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Soil Water Retention in the Semiarid Region of Brazil

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Abstract

From the physics point of view, soil structure is a dynamic attribute that is affected by genetic conditions and anthropogenic changes and requires an integrated approach. Soil water retention curve is one of the main tools used in soil structure evaluations. The objective of this work was to evaluate the structural and chemical attributes of soils of different classes and agroecosystems in the Terra de Esperança Settlement (Governador Dix Sept Rosado, Rio Grande do Norte, Brazil) to distinguish these environments. Disturbed and undisturbed soil samples were collected in horizons of 10 soil profiles of the soil classes: Cambissolo Háplico (Haplustepts), Latossolo Vermelho-Amarelo (Eutrustox), Chernossolo Rêndzico (Calciustolls), and Neossolo Flúvico (Usticfluvents). The soil physical attributes evaluated were granulometry, soil density, total porosity, aeration porosity, macroporosity, microporosity, field capacity, permanent wilting point, available water, and water retention curve. The results were expressed in averages of four replicates per horizon (in laboratory) by multivariate analysis, which detected the most sensitive attributes for the distinction of the environments. The soil physical attributes of the different classes and its inorganic fractions, especially silt and clay, were determinant to distinguish the environments; they affected the microporosity; aeration porosity; and available water. The source material of the Chernossolo Rêndzico, which is rich in calcium and magnesium, affected its physical attributes, characterized by the predominance of the silt fraction. Clay was the determinant fraction of the Cambissolo Háplico, and Neossolo Flúvico; and the sand fraction on the surface layer, and clay fraction in the Bw horizon were determinant of the Latossolo Vermelho-Amarelo. The more expressive physical attributes were soil density, sand content, macroporosity (Latossolo Vermelho-Amarelo), microporosity, field capacity, available water, permanent wilting point, total organic carbon, mass-based moisture, volume-based moisture, clay, aeration porosity (Cambissolo Háplico, and Neossolo Flúvico), and silt (Chernossolo Rêndzico).

Keywords: soil water, structure, semi-arid, native vegetation

1. Introduction

The Brazilian semiarid region comprises almost 90% of the Northeast region; its climatic pattern, characterized by low rainfall and high evapotranspiration rates, is a determinant of the Caatinga biome. In general, it has underdeveloped (shallow) soils with physical restrictions for agriculture and good chemical characteristics.

The soil water retention varies in this region due to intrinsic characteristics, management, and agricultural crops used in its soils; thus, information on water retention variability is essential for the conservation of its soil, water, and plant resources, with emphasis on agricultural production.

Local studies on soil structural attributes are incipient, generating difficulties for the adoption of appropriate techniques based on the maintenance of the soil productive capacity while considering local characteristics. Thus, studies on soil hydraulic properties are necessary; the soil water retention curve is one of the main tools for these studies.

Based on the hypothesis that the soil physical attributes are affected by its position in the landscape, and agricultural uses due to genetic conditions, and anthropogenic changes, the objective of this work was to evaluate the structural and chemical attributes of soils of different classes and agroecosystems by correlating their soil water retention curve with inorganic fractions and total organic carbon to distinguishing the study environments.

2. Method

The study was carried out in Governador Dix Sept Rosado, in the Chapada do Apodi microregion, Rio Grande do Norte, Brazil (05°27′32.4″S, 37°31′15.6″W). According to the Köpper classification, the climate of the region is BSwh, tropical semiarid, characterized by scarce and irregular rainfall (annual average of 673.9 mm), summer rains, high evaporation, high temperatures (average temperature of 27 °C), and relative air humidity of 68.9%. The natural vegetation of the region is hyper-xerophilic Caatinga.

Ten areas were selected and georeferenced for this study, based on the local land uses and defined by soil profiles (P): Cambissolo Háplico (Haplustepts) with native forest (NF) (P1); Cambissolo Háplico in a collective area with NF (P2); Cambissolo Háplico in an agroecological area with NF (P3); Latossolo Vermelho-Amarelo (Eutrustox) with cashew (*Anacardium occidentale*) (P4); Chernossolo Rêndzico (Calciustolls) with pasture (P5); Cambissolo Háplico with pasture (P6); Cambissolo Háplico with NF (P7); Neossolo Flúvico (Usticfluvents) in a permanent conservation area with oiticica (*Licania rigida*) (P8); Cambissolo Háplico with NF (P9); and Cambissolo Háplico in a collective area with cajarana (*Spondias dulcis*) (P10). The soils of these areas were classified according to the Brazilian Soil Classification System (Santos et al., 2013).

Disturbed and undisturbed soil samples were collected in the soil horizons of these areas. The disturbed soil samples were placed in plastic bags and taken to the Research Laboratory of the Federal Rural University of the Semi-Arid Region (UFERSA). They were air dried, disaggregated, and sieved in a 2 mm mesh sieve to obtain the air dried fine earth. Then, these samples were subjected to physical analyses to determine their granulometry, clay dispersed in water, clay flocculation degree, and total organic carbon content (TOC). The undisturbed soil samples were collected using an Uhland auger and rings (height of 0.05 m and diameter of 0.05 m) to analyze their soil water retention curve (macroporosity, microporosity, total porosity, aeration porosity, field capacity, permanent wilting point, and available water) and soil density (SD).

