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ASSOCIATIONS BETWEEN ATTRIBUTES OF NITISOLS AND THE CLIMATE OF THE SOUTHERN COAST OF PERNAMBUCO[1]

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ABSTRACT – Nitisols are livelihood sources of agricultural and socio-economic development in several underdeveloped countries worldwide, including Brazil. Brazilian Nitisols are usually associated with basaltic rocks found in the Southern and Southeastern regions of the country. However, Nitisols derived from basalt also occur on the southern coast of Pernambuco state, a region under full urban, agricultural, and industrial development. Aiming to understand the relationship between climate and attributes of Nitisols from the southern coast of Pernambuco, we performed morphological descriptions, physical and chemical analyzes, iron selective extraction, and soil mineralogy (sand, silt, and clay) for three basaltic soil profiles along a land slope. The results suggest a strong weathering of the profiles due to climate conditions, besides a great loss of basic cations and xanthization process, resulting in the natural genesis of acric Nitisols with yellowish coloration, which has not been yet cataloged for this soil order in the Brazilian taxonomic system. In addition, there is a variation for physical attributes of Nitisols along the slope.

Keywords: Tropical soils. Soil-environment relationship. Xanthization process.

ASSOCIAÇÕES ENTRE OS ATRIBUTOS DE NITOSSOLOS E O CLIMA DA COSTA SUL DE PERNAMBUCO

RESUMO – Os Nitossolos dão suporte ao desenvolvimento agrícola e socioeconômico de muitos países subdesenvolvidos do mundo, incluindo o Brasil. Os Nitossolos brasileiros estão geralmente associados às rochas basálticas das regiões Sul e Sudeste. Entretanto, Nitossolos derivado de basalto também ocorrem na costa sul de Pernambuco, uma região em pleno desenvolvimento urbano, agrícola e industrial. Objetivando compreender as relações entre o clima e os atributos dos Nitossolos da costa sul de Pernambuco, foram realizadas descrições morfológicas, análises físicas e químicas, extrações seletivas de ferro e a determinação da mineralogia das frações areia, silte e argila de três perfis derivados de basalto ao longo de uma vertente. Os resultados demonstram que o clima da região implica em forte intemperização dos perfis, em grande perda de bases e favorece o processo de xantização, resultando na singular gênese de Nitossolos com matizes amarelados e caráter ácrico, fato que até o momento ainda não foi catalogado para esta ordem no sistema taxonômico brasileiro. Os resultados também demonstram a variação dos atributos físicos dos Nitossolos ao longo da vertente.

Palavras-chave: Solos tropicais. Relação solo-ambiente. Processo de xantização.

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INTRODUCTION

Soils under tropical climates provide support to much of the agricultural production of underdeveloped countries, supplying the worldwide rising demand for food (LEPSCH, 2011). Nitisols take part in this global scenario because they cover large areas in developing regions of the African continent, Southwestern Asia, Australia, and South America (FAO, 2006).

Nitisols described in Kenya (QURESHI; NJIHIA, 1984) and in Australia (CSIRO, 1989) show a positive charge balance and an acric character. An acric character evidences an advanced soil weathering, indicating high loss of exchangeable bases and increase of positive charges from the formation of Fe and Al oxides and hydroxides in the clay fraction (LEPSCH, 2011). Notwithstanding, the Brazilian System of Soil Classification (SiBCS) admits the acric character only for Latossolos (Ferralsols) (FAO, 2006; SANTOS et al., 2013).

In Brazil, Nitisols are associated with basaltic rocks from Paraná basin (CANER et al., 2014). Altered basaltic rocks, which are rich in ferromagnesian minerals, generally give rise to Red Nitisols with a negative net charge and absence of acric character (COOPER; VIDAL-TORRADO, 2005). These types of soils are usually found in the Southern and Southeastern regions of the country, under a hot weather with dry winters. Sugarcane industry is the sector that most uses these soils, followed by citrus, coffee, and other agricultural commodities of importance to the global market (LEPSCH, 2011).

