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MORPHOLOGICAL, PHYSICAL AND CHEMICAL CHARACTERIZATION OF LUVISOLS UNDER RAINFALL GRADIENT IN THE SEMI-ARID REGION OF PARAÍBA

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Abstract: The climate is an important factor in the formation of soils and can be determinant in its characteristics. The aim of this study was to evaluate the influence of rainfall gradient on the formation process of Luvisols in the semiarid region, studying their morphological, physical and chemical attributes. Three soil profiles were described and collected under the following rainfall conditions: very dry < 400 mm, 400 > dry < 600 mm and sub-humid > 600 mm. The soils were analyzed for physical (particle size, clay dispersed in water, soil and particle density, degree of flocculation and porosity) and chemical properties (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}, $Al^{3+,}$ H^{+} + Al, COT, P and pH). It was noted the influence of rainfall in the pedogenetic processes that resulted in deeper soils the greater the rainfall in the region; the influence of precipitation on physical attributes was evidenced in clay contents; no clear influence of rainfall on fertility was noted. Thus, it was not possible to identify an isolated influence of rainfall levels on the chemical properties of soils. In general, the Luvissols in the very dry condition showed a higher content of nutrients available to the plants compared to other Luvisols.
Keywords: Soil classification, pedogenesis, rainfall.

INTRODUCTION

The semi-arid region of Northeastern Brazil, due to different climatic conditions, vegetation, types of rocks and relief formations, present the most diverse environments and, consequently, the most diverse types of soils. These soils have relevant morphological, physical, chemical and mineralogical attributes, which makes it possible to subdivide them into relatively more homogeneous classes. The diverse environments in the Northeast, especially in the semi-arid, with areas of stronger geological formation, sedimentary basins and areas of crystalline sedimentation, it is possible to find sandy and deep textured soils close to clayey and shallow soils, highlighting the need to study and better understand the general characteristics of the main soil classes (Marques et al., 2014; Silva et al., 2019).

In a large part of the semiarid region, soils do not fully absorb water, even when rainfall occurs with accumulation. This happens because some soils have a B-textural horizon with high levels of clay with high activity, making the soil poorly permeable and limiting water infiltration in the soil profile. Another important factor that prevents the filtration of water in the soil and enables an increase in surface runoff of water is the compaction of the soil through the trampling of animals, mainly in Luvissolos (Araújo, 2011).

Among the factors and processes of soil formation, the climate is often highlighted in relation to the others, as it acts in an active and differentiated manner, since a material derived from the same rock can form different types of soils if subjected to climatic conditions different. On the other hand, different materials can form similar soils when subjected, for a long period, to the same climatic environment (Ribeiro et al., 2012).

Thus, it is possible to state that the action of weathering varies from region to region, being conditioned by its controlling factors, with emphasis on the climate, mainly as a function of precipitation and temperature variables. In areas with high temperature and low rainfall, physical weathering predominates, which corresponds to the rupture of rocks, by the action of mechanical efforts, while chemical weathering is highly dependent on the amounts of water entering the system (Toledo et al., 2001).

In semi-arid environments there is a significant variation in the chemical and microbiological properties of the soil due to the seasonal climate to which these environments are subjected, as their main limitation is water deficit (Martins et al., 2010).

The physical, chemical, morphological and mineralogical characterization studies of soils constitute a way to provide subsidies for the development of practices of use, management and conservation of soils (Jacomine, 1996). In the Northeast region, studies of this nature are still relatively scarce. The few carried out were for purposes of fertility (Oliveira et al., 2000) and agricultural production in the semiarid region (Menezes et al., 2008; Galvão and Salcedo, 2009).

In the semiarid region, even though the soils are underexplored due to climatic conditions, Santos et al. (2012) emphasize the importance of these studies, especially from a pedological point of view. In addition to providing more accurate knowledge about the different orders of soils, they allow systematizing information on soil properties, which may serve as a subsidy for the development of management practices and sustainable use, as well as for the recovery of degraded areas. Given the above, the study aimed to evaluate the influence of rainfall gradient on the morphology and physical and chemical properties of three Luvisols in the semi-arid region of Paraíba.

MATERIAL AND METHODS

The studies were conducted under three rainfall conditions in the state of Paraíba, designated as follows: very dry - MS (precipitation < 400 mm), dry - SC (precipitation > 400 mm and < 600 mm) and sub-humid - SU (precipitation > 600 mm). The sampling points and the moisture gradient can be seen in Figure 01.

Located within the Equatorial belt, the state of Paraíba has a hot climate, with an average annual temperature of around 26°C. Regarding rainfall, it is the northeastern state that presents the greatest spatial variability of rainfall. In the Cariri region of Paraíba, the municipality of Cabaceiras is considered the driest in Brazil, with an average rainfall of approximately 300 mm; while the capital João Pessoa, located on the coastal strip and distant approximately 150 km, presents an average annual rainfall that exceeds 1,700 mm.

The areas were selected considering a rainfall gradient and grouped according to the similarity of their characteristics (average rainfall) and the possibility of occurrence of Luvisols. Figure 01 shows the monthly average precipitation indices in each climatic condition, according to data from the Paraíba State Water Management Executive Agency (AESA/PB).

A trench was opened in each selected area, followed by the morphological description of the soil profiles and the collection of deformed and undisturbed samples, according to Santos et al. (2015). The analyzes of the physical attributes of the soils were carried out according to the methodology presented by Teixeira et al. (2017) and included the following determinations: particle size, clay dispersed in water (ADA), soil and particle density, flocculation degree and total porosity.

