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HYDROMORPHIC SOILS OF THE RIO DE LA PLATA COASTAL PLAIN, ARGENTINA

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Abstract: The Río de la Plata coastal plain is a 5 to 10-km wide strip, extending along nearly 200 km on the right bank of this estuary, in northeastern Buenos Aires Province, Argentina. The climate is temperate humid (mean annual temperature and rainfall: 16.2ºC and 1040 mm). The coastal plain is covered with materials derived from intense sedimentation and littoral transport. These factors have interacted with marine ingressions and regressions occurred after the Last Glaciation Maximum. A large part of the coastal plain is covered with hydromorphic soils whose geochemical properties and response to environmental factors are not totally understood. The objectives of this work are: a) to describe the redoximorphic features of the soils; b) to analyze the temporal evolution of the main hydromorphic variables; and c) to establish the relationships between genetic factors and the hydromorphic variables. The evolution of Eh, pH, Fe^{2+}, Mn^{2+} and moisture was analyzed monthly during two years in two representative soils: a Fluvaquent formed in fluviatile sands of the alluvial plain of Río de la Plata and a Natraquert developed in estuarine clays of a mudflat. Both soils exhibit different stability regarding their hydromorphic dynamics. The Fluvaquent is a very unstable system due to its coarse texture, which allows a rapid water movement from diverse sources (rain, phreatic water and floods), showing a heterogenous distribution of the redoximorphic features in the soil. The lowest horizon (2Cg) is nearly permanently saturated and reduced by phreatic water; it exhibits homogenous low-chroma colors and has the lowest Eh mean value. The overlying horizon (2Cxg), where the anoxic conditions fluctuate, has mottles and localized hardening due to the precipitation of Fe and Mn oxides, indicating oxidizing conditions during some part of the year. These changes are reflected rapidly in Eh values, but not in Fe^{2+} and Mn^{2+} contents, which involve physico-chemical equilibria that are not instantaneous. Floods affect mainly the two upper horizons and there is little influence of evapotranspiration. The Natraquert exhibits more stable geochemical conditions due to its clayey texture, which prevents a rapid oxygen access, even during summer when a short deficit period occurs. It has homogenous reduced colors in the matrix. This soil is affected by waterlogging without influence of floods, whilst the phreatic water only affects the deepest horizons. High Eh values and Mn^{2+} segregation are observed. Evapotranspiration has an influence on the upper horizons.

Resumen: La planicie costera del Río de la Plata es una franja de 5 a 10 km de ancho que se extiende a lo largo de casi 200 km, sobre la ribera derecha de este estuario, en el noreste de la provincia de Buenos Aires, Argentina. El clima es templado húmedo (temperatura y precipitación media anual: 16,2ºC y 1040 mm). La planicie costera está cubierta por materiales provenientes de sedimentación y transporte litoral que actuaron durante ingresiones y regresiones marinas del Último Máximo Glacial. Una gran extensión está cubierta por suelos hidromórficos cuyas propiedades geoquímicas y la influencia de los

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factores del medio que las determinan no se conocen completamente. Los objetivos de este trabajo son: a) describir los rasgos redoximórficos de los suelos; b) analizar la evolución temporal de las principales variables hidromórficas; y c) establecer las relaciones de los factores genéticos con los valores medidos. Se analizó mensualmente durante dos años la evolución de Eh, pH, Fe^{2+}, Mn^{2+} y humedad en dos suelos representativos: un Fluvacuent formado en depósitos arenosos fluviales de la planicie aluvial del río de la Plata y un Natracuert desarrollado en la llanura de fango con sedimentos arcillosos marino-estuáricos. Ambos suelos mostraron variación de las variables hidromórficas con distinto grado de intensidad. El Fluvacuent es un sistema hidromórfico muy inestable debido a que la textura gruesa del material permite el movimiento rápido del agua proveniente de distintos orígenes (precipitaciones, agua freática e inundaciones por sudestadas), con distribución heterogénea de rasgos redoximórficos en el suelo. El horizonte más profundo (2Cg), está casi permanentemente saturado y reducido por agua freática; presenta colores de baja intensidad casi uniformes y los valores medios de Eh más bajos. En el horizonte suprayacente (2Cxg), con saturación y estado reducido intermitente, hay moteados y endurecimiento localizado debidos a la precipitación de óxidos de Fe y Mn, que indican condiciones óxicas en algún momento del año. Las condiciones anóxicas fluctuantes se reflejan en cambios rápidos de Eh, pero no en los contenidos de Fe^{2+} y Mn^{2+}, ya que éstos se rigen por equilibrios físico-químicos que no son inmediatos como lo es el potencial de óxido-reducción. Las sudestadas afectan principalmente a los dos horizontes superiores, con influencia mínima de la evapotranspiración. El Natracuert posee condiciones geoquímicas más estables en el tiempo debido a la textura arcillosa, la cual impide el acceso rápido de oxígeno aún en verano, cuando se produce un corto período de déficit hídrico. Presenta colores de la matriz homogéneos que indican condiciones reductoras. Este suelo está afectado por anegamiento sin influencia de las sudestadas y el agua freática sólo afecta los horizontes más profundos. Se observan valores altos de Eh y elevada segregación de Mn^{2+}. La evapotranspiración tiene influencia en los horizontes superiores.

Keywords: hydromorphic soils, iron, manganese, Eh, Argentina.
Palabras claves: suelos hidromórficos, hierro, manganeso, Eh, Argentina.

INTRODUCTION

Wetlands are complex ecosystems that share a number of properties such as saturated soils for at least some part of the year, generally showing distinct hydromorphic features, and supporting plants adapted to waterlogging conditions. Wetlands act as sink, source or transformer of nutrients in biogeochemical cycles and perform additional functions such as flood protection, water supply and groundwater recharge, prevention of saltwater intrusion, shoreline erosion control, and organic carbon sequestration. A comprehensive knowledge of their components and dynamics is essential for their correct management and preservation. This knowledge includes the study of the dynamics of key elements such as Fe and Mn, which are important electron sinks and participate in adsorption, complexation and redox mechanisms (Bartlett, 1999).

Frequent and prolonged water saturation of soils and sediments give rise to biogeochemical processes different from those occurring in aerated soils due to a decrease or loss of molecular oxygen, whose diffusion in aqueous media is low. When oxygen is depleted or its concentration is very low, microorganisms use other electron acceptors to mineralize soil organic matter such as NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-} and CO_2; this sequential transformation corresponds to a decrease of the redox potential (Ponnamperuma, 1972).