In the northeast of Brazil, in the Southern coast of Pernambuco state, Nitisol formation is associated with basaltic rocks from the volcano-sedimentary basin of Cabo, under hot and constantly humid climate. Despite the high iron input from basalt weathering, some of these Nitisols show a yellowish hue, due to, among other factors, a better soil moisture maintenance (OLIVEIRA; FERREIRA; MARQUES, 2004). Soil water regime is also associated with the yellowish coloration of Nitisols with high levels of Fe, as described in Kenya (QURESHI; NJIHIA, 1984) and in Australia (CSIRO, 1989).

The study region presents a major urban, agricultural, and industrial development owning to the sugarcane agro-industry growth and the port complex of Suape (NASCIMENTO et al., 2008). Among the few pedological studies developed in Cabo volcano-sedimentary basin, the one of Oliveira, Ferreira and Marques (2004) should be highlighted. In view of the above, further research on the soil-environment relationship are necessary for this region. Therefore, this study aimed to understand the relationship between attributes of three soil profiles of basalt-derived Nitisols, distributed along a slope, with the characteristic climate of the southern coast of Pernambuco state (Brazil).

MATERIAL AND METHODS

The study area is located on the southern coast of Pernambuco state in northeastern Brazil (Figure 1). The area is located within a region that geologically comprises the basaltic rocks of the volcano-sedimentary basin of Cabo (NASCIMENTO et al., 2008). A megathermal tropical climate (As') prevails in the region (KÖPPEN, 1931), with maximum temperatures close to 31 ºC and average annual rainfall of 2050 mm (DA SILVA; QUELUZ; KLAR, 2013).

Three profiles were selected in a basalt slope, being described and sampled following Santos et al. (2015), and classified according to the SiBCS and WRB (FAO, 2006; SANTOS et al., 2013). Profile 1 (P1), 2 (P2), and 3 (P3) are respectively located in the upper (08º32'32.9" S and 35º04'45.3" W), middle (08º32'32.9" S and 35º04'47.7" W) and lower (08º32'33.0" S and 35º04'49.0" W) thirds of the slopes, at altitudes of 51, 32, and 27 meters, respectively. The area has been grown with sugarcane, being surrounded by sub-evergreen native forest remnants. The local relief is wavy within the domain of "seas of hills" (NASCIMENTO et al., 2008).

Physical and chemical analyzes were performed from fine earth fraction samples according to Donagema et al. (2011), including: (1) grain size, (2) particle density, (3) soil density, (4) total organic carbon (TOC), (5) pH in water and in 1 mol L^{-1} KCl (1: 2.5 ratio), and (6) exchangeable Ca^{+2}, Mg^{+2}, Al^{+3}, Na^{+}, and K^{+}. From these analysis data, we could estimate the degree of flocculation (DF), DpH, sum of bases (S), cation exchange capacity (CEC), and aluminum saturation (m).

Iron contents extracted by ammonium oxalate (Fe_o), by sodium dithionite-citrate-bicarbonate (Fe_d), and by H_2SO_4 via sulfuric attack (Fe_t) were determined. Afterwards, we calculated the ratios Fe_o/ Fe_d and Fe_d/Fe_t (CORNELL; SCHWERTMANN, 2003). From the SiO_2, Al_2O_3, and Fe_2O_3 contents, obtained by sulfuric attack, Ki and Kr values were calculated. All elements were determined by means of atomic absorption spectrometry.