The analyzes of the chemical attributes of the soil included determination of the exchangeable base contents (Ca^{2+}, Mg^{2+}, Na^+ and K^+), Al^{3+} and potential acidity $H^+ + Al^{+3}$, adopting KCl 1 mol L^{-1} as an extracting solution; phosphorus (assimilable P), pH in water and pH in KCl and electrical conductivity (EC) (Teixeira et al., 2017). Based on chemical determinations, sum of bases (S), cation exchange capacity (CTC), base saturation (V), percentage of sodium saturation (PST) and percentage of aluminum saturation (m) were calculated. The determination of organic carbon (CO) was based on the methodology of Yeomans and Bremner (1988).

The taxonomic classification of the studied soils was carried out based on morphological, physical and chemical attributes, carried out according to the Brazilian System of Soil Classification – SiBCS (Santos et al., 2018).

RESULTS AND DISCUSSION

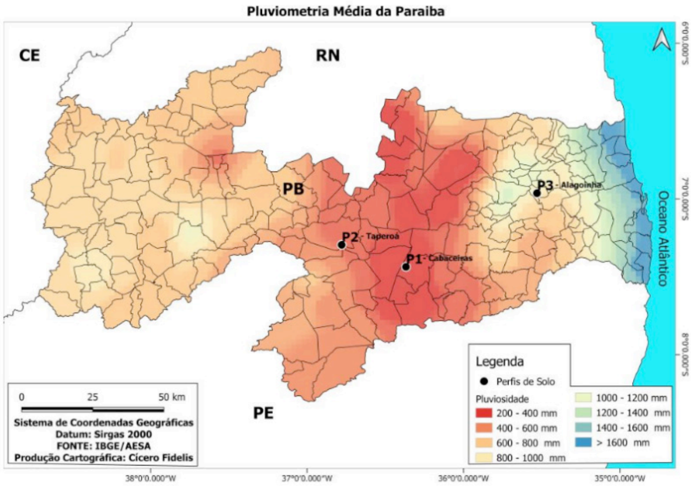
MORPHOLOGICAL ATTRIBUTES

The morphological attributes of the studied Luvisols are presented in Table 01. Their respective photographs and analysis bulletins can be consulted in Saraiva (2016). In Luvisols, the influence of rainfall on pedogenetic processes is clearly noted, which resulted in deeper soils the greater the rainfall in the region. This is evident both when observing the depth of the solum (A+B), as in the total depth of the profiles, which was 110, 123 and 162 cm for the soil in the very dry, dry and sub-humid condition, respectively. These soils are a little deeper than the old Bruno non-Calcic ones described in Brasil (1972) in similar climate and relief conditions. In general, the studied soils have very varied morphological characteristics that can be associated both with the source material and with the climate, forming a complex association of relevant factors in the formation and evolution of the soils.

The P1 – Luvissol of Cabaceiras (very dry environment) presented a sequence of horizons A-BA-Btv-BCz-Crnz, with an A horizon measuring 10 cm thick, textural class free sand and weak structure. According to Santos et al. (2018), due to its external conditions of climate and vegetation, it falls into weak type A, although it presents base saturation greater than 65% and carbon content greater than6 g kg^{-1} (Table 03).

In P2 – Luvissol of Taperoá (dry environment) it has a sequence of horizons of the Az-AB-Btv-CBvn-Cnz type, with an A horizon measuring 11 cm thick, loamy-sandy texture and moderate structure. Due to its more developed structure and finer texture than P1 according to SiBCS (Santos et al., 2018), it is a moderate A horizon.

Average Pluviometry of Paraíba

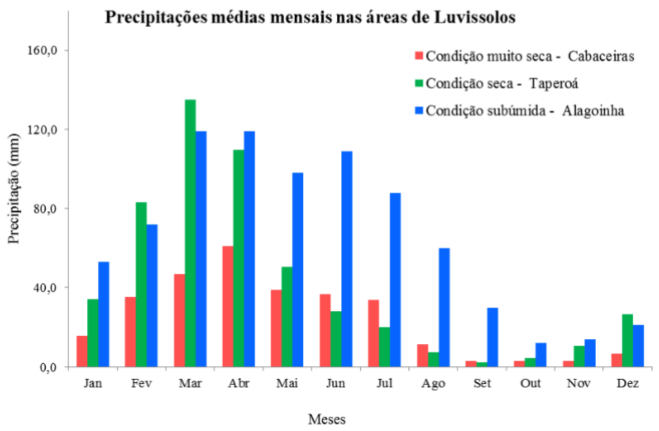


0 25 50 km
Geographic coordinate system
Datum:Dihmas 2000
Source: IBGE/AESA
Cartographic Production: Cicero Fidelis

Subtitle
Soil profiles
Rainfall

Figure 01: Average rainfall map of the State of Paraíba, indicating the collection points of Luvisol profiles in a rainfall gradient (Adaptado de AESA, 2007).

Precipitation (mm)



Average monthly rainfall in the Luvisols areas
Very dry condition - Cabeceiras
Dry condition - Taperoá
Subhumid condition - Alagoinha

Figure 02 – Histogram of mean monthly precipitation in the pluviometric gradient (source: AESA).