Hydromorphism is a condition affecting soils in different climates and landforms. Hydromorphic soils are widespread in Argentina and are well represented in the Pampean Region, particularly in the Paraná River Delta, the Río de la Plata coastal plain and the "Depressed Pampa" in Buenos Aires Province. In these areas the studies have focused on biological and hydrological aspects, including natural and man-modified ecosystems (Kalesnik and Malvárez, 2003; Vilanova *et al*., 2006). Conversely, few studies deal with geochemical properties and dynamics of hydromorphic soils and their relationship with other environmental factors. In this respect, Taboada and Lavado (1986) found a relationship between Eh and the presence of hydromorphic features. Guichon *et al*. (2000) studied a toposequence of slightly hydromorphic soils and found that Fe^{2+} and Mn^{2+} mobilization is linked to topography and that Eh depends on the rainfall occurred in the four days previous to each measurement. Imbellone *et al*. (2001) investigated the geochemical evolution in Vertic Argiudolls planted to rice in relation to management practices and found a maximum segregation of soluble Fe^{2+} and Mn^{2+} during the flooding periods. Geochemical studies of hydromorphic soils are nearly absent in Argentina and rarely performed in South America. Some works along this line have been recently conducted in Brazil (Otero *et al*., 2008) and in marshes of the Patagonian littoral (Bouza *et al*., 2008). This scarcity of specific research is in contrast with the deep knowledge of the hydromorphism process gained in other parts of the world since the beginnings of soil science, especially by the French (Duchaufour, 1977) and German (Schlichting, 1973) schools. Also well developed are applied studies oriented to soil classification, management of paddy soils, soil pollution as well as those related to different branches of natural sciences such as Quaternary research, paleomagnetism, etc. (Zobell, 1946; Patrick and Henderson, 1981; Barlett, 1986; Patrick and Jugsujinda, 1992; Richardson and Vepraskas, 2000; Fiedler and Sommer, 2004).

A large part of the Río de la Plata coastal plain is covered with wetland soils whose geochemical properties and the influence of the different components of the environment are not totally understood. The objectives of this work are: a) to describe the redoximorphic features of the soils; b) to analyze the temporal evolution of Eh, pH, Fe^{2+}, Mn^{2+} and moisture in two poorly drained soils located in different topographic positions and developed in different materials; and c) to establish the relationships of genetic factors with the hydromorphic variables.

STUDY AREA

Geology and geomorphology

The Río de la Plata coastal plain extends along nearly 200 km on the right bank of Río de la Plata, in northeastern Buenos Aires Province. Fluviatile and marine actions have given rise to several landforms. This study was carried out in two different settings: a) mudflat (marine-estuarine sediments) and b) alluvial plain (fluviatile sediments) (Fig. 1). The mudflat is affected by prolonged waterlogging due to the flat relief and low permeability of the sediments and the alluvial plain is subject to high water table and floods from the Río de la Plata and small creeks that cross the area.

The stratigraphic column consists of a basal Plio-Pleistocene unit including the Puelches Formation (sandy fluviatile sediments of Mid Upper Pliocene age) and the "Pampean Sediments" (Ensenada Formation, Riggi *et al*., 1986) deposited from the Upper Pliocene to the Upper Pleistocene. The top of Ensenada Formation is defined by an erosive unconformity overlain by Holocene sediments (Las Escobas Formation, facies Villa Elisa and Punta Lara, and Atalaya Formation, Cavallotto, 1995) deposited after the Last Glacial Maximum, as a consequence of the transgressive-regressive episodes related to the last deglacial-postglacial cycle and constitute the parent materials of the soils. The studied soils are a Natraquert and a Fluvaquent formed in the Facies Villa Elisa of Las Escobas Formation and Río Santiago Formation, respectively.

Climate

Mean annual precipitation is 1040 mm with a fairly uniform seasonal distribution (summer 27.8%, autumn 27.8%; winter 18.8% spring 25.6%). Mean annual temperature is 16.2ºC with means of 10.4ºC in winter and 22.0ºC in summer; extreme temperatures are 41ºC and -5ºC (Data from La Plata city, Facultad de Ciencias Astronómicas y Geofísicas, UNLP. Period 1909-2005). According to the method of Thorthwaite (1948) the climate is humid, mesothermal, with low or zero water deficit and low summer thermal concentration.

The soil moisture regime of the zonal soils is *udic* (Soil Survey Staff, 1999), but the most widespread regime in the coastal plain is *aquic,* or even *peraquic,*

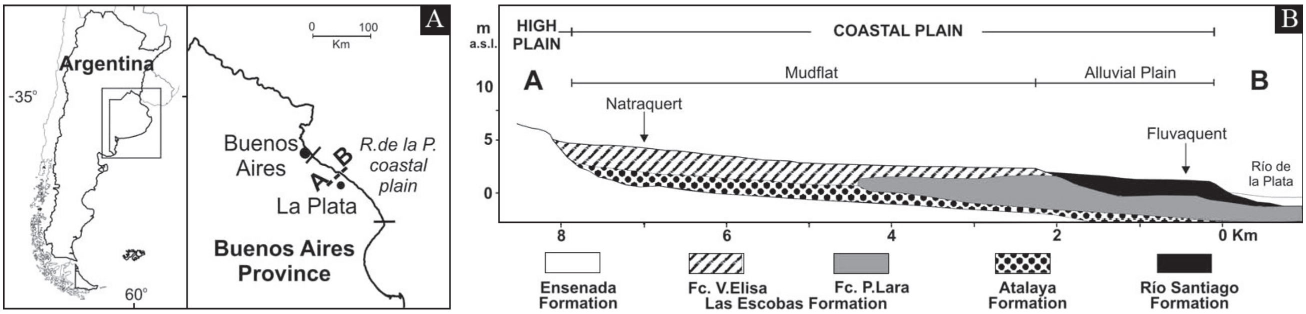

Figure 1. a) Location maps and b) Schematic profile of the study area. Natraquert: 34° 50' 30"S, 58° 04' 20"W. Fluvaquent: 34° 47'10"S, 58° 00' 50"W.

since most of the soils are saturated with water for prolonged periods. The soil temperature regime is *thermic* (mean annual temperature at 50 cm depth: 17.2°C; mean winter and summer temperatures: 11.0 and 21.4°C, respectively), estimated from the air temperatures according to Soil Taxonomy (Soil Survey Staff, 1999). The coastal plain, especially the alluvial plain, is periodically subject to flooding due to a meteorological phenomenon locally known as "sudestada". It consists of strong, gusty southeastern winds, generally accompanied by rain or drizzle which cause an elevation of the estuary water level and overflow of small creeks that cross the alluvial plain.

