DOI: 10.1590/S1413-70542015000500001

CHARACTERIZATION AND CLASSIFICATION OF FLOODPLAIN SOILS IN THE PORTO ALEGRE METROPOLITAN REGION, RS, BRAZIL

Caracterização e classificação de solos de várzea na região metropolitana de Porto Alegre, RS

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ABSTRACT

In the Porto Alegre metropolitan region (PAMR) there are a significant proportion of floodplain soils, mainly Planosols and Gleysols, in relation to upland soils. This study aimed to evaluate the morphological, chemical and physical characteristics, and to classify floodplain soils in the PAMR. Six soil profiles were evaluated under different sedimentary lithologies and drainage classes, and samples were collected for chemical and physical analyzes. Two orders of mineral soils (Planosols and Gleysols) and one order of organic soil (Organosols) were identified. The soils were moderately deep to deep and stratified. In mineral soils hue ranged between 7.5YR and 2.5Y, with the occurrence of Bg, Btg or Cg gley horizons, while in organic soil the colors were neutral. Sand and silt were the predominant particle sizes according to the origin sedimentary deposits. The organic carbon content was negatively related to soil density and positively related to soil specific surface area and with soil cation exchange capacity. Soil chemical characterization showed expressive variation in bases, aluminum and sodium saturation. Ki index and $Fe_{(CBD)}/Fe_{(H2SO4)}$ ratio indicated a low soil weathering degree. The different sedimentary lithologies and the soil hydromorphism degree were the main factors related to differences in morphological, physical and chemical characteristics of soils in the PAMR.

Index terms: Hydromorphic soils; quaternary sediments; specific surface area.

RESUMO

Na região metropolitana de Porto Alegre (PAMR) é expressiva a proporção de solos de várzea em relação aos solos de terras altas, com predomínio de Planossolos e Gleissolos. Este estudo objetivou caracterizar a morfologia, a física e a química, e classificar taxonomicamente solos em posições de várzea na PAMR. Foram abertas seis trincheiras em relevo plano, sob diferentes litologias sedimentares e classes de drenagem,onde foram realizadas a descrição morfológica dos perfis de solos e a coleta de amostras para as análises físicas e químicas.Foram identificadas duas ordens de solos minerais (Gleissolo e Planossolo) e uma orgânica (Organossolo). Os solos foram moderadamente profundos a profundos e estratificados. Nos solos minerais a matiz variou entre 7,5YR e 2,5Y, com ocorrência de horizontes gleizados Bg, Btg ou Cg, enquanto no Organossolo as cores foram neutras. A granulometria dos solos, com predominância das frações areia e silte, variou conforme os depósitos sedimentares de origem. A expressiva amplitude dos teores de C orgânico mostrou relação negativa coma densidade do solo, e positiva com a área superficial específica e a capacidade de troca de cátions. Os atributos químicos também se mostraram discriminantes entre os solos avaliados, com ocorrência de distrofismo e eutrofismo, variações amplas dos teores de Al^{3+} trocável e ocorrência de caráter solódico. Nos solos minerais o índice Ki e a relação $Fe_{(CBD)}/Fe_{(H2SO4)}$ indicaram um grau incipiente de desenvolvimento dos solos. O material de origem e o grau de hidromorfismo foram os principais fatores responsáveis pelas diferenças nas características morfológicas, físicas e químicas dos solos na PAMR.

Termos para indexação: Solos hidromórficos; sedimentos quaternários; área superficial específica.

INTRODUCTION

In general, floodplain soils are considered the soils found along the plains of rivers, lakes and lagoons, where they develop in sediments from various sources under various drainage classes often with hydromorphic conditions. In Rio Grande do Sul, the floodplain soils occupy an area of approximately 53,000 km^2 (19% of the territory). This proportion changes significantly in the Porto Alegre metropolitan region (PAMR), where the floodplain soils occupy about 60% of the area. In recent decades, the occupation of floodplain soils with agricultural activities has intensified in this region, especially for rice, corn and bean crops, as well as pastures and vegetables (Hasenack et al., 2008). On the other hand, urbanization pressure has increased recently, which can result in important changes in local environment.

Geographically, these soils are part of intermediate ecosystems between the highlands and aquatic ecosystems, with environmental importance for the conservation of water resources and the maintenance of fauna and flora. In this sense, it is important that the use of floodplain

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Received in may 20, 2015 and approved in july 6, 2015

soils take into account their pedogenetic peculiarities, ensuring the sustainability of agricultural activities and the conservation of natural resources.

In the PAMR there are two distinct geological features: the crystalline base and quaternary sediments (sands, silts and clays). The first consists of a set of granitic bodies with local names amid an intricate granite-gneiss complex (Schneider et al., 1974). The quaternary sedimentary deposits, of colluvial-alluvial and aeolian origin, involve Pleistocene (paleodunes, fluvial deposits and colluvial paleosols) and Holocene formations (recent alluvial sediments) (CPRM, 2006). According to Rio Grande do Sul soil reconnaissance surveys (Brazil, 1973; Radambrasil, 1986) and of the city of Porto Alegre (Schneider et al., 2008), the main soil orders occurring in the floodplain areas of the PAMR are Haplic Planosols, Haplic Gleysols and Melanic Gleysols with Fluvic Neosols and Haplic Organosols occurring in lesser proportions (Streck et al., 2008).