Horizons	Depth (cm)	Color		Texture	Structure	Consistency		
		Humid	Dry			Dry	Humid	Wet
P1 – CHROMIC LUVISOL Solodic vertisolic saline ortic - very dry condition (Cabaceiras)								
A	0-10	5 YR 3/3	2,5 YR 3/6	FAr	3 MPq-Pq, Bs	LD	Fr	Pl Pe
BA	10-22	2,5 YR 3/4	2,5 YR 3/4	FAr	3-4 MPq-Pq, Bs	D	Fr	Pl MPe
Btv	22-48	2,5 YR 4/3	2,5 YR 4/4	FAr	4, Md-Gr, Pr-Ba	ED	Fi	MPl MPe
BCz	48-60	5 YR 4/4	5 YR 5/4	FAA	4, MPq, Pr, Ba-Bs	D	Fr-Fi	Mpl Pe
Crnz	60-110			Ar				
P2 – CHROMIC LUVISOL Solodic vertisolic saline ortic - dry condition (Taperoá)								
Az	0-11	2,5 YR 2,5/4	2,5 YR 3/6	FAA	4 Md-Gr, Pr	ED	Fi	Pl LPe
AB	11-24	2,5 YR 3/6	2,5 YR 4/6	FAr	4 Md-Gr, Pr	MD	Fi	Pl LPe
Btv	24-63	10 R 4/3	10 R 3/6	FAg	5 Md-Gr e MGr, Pr	MD	MFi-EFi	MPl Pe
CBvn	63-89	10 YR 5/8	2,5 Y 6/6	FAA	5 Md-Gr e MGr, Pr	D	Fr	LPl NPe
Cnz	89-123	2,5 Y 5/6	2,5 Y 7/6	FAr	5 Md-Gr, Pr e Ba-Bs	Mc	MFi	NPl NPe
P3 – CHROMIC LUVISOL Solodic Abrupt Orthic - Subhumid Condition (Alagoinha)								
A	0-25	10 YR 4/4	10 YR 5/3	FAA	3 Md-Gr, Ba-Bs,	LD	Fr	LPl LPe
AB	25-36	7,5YR 4/4	7,5YR 5/6	FAr	5 Gr-MGr, Ba-Bs	ED	Fi	Pl Pe
Btv	36-79	2,5YR 3/4	2,5YR 4/6	FAA	5 Md-Gr, Ba	MD	Fi	MPl Pe
Cn/Crn	79-140	7,5YR 5/6	7,5YR 4/6	FAr	4 Pq-Md, Ba	ED	Fi	Pl LPe
Crn/R	140-162+			ArF				

Texture: Air – Sand, ArF – Dull sand, Sl – Silt, FAr – Sandy loam, FSl – Loam silty, Fr – Dull, FAA – sandy clay loam; FAS – Clay silty, FAg – Clay loam, AgS – Clay silty, AAr – Sandy clay, Ag – clay, MAg – Very clayey. Structure: 1 - Simple grain, 2 - Solid, 3 - Weak, 4 - Moderate, 5 - Strong; Lm – laminar; Pr – prismatics; Cl - columnar; Ba – Angular blocks; Bs – Subangular blocks; Gn - Granular. M – A lot, Pq – small, Md – Medium, Gr – large. Consistency: St – loose, Mc – soft, LD – slightly hard, D – hard, MD – very hard, ED – extremely hard; MFr – very friable, Fr – friable, Fi – firm, MFi – very firm, EFi – extremely firm; NPl – non-plastic, Pl – plastic, LPl – slightly plastic, MPl – very plastic; NPe not sticky, Pe - sticky, LPe - slightly sticky, MPe - very sticky.

Table 01: Morphological characteristics of the three profiles of Luvisols studied on rainfall gradient in the semiarid region of Paraíba.

The horizon sequence of P3 – Luvissol of Alagoinha (subhumid environment) was A-AB-Btv-Cn/Crn-Crn/R. The A horizon, including its transition to the subsurface horizon, is 36 cm thick, which is superior to other rainfall conditions. It fits in the sandy loam texture class, dark yellowish-brown color and weak structure, with base saturation below 65% (Table 03), therefore being considered a moderate A horizon.

Considering the general appearance of the profiles of the studied Luvisols, there was great variation in their colors, as well as between the horizons of the same profile, passing through shades of brown, red and yellow, as also observed by Oliveira et al. (2009), where they stated that this is a common feature of Luvisols in the semiarid region. The colors of Luvissols are generally due to soil formation processes that involve the release and dispersion of iron particles (Prado, 2005).

Luvisols showed texture variation between horizons, as expected, since a striking property of this soil class is the presence of a textural B horizon characterized by having a sandy loam or finer texture. The degree, class and type of structure varied widely between and within profiles. The structure of the superficial horizons was in subangular blocks, at P1; prismatic at P2 and in angular and subangular blocks at P3. As for consistency, there is also great variation, in the dry state, with a tendency towards higher hardness classes. It ranged from slightly hard to extremely hard on the surface horizons and from extremely hard to very hard on the subsurface horizons. The wet consistency of the superficial horizons was friable and firm, whereas in the subsurface horizons it was firm and very to extremely firm; therefore, the wet consistency presented quite variable between horizons and between the studied profiles.

PHYSICAL ATTRIBUTES

The results of the analysis of the physical attributes of the studied Luvisols are shown in Table 02. The coarser fractions (pebble and gravel) represent between 0.6% and 15% of the soil mass and have greater expression in the Cr horizon of P1.

In the surface horizons (A) of the Luvisols the sand contents ranged from 494 to 605g kg^{-1} soil, decreasing due to the increase of humidity in the environment. In the subsurface horizons (Btv) they ranged between 428 and 512 g kg^{-1} soil and in the lower horizons (C and/or Cr) from 658 to 810 g kg^{-1}, no clear relationship with the moisture content of the environment. Considering the entire profile, there was a predominance of the coarse sand fraction in the soil in the very dry condition and fine sand in the other conditions. In addition, it was possible to notice that there was an increase in the proportion of fine sand in relation to coarse sand, due to the increase in the humidity of the environment, especially in the superficial horizons, showing a clear influence of precipitation in the transformation of the source materials into materials of particle size smaller. Medeiros et al. (2013) evaluating the physical characterization of 6 soil profiles under cattle ranching in the semiarid region of Seridó - RN, observed that the largest amounts of pebbles and gravel were found in Luvissol and Neosol with greater presence of fine soil because it is a soil near streams or rivers.