Soils

In the mudflat the dominant soils are *Vertisols* (*Natraquerts, Epiaquerts*). They have very high clay content (60-80%), with a very high shrink-swell potential. The soils of the alluvial plain are weakly developed and have variable textures, from sandy to clayey. *Entisols* are the most widespread soils, (mainly *Fluvaquents* and some *Endoaquents*). Practically all of the soils of the coastal plain are poorly drained due to waterlogging, flooding or high water table. Selected properties of the studied soils are shown in Table 1.

Redoximorphic features. The soils of the Río de la Plata coastal plain exhibit different and usually well developed redoximorphic features. The Fluvaquents, unlike other hydromorphic soils described as "problem soils" due to a lack of redoximorphic features (Clausnitzer *et al*., 2003), have features that clearly indicate variable aeration conditions. The strong hydromorphic differentiation is revealed by variations in the redoximorphic features. At the bottom of the profile, a nearly permanently saturated horizon (2Cg) with a reduced matrix and almost uniform gley colors (2.5Y 5/3 when dry) is found.

Iron and manganese deposits of the Fluvaquent occur in the zone of irregular capillary rise corresponding to the 2Cxg horizon where the anoxic condition fluctuates. This zone includes at its top a 2-4 mm thick, hard, platy layer, yellowish red (5YR 5/6 and 5YR 5/8) in color, formed by the accretion of pedogenic oxides. The matrix has low chroma when moist (dark gray: 10YR 4/1) and high chroma when dry (light yellowish brown: 10YR 6/4). All the horizon has a motley pattern due to the redistribution of Fe, with zones of depletion or concentration of pedogenic oxides. There are also nodules and low-chroma mottles, more abundant in the hardened layer. They have a heterogeneous morphology related to root metabolism, with a dark core (black: N 2/0 when moist) with dominant manganese oxides and an outer zone with a predominance of iron oxides (strong brown 7.5YR 4/6 when moist and yellowish red 5YR 5/8 when dry). Some bleached domains are also observed. The A horizon is not affected by phreatic water but is frequently flooded. In summary, two possible distribution patterns are observed: on the one hand, the 2Cg horizon developed under strong reducing conditions and loss of elements through phreatic water, and on the other hand, the heterogeneous aeration of the surface horizons (A and 2Cxg) with redistribution of elements within the profile.

The Natraquert exhibits little color differentiation, but a lower oxidation degree than in the Fluvaquent is observed. The characteristic redoximorphic features are low chroma matrix and mottles. The hue of the lowest horizon changes because its parent material is different (loess).

Soil color is a morphologic feature used as an index of anaerobiosis and to characterize the aquic

Horizon	Depth (cm)	pH (paste)	EC (dS m^{-1})	OM (%)	Sand (%)	Silt (%)	Clay (%)	Color (matrix) dry	Color (matrix) moist	Structure (type)	Mottles/ Fe-Mn concr.
Natraquert. Location: 34° 50' 30"S; 58° 04'20"W. Altitude: 4.50 m asl.											
A	0-10	7.6	3.1	7.15	4.1	37.4	58.5	10YR 6/2	10YR2/2	granular	-/-
Bssg1	10-31	8.5	2.5	3.38	3.4	29.4	67.2	2.5Y 6/2	2.5Y 3/2	ang.bl.	-/-
Bssg2	31-70	8.2	1.8	0.74	2.0	21.0	77.0	5Y 4/1	5Y 3/1	ang.bl	-/-
Bssg3	70-115	7.7	1.2	0.74	1.7	21.8	76.5	5Y 4/1	5Y 3/1	ang.bl	-/**
2Cg	115-135+	7.3	<1.0	0.19	27.5	57.4	15.1	7.5YR 8/3	7.5YR 4.5/4	massive	-/-
Fluvaquent. Location: 34° 47'10" S; 58° 00'50"W. Altitude: 2.00 m asl.											
A	0-10	5.5	< 1.0	6.99	64.9	13.3	21.8	10YR 5/2	10YR 3/2	granular	-/-
2Cxg	10-27	6.3	< 1.0	0.26	94.3	3.3	2.4	10YR 6/1	10YR 4/1	massive	***/***
2Cg	27-48+	5.6	< 1.0	0.43	96.9	1.8	1.3	2.5Y 5/3	10Y 4/1	massive	**/**

Table 1. Selected properties of the studied soils. (EC: electrical conductivity, OM: organic matter (Walkley-Black method), *** abundant, **common, * few, - none.)

conditions (Soil Survey Staff, 1999). In the Aquents and Aquerts of the Río de la Plata coastal plain, the color index proposed by Megonigal *et al*. (1993) revealed that for chromas = 2, 75% of the soils have an index ≤ 2, and for chromas < 2, 12.5 % has an index ≤ 2 (Cumba and Imbellone, 1999).

Vegetation

The coastal plain has a variety of plant communities, most of them adapted to poor drainage and in some cases to sodicity/salinity. In the mudflats, the more frequent communities are: saltgrass meadows with *Distichlis spicata, D. scoparia,* accompanied by Bermuda grass *(Cynodon dactylon)* in Natraquerts, and freshwater meadows and marshes with duraznillo *(Solanum glaucophyllum),* carda *(Eryngium pandanifolium),* sedges *(Cyperus prolixus, Carex sp.), Eleocharis sp.* and *Sagittaria trifolia* in Epiaquerts.

The alluvial plain has a more complex mosaic of communities. The higher areas (natural levees) are partially covered with the southernmost forest gallery in the world, where tree and shrub species of subtropical origin are found, such as: laurel blanco (*Ocotea acutifolia*), chal-chal *(Allophyllus edulis),* lecherón *(Sebastiania brasiliensis),* among others. Other vegetation communities include more or less hygrophilous species: ceibo *(Erythrina crista-galli),* rushes *(Scirpus californicus, Juncus pallescens),* willows *(Salix humboltiana),* espadaña *(Zizaniopsis bonariensis),* cattail *(Typha latifolia),* etc. (Vervoost, 1967).