The significant heterogeneity of soils in floodplain areas is inherent to hydromorphic environments (Corrêa et al., 2003; Souza Júnior et al., 2007; Coringa et al., 2012; Guimarães et al., 2013), in which the topographic location and drainage capacity, water quality, sediment type and seasonal flooding influence pedogenetic features. The objective of this study was to characterize the morphology, physical and chemical, as well as taxonomically classify floodplain soils developed in different parts of the PAMR.

MATERIAL AND METHODS

Environmental characteristics

The study areas are located in the metropolitan region of Porto Alegre, between the coordinates 29º45' and 30º15' S (latitude) and 50º30' and 51º30' W (longitude), in the cities of Porto Alegre, Cachoeirinha, Eldorado do Sul and Viamão (Figure 1). The climate is humid subtropical, with an average annual temperature of 19.5 °C, the coldest month being 14 ºC, and an average rainfall of 1309 mm yr^{-1}, with a summer dry period (Maluf, 2000).

The geology consists of Quaternary sedimentary deposits from the Pleistocene and Holocene, consisting predominantly of weakly consolidated sandstone, silty-clay sediments and tuffaceous deposits (Radambrasil, 1986; CPRM, 2006). The vegetation has the influence of alluvial forests and floodplain forests (semideciduous forest phytoecological region); and of wetland areas, with lagoon and alluvial influence (Pioneer Formations phytoecological region).

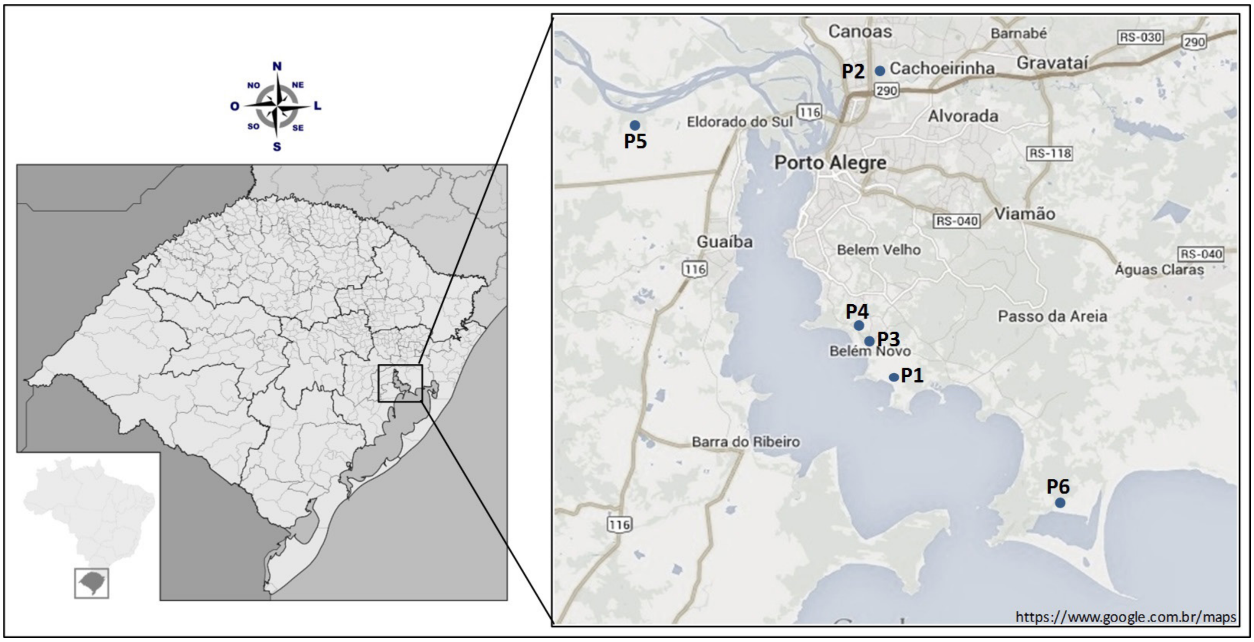

Figure 1: Location of the soil profiles studied: P1 (cambisolic Eutrophic Ta Haplic Gleysol), P2 (cambisolic Dystrophic Ta Haplic Gleysol), P3 (neofluvisolic Eutrophic Ta Haplic Gleysol), P4 (solodic Haplic Eutrophic Planosol), P5 (plinthosolic Dystrophic Haplic Planosol) and P6 (typic Sapric Haplic Organosol).

Description of soil profiles, collection and sample preparation

For the study, six trenches were dug at different points of the PAMR (Figure 1, Table 1) on flat relief positions (0-2% slope), with soil drainage classes ranging from moderate to imperfectly drained and poorly drained. In the trenches, morphological descriptions of soil profiles and the collection of disturbed and undisturbed soil samples were conducted according to Santos et al. (2005). The disturbed soil samples were air dried, and passed through 2 mm mesh sieve to obtain fine air-dried soil fraction (FADS). The total clay (Ø < 0.002 mm) was collected after sedimentation of the soil dispersion with 1 mol L^{-1} NaOH flocculated with a 0.1 mol L^{-1} HCl washed with a ethanol/water solution at a 1:1 ratio, oven-dried at 60 °C and ground.