The silt contents of Luvisols ranged from 198 to 318; from 158 to 230 and from 146 to 228 g kg^{-1} soil at surface (A), subsurface (Btv) and lower (C and/or Cr) horizons. The highest levels of silt in the A horizons are related to the loss and/or translocation of clay to the subsurface horizons, as explained by Souza et al. (2010). The lesser variation of silt between soil horizons in the subhumid condition can be explained by the greater action of weathering in this environment.

Horizon	Depth	Calhau	Casc.	TFSA	Fine Earth Granulometric Composition					ADA	GF	Rel. Silt/ Clay	Densities		Porosity
					Coarse sand	Thin sand	Total sand	Silt	Clay				Soil	Part.	
	cm	g kg-1									%		--kg dm-3--		dm3 dm-3
P1 – CHROMIC LUVISOL Solodic vertisolic saline ortic - very dry condition (Cabaceiras)															
A	0-10	0	31	969	314	291	605	268	127	52	62	2,11	1,36	2,75	0,51
BA	10-22	0	78	922	327	212	539	244	217	26	79	1,13	1,65	2,68	0,38
Btv	22-48	0	17	983	265	163	428	218	354	68	58	0,62	1,81	2,67	0,32
BCz	48-60	0	50	950	330	252	582	269	149	54	82	1,80	1,80	2,66	0,32
Crnz	60-110+	0	149	851	629	182	810	146	44	26	60	3,33	nd	2,60	nd
P2 – CHROMIC LUVISOL Solodic vertisolic saline ortic - dry condition (Taperoá)															
Az	0-11	71	14	915	153	381	534	198	268	26	86	0,74	1,74	2,43	0,29
AB	11-24	8	33	958	229	461	690	155	155	38	80	1,00	1,70	2,52	0,33
Btv	24-63	0	14	986	204	308	512	158	330	53	83	0,48	1,79	2,52	0,29
CBvn	63-89	0	12	988	148	438	586	223	191	65	21	1,17	1,71	2,59	0,34
Cnz	89-123	0	41	959	202	456	658	228	114	39	71	2,00	1,68	2,68	0,37
P3 – CHROMIC LUVISOL Solodic Abrupt Orthic - Subhumid Condition (Alagoinha)															
A	0-25	0	28	972	167	327	494	318	188	52	72	1,69	1,65	2,60	0,36
AB	25-36	0	37	963	243	404	647	247	106	64	40	2,33	1,62	2,50	0,35
Btv	36-79	0	6	994	220	270	490	230	281	93	67	0,82	1,62	2,58	0,37
Cn/ Crn	79-140	0	11	989	304	365	669	268	63	39	38	4,25	1,75	2,57	0,32
Crn/R	140-162+	0	0	1000	392	350	742	226	32	26	19	7,00	nd	2,64	nd

Hor.: horizon; Depth: depth; Casc: Gravel; TFSA – Air Dry Fine Earth; ADA: Clay dispersed in water; GF: degree of flocculation; Part.: particle.

Table 02: Physical characteristics of the three profiles of Luvisols studied on rainfall gradient in semiarid climate.

There was great variation in the clay contents of the studied Luvisols. Among the surface horizons (A), the values ranged between 127 and 268 g kg^{-1} soil; in the subsurface (Btv), from 281 to 354 g kg-1 soil; and in the lower ones (C and/or Cr), from 32 to 114 g kg^{-1} soil. When comparing the clay contents of similar horizons, it is possible to observe that the highest are in the dry condition profile – Luvissolo Taperoá (P2). In each soil profile, the clay contents were concentrated in the subsurface horizons (Btv), which are diagnostic for this soil class and have clay accumulation as a particularity (Santos et al., 2018). Clays can be formed *in situ*, translocated or their accumulation can be the result of differential erosion. However, under the conditions of the semi-arid northeast, as reported by Oliveira et al. (2008), clays from subsurface horizons form *in situ* and result from greater moisture retention for a longer period of time, which favors the weathering of minerals.

It was not possible to correlate the clay distribution pattern along the profiles with the precipitation indices of each study area. It is likely that the lower clay contents of the sub-humid condition are the result of differences in the nature of the source material (not so rich in mafic minerals) and of material loss processes favored by runoff due to the position of the profile in the landscape, middle third of the slope, in an area of undulating relief.

The clay dispersed in water (ADA) of the Luvisols ranged from 26 to 52 g kg^{-1} soil on surface horizons (A), from 53 to 93 g kg^{-1} soil in the subsurfaces (Btv), and from 26 to 39 g kg^{-1} soil on the C or Cr horizons. The degree of flocculation (GF) ranged from 62% to 86%; 58% to 83% and 19% to 71% for surface (A), subsurface (Btv) and lower (C and/or Cr) horizons, respectively. In general, the highest values are those of the superficial horizons, indicating greater stability of aggregates in these horizons, probably influenced by the higher organic matter contents.

The Luvissol A horizon in the very dry condition was the one with the lowest soil density (1,36 kg dm^{-3}), when compared to the others. This value is similar to the Luvissolo A horizons studied by Araújo et. al. (2004). In Btv horizons, the lowest soil density is in the sub-humid soil condition (1,62 kg dm^{-3}).

The particle density of Luvisols, depending on the mineralogy of the soils, ranged from 2.75 to 2,43 kg dm^{-3}; 2.52 to 2.67 kg dm-3 and 2.60 to 2.68 kg dm-3 at the surface (A), subsurface (Btv) and inferior (C and/or Cr) horizons, respectively. These values are similar to those obtained by Corrêa et. al (2003) in Luvissols of the Sertão Paraibano.

CHEMICAL ATTRIBUTES

The results of the analysis of the chemical attributes of the Luvisols under the three study conditions are shown in Table 03, and indicate these soils have a pH ranging between acid (6.01) and alkaline (7.69) in the superficial horizons (A).