METHODS

Twenty-four nearly monthly Eh and pH determinations and samplings were made in the two upper horizons of the Natraquert and the three horizons of the Fluvaquent from April 1998 to July 2000. Each of those values corresponds to the average of 3 to 5 readings, following the method of Vizier (1970). Eh was measured *in situ* with a millivoltmeter with platinum-tipped electrodes and a calomel reference electrode. The platinum electrodes were calibrated with the Zobell solution, using the equation corrected by Lévy and Toutain (1979) adapted for the calomel electrode [Eh = 182 mV + 2.4 (25 - T°C)]. Eh measurements were corrected to pH 7 with the factor dE (V)/dpH = -0.05974 volts (Bohn, 1971). Extraction of Fe^{2+} and Mn^{2+} was made with a 3% $AlCl_3$ solution (Ignatieff, 1941). Fe^{2+} was analyzed by colorimetry with o-phenanthroline, and Mn^{2+} by atomic absorption spectrophotometry. Moisture was determined gravimetrically. Soil samples were kept in air-tight plastic jars immediately after collection, refrigerated during transport and stored in refrigerator at 4ºC until analyses, which were performed within 24 hours. Reaction (pH) was measured potentiometrically in the field. Other analyses, made in air-dried samples and sieved to pass a 2 mm sieve, include: organic carbon (Walkley-Black method), particle-size distribution (pipet method) and electric conductivity (measured in the saturation extract) (USDA, 1996). Real evapotranspiration was calculated by the serial water balance method on a daily basis (Thornthwaite and Mather, 1957; Pascale and Damario, 1977). The experimental design was slightly different in both soils; in the Fluvaquent all the parameters were measured in all the horizons, whereas in the Natraquert, Eh and pH were measured only in the two upper horizons because the clayey texture prevented electrode insertion at a greater depth.

Soil morphology was described employing the Soil Survey Manual (Soil Survey Division Staff, 1993). Soils were classified at Great Group level according to the Soil Taxonomy system (Soil Survey Staff, 2006).

RESULTS

Data of Eh, Fe^{2+}, Mn^{2+}, moisture (M%) and pH are included in Appendixes 1 and 2. The basic statistical parameters (mean, maximum, minimum, and standard deviation) for each horizon of the two studied profiles were calculated (Table 2). The factor analysis was made by using the original data measured for each variable according to the normalized varimax rigid rotation method (Merodio, 1985; Davis, 1986). A correlation matrix between the variables and the external factors for each soil was calculated to detect possible relationships with each other.

Parameters

Fluvaquent. In the A horizon, Eh and Fe^{2+} values have little differences compared to the underlying horizon (2Cxg), whilst the variability of these parameters is intermediate between the two other horizons. Although the mean and standard deviation of Mn^{2+} in the A horizon are higher than in the 2Cxg and 2Cg horizons, the distortion caused by the anomalous measurement of May 4, 1999 (276.48 ppm) (Appendix 1) should be considered. The A horizon also differs from the other horizons in its higher and more variable moisture contents. The 2Cxg horizon differs from the others in its lower and less variable contents of Fe^{2+} and Mn^{2+}. Nevertheless, it shows the highest variation and the lowest Eh values. The 2Cg horizon is characterized for its higher Fe^{2+} and Mn^{2+} contents. It has also the lowest variability and mean of Eh, although no extremely low values were observed. In the 2Cxg and 2Cg horizons, similar moisture values were found. The variability of this parameter was of the same order of magnitude in both horizons and lower than in the A horizon. The means and standard deviations for pH values are similar in the three horizons (Table 2).

In order to understand a) the relationship between the variables measured and its behavior in each horizon and b) the influence of these variables in the hydromorphic conditions of each horizon, a factor analysis with normalized varimax rotation was used. Data of the five parameters were used; the maximum number of variables was limited to three in order to concentrate on them the influence of all the parameters. The factor analysis accumulates 83% of the system variance (Table 3).

Horizon differentiation was marked by the factor scores representing the variables Mn^{2+}- Moisture (*x* axis) and Eh-Fe^{2+} (*y* axis) for each horizon (Fig. 2). In order to emphasize the differences between the horizons, graphs showing the original data were drawn up. Moisture in the A horizon was always above 45%, whereas in the other horizons that value was rarely exceeded (Fig. 3a). The 2Cg horizon has higher Mn^{2+} contents than the overlying horizon, exceeding 15 ppm in more than half of the measurements. This horizon has generally Fe^{2+} contents higher than 15 ppm (Fig. 3b) and Eh values below 250 mV. In the other horizons, those values were seldom reached.

Natraquert (Appendix 2). The A and Bssg1 horizons have slightly more Fe^{2+} than the three lower horizons. Mn^{2+} content is also higher in the first group of horizons but the difference with the second group is much more marked. Likewise, the variability of those parameters is also much higher in the upper part of the profile. The lowest moisture content is found in the 2Cg horizon. Moisture variability is similar in the B horizons but it differs in the A and 2Cg horizons. The A horizon has lower Eh values and higher moisture content than the Bssg1 horizon (Table 2).

Factor analysis was also applied in this soil in order to clarify the relationship between the variables and its behavior for each horizon. This treatment was made in two steps (Tables 4 and 5) since Eh and pH were not measured in the three lower horizons. The A and Bssg1 horizons are separated clearly from the others on the basis of the factor scores representing the variables Mn^{2+} and moisture (Fig. 4a). The original data reveal this separation. In most cases, Mn^{2+} contents in the upper horizons exceed 30 ppm,