Physical analyses

Physical testing included granulometric composition of the soil by the pipette method using NaOH 1 mol L^{-1} as the chemical dispersant; natural clay, the bulk density (BD) by the volumetric ring method, the particle density (PD) in a volumetric flask (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 1997), calculating the degree of flocculation (FD). The specific surface area (SSA) of the clay fraction was estimated by the water adsorption method at 20% relative moisture (Quirk, 1955).

Chemical analysis

The chemical analyzes included pH in water and KCl; Ca^{2+}, Mg^{2+} and Al^{3+} content extracted by 1 mol L^{-1} KCl and determined by atomic absorption spectroscopy; the contents Na^+, K^+ and available P extracted by Mehlich-1, with the quantification of Na^+ and K^+ conducted in a flame spectrophotometer, and that of P in a colorimeter; acidity at pH 7 (H+Al), extracted with calcium acetate at pH 7 and determined by titration; and electrical conductivity of the saturated paste (Embrapa, 1997). From these results the following were calculated: cation exchange capacity (CEC), clay fraction activity (CFA), the sum of bases (SB), base saturation (V), the aluminum saturation (m) and the exchangeable sodium percentage (ESP). The determination of total organic carbon (TOC) was performed by dry combustion in a SHIMADZU VCSH carbon analyzer.

The SiO_2, Fe_2O_3, Al_2O_3, K_2O, P_2O_5 and MnO contents were determined after acid digestion (extracted by the sulfuric acid method) (Embrapa, 1997). From these levels the Ki index ((SiO_2*1.70)/Al_2O_3) was calculated. Fe relative to total pedogenic iron oxide (Fed) was extracted with dithionite-citrate-bicarbonate at 80 °C in two successive extractions (Mehra; Jackson, 1960; Inda Junior; Kämpf 2003). Fe related to low crystalline iron oxide (Feo) was extracted with 0.2 mol L^{-1} ammonium oxalate at pH 3 in the dark (Schwertmann, 1964). The Fe contents in the extracts were determined by atomic absorption spectroscopy.

Table 1: Identification and land use of the profiles studied.

Profile	City	Drainage	Geology (CPRM, 2006)	Land use
P1	Porto Alegre	Imperfectly drained	Colluvium-alluvial deposits: Sandstone, Conflomerate; Diamictite; Pelites; Conglomeratic Sandstone.	Pasture followed by fallow
P2	Cachoeirinha	Poorly drained	Colluvium-alluvial deposits: Sandstone, Conflomerate; Diamictite; Pelites; Conglomeratic Sandstone.	Rice followed by fallow
P3	Porto Alegre	Poorly drained	Holocenic barrier deposits-lagoon crests and beach deposits: Sand	Fallow
P4	Porto Alegre	Moderately to implerfectly drained	Colluvium-alluvial deposits: Sandstone, Conflomerate; Diamictite; Pelites; Conglomeratic Sandstone.	Pasture
P5	Eldorado do Sul	Imperfectly drained	Pleistocenic barrier deposits-lagoon plain deposits: Sand	Rice followed by fallow
P6	Viamão	Poorly drained	Holocenic barrier deposits-peateries: Peat	Pasture

RESULTS AND DISCUSSION

Morphological and physical characterization

The soil profiles were considered moderately deep (> 50 cm e ≤ 100 cm) to deep (> 100 cm e ≤ 200 cm) (Embrapa, 2013), with horizon sequences A-B, A-E-B and A-B-C (Table 2), although the C horizon had occurred shallow depths in some profiles, like at 18 cm depth in the P3 profile. All soils were quite stratified, presenting a sequence of various thin horizons, as is characteristic of soils formed under conditions where material deposition predominates (Souza Júnior et al., 2001; Corrêa et al. 2003; Guimarães et al., 2013). Despite the hydromorphism action in all soils, in the P3 and P6 profiles were observed A-C horizons sequences and H1-H2-H3, respectively. In these profiles, the greater influence of the water table due to the proximity of water bodies limited the differentiation of characteristics, such as structure, as well as the development of other pedogenic processes besides hydromorphism and paludization.

In mineral soils yellowish colors predominated, with hues between 7.5 YR and 2.5 Y, while in the P6 profile the colors were neutral. All the mineral soils had gleyed Bg, Btg or Cg horizons. The colors of the matrix had low chromas, and mottling occurred with higher values and chromas in profiles P2, P3, P4 and P5. In horizon 2Cg2 of Profile P3 variegated colors occurred.

The P1, P2 and P3 profiles had no significant changes in the textural classes of the horizons, clay (P1) and clayey loam (P2 and P3) textures predominating. The greater clay content in Btg horizons, associated with color and structure soil characteristics, was sufficient to characterize a planic B horizon (Embrapa, 2013) in the P4 and P5 profiles, where the texture changed from sandy loam (P4) or clayey loam (P5) to clay. The E horizon in the P5 was loamy below the A horizon. A structure in medium to large sized angular and subangular blocks was dominant in most horizons, while in the deeper horizons of profiles P1, P3 and P6 there occurred massive structure. The dominant moist consistency ranged between friable and firm in all profiles. The wet consistency ranged from aplastic and non-sticky to plastic and very sticky, following the tendency to major plasticity and stickiness in clayey horizons.

