisol											
A	0.00-0.20	75	58	177	316	212	838	85	77	1.56	LS
Bt1	0.20-0.35	40	52	153	284	208	738	81	181	1.41	SL
Btf2	0.35-0.60	42	61	150	220	176	649	95	256	1.36	SCL
Btf3	0.60-0.75	32	37	140	124	157	490	183	327	1.26	SCL

VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; BD: Soil bulk density; TC: textural classification; LS: loamy sand; SL: sandy loam; SiL: silty loam; SiCL: silty clay loam; C: clay; SCL:sandy clay loam.

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In general, the Cambisol and Acrisols (P2 and P4) presents sandy textures in their profiles with sand proportion higher than 603 g kg^{-1} (Table 1). In contrast, the clay proportion does not exceed 260 g kg^{-1}, except in the Btf3 horizon (P4), which has clay proportion of 327 g kg^{-1}. The Luvisol (P3) had sand proportion that varies from 183 g kg^{-1} in horizon A to 466 g kg^{-1} in horizon Cr, which highlights the elevated silt proportion on the profile (except horizon Bt2). Soil texture is an important characteristic of the agricultural soils. It affects mechanization, fertilization and irrigation management. This physical characteristic impacts in the retention and water availability because the soil particle size distribution affects the pore size distribution (Barros et al., 2009). Among the studied profiles, due to its sandy texture, the Cambisol requires a higher frequency of water application associated with the smaller irrigation blades.

The fractioning of the sand classes (Table 1) shows that the Cambisol and both Acrisols contain predominantly fine and very fine sand fractions. Also present significant proportion of medium to very coarse and coarse sand. More than 60 % of the total sand of these three soils profiles is composed by fine and very fine fractions. In the Luvisol (P3), despite of the lowest sand proportion, more than 70 % is composed by fine and very fine fractions associated higher clay and silt content. This provides higher microporosity and, consequently, higher water retention capacity compared to the same soil class with a similar texture but with predominance of coarser fractions. However, as there is a textural gradient, with reduction of hydraulic conductivity in the profile the application of larger irrigation depths should be associated to a longer irrigation time.

Only the Cambisol present increased soil bulk density at depth (from 1.50 to 1.55 Mg m^{-3}), while in the Acrisols (P2 and P4) (1.56 - 1.26 Mg m^{-3}) and Luvisol (1.38-1.55 Mg m^{-3}) decreased (Table 1). All soil bulk densities are below the critical values for sandy soils (1.80 Mg m^{-3}), but not for clay soils (1.40 Mg m^{-3}) (Reichert et al., 2015; Reichert et al., 2014). The soil bulk densities observed are not restrictive for development of plants roots. Santos and Ribeiro (2000), studying the effect of irrigated cultivation on the properties of the Oxysol and Acrisol, in the São Francisco valley region, observed an increase in soil density, reduction of macroporosity, total porosity and in the hydraulic conductivity. According to researchers the changes were proportional to the intensity of soil movement and the use of water. This process is due to the reduction of total porosity and macroporosity, due to the intensive use of machines and irrigation, with consequent eluviation of fine particles.

The distribution of pores by diameter classes was described in Table 2. The total porosity ranges from 0.396 to 0.572 m^3 m^{-3}, consistent with the range for soils with sandy textures (of 0.44 to 0.50 m^3 m^{-3}) reported by Cunha et al. (2011). The Cambisol shows decreases in total porosity and macroporosity at depth, and increases in soil bulk density and microporosity. This happens due to reduction in total sand proportion, especially fine and very fine fractions, and by increase in the ratio of silt to clay.

The total porosity, and particularly, micropores and cryptopores volumes, increased with depth in the Acrisol (P2) (Table 2). This increase may be associated with a higher clay proportion in the subsurface. According to Santos et al. (2013), this is characteristic of the soil, the increasing soil water retention is directly related to the proportion of fine particles. Silva et al. (2005) evaluated Acrisol in sugarcane region of Alagoas state and observed increase in the total pore volume of the 0.40 and 0.80 m compared to 0.20 and 0.40 m soil layer in natural vegetation area. This result is potentially related to increase in clay proportion. In Acrisol (P4), total porosity and macroporosity values decreased in depth, with increased microporosity.

The highest total porosity (range 0.416 m^3 m^{-3} and 0.572 m^3 m^{-3}) occurs in the Luvisol, being attributed to higher clay proportion. This favors the aggregates formation and the development of intra-aggregate pores. Carvalho et al. (2014) attribute the formation of very small pores to textural characteristics of the soil. According to researchers, soil compaction would not affect the sizes of micropores and cryptopores that are located inside the aggregates. However, these soils physically limit the water movement due to presence of sand particles with different diameters besides the high proportion of silt. This mainly occurs when the finer fractions predominate in the spaces between coarser fractions. Araujo Filho et al. (2013) evaluated soils from the semiarid region and observed low infiltration, which may reflect in high susceptibility to erosion.