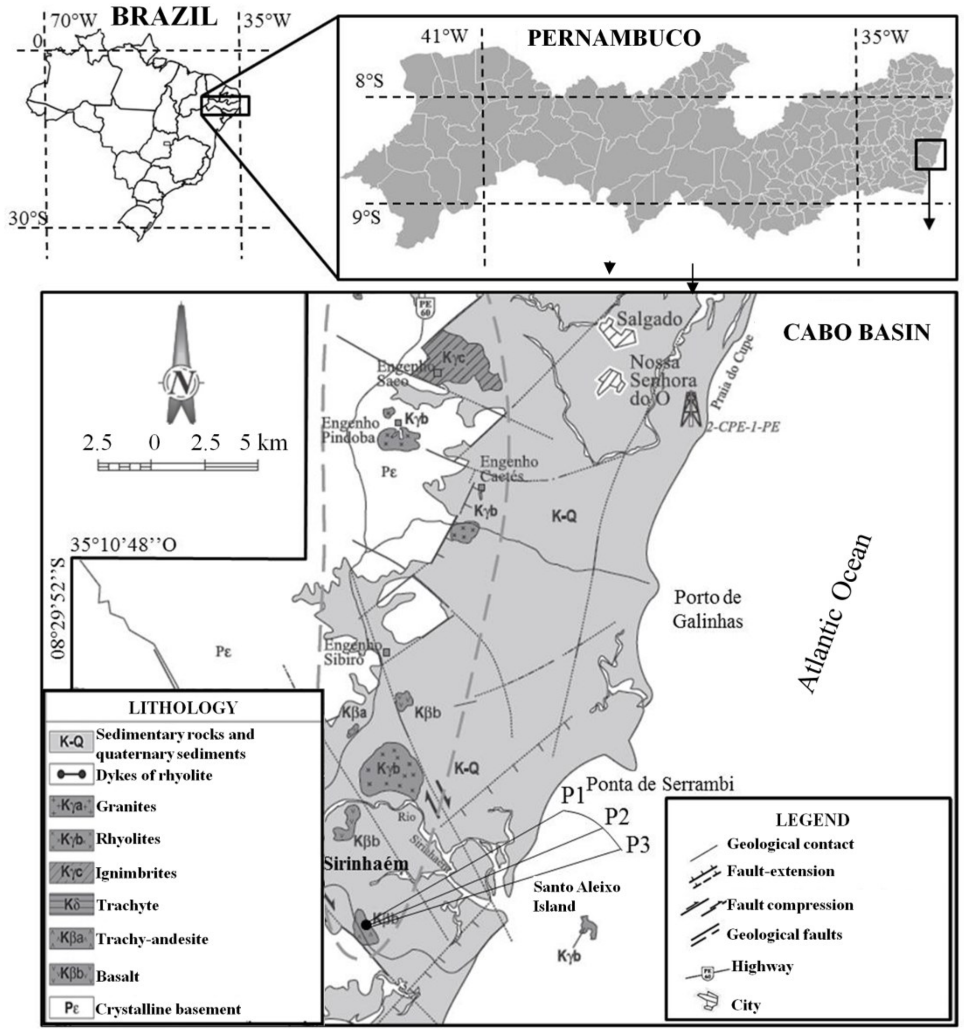

Figure 1. Location of the profiles in the volcano-sedimentary basin of Cabo. Modified from Lima Filho (1998).

Crystalline iron oxides were concentrated and determined in the clay fraction (SINGH; GILKES, 1991). The Gt/ Gt+Hm ratio was determined from oxide-concentrated samples. For clay minerals, the obtained clay fraction was treated to remove organic matter and oxides. Saturation treatments were applied with $MgCl_2$ and KCl solutions, with readings at room temperature and after heating at 550 ºC. For that, oriented aggregate and non-oriented powder samples were prepared on glass slides.

Clay and silt fractions were analyzed by X-ray diffraction (Shimadzu XRD-6000). For oriented-aggregate samples, the scanning range was from 2 to 35º 2ϴ, at a speed of 0.5º 2ϴ min^{-1}. While for non-oriented powder samples, the range varied between 3 and 70º 2ϴ, at 1º 2ϴ min^{-1}. For both, a current of 20 mA was used, as well as a graphite monochromatized CuKα radiation at 40 kV.

Database and criteria of Brown and Brinddley (1980) and Moore and Reynolds (1989) were used for interpreting the diffractograms. The dominance of oxides was inferred by the relationship between the reflection intensities of the planes goethite (110) and hematite (102).

Differential thermal and thermogravimetry analyses (DTA–TG) were performed simultaneously within a temperature range of 35 to 1,100 °C, with a heating rate of 10 °C min-1, under N_2 atmosphere. Data were computed using Proteus software v 5.1 (Netzsch). Gibbsite and kaolinite amounts were determined according to Karathanasis (2008).