The predominant particle size fractions in the soils were silt and sand (Table 3). In P1 and P4 profiles, silt and sand contents were similar, confirming development from the same sedimentary deposits (Table 1). Profiles P2 and P5 also presented a similar particle size distribution, with a predominance of silt (> 359 g kg^{-1}), although the geology indicated that these profiles have developed from different sedimentary materials (Table 1). Profile P3, showed significant sand contents (> 582 g kg^{-1}), which is in agreement with formation from sandy near beach deposits, showing higher energy flows in the transport of coarser material, as also observed by Souza Junior et al. (2007) in sedimentary areas of the coast of São Paulo state. Except in the P4 and P6 profiles, the fine sand fraction having greater expression than coarse sand.

Considering the fine sand/coarse sand (FS/CS) ratio, it is expected that the homogeneous material relationship is maintained uniform along the horizon at depth and, where there are discontinuities, as in the case of the sedimentary packages, the relationship also changes (Novais Filho et al., 2012). As expected, sediments of different origins were found among the soil profiles, with the lowest FS/CS ratios being found in P4 and the greatest in P3. In addition, significant changes in the FS/CS ratio in P2 and P3 profiles indicated discontinuities in the sedimentary packages existing in these soils.

A high proportion of silt in relation to clay (silt/clay ratio) suggests an intermediate degree of weathering in the studied soils (Embrapa, 2013). This is consistent with the relatively recent sediments from which the soils were formed and the low soils landscape positions, that may have inhibited a high weathering degree. The levels of clay dispersed in water showed a positive relationship with the sum of bases, mainly with the amounts of soil magnesium and sodium (Table 4), expressed through the lower of flocculation degrees the clays, as found in floodplains soils in Paraíba state by Correa et al. (2003).

The particle density (PD) varied between 2.38 and 2.59 g cm^{-3}. The bulk density (BD) showed a positive relationship with silt and inverse with the sand and organic carbon content (Table 4). In Profile P2, the relatively high uniform BD values along the profile (1.62 to 1.77 g cm^{-3}) may be due to the large solid, prismatic soil structures (Oliveira et al., 2003), associated with the high silt of that soil. In the other mineral profiles, BD ranged between 0.94 and 1.51g cm^{-3}. In profile P6, the low BD (< 0.30 g cm^{-3}) reflected its predominantly organic make up. The specific surface area (SSA) has an expressive range, varying from 3.9 to 90.6 m^2 g^{-1} in the mineral soils and reaching values close to 140 m^2 g^{-1} in the Organosol (Table 3). This variation in SSA values, estimated by water adsorption, was positively related to the organic carbon content, as found in other studies (Tomasi et al., 2012; Fink et al., 2014), and inverse with the silt content (Table 4). When considering the profiles individually, it was observed that the profiles P1, P4 and P5, greater SSA values occurred in horizons with higher contents of clay and pedogenic iron oxide (Fed).

Table 2: Main morphological attributes of lowland soils in the Metropolitan Region of Porto Alegre, RS.

Hor.	Depth (cm)	Color		Texture class[3]	Structure[4]	Consistence[5]
		Matrix	Mottle			
P1 - cambisolic Eutrophic Ta Haplic Gleysol						
A	0-18	10YR 3/3	-	Clay	M, S/M, AB	Fr, PL and S
Bg	18-43	10YR 3/2	5YR 5/8	Clay to very clayey	M, M, AB	P, SS/S
BCg	43-60	5YR 3/2	10YR 6/6	Clay	MS	F, P and S
Cg	60-80+	5YR 3/2	10YR 6/6	Clay	MS/G, AB	Fr, P and S
P2 - cambisolic Dystrophic Ta Haplic Gleysol						
Ap	0-5	7.5YR 4/2	-	Clay-loam	M, S/M, SB	Fr, P and S
A1	5-23	10YR 4/2	-	Clay-loam	W, L, BS/MS	F, P and S
ABg	23-40	10YR 4/2	7.5YR 4/6	Clay-loam	M, L, SB	VF/F, P and S
2Bg1	40-76	10YR 5/2	10YR 5/6	Clay-loam to clay	M/W, L, P	VF, P and S
3Bg2	76-95+	10 YR 5/2	10 YR 5/6	Clay-loam to clay	M/W, L, P	SFr, P and S
P3 - neofluvisolic Eutrophic Ta Haplic Gleysol						
A1	0-13	2.5Y 4/1	5YR 4/4	Clay-loam	W, VL, SB	F, SP and SS
2Cg1	18/22-35	2.5Y 4/1	5 YR 4/4	Clay-loam	W, VL, SB/MS	F, NP and NS
2Cg2	35-70	2.5Y 5/1, 2.5Y 6/2, 5YR 8/1[2]		Clay-loam	MS	L/VF, NP and NS
3Cg3	70-90+	3/10 BG	-	Clay-loam	MS	F, SP and NS
P4 - solodic Haplic Eutrophic Planosol						
Ap	0-7	10YR 3/3	-	Sandy loam	M, S, G	F, SP and LPJ
A	7-23	10YR 4/4	7.5YR 5/8	Loamy sand to sandy loam	M, M/L, SB	F, SP and LPJ
AB	23-50/54	10YR 4/2	7.5YR 5/8	Clay-loam	M, M, SB	P and S
Btg	50/54-90+	10YR 3/1	2.5YR 4/8, 10YR 6/8[1]	Clay	M, M/L, P/SB	Fr, P and S
P5 - plinthosolic Dystrophic Haplic Planosol						
Ap	0-24	2.5Y 3/3	10R 4/6	Loam	M, M, SB/G	VF, SP and NPJ
A	24-29/32	10YR 4/2	-	Loam	M, M, SB	Fr, SP and LPJ
E	29/32-60/85	7.5YR 4/2	7.5YR 5/6	Loam	M, M/L, AB	Fr, SP and LPJ
Btg	60/85-120+	10YR 4/1	7.5YR 5/8, 2.5 YR 4/8[1]	Clay	M, M/L, SB	Fr, P and VS
P6 - typic Sapric Haplic Organosol						
H1	0-22	Black 2.5/N,	-	Muck	M, M, C	SFr, NP and NS
H2	22-46	Black 2.5/N	-	Muck	W, M, C	F, SP and SS
H3	46-100+	Black 2.5/N	-	Muck	MS	F, SP and SS