Parameter	Soil	Horizon	Variable				
			Eh	Fe^{2+}	Mn^{2+}	Moisture	pH
Mean	Fluvaquent	A	309.5	4.85	27.95	73.08	6.65
		2Cxg	373.13	1.01	5.56	33.15	6.67
		2Cg	190.21	48.25	21.96	34.29	6.73
	Natraquert	A	321.1	1.75	72.18	74.77	7.85
		Bssg1	441.92	1.00	93.94	62.25	8.04
		Bssg2	-	0.58	13.80	74.94	-
		Bssg3	-	0.57	8.27	76.28	-
		2Cg	-	0.48	6.22	46.63	-
Minimum	Fluvaquent	A	27	<0.09	2.00	37.1	5.7
		2Cxg	-54	<0.09	<0.09	25.63	5.2
		2Cg	47	4.81	3.16	34.29	6.73
	Natraquert	A	215	<0.09	5.71	40.04	7
		Bssg1	313	<0.09	22.86	40.06	7.3
		Bssg2	-	<0.09	1.94	48.01	-
		Bssg3	-	0.10	1.39	58.37	-
		2Cg	-	<0.09	0.9	32.92	-
Maximum	Fluvaquent	A	406	61.32	276.48	118.75	7.7
		2Cxg	535	16.47	43.38	43.58	7.3
		2Cg	362	94	61.35	64.31	7.5
	Natraquert	A	475	11.43	177.19	108.38	8.6
		Bssg1	540	8.63	389.19	83.04	8.8
		Bssg2	-	5.33	40.97	88.2	-
		Bssg3	-	2.8	26.33	100	-
		2Cg	-	2.6	14.65	55.76	-
Standard Deviation	Fluvaquent	A	91.96	12.71	57.65	21.66	0.50
		2Cxg	148.52	3.32	8.95	5.58	0.41
		2Cg	78.14	28.26	15.11	8.09	0.35
	Natraquert	A	67.43	2.99	55.44	17.34	0.54
		Bssg1	57.65	2.03	76.06	11.56	0.46
		Bssg2	-	1.14	10.39	11.49	-
		Bssg3	-	0.82	7.24	10.69	-
		2Cg	-	0.74	3.60	4.89	-

Table 2. Basic statistical parameters of the Fluvaquent and Natraquert horizons (Eh and pH measured only in A and Bssg1 horizons of the Natraquert).

a value seldom reached in the lower horizons (Fig. 4b). This figure also shows that the representative points of the 2Cg horizon are mostly below 55% moisture.

The factor analysis of A and Bssg1 horizons (Table 5) shows that although there is an overlapping of the fields, the A horizon has higher moisture and lower Eh and pH than the Bssg1 horizon (Fig. 5a), whereas in the latter horizon, the Mn^{2+} contents is higher. This is confirmed by the mean content of Mn^{2+} in those horizons (Table 2). The original data show that in the A horizon, moisture is generally higher and Eh is lower than in the Bssg1 horizon (Fig. 5b).

Relationship with external factors

In order to investigate the influence of environmental factors on soil properties, a correlation matrix was computed between the Eh, Fe^{2+}, Mn^{2+}, moisture, pH and a number of external factors, which vary according to the soils (Appendix 3). In addition to analyzing the significant correlations, the cases with correlation values above 0.20 were considered because they could reflect some type of relationship between the external factors and the variables.

In the Fluvaquent, the external factors used are: a) number of days elapsed since the last flood

Factors	Eigenvalue	Total variance (%)	Total variance (cumulative %)
1	1.73	34.61	34.61
2	1.33	26.65	61.25
3	1.12	22.36	**83.61**

Loading matrix

Variables	Factor 1	Factor 2	Factor 3
Eh	0.613	0.026	**-0.647**
Fe^{2+}	0.027	0.010	**0.920**
Mn^{2+}	0.127	**0.794**	0.500
Moisture	-0.235	**0.821**	-0.329
pH	**0.917**	-0.088	0.039

Table 3. Results of the factor analysis with normalized varimax rotation obtained from the variables Eh, Fe^{2+}, Mn^{2+}, moisture and pH of all the Fluvaquent horizons (number of factors restricted to 3).

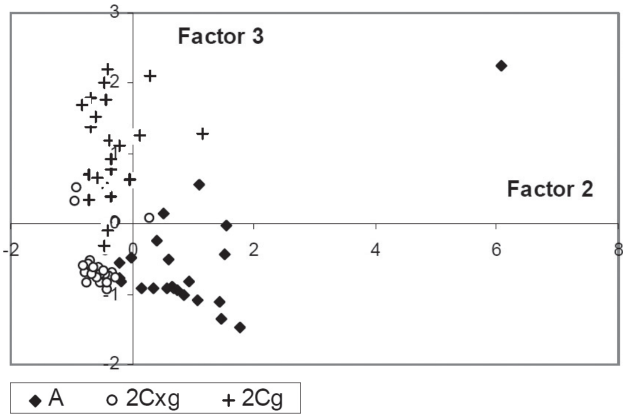

Figure 2. Plot of factor scores on factors corresponding to the factor analysis of the Fluvaquent horizons (Table 3). Factor 2 vs Factor 3.

(Flood), b) water-table depth (WTD) and c) real evapotranspiration (RET) accumulated in the seven days previous to the date of measurement. Only seven significant correlations were obtained (Table 6). Some correlations with values above 0.20, which might also indicate a probable influence of the external factors on some of the variables, are: a) A horizon: Flood - Eh; WTD - Mn^{2+}; b) 2Cxg horizon: Flood - Eh, c) 2Cg horizon: Flood - Fe^{2+}, and WTD and RET with the variables Eh, Mn^{2+} and moisture.

In the Natraquert, the external factor Flood was excluded for the analysis due to the higher topographic position of this soil. On the basis of previous studies (Guichon *et al*., 2000), RET was calculated considering the value accumulated during the 15 days prior to each measurement; WTD was considered only in the two lower horizons. Eight significant correlations were found (Table 6) for Eh, moisture and pH. With respect to Fe^{2+} and Mn^{2+}, no significant association was detected with the external factors in any horizon. Likewise, the correlation coefficients would suggest some relationships between RET and Fe^{2+} in the A horizon (-0.24), and between WTD and Fe^{2+} in the 2Cg horizon (-0.30).

DISCUSSION

The results of the parameters measured reflect fairly clearly the differences between both soils and between different horizons in each soil; the relationship between external factors and the hydromorphism degree is also evident. Both soils are hydromorphic, but the local genetic factors, both static and dynamic, differ in type and degree. Thus, two totally different soils have evolved, where the water dynamics (infiltration, percolation, retention and leaching) is conditioned by topographic position, texture, vegetation and water source. The Fluvaquent develops in sandy (65-95% sand) coastal levees, under a gallery forest. Surface water derives from floods (southeastern storms) and groundwater from phreatic rise; there is less influence of rainwater, evapotranspiration is low and infiltration and percolation are rapid. The Natraquert develops in a nearly level mudflat with clayey sediments (2-4% sand), covered by herbaceous and shrubby species. Water input is from rainwater and phreatic water and losses are mainly due to evapotranspiration, whereas infiltration and percolation are low.

Fluvaquent

This soil has morphologic features indicating varying hydromorphic conditions in each horizon. Thus, the 2Cg horizon has colors which indicate a reduced matrix, whereas the 2Cxg horizon exhibits a motley pattern indicating an alternation of oxidating and reducing conditions, which affect this horizon irregularly. Regarding the hydromorphic parameters, the A horizon differs from the other horizons in the lower content and higher variability of moisture, which could be ascribable to its texture and higher organic matter content.

