Revista Ciência Agronômica, v. 47, n. 4, p. 599-608, out-dez, 2016
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Artigo Científico
ISSN 1806-6690

Characterization and pedogenesis of mangrove soils from Ilhéus-BA, Brazil[1]

Caracterização e pedogênese de solos de mangue de Ilhéus- BA, Brasil

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ABSTRACT - Despite its importance, studies of mangrove soils are scarce, especially from a pedological perspective. The objective of this work was to study the genesis of soils in a mangrove environment in northeastern Brazil (Ilhéus, Bahia) through a morphological, physical, chemical and mineralogical characterization. All soils presented a sandy texture, which is related to the parent material (Quaternary sand deposits). The tidal flooding and resulting hydromorphic conditions is responsible for dominance of dark grey colors, and high organic matter contents (paludization process). As well as the high values of electrical conductivity (EC) and dominance of Na^+ in the saturation extract (salinization and solodization processes, respectively). Contrastingly, the M3 profile, with aninga *(Montrichardia linifera)* vegetation, a non-exclusive mangrove plant, showed colors with high chromas due to a lesser influence of tidal flooding. The pH values and the $SO_4^{=}/Cl^-$ ratios indicated the presence of sulfidic material and, thus, the occurrence of the sulfidization process. The soil organic matter fractionation evidenced the humin as the fraction with the highest content, probably because of removal of most soluble fractions due to tidal action. Similar to mangrove soils from southeast Brazil, the XRD analysis identified kaolinite, mica and expandable 2:1 minerals in the clay fraction.

Key words: Mangrove ecosystem. Sulfidization. Paludization. Salinization. Solodization. Soil organic fractions.

RESUMO - Apesar de sua importância, estudos sobre solos de manguezais são escassos, principalmente quanto a pedogênese. O objetivo deste trabalho foi estudar a gênese de alguns solos de manguezais da cidade de Ilhéus (nordeste brasileiro), através de sua caracterização físico-química, morfológica e mineralógica. Todos os solos apresentaram textura arenosa, o que está relacionado ao seu material de origem (depósitos arenosos Quaternários). A ação das marés condiciona o hidromorfismo e leva os solos a apresentar predomínio de coloração cinza-escura e conteúdo elevado de matéria orgânica (processo de paludização). Ainda, valores elevados de condutividade elétrica (CE) e dominância de Na^+ no extrato da pasta saturada (processos de salinização e solodização, respectivamente). Em contraste aos demais, o perfil M3, com vegetação de aninga *(Montrichardia linifera)*, uma planta não exclusiva de manguezais, mostrou cromas mais elevados devido à menor influência do efeito das marés. Os valores de pH e a relação $SO_4^{=}/Cl^-$ indicam a presença de materiais sulfídricos e consequentemente a ocorrência do processo de sulfidização. O fracionamento da matéria orgânica do solo evidenciou a humina como a fração com maiores valores, provavelmente devido ao efeito das marés, removendo as frações mais solúveis. Como em solos de manguezais do sudeste brasileiro, a difratometria de raios-X identificou caulinita, mica e minerais expansíveis 2:1 na fração argila.

Palavras-chave: Manguezal. Sulfidização. Paludização. Salinização. Solodização. Fracionamento da matéria orgânica do solo.

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DOI: 10.5935/1806-6690.20160072
[1]Recebido para publicação em 24/02/2015; aprovado em 20/12/2015
Parte da Dissertação de Mestrado do primeiro autor, pesquisa financiada pela FAPEMIG
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INTRODUCTION

Mangroves are among the most productive and biologically important ecosystems in the world. They are distributed in the inter-tidal regions between the sea and land in the tropical and subtropical regions (ALONGI, 2011), predominantly between 5º N and 5º S latitudes (GIRI *et al*., 2011).