[1]Plinthite; [2]Variegate; [3]Inferred at the field soil description; [4]Structure: development degree (W: weak, M: moderate), size (S: small, M: medium, L: large, VL: very large), type (G: granular, C: crumb, SB: subangular blocky, AB: angular blocky, P: prismatic, MS: massive); [5]Consistence: when moist (L: Loose, VF: very friable, F: friable, SFr: slightly firm, Fr: firm), when wet (NP: nonplastic, SP: slightly plastic, P: plastic, VP: very plastic, NS: nonsticky, SS: slightly sticky, S: sticky, VS: Very sticky).

Table 3: Main physical attributes of lowland soils in the Metropolitan Region of Porto Alegre, RS.

Hor.	water dispersible clay	clay	silt	FS	CS	total sand	FS/CS %	FD	silt/ clay	PD	BD	SSA
	---------------------- g kg^{-1} --------------------									---- g cm^{-3} ----		m^2 g^{-1}
P1 - cambisolic Eutrophic Ta Haplic Gleysol												
A	185	260	410	291	39	330	7.5	29	1.6	2.38	1.38	29.6
Bg	315	400	373	179	49	228	3.7	21	0.9	2.41	1.42	53.3
BCg	245	290	339	183	188	371	1.0	16	1.2	-	1.41	36.7
Cg	238	310	318	328	44	372	7.5	23	1.0	-	-	47.0
P2 - cambisolic Dystrophic Ta Haplic Gleysol												
Ap	69	187	493	283	37	320	7.6	63	2.6	2.47	1.62	6.1
A	102	205	495	279	21	300	13.3	51	2.4	2.52	1.77	7.4
ABg	117	220	510	249	21	270	11.9	47	2.3	-	1.64	6.1
2Bg1	206	260	523	212	5	217	42.4	21	2.0	-	1.67	3.9
3Bg2	217	265	455	267	13	280	20.5	18	1.7	2.51	1.76	7.4
P3 - neofluvisolic Eutrophic Ta Haplic Gleysol												
A	-	96	222	650	33	682	19.7	-	2.3	2.49	0.94	78.4
2Cg1	-	70	70	847	13	860	65.2	-	1.0	-	-	84.6
2Cg2	-	-	-	-	-	-	-	-	-	-	-	-
3Cg3	-	65	353	458	188	582	2.4	-	5.4	2.53	-	70.0
P4 - solodic Haplic Eutrophic Planosol												
Ap	84	144	440	244	172	415	1.4	42	3.1	2.48	1.51	28.7
A	159	160	399	179	263	441	0.7	1	2.5	2.53	-	24.6
AB	190	280	310	147	263	410	0.6	32	1.1	2.48	1.49	45.2
Btg	339	420	257	125	198	324	0.6	19	0.6	2.48	1.42	90.6
P5 - plinthosolic Dystrophic Haplic Planosol												
Ap	128	153	568	253	27	279	9.4	17	3.7	2.50	1.38	13.8
A	83	149	441	371	40	410	9.3	44	3.0	2.50	-	5.8
E	79	160	504	307	30	336	10.2	51	3.2	2.53	-	11.9
Btg	233	355	359	246	40	286	6.2	34	1.0	2.59	1.36	34.3
P6 - typic Sapric Haplic Organosol												
H1	7	-	-	-	-	-	-	-	-	-	0.26	135.6
H3	7	-	-	-	-	-	-	-	-	-	0.14	139.7

FD (floculation degree), PD (particle density), BD (bulk density), SSA (specific surface area), FS (fine sand), CS (coarse sand).

Chemical characterization

The high total organic carbon (TOC) in the profile P6 horizons (between 410 and 453 g kg^{-1}) (Table 5) indicates an intense paludization process in this locale, confirming the description of the material as of turfy origin (Table 1), and the classification of these horizons as organic material diagnostic attribute (TOC $\geq$ 80 g kg^{-1}) according to the Brazilian System of Soil Classification (SiBCS) (Embrapa, 2013). In the other soils, classified as mineral material soils, the TOC content was high in the surface and decreased at depth. In Profile P3, this decrease was followed by an increase in the 3Cg3 horizon, corroborating the occurrence of a lithological discontinuity also expressed by the grain size of that horizon (Table 3).