In general, soil pH in the range of 5.5 to 6.5 is favorable for most plants (Meurer, 2012), including potatoes, beans and corn, which are widely cultivated in the Brazilian semiarid region. The Luvissol in the subhumid condition had the lowest pH values. This is possibly related to the loss of basic cations (Ca and Mg) and the consequent reduction in negative charges in the soil. The results obtained in this work are similar to those presented by Corrêa et al. (2003) in a profile of Luvissolo in the semiarid region of Paraíba.

The pH values in water were higher than those in KCl, resulting in negative Δ pH (data not shown) in all analyzed samples. This indicates a predominance of negative charges on the surface of the colloids and a lower point of zero charge (PCZ), as also observed by Oliveira et al. (2009) studying Luvisols

Hor.	Prof.	pH	pH	CO	P	Ca	Mg	Na	K	SB	Al	H	CTC	Valor V	PST	m	CE
	(cm)	H_2O	KCl	g kg^{-1}	mg kg^{-1}	(cmol$_c$ kg^{-1})								(%)			dS/m
P1 – CHROMIC LUVISOL Solodic vertisolic saline ortic - very dry condition (Cabaceiras)																	
A	0 - 10	7,69	6,48	8,82	7,06	3,43	3,60	0,17	0,49	7,69	0,30	0,43	8,42	91,33	2,02	3,56	0,00
BA	10 - 22	7,32	5,61	5,20	2,30	4,23	4,27	0,21	0,15	8,86	0,30	0,90	10,06	88,07	2,09	2,98	0,00
Btv	22 - 48	7,70	5,41	5,73	3,30	8,03	5,07	0,65	0,05	13,80	0,30	0,74	14,80	92,99	4,38	2,02	3,24
BCz	48 - 60	7,27	4,62	3,79	15,66	7,90	8,25	0,82	0,04	17,01	0,33	0,71	18,00	94,24	4,54	1,83	6,12
Crnz	60 - 110 +	7,39	4,91	3,17	89,38	4,53	5,37	0,71	0,06	10,67	0,33	0,21	11,16	95,18	6,34	2,94	6,12
P2 – CHROMIC LUVISOL Solodic vertisolic saline ortic - dry condition (Taperoá)																	
Az	0 - 11	7,67	6,38	9,37	9,89	5,10	5,13	0,15	0,28	10,66	0,30	0,20	11,16	95,52	1,34	2,69	6,90
AB	11 - 24	7,84	6,57	3,39	10,17	2,33	2,67	0,12	0,15	5,27	0,30	0,31	5,88	89,63	2,04	5,10	2,32
Btv	24 - 63	7,13	4,76	3,48	2,25	4,83	5,04	0,60	0,13	10,60	0,30	1,89	12,79	82,88	4,69	2,35	2,42
CBvn	63 - 89	8,10	5,28	3,21	33,67	4,73	5,80	0,73	0,10	11,36	0,30	0,90	12,56	90,45	5,81	2,39	2,04
Cnz	89 - 123+	8,65	6,25	1,16	127,31	6,56	5,94	1,19	0,11	13,80	0,30	0,03	14,13	97,66	8,42	2,12	5,28
P3 – CHROMIC LUVISOL Solodic Abrupt Orthic - Subhumid Condition (Alagoinha)																	
A	0 - 25	6,01	3,79	7,41	1,32	1,00	1,13	0,09	0,09	2,31	0,30	4,30	6,93	33,29	1,30	4,33	1,72
AB	25 - 36	6,27	3,53	7,05	1,73	1,06	3,11	0,26	0,09	4,52	0,30	4,40	9,26	48,82	2,81	3,24	0,93
Btv	36 - 79	6,25	3,46	5,45	1,63	0,86	6,04	0,57	0,06	7,53	0,30	4,20	12,10	62,24	4,71	2,48	1,31
Cn/ Crn	79 - 140	6,52	3,37	5,27	1,84	0,53	5,80	1,04	0,08	7,45	0,30	3,10	10,87	68,53	9,57	2,76	1,27
Crn/R	140 - 162+	6,40	3,33	nd	2,62	0,56	4,31	0,79	0,07	5,73	0,30	2,70	8,75	65,50	9,02	3,43	1,60

Hor.: Horizon; Prof.: depth; CO: Total Organic Carbon; N; Nitrogen; P: phosphorus; Ca: Calcium; Mg: Magnesium; Na: Sodium; K: Potassium; SB: Sum of Bases; Al: Aluminum; H: Hydrogen; CTC: Cation Exchange Capability; Value V: Saturation per base; PST: Sodium saturation; m: Saturation by aluminum; CE: Electrical Conductivity; na - not determined.

Table 03: Chemical characteristics of the three profiles of Luvisols studied on rainfall gradient in semiarid climate.

from the northeastern semiarid region.

The surface horizons (A) of the Luvisols had carbon contents varying between 7,41 and 9,37 g kg^{-1} soil. These quantities can be directly related to soil management in each rainfall condition (caatinga for very dry and dry conditions and annual crops for sub-humid conditions). Losses of CO, N and P in cultivated areas when compared to areas with caatinga were reported by Fraga and Salcedo (2004) in ten locations in the states of Paraíba and Pernambuco. These losses, according to Menezes et al. (2005), are related to the removal of native vegetation, soil cultivation, burning and erosion, or even the runoff and evaporation of water from the soil.

In the other horizons, the carbon contents are lower than those of the A horizon, and it is possible to notice a clear decline of these contents in the deeper horizons in relation to the soil surface, where normally a greater number of roots and greater microbiological activity are concentrated. The results obtained in this work are similar to those observed by Oliveira et. al (2009) and Martins et. al (2010) who studied Luvissols, in the semiarid region of Pernambuco, with a solodic character and in degraded areas, respectively.