They provide important and unique ecosystem goods and services to human society and coastal marine systems, helping to stabilize shorelines and to reduce the devastating impact of natural disasters such as tsunamis and hurricanes (GIRI *et al.*, 2011; MUKHERJEE *et al.*, 2010). Animals found within mangroves include a great variety of taxa, many of which are threatened by human activities in the coastal zones (NAGELKERKEN *et al*., 2008). More recently, mangroves, and especially the soils in this environment, have been referred to as an important drain of atmospheric CO_2, storing about 10% of the carbon in the ocean (DUARTE; MIDELLBURG; CARACO, 2005) and standing out as a key ecosystem in the global carbon sequestration (DONATO *et al*., 2011; LIU *et al*, 2014). Considering the existing relationship among mangroves and the global carbon dynamics, much of the role these ecosystems play can be comprehended thorough an understanding of their soils characteristics and pedogenesis.

Soils under mangrove vegetation, in many surveys in Brazil, were described simply as "*indiscriminate mangrove soils*" map unities (PRADA-GAMERO; VIDAL-TORRADO; FERREIRA, 2004). Due to the difficult access to the areas, the mangrove soils usually are not sampled, thus the lack of morphological descriptions and physical and chemical analyses, which led to the nondiscrimination of the soil classes in these ecosystems.

Recent studies, especially in the state of São Paulo, Brazil, classified the mangrove soils according to the Brazilian System of Soil Classification, mostly as 'Gleissolos' and 'Organossolos' (Gleysols and Histosols; i.e.) (FERREIRA *et al*., 2007a; PRADA-GAMERO; VIDAL-TORRADO; FERREIRA, 2004). However, there are very few studies of mangroves from the northeastern Brazil (ARAÚJO JÚNIOR *et al*., 2012; NÓBREGA *et al.*, 2014; NÓBREGA *et al.*, 2015), especially from a pedological perspective. Mangrove soils from NE Brazil are influenced by very different climate conditions when compared to mangrove forests from other parts of the coast. In this context, this study aimed to study the genesis of mangrove soils from northeastern Brazil (Ilhéus, Bahia), through the characterization of their morphological, physical and chemical characteristics and through the study of their organic and mineral fractions.

MATERIAL AND METHODS

Soil sampling was performed in the mangroves of Ilhéus-BA, Brazil, along the Almada River, during low tides using a sampler adapted to flooded soils Napoleão-SONDATERRA®.The profiles M1, M2 and M3 are located 9 km away from the river mouth, the first one is closest to the river shore and the last one, farthest. M4 and M5 profiles are located, respectively, 5 km and 1 km away from the mouth of the Almada River (Figure 1). The vegetation was different in each one of the sampling sites, as shown in Table 1.

The areas are located in the Sedimentary Deposits Domain, formed by Cenozoic sediments of the unity Marine and Fluviomarine Plains. It has a flat landscape, including beaches, beach ridges, mangroves, deltas and the sedimentary basin of the Almada River (ARCANJO, 1997). The presence of a sandbar prevents the direct discharge of this river to the ocean in northeastern Ilhéus, leaving the last segment of the river lower course running parallel to the shore for about 9 km, thus influencing the tidal effect on the soils.

The climate is classified as Af, hot and humid, according to Köppen's classification, with rainfall of the driest month higher than 60 mm and average temperature of the coldest month higher than 18 ºC. In Ilhéus-BA, the annual rainfall is higher than 1900 mm (ARCANJO, 1997).

Figure 1 - Location of the soil sampling sites along the Almada River, Ilhéus-BA, Brazil (Source: Google Earth)