RESULTS AND DISCUSSION

The climate in Pernambuco's south coast promoted the formation of well-structured and pedogenetically-developed soils with yellowish hues, being the three profiles classified as Nitossolos Háplicos Acriférricos típicos (SANTOS et al., 2013) or Nitisols (FAO, 2006) with very clayey texture, under a sub-evergreen tropical forest stage, on a gently wavy relief (Figure 2).

Figure 2. Image of the three profiles described in the south coast of Pernambuco.

The soil position within the slope had no strong influence on its morphological attributes. Such uniformity can be attributed to a wide susceptibility of basalt saprolite to constantly hot and humid climates, as in the region, resulting in a uniform development regardless of the land position.

The high degree of weathering of the soil profiles led to clayey textures and structuring degree from moderate to strong in the surface horizons. Bt horizons have highly clayey textures and moderate cerosity, evidencing an increasing clay fraction in the subsurface (Table 1).

Table 1. Morphological attributes of the three profiles.

Horizon	Depth (m)	Texture	Color	Cerosity	Structure		
					Grade	Size	Shape
				P1 (Upper third)			
Ap	0 – 0.2	Clay	7.5YR 3/3	Absent	Mod	Sm; Med	Gr e Bl Sub
BA	0.2 – 0.5	Vr clayey	7.5YR 4/4	Mod; Abun	Mod	Vr Sm; Sm	Bl Sub; Ang
Bt1	0.5 – 0.9	Vr clayey	7.5YR 4/4	Mod; Abun	Mod	Vr Sm; Sm	Bl Sub; Ang
Bt2	0.9 – 1.6	Vr clayey	7.5YR 4/6	Mod; Abun	Mod	Sm; Med	Bl Sub; Ang
Bt3	1.6 – 2.0+	Vr clayey	7.5YR 4/6	Mod; Abun	Mod	Sm; Med	Bl Sub; Ang
				P2 (Middle third)			
Ap	0 – 0.2	Clay	10YR 3/4	Absent	Mod	Vr Sm; Sm	Gr; Bl Sub
BA	0.2 – 0.5	Vr clayey	10YR 4/4	Mod; Abun	Mod	Vr Sm; Sm	Bl Sub; Ang
Bt1	0.5 – 1.0	Vr clayey	10YR 4/4	Mod; Abun	Mod	Vr Sm; Sm	Bl Sub; Ang
Bt2	1.0 – 1.7	Vr clayey	10YR 4/4	Mod; Com	Mod	Vr Sm; Sm	Bl Sub
Bt3	1.7 – 2.0+	Vr clayey	10YR 4/4	Mod; Com	Mod	Vr Sm; Sm	Bl Sub
				P3 (Lower third)			
Ap	0 – 0.1	Clay	10YR 3/3	Absent	Mod	Vr Sm; Sm	Gr
AB	0.1 –0.2	Vr clayey	10YR 4/4	Mod; Abun	Mod	Sm; Med	Bl Sub
BA	0.2 – 0.4	Vr clayey	10YR 4/4	Mod; Abun	Mod	Sm; Med	Bl Sub; Ang
Bt1	0.4 – 0.9	Vr clayey	10YR 4/4	Mod; Abun	Mod	Sm; Med	Bl Sub
Bt2	0.9 – 1.5	Vr clayey	10YR 4/4	Mod; Abun	Mod	Sm; Med	Bl Sub
Bt3	1.5 – 2.0^{+}	Vr clayey	10YR 4/4	Mod; Com	Mod	Sm; Med	Bl Sub

Mod = moderate; Abun = abundant; Com = common; Sl = small; Med = medium; Gr = granular; Bl = blocky; Sub = subangular; Ang = angular.

The original basalt mineralogy, rich in ferromagnesian minerals (CAMPOS et al., 2012), raised particle density values (Table 2); however, soil density was lower than 1.4 g cm^{-3} (Table 2). It can be associated with some factor such as sand-fraction low content, clay-content prevalence (Table 2), secondary mineralogy, and high the microporosity of these soils (CANER et al., 2014). The soil density values found here are lower than are those reported by Oliveira, Ferreira and Marques (2004) for soils in this region. These smaller values should be associated with a minor contribution of tertiary sandy quartz sediments and eolic sediments in the Nitisols studied here.