The pH values in water were low, most under 5.5, except for the Cg1 horizon of profile P3 and horizons A and E of the P5 profile, the latter probably was influenced by its recent use under irrigated rice. In the P6 profile, the soil reaction was strongly acidic (4.1 to 4.3), as a result of the organic character of this soil. The higher pH values in water compared to the pH values in KCl indicate the predominance of a net negative charge in all soils. The cation exchange capacity (CEC) ranged from 5.7 to 33.3 $cmol_c\ kg^{-1}$ in the mineral soils. According to the CQFS-RS / BS (2004), the CEC values in the profiles P2 and P5 were classified as medium (5.7 to 11.9 $cmol_c\ kg^{-1}$), followed by the profiles P1 and P4 with values classified as medium to high (9.1 to 22.4 $cmol_c\ kg^{-1}$), and profile P3 with values classified as high (26.9 to 33.3 $cmol_c\ kg^{-1}$). In these mineral soils, the content of silt and Fe relative to the poorly crystallized iron oxides (Feo) (e.g. ferrihydrite and lepidocrocite) was positively related to CEC (Table 4), possibly because the poor drainage inhibits weathering while favors the formation of poorly crystallized iron oxides. The high CEC values determined in the P6 profile (64.4 and 73.4 $cmol_c\ kg^{-1}$) occurred due to the organic character of the soil (Souza Júnior et al., 2001), as was expressed by the positive relationship with TOC (Table 4). A relation between CEC and clay fraction activity (CFA) in subsurface horizons B or C of most of the mineral soils was found. The CFA values were above 27 $cmol_c\ kg^{-1}$ of clay, characterizing high clay-activity in the soils (Embrapa, 2013).

Table 4: Correlation among physical and chemical properties determined for the lowland soils studied.

Correlation	R^2	P	n
ADA=86.804+(17.236*SB)	0.405	0.006	17
ADA=107.213+(27.125*Mg)	0.510	0.001	17
ADA=124.267+(159.066*Na)	0.473	0.002	17
BD=0.923+(0.00136*silt)	0.455	0.008	14
BD=1.923-(0.00132*sand)	0.515	0.004	14
BD=1.515-(0.00307*TOC)	0.850	<0.001	16
SSA=32.223+(0.245*TOC)	0.563	<0.001	22
SSA=116.843-(0.211*silt)	0.787	<0.001	20
CEC=37.070-(0.0597*silt)	0.767	<0.001	20
CEC=8.298+(3.346*Feo)	0.323	0.017	17
CEC=12.594+(0.131*TOC)	0.815	<0.001	22
CEC=-7.887+(0.538*CFA)	0.865	0.007	6
Ca=-0.126+(0.126*SSA)	0.483	<0.001	20
Mg=-0.0555+(0.101*SSA)	0.870	<0.001	20
Na=-0.0252+(0.0125*SSA)	0.834	<0.001	20
SB=-0.0717+(0.241*SSA)	0.710	<0.001	20
Al=-1.717+(0.0168*clay)	0.710	<0.001	20
H+Al=1.077+(0.0198*clay)	0.637	<0.001	20
Ki=7.158-(0.0098*clay)	0.336	0.015	17
Feo/Fed=0.180+(0.0141*TOC)	0.324	0.017	17

Ki=$(1.7SiO_2)/Al_2O_3$; BD: bulk density; CEC (cation exchange capacity); SSA (specific surface area); TOC (total organic carbon); Fed (iron extracted by sodium citrate-bicarbonate-dithionite); Feo (iron extracted by ammonium oxalate); ADA (water dispersible clay); CFA (clay fraction activity).

Table 5: Chemical properties including C and P for the lowland soils studied in the Metropolitan Region of Porto Alegre, RS.