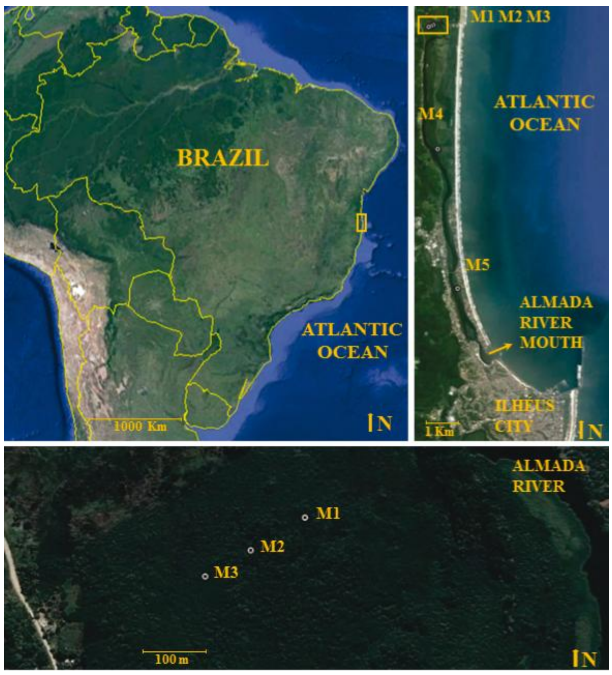


Table 1 - Location of the mangrove soil sampling sites and their predominant vegetation

Soil	Location	Predominant vegetation
M1	14°40’52” S 39°04’28” W	Siriba (*Avicennia sp*)
M2	14°40’51” S 39°04’30” W	Guaxumba (*Hibiscus sp*), Cortiça (*Pterocarpus officinalis*)
M3	14°40’50” S 39°04’27” W	Aninga (*Montrichardia linifera*)
M4	14°43’06” S 39°04’13” W	Mangue vermelho (*Rizophora mangle*), Mangue branco (*Avicennia sp*)
M5	14°45’30” S 39°03’44” W	Mangue vermelho (*Rizophora mangle*)

The soil morphological description and sampling was performed according to Santos *et al.* (2013). For physical, chemical and mineralogical analyses, the samples were air-dried and sieved through a 2-mm grid, to obtain the air-dried fine earth (ADFE), except for the saturated paste extract, which was extracted immediately after sampling according to Embrapa (2011). Physical analyses were performed according to the procedures in Embrapa (2011), and the ADFE granulometric composition was determined by the pipet method, using sodium hexametaphosphate buffered by sodium carbonate as dispersing chemical agent, after the removal of salts with alcohol (60%). Clay fraction was determined by the particles sedimentation velocity, according to the Stokes’ law. Sand contents were obtained by sieving and silt contents were calculated by the difference between the sand and clay fractions. The contents of clay dispersed in water (CDW) were determined by the same procedure, but without using a dispersing chemical agent.

Chemical analyses were performed according to the methods recommended by Embrapa (2011), and included pH in water, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Al^{3+} and H+Al. From these data, CEC at pH 7.0, sum of bases (SB), base saturation (V), aluminum saturation (m) and exchangeable sodium percentage (ESP) were calculated.

Total carbon was determined according to Yeomans and Bremner (1988). The organic matter chemical fractionation was performed using the differential solubility principle (HAYES *et al.*, 1989), adapted (BENITES; MADARI; MACHADO, 2003).

X-ray diffractometry was performed on silt and clay fractions of selected samples. For silt and clay fractions, respectively, concave glass slides (non-oriented), irradiated from 8 to 60º 2θ, and oriented glass slides, irradiated from 5 to 50º 2θ, were prepared and analyzed in an X-ray diffractometer with cobalt tubes. For clay fraction, a pretreatment with bicarbonate-citrate-dithionate was performed to remove iron oxides and also treatments with potassium at room temperature, 350 and 550 ºC; saturation with magnesium and, when necessary, magnesium+glycerol (JACKSON, 1969).

RESULTS AND DISCUSSION

Except for M3, all the studied soils presented sandy-loam or coarser textures. This can be related to the sandy nature of the parent material, since the Almada River basin is formed by marine sediments from an ancient bay filled with sand sediments (ARCANJO, 1997). Some authors emphasize the occurrence of clayey-silty or silty textures in mangrove soils (SCHAEFFER-NOVELLI *et al.*, 2000). This claim does not hold true for the studied soils in the Almada River basin (Table 2), and also for other mangroves in Brazil (FERREIRA *et al.*, 2007b; PRADA-GAMERO; VIDAL-TORRADO; FERREIRA, 2004; SOUZA JÚNIOR *et al.*, 2007) and in the world (ARRIVABENE *et al.*, 2015). After the lowering of the sea level in the last 5,000 years (SUGUIO *et al.*, 1985), these sediments remained in place, resulting in a sandy substrate. Small proportions of finer fractions are probably related to the later fluvial sedimentation. The fact that the river does not flow in its last segment as a tide channel, but flows straight and parallel to the shore due the presence of a sandbank, could also have contributed to the movement of great part of the sediments to the sea, resulting in less clayey soils in these sites.