Granulometric analysis was performed through the pipette method, using air dried fine earth (20 g) and chemical dispersant (sodium hexametaphosphate) with slow mechanical agitation, using a 50 rpm Wagner shaker, for 16 hours. Clay dispersed in water was determined using air dried fine earth and distilled water slowly mechanically shaken, using a 50 rpm Wagner shaker, for 16 hours. Clay flocculation degree (FD) was calculated according to the methodology described in the manual of methods of physical analysis (Teixeira et al., 2017), using Equation 1:

$$FD = \frac{(Total\ clay - Clay\ dispersed\ in\ water)}{Total\ clay} \times 100 \tag{1}$$

Ten undisturbed soil samples of each horizon of each soil class were used to determine their soil water retention curves, soil density, total porosity, macroporosity, and microporosity.

Soil tensions (0, 6, 10, 33, 50, 100, 200, 500, and 1500 kPa) were used to develop soil water retention curves. The tensions were applied in a tension table using low (0, 6, and 10 kPa), medium (33, 50, and 100 kPa), and high (200, 500, and 1500 kPa) tension chambers. The soil water retention curves were adjusted based on the van Genuchten (1980) equation, using the Soil Water Retention Curve program (SWRC 3.0 beta) (Dourado Neto et al., 2001). The matric potential (ϕm) was considered as an independent variable, and the volumetric moisture (θ) as a dependent variable in Equation 2:

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha \cdot |\phi_m|)^n\right]^m} \tag{2}$$

where, θ_r is the residual volumetric moisture ($m^3\ m^{-3}$); θ_s is the saturated volumetric moisture ($m^3\ m^{-3}$); $|\phi_m|$ is the matric potential (kPa); and α, m, and n is the empirical parameters of the equation.

Soil density was determined by the volumetric ring method, calculating the ratio of dry soil mass at 105 °C to the ring total volume (Teixeira et al., 2017).

Soil physical analyses were performed in the Soil Physics Laboratory and Plant Fertility and Nutrition Laboratory of the Soil, Water and Plant Analyses Laboratory Complex of the Agricultural Sciences Center of the UFERSA (LASAP-CCA-UFERSA), following the methodology described by Teixeira et al. (2017).

Soil physical attributes were presented in tables and expressed by the average of four replicates per horizon of each soil class. Multivariate analysis (Principal Component Analysis) was used to identify the most sensitive attributes to distinguish the environments evaluated, using the Statistica 7 program (StatSoft, 2004).

3. Results

The textures found in the soil horizons varied in the different soil classes studied, with prevalence of the textures sandy clay loam in Cambissolos Háplicos (Haplustepts) (CH), silt loam in the Chernossolo Rêndzico (Calciustolls) (CR), clay in the Neossolo Flúvico (Usticfluvents) (NF), and sandy loam in the Latossolo Vermelho-Amarelo (Eutrustox) (LVA) (Table 1).

Table 1. Soil particle size distribution, texture classification, clay in water, silt to clay ratio, and clay flocculation degree (FD) in horizons of soils of different classes. Terra de Esperança Settlement, Rio Grande do Norte, Brazil

Horizon	Depth	Particle size distribution					Texture classification (Brazilian Soil Science Society)	Clay in water	Silt:Clay	FD
		Coarse sand	Fine sand	Total sand	Silt	Clay				
	-- cm --	------------------------ g kg^{-1} ------------------------						--- g kg^{-1} ---		-- % --
Profile 1: Cambissolo Háplico (Haplustepts) with native forest 05°29'13.0"S; 37°24'33.1"W										
A moderate	0-8	364	124	489	174	337	sandy clay loam	275	0.52	18.40
Bi	8-37	457	81	537	97	366	sandy clay	280	0.27	23.50
C	37-51	616	26	642	106	252	sandy clay loam	172	0.42	31.75
Profile 2: Cambissolo Háplico (Haplustepts) in a collective area with native forest 05°30'17.6"S; 37°27 01.3"W										
A slight	0-3	530	143	673	94	233	sandy clay loam	195	0.40	16.31
AB	3-7	477	144	621	126	253	sandy clay loam	244	0.50	35.6
Bi	7-22	429	139	569	151	281	sandy clay loam	246	0.54	12.46
BiC	22-36	427	133	560	170	270	sandy clay loam	230	0.63	14.81
CB	36-52	409	127	536	182	282	sandy clay loam	224	0.65	25.7
Profile 3: Cambissolo Háplico (Haplustepts) in an agroecological area with native forest 05°30'22.9"S; 37°27'06.8"W										
A slight	0-4	515	176	691	90	219	sandy clay loam	188	0.41	14.16
BA	04-10	524	155	679	77	244	sandy clay loam	217	0.32	11.07
Bi	10-42	475	162	637	65	298	sandy clay loam	264	0.22	11.41
BiC	42-70	564	110	674	63	264	sandy clay loam	263	0.24	0.38
Profile 4: Latossolo Vermelho-Amarelo (Eutrustox) with cashew (Anacardium occidentale) 05°29'42.7"S; 37°28'30.3"W										
A	0-7	661	246	907	35	58	sand	54	0.60	6.90
AB	7-25	492	114	606	50	344	sandy clay	303	0.15	11.92
BA	25-50	571	87	658	47	295	sandy clay loam	250	0.16	15.25
Bw	50-200^{+}	710	78	788	38	175	sandy loam	132	0.22	24.57
Profile 5: Chernossolo Rêndzico (Calciustolls) with pasture 05°32'21.18"S; 37°26'01.2"W										
Ak	0-20	93	116	209	617	174	silt loam	157	3.55	9.77
Ck1	20-50	110	108	218	574	208	silt loam	145	2.76	30.29
Ck2	50-120	70	100	169	640	191	silt loam	134	3.35	29.84
Ck3	120-140^{+}	90	90	179	696	124	silt loam	122	5.61	1.61
Profile 6: Cambissolo Háplico (Haplustepts) with pasture 05°32'24.0"S; 37°25'59.4"W										
A	0-5	417	108	526	207	267	sandy clay loam	250	0.78	6.37
Bi	5-27	451	126	577	118	305	sandy clay loam	276	0.39	9.51
Profile 7: Cambissolo Háplico (Haplustepts) with native forest 05°28'40.7"S; 37°26'16.3"W										
A	0-7	389	92	482	171	347	sandy clay	294	0.49	15.27
AB	7-15	416	90	507	114	379	sandy clay	364	0.30	3.96
BA	15-35	373	92	465	119	416	sandy clay	361	0.29	13.22
Bi	35-75	345	93	439	147	414	clay	381	0.36	7.97
Profile 8: Neossolo Flúvico (Usticfluvents) in a permanent conservation area with oiticica (Licania rigida) 05°29'45.5"S; 37°27'50.6"W										
A	0-30	274	78	352	135	513	clay	274	0.26	46.59
C	30-100	257	91	348	123	529	clay	403	0.23	23.82
Profile 9: Cambissolo Háplico (Haplustepts) with native forest 05°28'54.7"S 37°24'52.7"W										
A	0-8	375	126	501	167	331	sandy clay loam	271	0.50	18.13
BA	8-19	351	120	471	127	401	sandy clay	334	0.32	16.71
Bi	19-60	284	100	383	131	485	clay	385	0.27	20.62
Cv (slinkensides)	60-200	273	95	369	119	513	clay	423	0.23	17.54
Profile 10: Cambissolo Háplico (Haplustepts) in a collective area with cajarana (Spondias dulcis) 05°29'50.9"S; 37°27'14.8"W										
A	0-12	399	101	500	166	334	sandy clay loam	324	0.50	2.99
AB	12-24	414	70	484	91	424	sandy clay	362	0.21	14.62
BA	24-41	356	67	424	89	488	clay	409	0.18	16.19
Bi	41-92	307	80	387	83	530	clay	379	0.16	28.49
BC	92-115	303	85	389	96	515	clay	371	0.19	27.96