Hor.	pH		TOC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SB	Al^{3+}	H+Al	CEC	P	m	ESP	V	CFA
	H_2O	KCl	g kg^{-1}	cmol$_c$ kg^{-1}								mg L^{-1}	%			cmol$_c$ kg^{-1}
P1 - cambisolic Eutrophic Ta Haplic Gleysol																
A	4.9	3.8	14.3	3.2	3.1	0.18	0.25	6.7	1.5	7.1	13.8	3.4	18	1	49	-
Bg	4.7	3.6	6.1	2.6	5.0	0.41	0.20	8.2	5.8	10.4	18.6	2.7	41	2	44	46.5
BCg	4.3	3.5	3.5	2.5	4.7	0.39	0.17	7.8	4.8	5.9	13.7	2.5	38	3	57	47.1
Cg	4.5	3.6	2.3	2.9	6.2	0.71	0.19	10.0	4.4	8.4	18.4	2.5	31	4	54	-
P2 - cambisolic Dystrophic Ta Haplic Gleysol																
Ap	5.1	-	11.0	1.3	0.9	0.04	0.06	2.4	0.6	3.6	6.1	19.5	19	1	39	-
A	5.4	-	7.1	1.6	0.9	0.05	0.05	2.7	0.6	3.0	5.7	13.9	19	1	47	-
ABg	4.9	-	3.9	2.4	0.8	0.05	0.03	3.2	0.5	3.6	6.8	14.1	12	1	48	-
2Bg1	5.1	-	3.3	1.3	0.4	0.06	0.03	1.8	2.3	5.8	7.6	1.4	58	1	23	29.0
3Bg2	4.6	-	1.9	0.8	0.5	0.13	0.04	1.6	2.6	6.9	8.5	0.9	64	2	17	32.0
P3 - neofluvisolic Eutrophic Ta Haplic Gleysol																
A	5.1	4.0	25.3	13.5	7.7	0.62	0.13	22.0	0.5	4.9	26.9	5.2	2	2	82	-
2Cg1	5.7	4.3	3.5	19.5	11.6	1.11	0.10	32.3	0.0	1.0	33.3	4.0	0	3	97	-
2Cg2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3Cg3	5.4	3.9	10.7	14.5	6.1	0.80	0.36	21.8	0.3	5.6	27.4	9.8	1	3	80	-
P4 - solodic Haplic Eutrophic Planosol																
Ap	5.0	4.0	34.4	2.6	2.9	0.31	0.31	6.1	1.6	3.1	9.2	7.9	21	3	66	-
A	4.8	3.9	4.6	1.3	1.5	0.16	0.18	3.1	1.6	6.0	9.1	2.7	34	2	34	-
AB	5.1	3.7	5.2	1.4	2.6	0.43	0.17	4.6	4.3	7.4	12.0	1.3	48	4	38	-
Btg	5.0	3.7	4.4	3.0	7.8	1.49	0.23	12.5	5.6	9.9	22.4	2.2	31	7	56	53.4
P5 - plinthosolic Dystrophic Haplic Planosol																
Ap	4.9	4.0	11.8	2.0	0.7	0.10	0.21	3.0	0.5	5.2	8.2	-	14	1	37	-
A	5.8	4.9	4.8	2.8	1.3	0.12	0.17	4.2	0.0	2.4	6.6	13.5	0	2	65	-
E	6.5	5.4	4.1	2.6	1.7	0.33	0.36	5.0	0.0	2.4	7.4	3.1	0	5	68	-
Btg	4.9	3.7	3.7	2.1	2.0	0.55	0.24	4.9	2.9	7.0	11.9	2.0	38	5	41	33.5
P6 - typic Sapric Haplic Organosol																
H1	4.1	3.3	410.1	7.1	5.0	0.30	0.20	12.6	3.7	51.8	64.4	6.8	23	1	20	-
H3	4.3	3.3	453.0	7.8	7.2	0.55	0.10	15.6	3.3	57.8	73.4	5.0	17	1	21	-

TOC (total organic carbon); SB (sum of bases); CEC (cation exchange capacity); m (Al^{3+} saturation); ESP (exchangeable sodium percentage); V (base saturation); CFA (clay fraction activity).

The composition of sorption-complex of soils showed strong relationship with SSA values and clay content (Table 4). Profiles P2 and P5, under less intense hydromorphic conditions, showed the lowest levels of basic cations ($S \leq 5$ $cmol_c$ kg^{-1}) and exchangeable Al^{3+} contents ranging from 0.5 kg $cmol_c^{-1}$ in the surface to 2.9 $cmol_c$ kg^{-1} at depth. In these profiles, the V values decreased and m increased at depth. In the P1 and P4 profiles, cation contents were intermediate (between 3 and 11 $cmol_c$ kg^{-1}) associated with high exchangeable Al^{3+} levels, resulting in intermediate V and m values. In this profile the Na^+ saturation (ESP) in the Btg horizon stands out, characterizing the solodic nature of this soil (Embrapa, 2013). In Profile P3 there were very high levels of basic cations (> 20 $cmol_c$ kg^{-1}) and a virtual lack of exchangeable Al^{3+}, resulting in very high V values (≥ 80%) and low m (≤ 2%). In Profile P6, with an organic material character, the cations and Al^{3+} contents were high, with low V and m values due to high organic contribution of H^+ in the exchange complex. The P contents ranged from low to very low in the P1 profile and in the subsurface in profiles P2, P4 and P5, to high and very high in the surface horizons of profiles P2, P3, P4 and P5. In Profile 6 the P content was considered average.

The total contents of the elements extracted by sulfuric acid attack in mineral soils are presented in Table 6. The P_2O_5 content and MnO were below 1 g kg^{-1}. The low amounts of Fe_2O_3 and MnO are possibly related to reduction processes and removal of manganese and iron occurring in wetland soils (Corrêa et al., 2003; Coringa et al., 2012). The SiO_2 contents were greater than the Al_2O_3 contents in all soils, contributing to the high Ki index values in most of the horizons (Table 6), which indicated the 2:1 occurrence of clay minerals. The iron concentrations related to the total pedogenic iron oxides (Fed) had a distribution similar to the Fe_2O_3 content between horizons and profiles analyzed. However, the Fed concentrations were lower than those of the total Fe (extracted by sulfuric acid attack) as indicated by Fed/Fet relationship (between 0.13 and 0.65), confirming the incipient stage of development and the conditions for preservation and/or neoformation of silicate minerals in the clay fraction (Moniz; Buol, 1982; Kämpf; Curi, 2000), indicated by the Ki ratio. The low Feo/Fed values of the subsurface layers, indicating the predominance of crystalline iron oxides, contrasted with the increase of the surface horizons determined by inhibition by organic matter in the development of the iron oxide crystallinity (Schwertmann, 1966; Biber; Santos; Stumm, 1994).