Table 2. Distribution of pores by diameter classes of four soils from Northeast semiarid region of Brazil

Horizon	Depth (m)	Porosity (m^3 m^{-3})				
		Macro	Micro		Crypto	Total
			low-retention	high-retention		
P1 – Cambisol						
A	0.00-0.10	0.253	0.096	0.012	0.059	0.420
BA	0.10-0.20	0.231	0.102	0.014	0.061	0.408
Bi1	0.20-0.40	0.202	0.111	0.017	0.071	0.401
P2 – Acrisol						
A	0.00-0.20	0.261	0.097	0.013	0.046	0.417
Bt1	0.20-0.40	0.256	0.087	0.012	0.073	0.428
Bt2	0.40-0.80	0.259	0.084	0.014	0.089	0.446
Btf3	0.80-0.120	0.234	0.090	0.016	0.114	0.454
Btf4	0.120-0.150^{+}	0.251	0.097	0.017	0.105	0.470
P3 – Luvisol						
A	0.00-0.17	0.057	0.150	0.038	0.253	0.498
Bt1	0.17-0.35	0.055	0.077	0.024	0.260	0.416
Bt2	0.35-0.50	0.078	0.076	0.018	0.359	0.531
BC	0.50-0.70	0.166	0.102	0.017	0.287	0.572
Cr	0.70-0.100+	0.028	0.126	0.021	0.336	0.511
P4 – Acrisol						
A	0.00-0.20	0.227	0.103	0.011	0.055	0.396
Bt1	0.20-0.35	0.250	0.094	0.015	0.091	0.450
Btf2	0.35-0.60	0.213	0.119	0.016	0.118	0.466
Btf3	0.60-0.75	0.221	0.120	0.024	0.143	0.508

The macropores volume is lower in Luvisol compared to other soils (Table 2). Soils with higher clay proportion are favorable for aggregation and tend to have more intra-aggregate porosity. The combination of granulometry, bulk density and soil aggregation is an important factor for macroporosity formation (Carvalho et al., 2014).

The soils with higher sand proportion, Cambisol (P1) and Acrisol (P2 and P4), have high macroporosity values. This can be attributed to less aggregation due to soil texture and arrangement of simple grains that favor macroporosity in sandy soils. The water retention curve is an essential part of the characterization of the hydric properties of the soil and is especially important in studies of the balance and water availability to plants, water dynamics and soil solutes, infiltration and irrigation management (Tormena and Silva, 2002).

The parameters of the data for all of the retention curves (Figure 2) were adjusted according to the van Genuchten equation.