The very high Eh variability in the 2Cxg horizon could suggest that it has a low buffering effect and

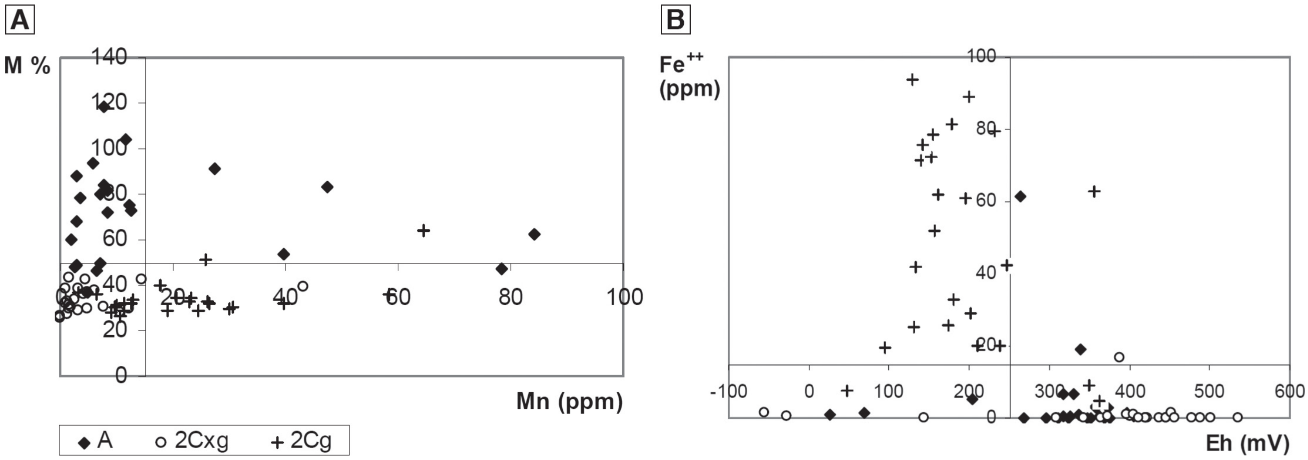

Figure 3: Plots of the values of the variables in the Fluvaquent horizons. A) Mn^{2+}- Moisture; B) Eh - Fe^{2+}.

that the diffusion of air and water is heterogeneous in the soil mass. However, Fe^{2+} and Mn^{2+} contents exhibit little variability. The external changes seem to be reflected rapidly in Eh, but not in Fe^{2+} and Mn^{2+} contents. It should be emphasized in this regard that Eh is an instantaneous and point measurement, which responds rapidly to changes, but records the soil conditions in an extremely small volume in a given moment. Conversely, Fe^{2+} and Mn^{2+} concentrations reflect complex physico-chemical equilibria involving a kinetics-controlled process, which is not instantaneous. Therefore, Fe^{2+} and Mn^{2+} concentration are the result of the presence of hydromorphic conditions prevailing during some days prior to the measurement. Moreover, Fe^{2+} and Mn^{2+} concentrations and moisture content are measured in a given soil volume. Therefore, their trend to precipitate or remain soluble will depend on the persistence of given hydromorphic conditions. In addition, the methods used to extract these elements, which include a very short shaking time (one minute), probably displace only a fraction of the soluble and exchangeable forms, mainly located in the macropores but not in the micropores. However, moisture measurements, which involve drying a soil volume at 105ºC, include water contained in both pore types. The 2Cg horizon is fairly stable, except in Fe^{2+} content, and its parameters reveal a greater degree of hydromorphism. These characteristics would be ascribable to a permanent high water table.

Natraquert

The nearly permanent saturation condition, observed in the field and confirmed by the analysis of moisture, is reflected in the homogeneous hydromorphic colors but not in high Fe^{2+} or low Eh values. Relatively high Mn^{2+} content was only found in the A and Bssg1 horizons. The very low content of Fe^{2+} is probably due to the relatively high values of Eh and pH because when the latter parameter is above 7.0, Fe^{2+} precipitates as $Fe(OH)_2$ (Garrels and Christ, 1965), but Mn^{2+} is not affected by this condition since precipitation occurs above pH 8.0. Likewise, the upper horizons exhibit a greater variability of Fe^{2+} and Mn^{2+} contents than the lower horizons; this would indicate greater fluctuations of hydromorphic conditions due to a more rapid gas exchange with the atmosphere and differences in organic activity. It should be mentioned in this respect that in the two upper horizons, the abundance of roots, especially from grasses and sedges, is remarkable. These live roots may modify the Eh values since some species are capable of transporting oxygen from their aerial parts to the roots, where it is released in the rhizosphere (Otero *et al.*, 2009). This translocation is usually made through air spaces in the root cortex known as aerenchyma, more developed in waterlogging-tolerant species like those found in the study area (Glinski and Lipier, 1990). The lower moisture content in the 2Cg horizon would be ascribable mainly to the coarser texture of this horizon.

Summing up, the different hydromorphic and genetic conditions of the soils are reflected in the higher Fe^{2+} contents and lower Eh in the Fluvaquent, which reveals a greater dynamic and hydromorphic condition compared to the Natraquert, whose greater stability would be ascribable to its much finer texture. However, in the A and Bssg1 horizons of the