The highest contents of clay fraction (219 g kg^{-1} to 530 g kg^{-1}) were found in Cambissolos Háplicos. The silt fraction was significant (574 g kg^{-1} to 696 g kg^{-1}) in the Chernossolo Rêndzico, whose texture was classified as silt loam (Table 1). This result was due to its source material, consisted predominantly of limestone of the Jandaíra formation. Melo et al. (2017) evaluated Chernossolos of the Chapada do Apodi and found similar result and attributed it to their source material—fine-grained fossiliferous limestone. The sand fraction predominated (606 g kg^{-1} to 907 g kg^{-1}) in the Latossolo Vermelho-Amarelo, whose texture was classified from sandy loam to sandy. This result is explained by the soil genesis, occurred from arenites in intense weathering process, with predominance of quartz—mineral that is resistant weathering processes.

The Neossolo Flúvico presented high clay contents (513 to 529 g kg^{-1}) and its texture was classified as clayey. This is unusual for this soil class; it is explained by the position of the soil in the landscape (colluvial area) normally low-lying areas receive sediments from other sites which have lighter clay fraction that is easily deposited in alluvial areas—and by the influence of its shallow water table. This affected the clay disperse in water in the C horizon of the Neossolo Flúvico (403 g kg^{-1}), with influence in the silt to clay ratio and flocculation degree, mainly in the diagnostic horizons, due to the high silt and clay content (Table 1).

The silt to clay ratio of the Chernossolo Rêndzico stood out with 2.76 g kg^{-1} to 5.61 g kg^{-1}; this denotes a low weathering degree (Table 1). Similar values (3.00 g kg^{-1} to 6.00 g kg^{-1}) were found by Melo et al. (2017), in the Chapada do Apodi. The clay flocculation degree was higher in the A horizon of the Neossolo Flúvico (46.59%), followed by the Chernossolo Rêndzico (30.29% in the Ck1, and 29.84% in the Ck2), due to its inorganic fractions (silt and clay).

In general, soil density was influenced by the source material of the studied soils (inorganic fractions); it was 1.01 g cm^{-3} to 1.63 g cm^{-3} in the Cambissolos Háplicos, which resulted in a greater microporosity and available water, followed by the Latossolo Vermelho-Amarelo (1.39 g cm^{-3} to 1.54 g cm^{-3}), which had less water available due to the predominance of sand (Table 1).

The subsurface horizons of the Chernossolo Rêndzico had predominance of micropores and available water due to the high silt and clay, and low sand fraction. Mota et al. (2008, 2013) found similar results in a Cambissolo (1.6 g cm^{-3}) and a Latossolo Vermelho-Amarelo (1.4 to 1.7 g cm^{-3}) in the Chapada do Apodi.

These diagnostic horizons presented expressive soil aeration porosity with increasing inorganic silt and clay contents, the same trend was found for the attributes total porosity, microporosity, field capacity, and available water (Table 2). According to the soil moisture as a function of its aeration porosity, the available water increased with increasing micropores. This denotes the interrelations between the original variables and the principal components, and the contribution of each variable as a function of each factor studied.

Significant correlations were found for soil density as a function of total porosity, microporosity, and aeration porosity, which denotes the complexity and dynamics of the soil structure (Table 2).