The M3 had the highest values of silt and clay, possibly because of its location, farther from the river, in a more protected compartment, where fine particles may preferentially deposit (SOUZA JÚNIOR *et al.*, 2007). The M3 soil differs from the others, not only in texture, but also with respect to vegetation coverage, with aninga (*Montrichardia linifera*), consisting of a non-exclusive mangrove plant; (Table 1), representing a distinct environment, with little or no seawater influence, as evidenced by the low values of EC (Table 6).

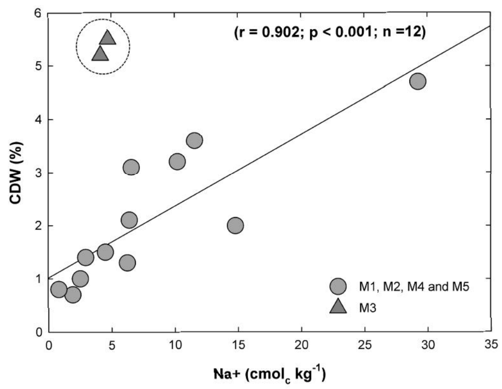
The CDW contents ranged from 0.7 to 5.5% and had a highly significant positive correlation with sodium when data of M3 was excluded (Figure 2), corroborating the transitional character of this mangrove and the low salinity influence.

All soils had a massive structure (Table 3) without aggregates and, therefore, without discernible peds.

Table 2 - Particle size distribution, clay dispersed in water (CDW), flocculation degree (FD) and silt/clay ratio of the studied mangrove soils along the Almada River, Ilhéus-BA, Brazil

Layer	Depth	Sand		Silt	Clay	CDW	FD	Silt/Clay
		Coarse	Fine					
	cm	----------	----------	g kg^{-1}	----------	----------	%	
				M1				
1st	0-10	680	180	100	40	7	84	2.5
2nd	10-20	620	160	160	60	13	79	2.7
3rd	20-30	600	210	140	50	20	62	2.7
4th	30-40	480	200	240	80	36	53	3.1
M2								
1st	0-10	650	210	80	60	8	87	1.3
2nd	10-20	630	200	80	90	10	89	0.9
3rd	20-30	540	230	180	50	31	42	3.4
M3								
1st	0-10	120	250	380	250	52	79	1.5
2nd	10-20	160	190	330	320	55	83	1.0
M4								
1st	0-10	410	450	120	20	14	38	5.5
2nd	10-20	400	430	140	30	21	26	5.1
3rd	20-30	430	450	100	20	15	18	5.8
M5								
1st	0-10	380	240	280	100	32	67	2.9
2nd	10-20	380	270	250	100	47	52	2.5

Figure 2 - Correlation between the contents of clay dispersed in water (CDW) and Na^+, excluding the soil M3



This condition results from the constant hydromorphism that prevents the development of soil aggregates. The decrease in cohesion caused by the water, the reduction in the amount of cementing agents (iron oxides) and the clay dispersion are determining factors for the absence of aggregates in these soils.

The soil color is also a response to hydromorphism. All soils presented dark grey colors, with low chromas and values (Table 3), which also reflect the influence of high organic matter contents (Table 4) on the soil color. M3 showed higher chroma colors, which is related to its physiographical position, more distant from the tidal action, and less influenced by tidal flooding. In M3, the oxidizing conditions favors the iron oxides precipitation (i.e. goethite, lepidocrocite and ferrihydrite) producing soil colors ranging from yellow to orange (KÄMPF; CURI, 2000). Mineralogy results showing the presence of goethite in the silt fraction (discussed below; Figure 3), corroborate this hypothesis.

The soil consistency did not vary, being mostly nonplastic and nonsticky, due to the high sand contents. Only M3, with higher silt and clay contents, presented some degree of stickiness and plasticity.