The CTC values in the superficial horizons (A) of each Luvissol were 8.42; 11.16 and 6,93 $cmol_c$ kg^{-1} soil for very dry, dry and sub-humid rainfall conditions, respectively (Table 04), following the same trend observed for carbon contents. These values are well below those found by Maia et al. (2006) and Martins et al. (2010) in Luvissols of the northeastern semiarid region. In the subsurface horizons (Btv) of the profiles studied, the CTC contents ranged from 12.10 to 14,80 $cmol_c$ kg^{-1} soil, with higher value in P1 (very dry condition) which is possibly related to the higher clay contents in the Bt horizon of this soil (Table 03). As is known, clay has a larger specific surface area than sand and silt, which allows for greater adsorption capacity for water and cations (Brady and Weil, 2013). In the C horizons the variation was from 8.75 to 14,13 $cmol_c$ kg^{-1} soil and the highest value was registered in P2.

Magnesium is the main cation present in the exchange complex, which together with calcium represents from 85 to 95% of the sum of bases in the studied Luvisols. In very dry rainfall conditions, there was a tendency to increase the soil CTC with increasing depth to the BC horizon. In the Cr horizon there was a reduction in the CTC value, probably because this horizon is not totally weathered and presents many similarities with the source material. In addition, it has a sandy texture (77% sand) that contributes little to the formation of negative charges in the soil.

The Luvisol in the dry condition showed a behavior similar to that in the very dry condition, with a predominance of the magnesium cation in all horizons, followed by calcium, which together (Ca + Mg) are the main contributors to the sum of bases of these soils (Table 04). According to a survey carried out with soils from the Northeast region by Menezes et al. (2005), the contents in the soil of Ca + Mg higher than 4 $cmol_c$ kg^{-1} are considered high and 90% of Luvisols fall into this class.

In sub-humid condition, Luvissol had the sum of Ca + Mg representing more than 80% of the sum of bases, ranging from 2,13 $cmol_c$. kg^{-1} soil on horizon A to 6,90 $cmol_c$ kg^{-1} soil on the horizon Btv. Increments in these values were observed with the increase in depth to the Btv horizon, and then reductions in the deeper horizons that still present clear features of the source material and non-weathered materials.

Base saturation (V) in the superficial horizons (A) of the studied soils was 96.04%; 91.5% and 33.59% for soils in dry, very dry and sub-humid rainfall conditions, respectively. Results similar to these were obtained by Maia et al. (2006) in Luvissol areas under native vegetation in the semiarid region of Ceará.

The lowest base saturation value (V = 33.59%) observed in the soil in the sub-humid rainfall condition may be related to leaching and/or more intense weathering due to the higher precipitation observed in this region (Figure 01), compared to too much. On the other hand, higher base saturation indices are influenced by the slow and continuous weathering of primary minerals; by the high water deficit during most of the year and by the large water losses due to runoff recorded for the dry and very dry regions (Oliveira et al., 2009).

In the subsurface horizons (Btv) the values of V are above 50% which, according to Santos et al. (2018), characterizes them as eutrophic, that is, they have a good capacity to supply nutrients. However, it is necessary to observe that the studied soils are found in semiarid regions that present serious impediments to agricultural production due to the limitation imposed by the semiarid condition with low rainfall and high evaporation, especially in the very dry pluviometric condition.

The Ca contents at the surface horizons (A) of each soil are: 3,4; 5,07; 0,97 $cmol_c.kg^{-1}$ for dry, very dry and sub-humid rainfall conditions, respectively. This suggests the loss of this nutrient in the sub-humid condition, possibly extracted by leaching or erosion, since the profile was located on a slope. These values are well below those found by Maia et al. (2006) and Martins et al. (2010) in Luvissols of the northeastern semiarid region.

The highest levels of P were found in the deepest horizons of the three profiles studied, a trend also observed by Gonçalves et al. (2019) and Silva (2018) who studied Luvisols under similar environmental conditions. The highest content of phosphorus found in soil and plants originates from rocks and minerals and is released through the Straaten weathering process (2007). The same author also explains that, many times, this phosphorus can be indicative of the source material, due to the substantial differences observed in the concentration of P in soils on different parent materials.

The high levels of phosphorus observed in the deeper horizons, BCz and Crnz of P2 and CBvn and Cnz of P3 may be related to the occurrence of phosphates in the source material of these soils (Fernandes et al., 2010 and Luz et al., 1992). Due to its high affinity for oxygen, P is not found in rocks and minerals in its elemental form, but mainly in the form of calcium phosphates, calcium and aluminum phosphates and iron phosphates (Straaten, 2007).

In Brazil, in general, the levels of P in the soil are low. Fraga and Salcedo (2004) and Galvão and Salcedo (2009) explain that in the semi-arid region this deficiency is aggravated by long periods of water deficit that make it difficult to replace nutrients by organic matter. However, as occurred in the present study, there are soils with high levels of phosphorus from the source material, generally schist (biotite-schist) and gneiss, especially in the semiarid region. This theme is still not very clear and requires more detailed studies to understand the origin and dynamics of phosphorus in these soils.

Electrical conductivity – EC is an attribute of particular importance in soils in semiarid regions, as it refers to the concentration of soluble salts in the horizons or layers of the soil profile, in addition, it is an attribute used to distinguish soil classes in taxonomic systems. Among the studied Luvisols, those in very dry and dry conditions showed, in some part of the profile, EC values between 4 and 7 dS/m, giving these soils a saline character (Santos et al., 2018).

In semi-arid climate conditions, this character assumes great importance due to the low rainfall recorded and the high evaporations that favor the accumulation of salts in the soil (Ribeiro et al., 2009). In addition, the use of saline water for irrigation, inadequate water and soil management and the absence of drainage, combined with unfavorable climatic conditions, have resulted in an increase in the area of soils degraded by salinity and sodicity (Ribeiro, 2010; Silva et al., 2019).