Table 2. Matrix of correlation between the soil physical attributes soil density (SD), mass-based moisture (U), volume-based moisture (θ), total porosity (TP), microporosity (MIP), macroporosity (MAP), aeration porosity (AP), field capacity (FC), available water (AW), permanent wilting point (PWP), and total organic carbon (TOC). Terra de Esperança Settlement, Rio Grande do Norte, Brazil

	SD	U	θ	TP	MIP	MAP	AP	FC	AW	PWP	TOC	Sand	Silt	Clay
SD	1.00													
U	0.19	1.00												
θ	0.19	1.00	1.00											
TP	-0.89	-0.24	-0.25	1.00										
MIP	-0.77	-0.26	-0.27	0.90	1.00									
MAP	-0.04	0.11	0.11	-0.06	-0.48	1.00								
AP	-0.77	-0.26	-0.26	0.88	0.95	-0.43	1.00							
FC	-0.45	-0.17	-0.17	0.60	0.66	-0.32	0.61	1.00						
AW	-0.36	-0.15	-0.15	0.45	0.45	-0.13	0.39	0.87	1.00					
PWP	-0.31	-0.09	-0.09	0.46	0.59	-0.42	0.57	0.58	0.10	1.00				
TOC	-0.20	0.08	0.07	0.19	0.18	-0.04	0.36	0.11	-0.13	0.43	1.00			
Sand	0.45	0.19	0.19	-0.54	-0.47	-0.02	-0.37	-0.57	-0.62	-0.12	0.18	1.00		
Silt	-0.18	-0.08	-0.08	0.14	-0.04	0.39	-0.06	0.15	0.32	-0.23	-0.07	-0.74	1.00	
Clay	-0.37	-0.14	-0.14	0.54	0.70	-0.52	0.60	0.56	0.39	0.48	-0.14	-0.33	-0.39	1.00

The physical attributes were grouped in ascending order of similarity; the first group was formed by soil density, field capacity, available water, permanent wilting point, mass-based moisture (U), and volume-based moisture (θ), which presented greater similarity and, consequently, smaller Euclidean distance, and was the most expressive group formed; the second group was formed by aeration porosity, total organic carbon (TOC), macroporosity, total porosity, and microporosity; the third group was formed by silt, clay, and sand contents (Table 2 and Figure 1).

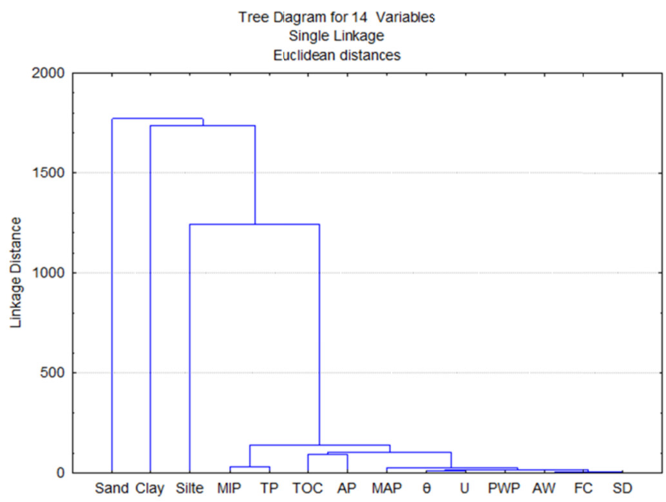


Figure 1. Vertical dendrogram of the distance matrix, by simple linkage method

According to the correlation circle (Figure 2), inorganic fractions were sparse, thus, the texture of the studied profiles varied; this determined the variables that better discriminate the soil classes, denoting an association and intercorrelation between these variables and the predominant characteristics of each profile.

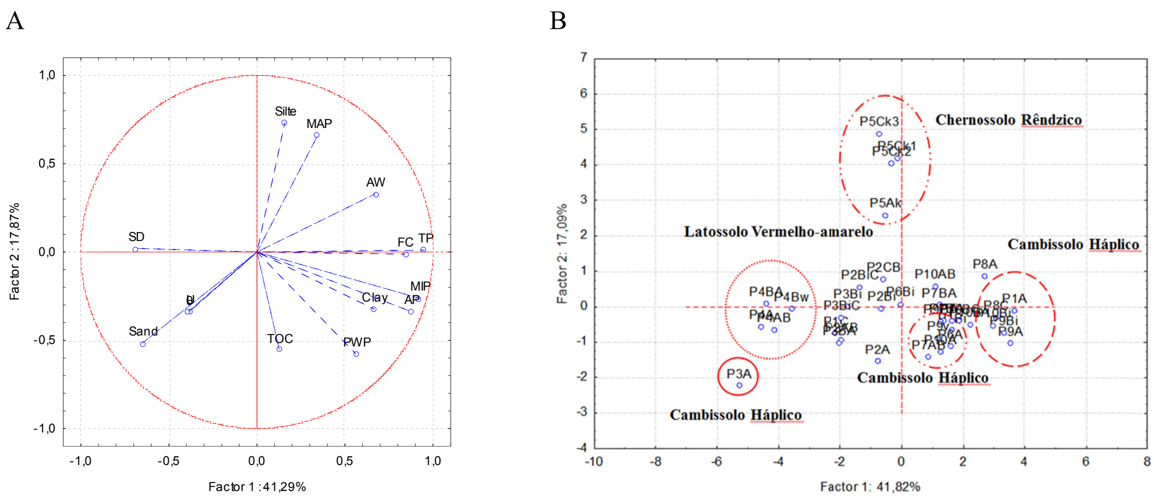


Figure 2. Distribution of the variables in the circle of correlations (A) and distribution of the clouds of sampling points, according to the correlation between factors (Factor 1 and Factor 2) and variables according to factor loadings (B)