The pH values (Table 4) ranged from moderately acid (5.6 to 5.8) to extremely acid (< 4.3; M1, M2

Table 3 - Structure, consistency and humid and dry colors of mangrove soils studied along the Almada River, Ilhéus-BA, Brazil

Layer	Depht (cm)	Structure		Plasticity	Stickiness	Color	
		Type	Grade			Dry	Moist
M1							
1st	0-10	none	Massive	Non-plastic	Non-sticky	7,5YR 3/1	10YR 3/2
2nd	10-20	none	Massive	Non-plastic	Non-sticky	7,5YR 3/1	10YR 3/2
3rd	20-30	none	Massive	Non-plastic	Non-sticky	7,5YR 3/1	10YR 3/1
4th	30-40	none	Massive	Non-plastic	Non-sticky	G1 3/N	G1 4/N
M2							
1st	0-10	none	Massive	Non-plastic	Non-sticky	5 YR 3/1	7,5YR 4/1
2nd	10-20	none	Massive	Non-plastic	Non-sticky	7,5 YR 3/1	7,5YR 4/1
3rd	20-30	none	Massive	Slightly plastic	Non-sticky	G1 3/N	7,5YR 4/1
M3							
1st	0-10	none	Massive	Slightly plastic	Slightly Sticky	10YR 3/2	10YR 5/3
2nd	10-20	none	Massive	Slightly plastic	Slightly Sticky	10YR 3/2	10YR 5/3
M4							
1st	0-10	none	Massive	Non-plastic	Non-sticky	G1 3/N	7,5YR 4/1
2nd	10-20	none	Massive	Non-plastic	Non-sticky	G1 3/N	7,5YR 4/1
3rd	20-30	none	Massive	Non-plastic	Non-sticky	G1 3/N	7,5YR 4/1
M5							
1st	0-10	none	Massive	Slightly plastic	Non-sticky	10Y 3/1	10Y 3/1
2nd	10-20	none	Massive	Slightly plastic	Non-sticky	10Y 2,5/1	10Y 3/1

and M5). The lowest pH values may be a result of the oxidation of sulfidic materials (i.e. pyrite, FeS_2), common in mangrove soils (NÓBREGA *et al.*, 2014). In fact, values of the $SO_4^{=}/Cl^-$ measured in the saturation paste (Table 5), lower or close to 0.05 in some soils, corroborate this claim and support the occurrence of the sulfidization process (GIBLIN, 1988; OTERO *et al.*, 2009) and the formation of iron sulfides. Thus in the more acidic soil layers, the iron sulfide oxidation would produce protons, according to reactions 1 and 2.

$$FeS + H_2O + 3/2O_2 \rightarrow Fe^{2+} + SO_4^{=} + 2H^+ \quad \text{Reaction 1}$$

$$FeS_2 + H_2O + 7/2O_2 \rightarrow Fe^{2+} + 2SO_4^{=} + 2H^+ \quad \text{Reaction 2}$$

The high organic carbon contents found in the mangrove soils (ranging from 39 to 95 dag kg^{-1}) are in agreement with the hydromorphic environment (TARGULIAN; KRASILNIKOV, 2007) where paludization, the process of organic matter accumulation under anaerobic conditions, occurs (SCHAETZL; ANDERSON, 2005).

Organic carbon contents vary with soil depth. Among the possible reasons are the bioturbation promoted by crabs (ARAÚJO JÚNIOR *et al.*, 2012), the irregular supply of organic matter by vegetation and sedimentation, and differences in redox conditions (FERREIRA *et al.*, 2010).

Despite the suitable environment for the formation of Histosols, the organic carbon contents (TOC) were not high enough to identify this soil class, according to the Brazilian System of Soil Classification and the International Soil Classification System (IUSS Working Group WRB, 2015). However, the values were significantly higher than those in other mangrove soils in northeastern Brazil (NÓBREGA *et al.*, 2013, 2014; SUÁREZ-ABELENDA *et al.*, 2013).