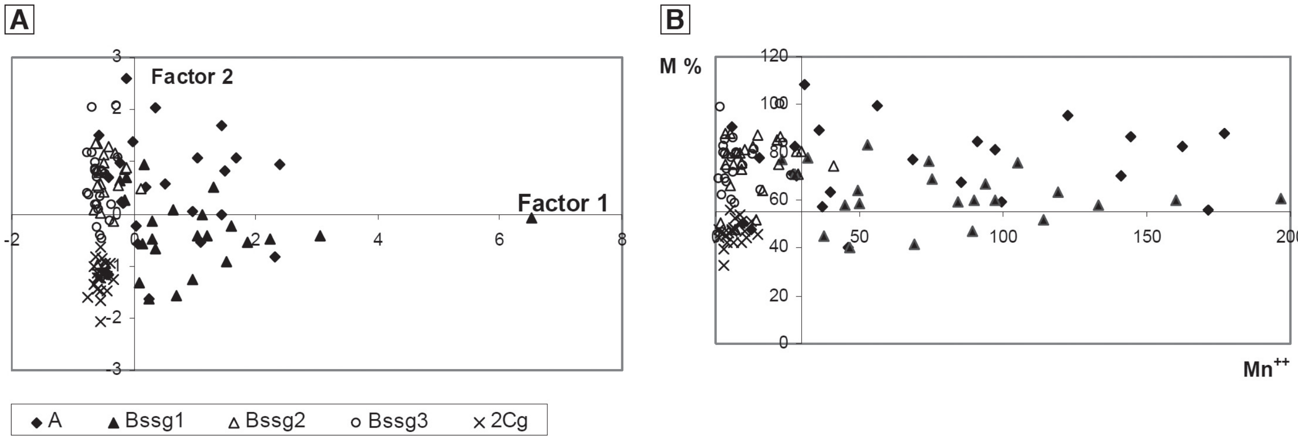

Figure 4. Plots of A) factor scores on factors corresponding to the factor analysis (Table 4). Factor 1 vs Factor 2. B) values of the variables Mn^{2+} and Moisture (all horizons of the Natraquert).

Natraquert, much more Mn^{2+} is dissolved than in the three Fluvaquent horizons; this might be linked to compositional differences in the parent materials, but further investigations would be necessary to elucidate this point.

Relationships with external factors

In the Fluvaquent, the external factors considered have different influence on each horizon and parameter. Floods might probably induce a decrease of Eh in the A and 2Cxg horizons (Table 6); this is complemented by the fact that the lowest Eh values measured in both horizons correspond to a flood occurred in the 4 days previous to the reading. Conversely, the greater Eh stability in the 2Cg horizon would be related to the water-table position. However, this external factor has no influence on Fe^{2+} content, but it affects Mn^{2+} concentration especially in the two lower horizons. These differences could be explained because floods are short and are reflected in the Eh, which is an instantaneous measurement, but not in Fe^{2+} and Mn^{2+} equilibria, which depend on slower chemical reactions. Besides, the coarse texture of this soil favors infiltration and percolation, which would be more rapid in the A horizon. Thus, in the two lower horizons, hydromorphic conditions would have longer duration, allowing Mn to be reduced but not Fe. The pH rise observed after the floods in the A horizon could be attributed to the slightly brackish waters of the estuary; the absence of this effect in the other horizons would indicate that salts concentrate in the upper horizon as a consequence of evapotranspiration.

Finally, evapotranspiration seems to be the external factor that less affects the parameters measured, even in the A horizon which is usually the most sensitive to this factor. The correlation

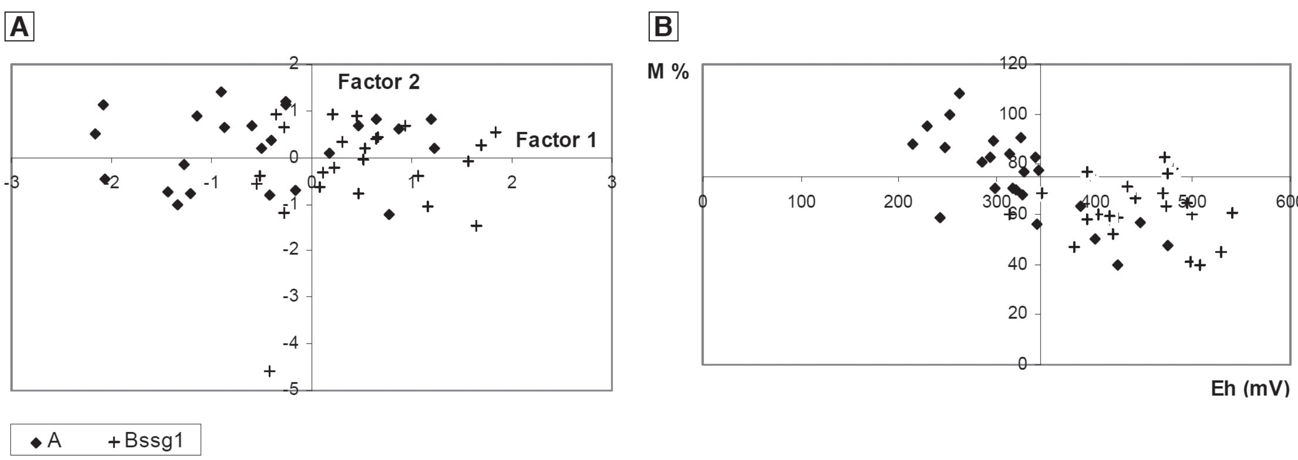

Figure 5. Plots of A) factor scores on factors 1 and 2 corresponding to the factor analysis (Table 5), performed with the five variables. B) values of the variables Moisture-Eh (two upper horizons of the Natraquert).

between RET and Fe^{2+} content in the 2Cg horizon could be attributed to the concentration of this element induced by the evapotranspiration from the tree canopy, which extracts more water from deep horizons than from the upper ones. Another significant correlation was found between RET and pH, which could be due to concentration of the soil solution in macropores upon evapotranspiration.

In the Natraquert, the external factor more affecting the measured parameters is evapotranspiration, mainly in the two upper horizons. In the A and Bssg1 horizons there are significant correlations with all the variables, except for Mn^{2+} and Fe^{2+} contents in Bssg1. In the middle horizons (Bssg2 and Bssg3) there is seemingly a correlation between water content and evapotranspiration. The deepest horizon would be the only one without correlation with this external factor. Curiously, no significant correlation was found between Mn^{2+} and evapotranspiration, despite the high content and variability of this element in the two upper horizons as compared with the other horizons.

Water-table fluctuations have seemingly little influence in the lower horizons. The correlation between this factor and water content in the Bssg3 horizon suggests that it may be affected by the capillary fringe. The permanent saturation by phreatic water in the lowest horizon (2Cg) would favor some Fe^{2+} segregation.

To summarize, field observations reveal that in the Fluvaquent the 2Cg horizon is usually saturated, whereas in the Natraquert this condition affects generally the whole profile throughout the year, except for a short period in summer. In the Natraquert, the behavior of the hydromorphic variables studied would be determined by evapotranspiration, vegetation and texture. In the Fluvaquent this dynamics is affected also by Flood and WTD. The effect of RET on the variables measured is more distinct in the Natraquert, since in the Fluvaquent those fluctuations are buffered by the tree and shrub cover and by the effect of other external factors.