Soil classification

Considering the morphological descriptions and analytical results, soil profiles were classified to the fourth category level of the Brazilian System of Soil Classification (Embrapa, 2013). The P1 and P3 profiles were classified in the same class until the great group level, being differentiated in the subgroup as follows: Profile P1 was classified as cambisolic Eutrophic Ta Haplic Gleysol (GXve-1) and Profile P3 as neofluvisolic Eutrophic Ta Haplic Gleysol (GXve-3). The classification of the P1 profile as eutrophic does not consider the high levels of exchangeable Al^{3+} throughout profile, including the occurrence of an alitic character found in the Bg diagnostic horizon. The P2 profile was classed in the same suborder as the previous profiles, differing in the great group level as follows: cambisolic Dystrophic Ta Haplic Gleysol (GXvd). The P4 and P5 profiles also composed the same suborder, differing at the great group level as follows: the P4 profile was classified as solodic Eutrophic Haplic Planosol (SXe) and the P5 profile as plinthosolic Dystrophic Haplic Planosol (SXd). The P6 profile was classified as typic Sapric Haplic Organosol (OXs).

Table 6: Total content of oxides from sulfuric acid digestion, Ki index and Fe from selective extractions for the lowland soils studied in the Metropolitan Region of Porto Alegre, RS.

Hor.	Sulfuric acid digestion (H_2SO_4 1:1)						Ki	Fed	Feo	Feo/Fed	Fed/Fet
	P_2O_5	Fe_2O_3	MnO	TiO_2	Al_2O_3	SiO_2					
	------------------------ gkg^{-1} ----------------------------							---- gkg^{-1} ----			
P1 - cambisolic Eutrophic Ta Haplic Gleysol											
A	0.3	17.0	0.3	6.2	50.5	133.0	4.52	3.6	0.8	0.22	0.21
Bg	0.2	45.0	0.3	7.0	98.5	195.5	3.40	14.7	2.5	0.17	0.33
BCg	-	-	-	-	-	-	-	-	-	-	-
C	0.1	25.0	0.2	6.2	82.5	178.0	3.72	3.8	0.3	0.08	0.15
P2 - cambisolic Dystrophic Ta Haplic Gleysol											
Ap	0.5	5.9	0.1	3.8	17.2	71.0	6.97	2.5	1.3	0.52	0.42
A	0.6	6.8	0.1	3.9	19.0	72.5	6.50	2.5	1.7	0.68	0.37
ABg	-	-	-	-	-	-	-	-	-	-	-
2Bg1	0.2	7.2	0.1	4.7	22.3	86.0	6.53	3.8	0.9	0.24	0.53
3Bg2	0.2	20.7	0.1	5.0	34.8	115.0	5.64	13.4	0.9	0.07	0.65
P3 - neofluvisolic Eutrophic Ta Haplic Gleysol											
A	0.6	7.2	0.1	4.0	23.1	98.0	7.21	2.9	1.8	0.62	0.40
2Cg1	0.6	90.0	1.7	3.0	31.0	142.0	7.78	12.0	3.8	0.32	0.13
2Cg2	-	-	-	-	-	-	-	-	-	-	-
3Cg3	0.6	71.5	1.5	3.1	29.5	137.5	7.93	10.8	6.4	0.59	0.15
P4 - solodic Haplic Eutrophic Planosol											
Ap	0.5	13.0	0.4	4.7	37.0	110.0	5.04	3.0	1.4	0.47	0.23
A	0.2	21.0	0.1	5.0	57.0	111.0	3.30	4.7	0.9	0.19	0.22
AB	-	-	-	-	-	-	-	-	-	-	-
Btg	0.2	34.0	0.3	6.2	118.0	224.7	3.29	14.1	1.1	0.08	0.41
P5 - plinthosolic Dystrophic Haplic Planosol											
Ap	0.4	17.0	0.2	6.7	30.5	74.0	4.14	5.5	2.8	0.51	0.32
A	0.5	11.0	0.8	5.6	21.0	61.0	4.93	4.7	1.6	0.34	0.43
E	0.1	25.0	0.1	3.6	15.0	37.0	2.11	9.7	0.8	0.08	0.39
Btg	0.1	53.7	0.3	8.2	82.8	142.0	2.91	22.3	0.9	0.04	0.42

CONCLUSIONS

The floodplain soils of the Porto Alegre metropolitan region show differences in morphological, physical and chemical characteristics, the main factors responsible are the source material and the degree of hydromorphism. The high silt/clay relationship, the occurrence of high clay activity, the high Ki index values and the low Fed/Fet relationship indicate that the soils show some degree of incipient weathering. The degree of hydromorphism, evaluated by attributes such as soil color and the organic carbon content, indicate a stronger hydromorphism in the profiles of neofluvisolic Eutrophic Ta Haplic Gleysol (Profile P3) and in the typic Sapric Haplic Organosol (P6 profile). The soil particle size varies depending on the origin of the sedimentary material, with a predominance of classes between sandy loam and clay textural classes. Wide variations of exchangeable aluminum content and aluminum saturation occur, as well as variation in the basic cation contents expressed by the eutrophic and dystrophic attributes. The influence of soil organic matter on chemical properties such as specific surface area and cation exchange capacity, and physical attributes such as bulk density reinforces its importance for the sustainability of the environment.

ACKNOWLEDGMENTS

To the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the financial support (Edital Universal). To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG).

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