Table 2. Physical and chemical attributes of the three profiles.

Hor	Granulometry			DF	Density		pH		ΔpH	S	Al^{3+}	CEC	m	TOC
	Sand	Silt	Clay		Soil	particle	H_2O	KCl						
	(g kg^{-1})			%	(g cm^{-3})					(cmol$_c$ kg^{-1})			%	g kg^{-1}
							P1 (Upper third)							
Ap	305	198	497	18	1.40	2.82	5.6	5.0	-0.6	0.6	0.05	6.2	8	12.5
BA	168	210	622	79	1.17	2.86	5.6	5.5	-0.1	0.2	0.05	3.9	20	9.7
Bt1	199	175	626	79	1.22	2.85	5.4	5.5	0.1	0.2	0.05	3.9	20	7.0
Bt2	186	139	675	81	1.21	2.81	5.3	5.4	0.1	0.2	0.05	3.5	23	5.8
Bt3	139	212	649	81	1.18	2.91	5.3	5.3	0.0	0.2	0.05	4.1	23	4.5
							P2 (Middle third)							
Ap	177	245	578	31	1.12	2.93	4.8	4.3	-0.5	0.4	0.3	9.2	41	21.5
BA	116	280	604	79	1.13	2.95	5.2	5.2	0.0	0.2	0.1	4.4	35	9.9
Bt1	129	223	648	81	1.07	2.93	5.2	5.4	0.2	0.2	0.05	3.5	24	7.1
Bt2	129	231	640	81	1.13	2.95	5.3	5.6	0.3	0.2	0.05	3.6	20	6.3
Bt3	310	62	628	81	1.12	2.87	4.9	5.0	0.1	0.1	0.1	4.0	63	6.2
							P3 (Lower third)							
Ap	119	303	578	39	1.05	2.74	5.7	5.1	-0.6	1.1	0.15	8.6	12	30.3
AB	106	261	633	79	1.17	2.81	5.0	4.6	-0.4	0.5	0.15	7.9	24	22.7
BA	78	304	618	79	1.16	2.80	5.5	5.4	-0.1	0.4	0.05	5.7	11	11.6
Bt1	78	273	649	81	1.03	2.86	5.2	5.3	0.1	0.3	0.05	5.2	13	8.8
Bt2	83	270	647	81	1.07	2.95	5.3	5.3	0.0	0.3	0.05	6.0	14	6.5
Bt3	82	271	647	81	1.16	2.93	5.0	4.6	-0.4	0.1	0.35	6.7	81	5.6

Hor = horizon; DF = degree of flocculation; S = sum of bases; CEC = cation exchange capacity; m = Al saturation; TOC = total organic carbon.

The local wet climate and soil good drainage implied a great loss of exchangeable bases, being the base lower than 0.6 cmolc kg-1 in all profiles (Table 2). CEC was also low, blow 27 cmol$_c$ kg^{-1} clay, and TOC decreased with soil depth (Table 2). Likewise, Sobrinho, Almeida and Erhart (2009) observed low values of base sum and CEC in soils derived from basalt in the highlands of Eastern Santa Catarina state. There was a wide variation of Al saturation, from 8 to 81 %; however, exchangeable aluminum rates were low, varying from 0.05 to 0.35 cmol$_c$ kg^{-1} (Table 2).

Regarding pH in water, the studied Nitisols revealed moderately acidic reactions, ranging from 4.8 to 5.7 in surface horizons, and between 5.2 and 5.4 in Bt1 (Table 2). These findings are consistent with the kaolinite mineralogy of these soils, in which H^+ is the main acidity component, being dissociated from silanol and aluminol groups (WEBER et al., 2005).

As for pH in KCl, values were superior to 5.0, making the ΔpH become positive in the diagnostic horizons (Table 2), giving rise to a positive charge balance to the soil. Furthermore, the sum of exchangeable bases plus KCl-extractable aluminum was less than 1.5 cmol$_c$ kg^{-1}. These chemical characteristics constitute the acric character (SANTOS et al., 2013).