The principal component analysis (Figures 1 and 2) identifies the correlation circle with a cloud of variables. Component 1 explained 41.82%, and Component 2 explained 17.09% of the variation found. The silt fraction was determinant in the description of Factor 2 (y axis). Silt was the discriminant variable of the Chernossolo

Rêndzico (P5) (Figures 2A and 2B); presence of calcium carbonate concretions is common in this soil class, especially in lower portions of the B or C horizons. The clay fraction was correlated to the variables total porosity, microporosity, aeration porosity, permanent wilting point, and clay content (Table 1), thus, this is a factor connected to inorganic fractions that were determinant to the distinctions of the environments.

The use of unit circles allows its overlapping to the first factorial plane, making possible to visually identify the connection between variables. The variables microporosity and aeration porosity were overlapped, and sand content, U and θ were overlapped, therefore, they have the same representativeness (Figures 2A and 2B).

The spacing between points shows the differentiation of the environments, denoting the distinction between horizons and indicating that the horizons of a same soil class have significant differences. The distribution of the clouds of variables and points of the Cambissolos Háplicos varied due to variation in their inorganic clay and sand fractions because of factors and processes of soil formation (limestone). The Latossolo Vermelho-Amarelo showed a correlation with soil density due to an intense weathering process in its formation that resulted in a good drainage and leaching of the exchangeable bases and, consequently, predominance of iron and aluminum oxides.

Table 3 shows the saturation water content (θs) and residual water content (θr), which express the maximum and minimum values of the soil water retention curve in the soil, respectively, obtained at the highest tension.

The soil water curve of P1 (Cambissolo Háplico) showed saturation moisture of 0.45 to 0.60 cm^3 cm^{-3}, with maximum of 0.60 cm^{-3} cm^{-3} in its A horizon. Its residual water content was 0.20 to 0.23 cm^{-3} cm^{-3}, with minimum of 0.20 cm^{-3} cm^{-3} in its C horizon (Table 5). This great retention is explained by the high fine sand content in its A horizon (124 g kg^{-1}) (Table 1). Similar results were found by Fidalski et al. (2013), who evaluated sandy soils and found higher soil water retention in horizons that had predominance of the fine sand fraction. The higher microporosity (53.03%), and total porosity (56.79%) of the A horizon (Table 3) may also explain these results, since the particle structural arrangement and pore distribution affect the available water, especially smaller diameter pores (Kiehl, 1979).

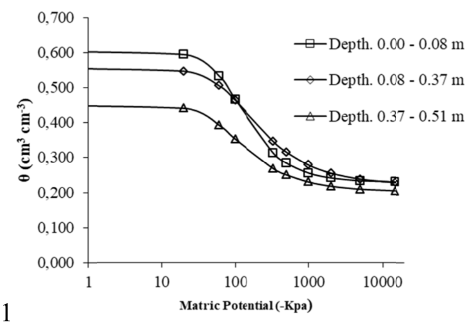
The results of the parameters of the soil water retention curve were described considering the soil classes - Cambissolos Háplicos (P1, P2 P3, P6, P7, P9 and P10), Latossolo Vermelho-Amarelo (P4), Chernossolo Rêndzico (P5), and Neossolo Flúvico (P8).

The residual water content (θr), saturation water content (θs), permanent wilting point (PWP), and available water (AW) of the Cambissolos Háplicos were similar and influenced the soil water curves (Table 3 and Figure 3).

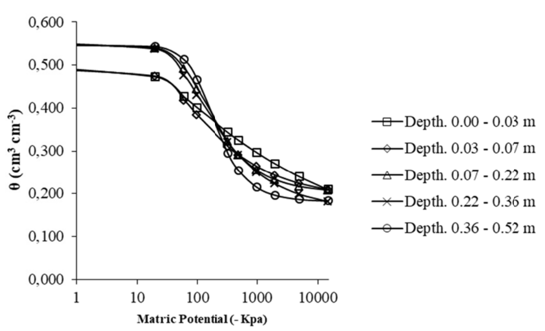
Table 3. Soil water retention curve parameters of Cambissolos Háplicos (Haplustepts). Terra de Esperança Settlement, Rio Grande do Norte, Brazil