CONCLUSIONS

The formation and development of Luvisols were influenced by the rainfall gradient in the semiarid region, which is very accentuated in the state of Paraíba, mainly expressed in the depth of the profiles, which followed the order: Luvisol – sub-humid condition > Luvisol – dry condition > Luvisol – very dry condition.

Precipitation indices influenced the physical properties of Luvisols, mainly reflected in the granulometry, since the soil in the sub-humid condition presented the highest proportions of clay, in the superficial horizons.

It was not possible to identify an isolated influence of the rainfall gradient on the chemical properties of Luvisols. In general, the dry condition Luvisol – Taperoá has higher levels of nutrients available to the plants in relation to the other studied Luvisols. As for natural fertility, there is the following order: Luvissol in the sub-humid condition < Luvissol in the very dry condition < Luvissol in the dry condition.

REFERENCES

AESA, **climatologia por municípios**, Available on the website http://www.aesa.pb.gov.br/aesa-website/meteorologia-chuvas/climatologia, acesso em 10/06/2015.

ARAÚJO, M. S. B.; SCHAEFER, C. E. G. R.; SAMPAIO, E. V. S. B. Frações de fósforo após extrações sucessivas com resina e incubação, em Latossolos e Luvissolos do semi-árido de Pernambuco. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 28, p. 259-268, 2004.

ARAÚJO, S. M. S. A Região Semiárida do Nordeste do Brasil; Questões Ambientais e possibilidades de Uso Sustentável dos Recursos. **Rios Eletrônica**–Revista Científica da FASETE.v. 5, 2011.

BRADY, N. C.; WEIL, R. R. **Elementos da Natureza e Propriedades dos Solos**. 3 ed. Porto Alegre: Bookman, 2013.

BRASIL. Ministério da Agricultura. **Levantamento exploratório-reconhecimento de solos do estado da Paraíba**. Rio de Janeiro: MA/CONTAP/USAID/BRASIL, 1972. 670p. (Boletim Técnico v. 15; Série Pedologia v.14).

CORRÊA, M. M.; KER, J. C.; MENDONÇA, E. S.; RUIZ, H. A.; BASTOS, R. S. Atributos físicos, químicos e mineralógicos de solos da região das várzeas de Sousa (PB). **Revista Brasileira de Ciência do Solo**, 27: 311-324, 2003.

FRAGA, V.S.; SALCEDO, I.H. Declines of organic nutrient pools in tropical semi-arid soils under subsistence farming. **Soil Sci. Soc. Am. J**. 68:215-224, 2004.

GALVÃO, S. R. S.; SALCEDO, I. H. Soil phosphorus fractions in sandy soils amended with cattle manure for long periods. **Revista Brasileira de Ciência do Solo**. v.33, p.613-622, 2009.

GALVÃO, S. R. S.; SALCEDO, I. H.; OLIVEIRA, F. F. Acumulação de nutrientes em solos arenosos adubados com esterco bovino. **Pesquisa Agropecuária Brasileira**, v.43, n.1, p.99-105, 2008.

GONÇALVES, M. G. M.; KER, J. C.; OLIVEIRA, F. S. de; RAMOS, L. O. S.; PACHECO, A. A.; CURI, N. Lateral loss of clay in the genesis of Luvisols in the Semi-Arid Depression of the Jequtinhonha Valley, Minas Gerais – Brasil. **Ciência e Agrotecnologia**, Lavras, MG, v.43:e0182219, 2019.

LUZ, L. R. Q. P. da; SANTOS, M. C. D.; MERMUT A. R. Pedogênese em um topossequência do semiárido de Pernambuco. **Revista Brasileira de Ciência do Solo**, Viçosa, MG v. 16, p. 95-102, 1992.

JACOMINE, P. K. T. Solos sob caatingas – Características e usos agrícola. In: ALVARES, V. H.; FONTES, L. E. F.; FONTES, M. P. F. (Ed.) **O Solo nos grandes domínios morfoclimáticos do Brasil e o desenvolvimento sustentado**. Viçosa: SBCS/UFV/DPS, 1996. p. 95-155.

KÖPPEN, W.; GEIGER, R. Klimate der Erde. Gotha: Verlag Justus Perthes. 1928.
MAIA, S. M. F.; XAVIER, F. A. da S.; OLIVEIRA, T. S. de; MENDONÇA, E. de S.; ARAÚJO FILHO, J. A. Impactos de Sistemas Agroflorestais e Convencional sobre a qualidade do solo no semiárido cearense. **Revista Árvore**, v. 30, n. 5, p. 837-848, 2006.

MARQUES, F. A.; NASCIMENTO, A. F.; ARAUJO FILHO, J. C.; SILVA, A. B. **Solos do Nordeste**. Embrapa Solos-Folderes/Folhetos/Cartilhas (INFOTECA-E), 2014.

MARTINS, C. M.; GALINDO, I. C. de L.; SOUZA, E. R. de & POROCA, H. A. Atributos químicos e microbianos do solo de áreas em processo de desertificação no semiárido de Pernambuco. **Revista Brasileira Ciência do Solo**, v. 34, p.1883-1890, 2010.

MEDEIROS, B. V. V.; MEDEIROS, L. C.; SOBRINHO, F. E.; GURGEL, M. T. Caracterização física e química de solos sob pecuária bovina no Semi-Árido do Seridó– RN. **Agropecuária Científica no Semiárido**, v. 9, n. 4, p. 08-16, 2013.

MENEZES, R. C. S.; GARRIDO, M. da S.; PEREZ M., A. M. Fertilidade dos solos no semiárido. In: **CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO**, 30., 2005. Recife. Palestras... Recife: UFRPE/SBCS, 2005. 1 CD-ROM.

MENEZES, R. S. C.; SAMPAIO, E. V. S. B.; SALCEDO, I. H. **Fertilidade do Solo e Produção de Biomassa no Semiárido**. Recife: Editora Universitária, 2008. 291p.