Although the acric character has already been described in Nitisols of Kenya (QURESHI; NJIHIA, 1984) and Australia (CSIRO, 1989). The SiBCS have not reported it yet (SANTOS et al., 2013).

Hence, our findings led us to suggest future studies for classification purposes in the region, mainly targeting at including the acric trait in Nitisols (Nitossolos) by the SiBCS.

Regular rainfalls throughout the entire year feature the climate encompassing the studied Nitisols. A constant rainfall on the southern coast of Pernambuco, associated with a good drainage, tend to raise the weathering rate of these Nitisols when compared to those described in the South and Southeast of Brazil (DA SILVA; QUELUZ; KLAR, 2013).

The high loss of exchangeable bases (Table 2) and the positive charge balance from the large amounts of Fe and Al oxides and hydroxides in the clay fraction, e.g. hematite, goethite, and gibbsite (Table 3), are described as chemical conditions necessary for acric character expression in soils (LEPSCH, 2011).

Table 3. Mineralogy of the sand, silt and clay fractions of the three profiles obtained by XRD.

Profile	Sand	Silt	Clay (1)	Clay (2)	Clay (3)
P1 (Upper third)	Qz, Fd	Qz,Fd, Mt, Kt, Gb, Gt	Kt, Gb, Gt, Hm	Kt	Gt, Hm
P2 (Middle third)	Qz, Fd	Qz, Fd, Mt, Kt, Gb, Gt	Kt, Gb, Gt, Hm	Kt	Gt, Hm
P3 (Lower third)	Qz, Fd	Qz, Fd, Mt, Kt, Gb, Gt	Kt, Gb, Gt, Hm	Kt	Gt, Hm

(1)= non-oriented clay; (2)= oriented clay aggregates; (3) = oxide concentrate; Qz = quartz; Fd = feldspar; Mt = magnetite; Kt = kaolinite; Gb = gibbsite; Gt; goethite; Hm = Hematite.

Even though favorable conditions also occur in Nitisols from Paraná River basin (CANER et al., 2014); the peculiar climate of the southern coast of Pernambuco should make them more prominent, enhancing an acrid character in the volcano-sedimentary basin of Cabo. The positive ΔpH in these soils could be attributed to gibbsite and crystalline iron oxides (DONAGEMMA et al., 2008). Goethite has a high PZC that exerts a strong influence on clay-fraction electrochemistry in some acric soils (CSIRO, 1989).

Soil structure and physical attributes of the three profiles had a potential impact on water dynamics through the surroundings. These environmentally interesting attributes make these soils resemble the Nitisols described in the Paraná River basin (COOPER; VIDAL-TORRADO, 2005), in Africa (QURESHI; NJIHIA, 1984), and those in Australia (CSIRO, 1989).

On the other hand, the studied Nitisols showed chemical and mineralogical attributes that are limiting to farming activities, mainly low CEC, and phosphorus fixation by iron oxides (Table 3). From an environmental point of view, the high point of zero charge (PZC) of iron oxides may contribute to sorption of heavy metals, which come from nearby agro-industry activities (CORNELL; SCHWERTMANN, 2003).

Local climate influence on the studied Nitisols can also be observed through their more yellowish hues (Table 1), which differ from the reddish hues of Nitisols from tropical climates with dry winter, as is the case of those developed from basaltic rocks in the Paraná River basin (GHINDIN et al., 2006). Even with hematite (Table 3) likely derived from drier paleoclimates, the yellow hues of the studied Nitisols are associated with goethite (Table 3), what reflects the current-climate influence, which is constantly moist, on conversion of hematite into goethite, the so-called xanthization. (OLIVEIRA; FERREIRA; MARQUES, 2004). The goethite dominance would be the result of hematite low stability under the current climatic condition of steady moisture (CORNELL; SCHWERTMANN, 2003).