Horizon	Depth	θ_r	θ_s	α	n	m	FC	PWP	AW
	--- cm ---	------	------	------	------	$cm^3\ cm^{-3}$	------	------	------
Profile 1: Cambissolo Háplico (Haplustepts) with native forest									
A moderate	0-8	0.23	0.60	0.01	2.06	0.51	0.48	0.22	0.26
Bi	8-37	0.22	0.56	0.01	1.73	0.42	0.48	0.23	0.25
C	37-51	0.20	0.45	0.02	1.79	0.44	0.37	0.21	0.16
Profile 2: Cambissolo Háplico (Haplustepts) in a collective area with native forest									
A slight	0-3	0.05	0.52	0.05	1.16	0.14	0.37	0.22	0.15
AB	3-7	0.18	0.50	0.02	1.43	0.30	0.39	0.21	0.18
Bi	7-22	0.20	0.55	0.01	1.76	0.43	0.39	0.22	0.17
BiC	22-36	0.16	0.56	0.02	1.52	0.34	0.44	0.18	0.26
CB	36-52	0.18	0.55	0.01	2.16	0.54	0.40	0.17	0.23
Profile 3: Cambissolo Háplico (Haplustepts) in an agroecological area with native forest									
A slight	0-4	0.17	0.39	0.01	2.15	0.53	0.28	0.16	0.12
BA	4-10	0.19	0.42	0.01	3.04	0.67	0.33	0.16	0.17
Bi	10-42	0.16	0.44	0.01	2.12	0.53	0.37	0.15	0.22
BiC	42-70	0.16	0.46	0.01	2.10	0.52	0.37	0.16	0.21
Profile 6: Cambissolo Háplico (Haplustepts) with pasture									
A	0-5	0.24	0.51	0.01	2.20	0.54	0.39	0.22	0.17
Bi	5-27	0.20	0.49	0.02	1.67	0.40	0.37	0.20	0.17
Profile 7: Cambissolo Háplico (Haplustepts) with native forest									
A	0-7	0.22	0.52	0.01	1.86	0.46	0.43	0.20	0.23
AB	7-15	0.25	0.52	0.01	1.92	0.48	0.38	0.25	0.13
BA	15-35	0.20	0.51	0.01	1.77	0.44	0.42	0.18	0.24
Bi	35-75	0.22	0.52	0.01	1.97	0.49	0.45	0.21	0.24
Profile 9: Cambissolo Háplico (Haplustepts) with native forest									
A	0-8	0.28	0.59	0.01	2.71	0.63	0.45	0.25	0.20
BA	8-19	0.20	0.55	0.02	1.62	0.38	0.41	0.22	0.19
Bi	19-60	0.26	0.55	0.01	2.36	0.58	0.45	0.22	0.23
Cv(slinkensides)	60-200	0.25	0.52	0.01	1.73	0.42	0.39	0.25	0.14
Profile 10: Cambissolo Háplico (Haplustepts) in a collective area with cajarana (Spondias dulcis)									
A	0-12	0.16	0.50	0.01	1.78	0.44	0.30	0.24	0.06
AB	12-24	0.16	0.50	0.01	1.78	0.44	0.41	0.15	0.26
BA	24-41	0.20	0.55	0.01	1.85	0.46	0.42	0.19	0.23
Bi	41-92	0.23	0.56	0.01	2.24	0.55	0.53	0.22	0.31
BC	92-115	0.23	0.55	0.02	1.54	0.35	0.43	0.21	0.22

Note. θ_r = residual water content; θ_s = water content of saturated soil; α, n and m = parameters of the equation; FC = field capacity; PWP = permanent wilting point; AW = available water.