MEURER, E. J. **Fundamentos de química do solo**. Porto Alegre, Evangraf. 5ª ed. p. 274, 2012.

NOVAIS, R. F.; KAMPRATH, E. J. Phsophorus supplyin capacities of previously heavily fertilized soils. **Soil Sci. Soc. Am. J.**, 42:931-935, 1978.

OLIVEIRA, L. B. de; FONTES, M. P. F.; RIBEIRO, M. R.; KER, J. C. Morfologia e Classificação de Luvissolos e Planossolos Desenvolvidos de Rochas Metamórficas no Semiárido do Nordeste Brasileiro. **Revista Brasileira de Ciência do Solo**, v. 33, p.1333-1345, 2009.

OLIVEIRA, L. B. de; FONTES, M. P. F.; RIBEIRO, M. R.; KER, J. C. Micromorfologia e Gênese de Luvissolos e Planossolos desenvolvidos de rochas metamórficas no Semiárido Brasileiro. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 32, p. 2407-2423, 2008.

OLIVEIRA, T. S. de; ASSIS JÚNIOR, R. N.; ROMERO, R. E.; SILVA, J. R. C. **Agricultura, Sustentabilidade e o Semiárido**. Fortaleza: UFC, 2000. 406 p.

PRADO, H. do. **Solos do Brasil: gênese, morfologia, classificação, levantamento e manejo**. 4. ed. rev. e ampl. Piracicaba, SP: Hélio do Prado, 2005. 281 p.

RIBEIRO, M. R. Origem e classificação dos solos afetados por sais. In: GHEYI, H. R.; DIAS, N. S.; LACERDA, C. F. (Eds.). **Manejo da Salinidade na Agricultura: Estudos Básicos e Aplicados**. Fortaleza: INCTSal, 2010. p.11-19.

RIBEIRO, M. R.; BARROS, M. de F. C.; FREIRE, M. B. G. dos S. Química dos Solos Salinos e Sódicos. In.: MELO, V. de F.; ALLEONI, L. R. F. (Eds.). **Química e Mineralogia do Solo: Parte II – Aplicações**. Viçosa, MG: SBCS, 2009. p. 449-484.

RIBEIRO, M. R.; OLIVEIRA, L. B.; ARAÚJO FILHO, J. C. Caracterização morfológica do solo. In: KER, J. C.; SCHAEFER, C. E. G. R.; VIDAL-TORRADO, P., (Ed.). **Pedologia: fundamentos**. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, 2012. cap. 3, p. 47-80.

SANTOS, H. G.; JACOMINE, P. K. T.; ANJOS, L. H. C. dos; OLIVEIRA, V. A. de; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A.; ARAÚJO FILHO, J. C. de; OLIVEIRA, J. B. de; CUNHA, T. J. F. **Sistema Brasileiro de Classificação de Solos**. 5. ed. rev. e ampl. Brasília, DF: Embrapa, 2018. 356p.

SANTOS, J. C. B. dos; SOUZA JÚNIOR, V. S. de; CORRÊA, M. M.; RIBEIRO, M. R.; ALMEIDA, M. da C. de; BORGES, L. E. P. Caracterização de Neossolos Regolíticos da Região Semiárida do Estado de Pernambuco. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 36, p. 683-695, 2012.

SANTOS, R. D. SANTOS, H. G. dos. KER, J. C.; ANJOS, L. H. C. dos; SHIMIZU, S. H. **Manual de Descrição e Coleta de Solo no Campo**. 7.ed. Viçosa, MG: Sociedade Brasileira de Ciência de Solos, 2015. 101 p. il.

SARAIVA, S. M. **Caracterização de Luvissolos, Neossolos Regolíticos e Planossolos ao longo de um gradiente pluviométrico no Semiárido brasileiro** 2016. 146 f. Tese (Doutorado em Ciência do Solo). Universidade Federal da Paraíba, Areia, PB, 2016. Available on the website: https://sig-arq.ufpb.br/arquivos/2017090057ee5156759678d0e81c9fd9/SARAIVA_2016_-_Tese_verso_Final.pdf

SILVA, W. T. de M.; ALVES, F. J. B.; LEONARDO, F. de A. P.; SANTOS, R. V dos.;FARIAS JÚNIOR, J. A. de Levantamento da textura do solo e da relação Silt/clay em regiões semiáridas do Nordeste. **Agropecuária Científica no Semiárido**, Patos, PB, v.14, n.4, p. 266-272, 2019.

SOUZA, R. V. C. C.; RIBEIRO, M. R.; SOUZA JÚNIOR, V. S. de; CORRÊA, M. M.; ALMEIDA, M. da C.; CAMPOS, M. C.; RIBEIRO FILHO, M. R.; SCHULZE, S. M.B.B. Caracterização de Solos de uma Topoclimossequência no maciço de Triunfo – Sertão de Pernambuco. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 34, p. 1259-1270, 2010.

TEIXEIRA, P. C.; DONAGEMMA, G. K.; FONTANA, A.; TEIXEIRA, W. G.. EMBRAPA - EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Manual de Métodos de Análise de Solo**. 3. ed. Brasília – DF : Embrapa Solos, p. 1 – 573, 2017.

TOLEDO, C. M.; OLIVEIRA, M. B. de; MELFI, A. J. Intemperismo e Formação do Solo. In.: TEIXEIRA, W.; TOLEDO, M. C. M.; FAIRCHILD, T. R.; TAIOLI, F. **Decifrando a Terra**. São Paulo: Oficina de Textos, 2001. P. 139-167.

YEOMANS, J.C.; BREMNER, J.M. A rapid and precise method for routine determination of organic carbon in soil. **Communications in Soil Science and Plant Analysis**, v.19, p.1467-1476, 1988.