Despite the morphological uniformity, soil profile position within the slope seems to alter silt and sand contents (Figure 3). Silt contents were higher in Ap horizons, which are at lower quotes (Figure 3A). This outcome was not observed in subsurface layers (Figure 3B), which shows a possible accumulation gradient along the transect, because of surface runoff of material from the ridge to the foothill.

A mineral absent in basalt rocks, quartz was present in the sand and silt fractions of the studied profiles (Table 3). It shows the contribution with sandy sedimentary materials from tertiary and with eolic sediments to the source material of the three soils (OLIVEIRA; FERREIRA; MARQUES, 2004). The decreasing contents of a sand fraction, in the surface (Figure 3A) and subsurface (Figure 3B) horizons, from the ridge to foothills might be related to a large contribution of Barreira's group with sedimentary material to the soil formation at the top of hills.

Unlike sand and silt, clay-fraction homogeneity among the three sections (Figure 3A and B) is connected to the low propensity of kaolinite-oxide clays to lateral flows over the slope (COOPER; VIDAL-TORRADO, 2005).

One of the most important processes associated with weathering in these Nitisols has to do with the local climate effect on the partial loss of silica and its consequent secondary formation of kaolinite and iron oxides (Table 4).

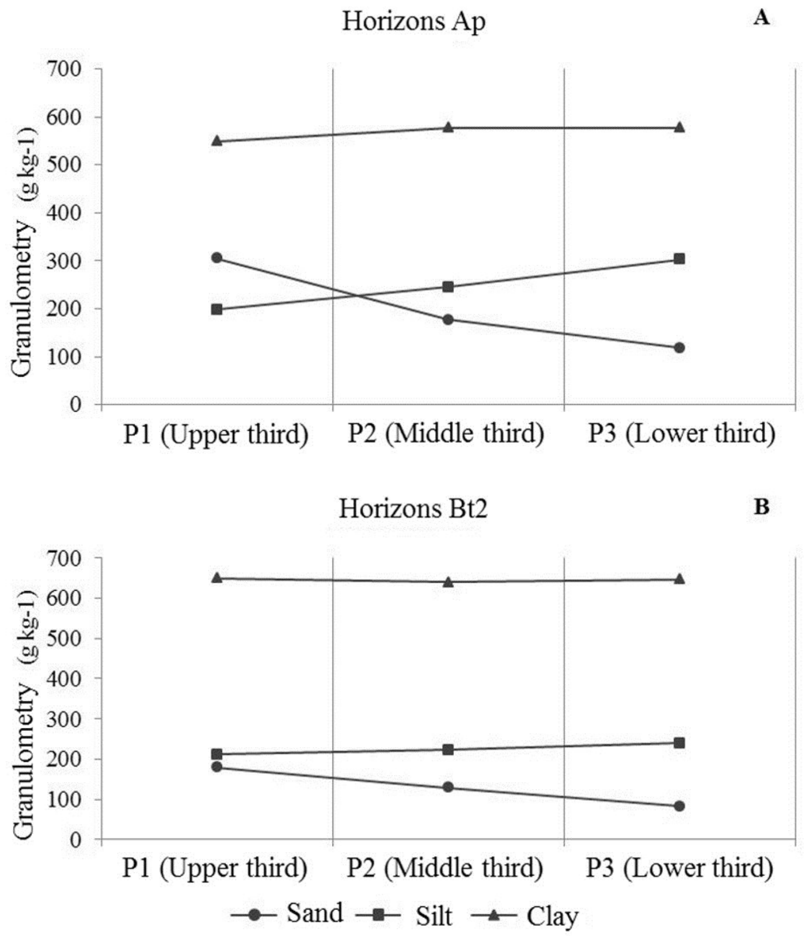

Figure 3. Variation of the sand, silt and clay fractions in the surface and subsurface horizons of the three profiles from the upper third to the lower third of the slope. (A) Granulometric variation in horizons Ap. (B) Granulometric variation in Bt2 horizons.

Table 4. Fe-total (Fe_t), Fe extracted by DCB (Fe_d) and OAA (Fe_o), Fe_o/Fe_d, Fe_d/Fe_t ratios, Gt/Gt+Hm ratio and molecular relationships Ki and Kr in horizons of the three profiles.