P1



P2

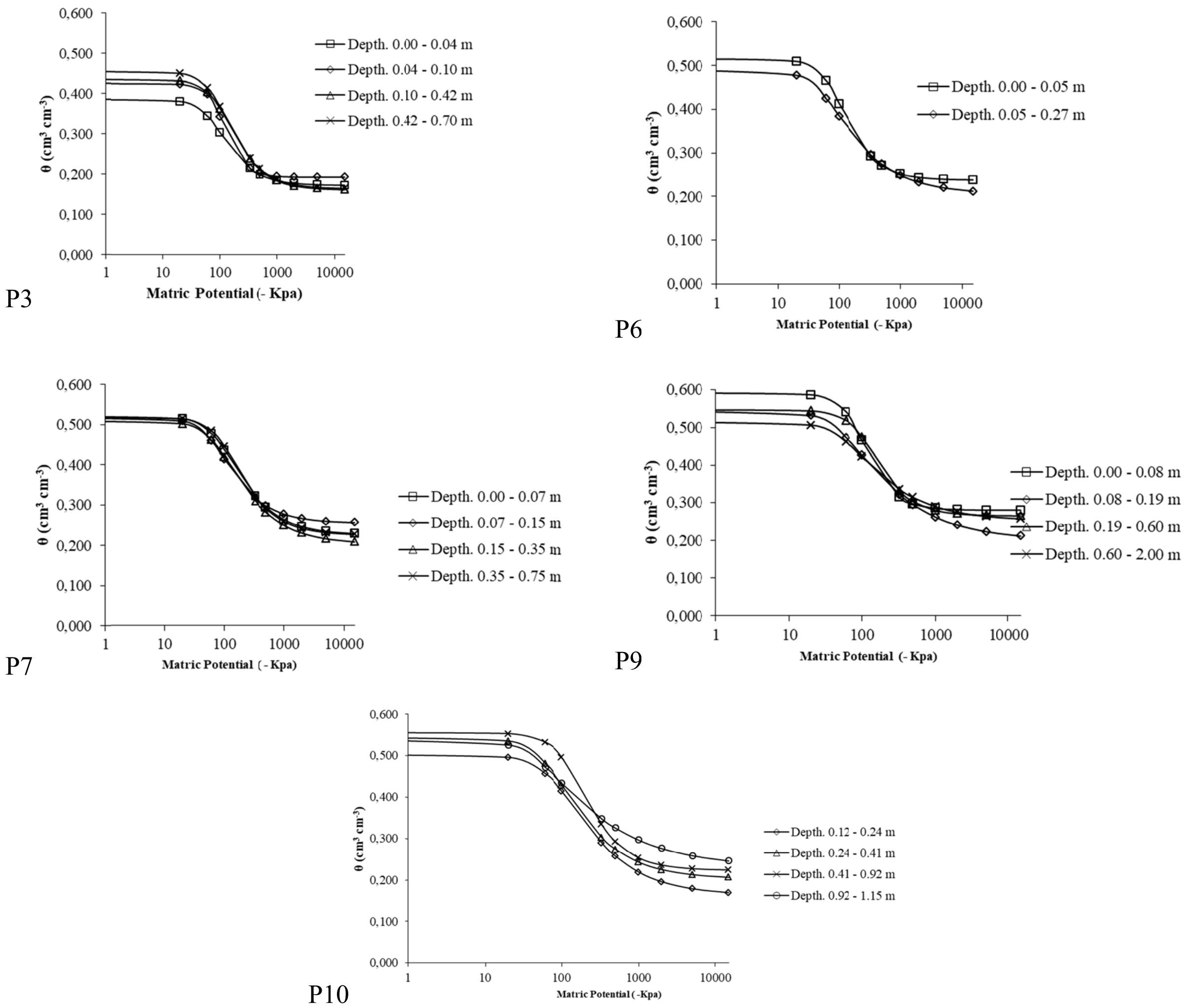


Figure 3. Soil water retention curve of horizons of Cambissolos Háplicos (Haplustepts) in the soil profiles (P): Cambissolo Háplico (Haplustepts) with native forest (NF) (P1); Cambissolo Háplico in a collective area with NF (P2); Cambissolo Háplico in an agroecological area with NF (P3); Cambissolo Háplico with pasture (P6); Cambissolo Háplico with NF (P7); Cambissolo Háplico with NF (P9); and Cambissolo Háplico in a collective area with cajarana (*Spondias dulcis*) (P10). Terra de Esperança Settlement, Rio Grande do Norte, Brazil

The water retention curves of the Cambissolos Háplicos (P1, P2, P6, P7, P9 and P10) were similar (Figure 3) and had slight variations with the applied tensions. P1 presented a volume-based moisture (θ) of 0.60 cm^3 cm^{-3}; this high θ can be explained by the granulometric composition (mainly clay) of the Cambissolos Háplicos, which affects the microporosity and, consequently, generated a greater soil water retention. The exception was P3, which had a high sand content (Figures 2) that can be explained by the spatial variability, with interconnected formation processes and factors. Oliveira et al. (2013) evaluated the effect of the micro relief on soil granulometric distribution in Cambissolos in the Chapada do Apodi and found similar results, since the fractures in the source material favors preferential water routes.

The available water of P2 was higher in the BiC horizon (0.26 cm^3 cm^{-3}), probably due to the presence of large amount of micropores (42.97%) in the soil profile and high silt (170 g kg^{-1}) and clay (270 g kg^{-1}) contents in this horizon, since the soil water retention increases with increasing clay content. Mota (2008) evaluated physical attributes of Cambissolos in the Chapada do Apodi and found higher water retention in soils with higher clay content (109 g kg^{-1} to 309 g kg^{-1}), and higher microporosity (31% a 33%).

The Latossolo Vermelho-Amarelo had lower available water than the other soil classes evaluated (Table 4), with a subtle increase in the Bw (25-50 cm layer) and BA horizons (Figure 4); this can be explained by their increased clay contents that results in higher aeration porosity and higher soil water retention at field capacity.

Table 4. Soil water retention curve parameters of the Latossolo Vermelho-Amarelo (Eutrustox). Terra de Esperança Settlement, Rio Grande do Norte, Brazil

Horizon	Depth	θ_r	θ_s	α	n	m	FC	PWP	AW
	---- cm ----	cm^3 cm^{-3}							
Profile 4: Latossolo Vermelho-Amarelo (Eutrustox) with cashew (Anacardium occidentale)									
A	0-7	0.07	0.44	0.01	3.47	0.71	0.09	0.06	0.03
AB	7-25	0.14	0.40	0.03	5.08	0.80	0.15	0.11	0.04
Bw	25-50	0.13	0.41	0.01	2.22	0.55	0.18	0.11	0.07
BA	50-200+	0.16	0.39	0.01	2.12	0.53	0.20	0.15	0.05

Note. θ_r = residual water content; θ_s = water content of saturated soil; α, n and m = parameters of the equation; FC = field capacity; PWP = permanent wilting point; AW = available water.

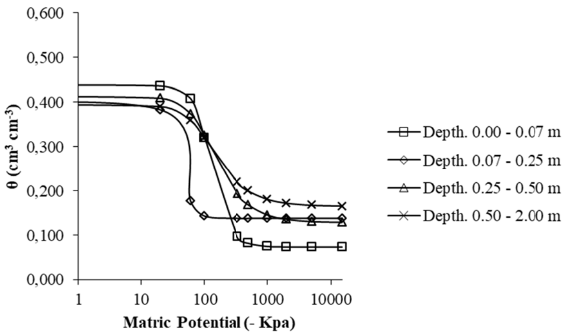


Figure 4. Soil water retention curve of horizons of the Latossolo Vermelho-Amarelo. Terra de Esperança Settlement, Rio Grande do Norte, Brazil

According to the soil water retention curve of the Latossolo Vermelho-Amarelo (Figure 4), it had the lowest available water in all horizons; its horizon Bw had higher available water due to its higher clay content. This result may be due to the granulometric composition of this soil, predominantly sandy in the surface layer, and the predominance of macroporosity that generated a lower soil water retention. Parahyba et al. (2015) evaluated the water retention of sandy soils and found reduced available water, especially in those with predominance of coarse sand. Sandy soils have larger pores, consequently, they easily lose water under low tensions, resulting in less water retained under low potentials, which are responsible for the soil moisture due to capillary forces (Reichardt, 1990).