As for the composition of the soil organic matter (SOM), and the carbon in the fractions humin (HUM), humic acids (HA) and fulvic acids (FA), the highest organic carbon contents occurred in the humin fraction. In general, the order was: HUM > HA > FA (Table 5). This distribution may result from the soil water saturation and tidal action, removing the most soluble fractions (FA and HA) and relatively enriching the SOM with the HUM fraction.

Table 4 - Chemical characteristics of the studied mangrove soils along the Almada River, Ilhéus-BA, Brazil

Layer	Depht cm	pH		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	S	Al^{3+}	H^{+}	T	V	M	PST	TOC
		H_2O	KCl	---------------------- $cmol_c\ kg^{-1}$ ----------------------							----------- % ------------				$g\ kg^{-1}$
							M1								
1st	0-10	5.8	4,8	7.04	5.19	0.16	1.96	14.35	0.16	8.10	22.6	64	1	9	42.7
2nd	10-20	5.7	5.0	8.10	7.03	0.27	6.27	21.67	0.15	9.12	30.9	70	1	20	71.8
3rd	20-30	5.7	5.1	10.23	13.25	0.36	14.81	38.64	0.35	11.30	50.3	77	1	30	66.8
4th	30-40	3.7	3.2	10.49	11.43	0.28	11.57	33.77	8.50	23.90	66.2	51	20	18	95.4
							M2								
1st	0-10	5.8	4.9	2.71	2.32	0.06	0.85	5.93	0.11	4.58	10.6	56	2	8	39.0
2nd	10-20	5.7	5.0	3.99	3.95	0.11	2.55	10.60	0.11	5.91	16.6	64	1	15	55.4
3rd	20-30	2.7	2.3	5.68	5.95	0.05	6.57	18.26	25.51	25.28	69.1	26	58	10	71.8
							M3								
1st	0-10	5.6	4.3	11.82	7.33	0.46	4.11	23.72	0.48	13.33	37.5	63	2	11	75.7
2nd	10-20	5.2	4.1	10.85	7.19	0.24	4.69	22.97	0.69	16.72	40.4	57	3	12	94.7
							M4								
1st	0-10	4.8	4.4	14.40	9.09	0.17	2.97	26.63	0.27	14.53	41.4	64	1	7	64.9
2nd	10-20	4.9	4.4	15.71	14.67	0.30	6.42	37.10	0.42	20.56	58.1	64	1	11	81.0
3rd	20-30	5.1	4.7	11.72	9.93	0.15	4.53	26.33	0.30	13.15	39.8	66	1	11	62.7
							M5								
1st	0-10	3.6	3.1	9.60	12.22	0.26	10.21	32.29	7.68	17.31	57.3	56	19	18	69.6
2nd	10-20	3.6	3.1	10.90	16.22	0.58	29.28	56.99	8.12	15.42	80.5	71	13	36	58.3

Table 5 - Organic carbon contents (TOC) and relative proportion of organic matter in mangrove soils along the Almada River, Ilhéus-BA, Brazil

Layer	Depht cm	Organic carbon			TOC_t[1]	C rec[2]	% of organic carbon		
		Fulvic acids	Humic acids	Humin			Fulvic acids	Humic acids	Humin
		---------------------- $mg\ kg^{-1}$ ----------------------					-------------------------- % --------------------------		
					M1				
1st	0-10	3.12	8,01	23.73	34.86	82	8.9	23.0	68.1
2nd	10-20	4.83	14.01	37.55	56.40	79	8.6	24.8	66.6
3rd	20-30	4.78	11.47	39.24	55.49	83	8.6	20.7	70.7
4th	30-40	6.55	11.45	52.20	70.19	74	9.3	16.3	74.4
					M2				
1st	0-10	1.91	7.70	16.14	25.76	66	7.4	29.9	62.7
2nd	10-20	2.99	11.16	23.37	37.52	68	8.0	29.7	62.3
3rd	20-30	4.58	11.95	39.67	56.19	78	8.1	21.3	70.6
					M3				
1st	0-10	5.28	11.52	36.66	53.46	71	9.9	21.6	68.6
2nd	10-20	4.82	16.84	45.53	67.18	71	7.2	25.1	67.8