Hor	Fe_d	Fe_o	Fe_t	Fe_o/Fe_d	Fe_d/Fe_t	(Gt/Gt+Hm) (1)	Ct (2)	Gb (2)	molecular relationships	
	g kg^{-1}						%		Ki	Kr
					P1 (Upper third)					
Ap	127.60	2.35	170.13	0.02	0.75	0.62	88	3	1.3	0.8
Bt1	196.60	1.50	211.40	0.01	0.93	0.81	83	Nd	1.9	1.1
Bt3	182.82	1.09	192.44	0.01	0.95	0.76	76	6	1.7	1.1
					P2 (Middle third)					
Ap	174.42	2.73	195.98	0.02	0.89	0.82	82	8	1.5	0.9
Bt1	203.18	1.67	207.33	0.01	0.98	0.81	82	Nd	1.6	1.0
Bt3	190.25	1.33	206.79	0.01	0.92	0.62	81	2	1.5	0.9
					P3 (Lower third)					
Ap	169.35	2.34	206.52	0.01	0.82	0.77	87	Nd	1.8	1.0
Bt1	186.19	1.3	211.58	0.01	0.88	0.79	85	Nd	1.8	1.1
Bt3	172.87	1.36	254.22	0.01	0.68	0.80	84	Nd	1.6	0.9

Hor = horizon.

The dissolution of basalt ferromagnesian minerals under the current tropical humid climate contributed to an accumulation of oxides and iron oxyhydroxide in the assessed Nitisols (COOPER; VIDAL-TORRADO, 2005). In the studied soils, goethite stands out by quantity, being evidenced in the Gt/ Gt+Hm ratio that varied from 0.62 to 0.81 (Table 4). Moreover, the contents of iron oxides and oxyhydroxide comply with the amount of iron extracted by DCB, reaching a value of 200 g kg^{-1} in the diagnostic horizons (Table 4).

Under good drainage conditions, local climate promotes partial hydrolysis of primary silicates, controlling the formation and stabilization of variable charge minerals (COSTA, 2012). This fact can be evidenced by the Ki and Kr indexes, 1.7 and 1.0, taking into account all the horizons of all the three profiles (Table 4). These values differentiate the current studied Nitisols from those studied in the geomorphological province of the *Cuestas Basálticas*, in the State of São Paulo (Brazil) (MEIRELES et al., 2012).

DTA–TG mineralogical analyses showed an unchanged kaolinite content regardless profile position (Table 4). Kaolinite formation is favored by the hot and humid local weather and by the source material rich in feldspar (NASCIMENTO et al., 2008), the main precursor for kaolinite (WEBER et al., 2005). The kaolinite contents found through DTA were similar to those described in soils derived from basalt in Southern and Southeastern Brazil (COOPER; VIDAL-TORRADO, 2005; GHINDIN et al., 2006).

The ratio Fe_o/Fe_d reached values of 0.01, confirming the dominance of iron crystalline phases (Table 4). The Fe_o averages of 1.5 g kg^{-1} reveal that Fe low crystallinity and amorphous phases, in these soils, are lower than were those described in Nitisols studied by Alcântara and Camargo (2010) in Ribeirão Preto – SP (Brazil).

Nonetheless, the haplic Nitisols studied here show a great diversity of mineralogical, physical, and geochemical attributes, raising issues regarding their agricultural and environmental potentials.

CONCLUSIONS

The climate in Pernambuco south coast provides a pedogenic environment suitable to a high loss of silica under good drainage conditions, leading to the secondary formation of kaolinite and iron oxides under monosialitization and ferralitization processes.

The current climate, hot and humid, favors the formation of hydrated oxides as the goethite to the detriment of the hematite, resulting in a xanthization process and development of Nitisols with yellowish hues.

A positive ΔpH, pH in KCl superior to 5.0, and a low Al^{+3} content contributed to the acric trait in the studied Nitisols, which has so far not been cataloged for this order at the Brazilian soil taxonomic system, and which also make them resemble the Nitisols described in Africa and Australia.

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