The Chernossolo Rêndzico presented lower water content in the surface layers, with increases in subsurface layers (Table 5). This result was due to the high silt and clay content in greater depths, especially in the 50-120 cm layer (Ck2 horizon), and its higher moisture saturation (θ_s = 0.51 cm^3 cm^{-3}) (Figure 2), which was represented in the cloud of variables and points that identified the more pronounced attributes in this class that differentiated it from the other environments (Figure 5).

Table 5. Soil water retention curve parameters of the Chernossolo Rêndzico (Calciustolls). Terra de Esperança Settlement, Rio Grande do Norte, Brazil

Horizon	Depth	θ_r	θ_s	α	n	m	FC	PWP	AW
	---- cm ----	cm^3 cm^{-3}							
Profile 5: Chernossolo Rêndzico (Calciustolls) with pasture									
Ak	0-20	0.22	0.44	0.012	2.32	0.57	0.33	0.21	0.12
Ck1	20-50	0.08	0.52	0.03	1.35	0.26	0.39	0.15	0.24
Ck2	50-120	0.00	0.51	0.02	1.30	0.23	0.40	0.09	0.31
Ck3	120-140+	0.00	0.49	0.02	1.29	0.23	0.39	0.10	0.29

Note. θ_r = residual water content; θ_s = water content of saturated soil; α, n and m = parameters of the equation; FC = field capacity; PWP = permanent wilting point; AW = available water.

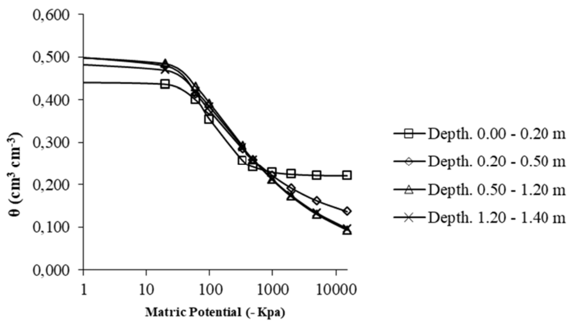


Figure 5. Soil water retention curve in horizons of the Chernossolo Rêndzico (Calciustolls). Terra de Esperança Settlement, Rio Grande do Norte, Brazil

The soil water retention curve of the Neossolo Flúvico (Figure 6) was similar to that of the Cambissolos Háplicos (Figure 3), with similar field capacity, permanent wilting point, available water, and saturation water content (Table 6). The results of the Neossolo Flúvico may be explained by its high clay content, and position in the landscape (sediment deposit area), which receives alluvial sediments. The unusual predominance of clay in this soil class generates greater water retention in its micropores, in unsaturated condition, where the capillary forces will be present in low tensions.

Table 6. Water retention curve parameters of the Neossolo Flúvico (Usticfluvents), Terra de Esperança Settlement, Rio Grande do Norte, Brazil

Horizon	Depth	θ_r	θ_s	α	n	m	FC	PWP	AW
	cm	$cm^3\ cm^{-3}$							
Profile 8: Neossolo Flúvico (Usticfluvents) in a permanent conservation area with oiticica (Licania rigida)									
A	0-30	0.16	0.56	0.01	1.58	0.37	0.46	0.16	0.30
C	30-100	0.18	0.57	0.01	1.64	0.39	0.44	0.18	0.26

Note. θ_r = residual water content; θ_s = water content with saturated soil; α, n and m = parameters of the equation; FC = field capacity; PWP = permanent wilting point; AW = available water.

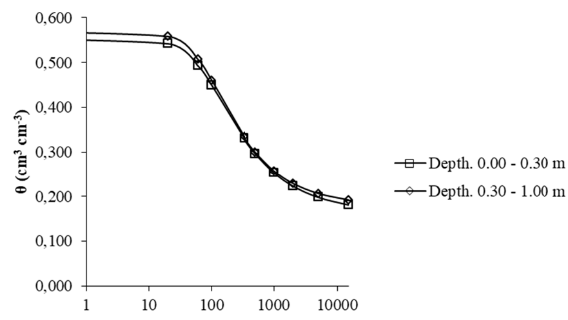


Figure 6. Soil water retention curve in horizons of the Neossolo Flúvico (Usticfluvents). Terra de Esperança Settlement, Rio Grande do Norte, Brazil

4. Conclusions

The soil physical attributes were efficient in distinguishing the environments, especially the inorganic fractions silt and clay, showing different microporosity, aeration porosity, and available water for the different soil horizons and classes.

The source material of the soil classes studied influenced their physical attributes. The inorganic fractions were determinant for the description of the Chernossolo Rêndzico (Calciustolls) (silt), Cambissolo Háplico (Haplustepts) (clay), Neossolo Flúvico (Usticfluvents) (clay), and Latossolo Vermelho-Amarelo (Eutrustox) (sand on the surface, and clay in the Bw horizon).

The most significant group of physical attributes was composed of soil density, field capacity, available water, permanent wilting point, mass-based moisture, and volume-based moisture, followed by macroporosity and aeration porosity.

The water retention in the soil was higher in the Cambissolos Háplicos, Neossolo Flúvico, and Chernossolo Rêndzico, with similarity within each class regarding field capacity, permanent wilting point, and available water, with predominance of inorganic clay and silt fractions. The Latossolo Vermelho-Amarelo presented lower retention and available water, with predominance of the sand fraction and increase of the clay fraction in the diagnostic horizon.

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