Table 5 Continued

				M4					
1st	0-10	3.44	5.24	40.51	49.20	76	7.0	10.7	82.3
2nd	10-20	4.15	7.84	57.25	69.23	85	6.0	11.3	82.7
3rd	20-30	2.57	4.35	40.29	47.20	75	5.4	9.2	85.3
				M5					
1st	0-10	4.55	5.28	42.47	52.30	75	8.7	10.1	81.2
2nd	10-20	4.37	3.98	38.37	46.73	80	9.4	8.5	82.1

[1]Total organic carbon content; [2]Recovered organic carbon

It should be pointed out that M4 and M5, both under vegetation of red mangrove (*Rizophora mangle*), a tannin-rich species, presented the highest proportions of carbon in the HUM fraction. Probably the tannin, a compound found in fulvic acids with phenolic characteristics and long permanence in soils (VAN BREEMEN; BUURMAN, 1998), in its original form (tannic acid), is polymerized or bound to larger structures, forming humin. Thus, the quality of the SOM in the studied mangrove soils seems to be affected by both soil physical and chemical characteristics and vegetation.

The analytical results for the saturation paste (Table 6) showed the influence of both salinization and solodization processes. They are evidenced by high values of electrical conductivity (EC) and dominance of Na^+ in the saturation extract and exchange complex (Table 4). The soluble ions occur in the following concentration order:

$$Cl^- \cong Na^+ > Mg^{2+} > SO_4^{2-} \cong Ca^{2+} > K^+ \cong HCO_3^- > CO_3^{2-}$$

The high concentrations of salts in the mangrove soils are directly related to the frequent tidal action. The influence of seawater action is evidenced by the similar proportions of the same ions in the soil and in the seawater (MELINDER; IGNATOWICZ, 2015).

According to the Brazilian System of Soil Classification, the soils M1 and M5 present a salic character (EC > 7 dS m^{-1}), and M2 a saline character (4 > E.C. < 7 dS m^{-1}). The processes of accumulation of salts and sodium seem to be ruled by the position of the soils in the estuary. In fact, the higher EC values were found in M5, which is located closer to the mouth of the Almada River and, consequently, more subjected to seawater influence. On the other hand, M3 presented the lower EC values (Table 6). Thus, these results are consistent with the different site locations as the vegetation grown in this area (*Montrichardia linifera*), is a plant that is mostly found in non-saline areas such as floodplain ecosystems of the Amazon and on the banks of rivers from southeast to north of Brazil (AMARANTE *et al.*, 2010).

The XRD analysis identified minerals similar to other mangrove soils studied in Brazil (ALBUQUERQUE *et al.*, 2014; FERREIRA *et al.*, 2007a; PRADA-GAMERO; VIDAL-TORRADO; FERREIRA, 2004; SOUZA JÚNIOR *et al.*, 2007). In all the mangrove soils form Ilhéus (BA) kaolinite (Kt) and mica (Mi) were present in the clay fraction. The diffractograms treated with potassium, at three different temperatures, evidenced the presence of both minerals (Figure 3).

Expandable 2:1 minerals (Mt) (identified by the characteristic shift from 1.7 nm to 1.77 nm interlayer distances) were also present in all soils, although they occur apparently in lower proportions when compared to Kt and Mi. In the M3 soil, the XRD peak at 1.53 nm, probably corresponded to the hydroxy-interlayered vermiculite (HIV), also evidenced by nonexpansion of "d" value in the magnesium+glycerol treatment. These peaks could be masking the presence of expandable 2:1 minerals in this soil.