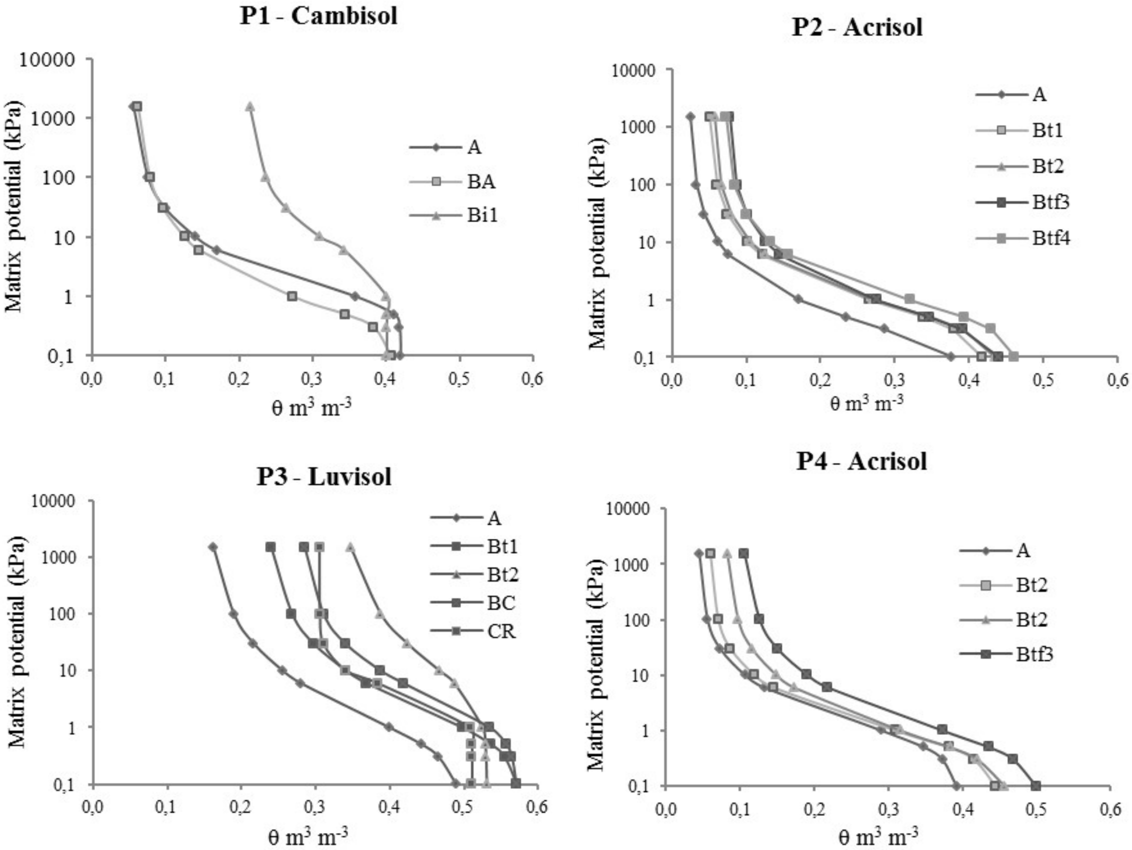

Figure 2. Characteristic moisture retention curves, adjusted with the van Genuchten model, for four soil profiles located in the region around Sobradinho Lake, Sobradinho-BA, Brazil

The microporosity of the low and high retention (Table 2 and Figure 2) represents the portion of the total porosity that retains water available for plants. The Luvisol contained 0.118 m^3 m^{-3} of micropores in horizon A and 0.150 m^3 m^{-3} of the 0.35 and 0.50 m (horizon Bt2). The horizon with lower micropores proportion also has most cryptopores. This indicates formation of more pores with largest number of small size fractions. Jorge et al. (2012) observed that micropores and cryptopores make up 65 % porosity total of Oxisols with clay ratios of approximately 700 g kg^{-1} and 48 % of the total porosity of Oxisols with clay ratios of 360 g kg^{-1}. This may cause lower water availability for crops because the water that is in cryptopores (< 0.0002 mm) is retained at pressures higher than 1500 kPa (PMP), which is limiting to plant development (Suzuki et al., 2014).

In Cambisol and Acrisol, the volume of micropores ranged from 0.076 m^3 m^{-3} in the horizon of the Acrisol (P2) to 0.343 m^3 m^{-3} in the horizon Bi1 the Cambisol (P1). Whereas the water retained in the micropores is subjected to tensions between 10 kPa (field capacity) and 1500 kPa (wilting point), and represents the maximum volume of available water for plant. This information can assist directly in the management of irrigated areas. The Acrisols present lowest values of water availability for plant (WA), with average 0.126 m^3 m^{-3} (P2) and 0.167 m^3 m^{-3} (P3). The Cambisol presents average 0.220 m^3 m^{-3} WA and the Luvisol presents the highest average among profiles studied (0.388 m^3 m^{-3}).

It is observed in Table 2 that profiles with higher sand proportion (Acrisol and Cambisol), that the micropores low retention (Mil) represents a major of the microporosity proportion. Since, for Luvisol (higher proportion of clay), the cryptopores represent the largest proportion of microporosity. It is observed that profiles with fine texture, with high specific surface, retain more water than coarser texture profiles. Rocha et al. (2014) observed higher proportion of Mil relative to the total volume of micropores. Thus, plants grown in these soils have good proportion of water available, resulting in lower energy expenditure, and better yield. However, it is necessary that the irrigation management is performed considering the moisture retention curve. This directly affects the determination of the irrigation frequency for the plant is not subject to water stress.

The retention curves for the Cambisol and Acrisol horizons have similar contours. However, in the Acrisol, the surface horizons have lower moisture values at the permanent wilting point. This is explained by the lower cryptopores proportion in these horizons, which have lower clay ratios than the subsurface horizons. However, this does not necessarily imply on higher water availability because the moisture values at the field capacity are also lower. The retention curves for the Cambisol (P1) and the Acrisols (P2 and P4) are consistent with the patterns for sandy soils (Nascimento et al., 2012). The retention curves for the Luvisol has the highest moisture values at saturation at the field capacity and at the permanent wilting point, which are explained by the lower sand ratios and macropores and the higher clay and cryptopores ratios.

Although there is difference between the assessed profiles, these values are considered small when compared to soils with higher clay proportion. In a situation similar to soils of the semiarid region, Nascimento et al. (2012) recommends manage irrigation with higher accuracy by practicing the high frequency and low intensity irrigation, maximizing the water utilization and reducing waste by deep percolation.

Conclusions

The textural difference among soil studied is expressed with greater emphasis on the amount of macropores, high retention micropores and cryptopores.

Fine and very fine sand are the most impacted granulometric fractions increasing macroporosity and reducing high tension microporosity and cryptoporosity.

Luvisol with predominance of silt and clay fractions, presents a greater risk of densification and erosion, thus the use of lower irrigation levels is recommended.

Acrisols and Luvisol, with predominance of fine and very fine sand fractions, present similar conditions of macroporosity and cryptopores with a low textural gradient.

Acrisols and Luvisol do not present major problems regarding the reduction of hydraulic conductivity along the profile.

Lower irrigation levels with higher application frequency are suggested due to the low water retention capacity and higher risk nutrients leaching.

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