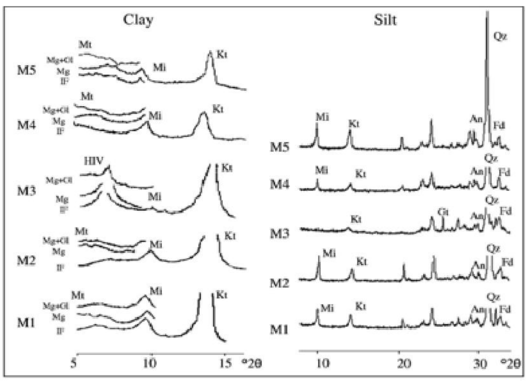
The dominance of kaolinite in the clay fraction is probably a contribution from the kaolinitic soils in the adjacent areas, formed from the Barreiras Geological Formation (FARIA FILHO; ARAUJO, 2003). The main Kt source is the catchment material transported to the estuary by the rivers. The expandable 2:1 clay minerals genesis is related to transformation and neoformation processes. According to Andrade et al (2014) an authigenic transformation process may take place in these soils in response to the high Fe activity in solution (produced by the pyrite oxidation) and high salt content in the water, which produces transitory kaolinite–smectite and illite–smectite phases.

The silt fraction showed the minerals quartz (Qz), mica (Mi), kaolinite (Kt), feldspar (Fd) and anatase (An). In the M3 the goethite (Gt) was detected, suggesting that the redox conditions are less reducing in this soil, or that there is an oscillation of soil redox conditions, as indicated by the soil colors.

Table 6 - Electrical conductivity (EC), pH, cations and anions in the saturation paste extract with water from the studied soils along the Almada River, Ilhéus-BA, Brazil

Layer	Depht cm	EC	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}	HCO^{-3}	SO_4^{2-}/Cl^-
		dSm^{-1}	cmol$_c$ L^{-1}							
					M1					
1st	0-10	1.53	0.09	0.18	0.03	1.01	1.26	0.05	0.09	0.04
2nd	10-20	4.68	0.23	0.66	0.12	3.50	4.45	0.07	0.11	0.02
3rd	20-30	8.32	0.43	1.48	0.19	6.89	9.18	0.14	0.15	0.02
4th	30-40	8.68	0.83	1.58	0.17	6.84	7.69	0.74	0.12	0.10
					M2					
1st	0-10	1.92	0.10	0.25	0.03	1.32	1.68	0.11	0.10	0.07
2nd	10-20	4.35	0.24	0.80	0.07	3.45	3.9	0.28	0.09	0.07
3rd	20-30	5.79	0.67	1.62	0.10	4.15	4.3	0.84	0.08	0.20
					M3					
1st	0-10	0.42	0.05	0.08	0.01	0.20	0.18	0.05	0.20	0.28
2nd	10-20	0.58	0.04	0.06	0.01	0.33	0.37	0.06	0.13	0.16
					M4					
1st	0-10	2.11	0.30	0.69	0.06	1.07	1.01	0.62	0.17	0.61
2nd	10-20	2.81	0.30	0.88	0.07	1.86	1.01	0.54	0.12	0.53
3rd	20-30	3.09	0.47	1.03	0.07	1.78	1.37	0.55	0.11	0.40
					M5					
1st	0-10	7.15	0.50	1.71	0.20	6.02	6.19	0.96	0.20	0.16
2nd	10-20	27.00	1.87	1.78	0.76	28.00	33.23	2.07	0.13	0.06

Figure 3 - Diffractograms of the fractions clay and silt samples of the bottom layer of each soil. Iron free (IF) clay samples treated with magnesium (Mg) and magnesium+glycerol (Mg+Gl)



Mt - montmorilonite, Mi - mica, Kt - kaolinite, HIV- hydroxy-interlayered vermiculite, An - anatese, Qz -quartz and Fd - feldspar

CONCLUSIONS

1. The pedogenetic processes in the studied mangrove soils were gleization, sulfidization, paludization, salinization and solodization, mostly influenced by the hydromorphism through tidal flooding;
2. The intensity of both salinization and solodization processes are governed by the physiographical position of the mangrove soils in the estuary;
3. The organic carbon contents (TOC) were not sufficient to identify Histosols, despite the suitable environment for its genesis. The humin fraction was the dominant organic fraction, probably due to the tide effect, removing the most soluble fractions;
4. Phyllosilicates in the clay fraction of the mangrove soils may be related to surrounding sediments of Barreiras Formation (dominantly kaolinite) and to an authigenic process (2:1 minerals).

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