Factors	Eigenvalue	Total variance (%)	Total variance (cumulative %)
1	1.42	47.17	47.17
2	0.94	31.40	78.57
3	0.64	21.43	100

Loading matrix

Variables	Factor 1	Factor 2	Factor 3
Fe^{2+}	0.177	0.074	**0.981**
Mn^{2+}	**0.984**	0.036	0.176
Moisture	0.035	**0.997**	0.071

Table 4. Results of the factor analysis with normalized varimax rotation calculated from the variables Fe^{2+}, Mn^{2+} and Moisture of all the Natraquert horizons.

Factors	Eigenvalue	Total variance (%)	Total variance (cumulative %)
1	2.40	47.93	47.93
2	1.15	23.02	70.95
3	0.75	15.01	85.96

Loading matrix

Variables	Factor 1	Factor 2	Factor 3
Eh	0.891	0.096	-0.157
Fe^{2+}	-0.131	-0.160	0.965
Mn^{2+}	-0.058	-0.965	0.156
Moisture	-0.806	0.178	0.219
pH	0.873	0.203	0.069

Table 5. Results of the factor analysis with normalized varimax rotation calculated from the variables Eh, Fe^{2+}, Mn^{2+}, moisture and pH of the A and Bssg1 horizons of the Natraquert (number of factors restricted to 3).

Reduction degree

With respect to the reduction degree, the Eh of both soils is highly variable. The period when the soil is in a reduced status can be estimated by taking as a proxy the percentage of time with Eh below 170 mV (onset of Fe-oxide reduction). This value is considered critical since Fe^{2+} mobilization and redistribution is favored when Eh drops below it at pH 7 (Fiedler and Sommer, 2004). Also, a redox potential of 300 mV is usually considered a boundary between reduced and oxygenated soil (Ponnamperuma, 1972) or 450 mV for Mn reduction (Fiedler and Summer, 2004). On the basis of these values, a scale was developed to characterize the redox status of the studied soils considering the horizon with the lowest Eh value, as follows: <170 mV: reduced soils; 170-300 mV moderately reduced soils; >300 mV non-reduced soils. According to this scale, both soils are moderately reduced. The Fluvaquent would be a moderately reduced soil since the average Eh of the 2Cg horizon is 190 mV.

Soil	Horizon	External factor	Correlations				
			Eh	Fe^{2+}	Mn^{2+}	Moisture	pH
Fluvaquent	A	Flood	0.22	-0.10	-0.09	0.15	**-0.42**
		W-T depth	-0.23	-0.17	-0.22	-0.15	-0.25
		RET x 7d	0.00	-0.00	-0.10	0.25	0.11
	2Cxg	Flood	0.21	-0.16	**-0.40**	0.14	0.05
		W-T depth	-0.08	-0.02	**-0.48**	**-0.48**	0.02
		RETx 7 d	-0.04	-0.15	-0.03	0.01	0.04
	2Cg	Flood	-0.05	-0.31	**-0.44**	-0.15	0.13
		W-T depth	0.30	-0.04	-0.29	-0.24	0.17
		RET x 7 d	-0.37	**0.49**	0.26	0.32	0.41
Natraquert	A	RET x 15d	**0.65**	-0.24	-0.02	**-0.63**	**0.66**
	Bssg1	RET x 15d	**0.48**	-0.01	-0.15	-0.47	0.51
	Bssg2	RET x 15d	-	0.12	0.06	-0.23	-
	Bssg3	RET x 15d	-	0.07	0.26	**-0.47**	-
		W-T depth	-	-0.14	0.11	**-0.44**	-
	2Cg	RET x 15d	-	0.11	0.37	-0.05	-
		W-T depth	-	-0.30	0.34	0.13	-

Table 6. Correlation matrix between the variables Eh, Fe^{2+}, Mn^{2+} and Moisture and the values of the external factors included in Appendix 3 for both soils, discriminated by horizon. Significance level: $p=0.05$.

Conversely, the Natraquert would be a non-reduced soil as the average value in the A horizon is 321 mV. However, if the months with water deficit (December, January, February) are excluded, the average value is 298 mV. Thus, this soil would be in a moderately reduced condition for 9 months in the year. The clay and silt loam horizons of the Natraquert have Eh that are nearer the oxidized than the reduced condition. However, field observations show that the soil is wet most of the year.

CONCLUSIONS

Redox reactions are usually sequencial in geochemical redox systems under control. In natural media, such as the studied soils, such sequenciality is not observed as a consequence of the time-space variability of the soil system. However, the Eh, Fe^{2+}, Mn^{2+} variations have permitted: a) to characterize the hydromophic state more precisely than the natural drainage classes (Soil Survey Division Staff, 1993), which use mainly qualitative criteria; b) to determine the lack of seasonality in the occurrence of maximum and minimum contents of soluble Fe^{2+} and Mn^{2+}; and c) to establish some relationships with the soil-forming factors. The soil-forming factors act in combination, affecting the water dynamics and the reducing capacity of the system, although the influence of texture is decisive.

None of the soils reached extremely reduced conditions since negative Eh values were measured exceptionally. The Fluvaquent exhibited lower Eh values in agreement with greater Fe^{2+} and Mn^{2+} segregation near the bottom of the profile. Conversely, in the Natraquert higher Eh values and a high Mn^{2+} segregation were recorded.

The low topographic position of the Fluvaquent and the vicinity to the Río de la Plata coastline lead to frequent floods (overflow of the Río de la Plata and nearby creeks) and a shallow water table. The marked variability of the properties measured is reflected in the abundance of redoximorphic features, which are more plentiful near the upper boundary of the fluctuating water table. Floods have a strong influence on the redox status since the waters transport particulate and soluble organic matter. The effect of rainfall is less important because water is partially retained by the forest and shrub canopy. The coarse texture has affected the dynamics of the hydromorphic processes by favoring rapid movement of water from different origins.

The redox status of the Natraquert denotes the strong influence of the fine texture and the flat relief which induce waterlogging. The A horizon is more intensively affected by rainfall because of the low permeability of the underlying horizons, whereas the phreatic water affects only the deepest horizons.Since the soil has a high water-holding capacity, a longer period of accumulated rainfall would be needed to produce changes in the redox status. In spite of the extended humid period, Eh and pH conditions do not permit an important Fe^{2+} solubilization, whereas the solubilization of Mn^{2+} is high.

The Fluvaquents and Natraquerts are Holocene, hydromorphic soils, widely distributed in the Río de la Plata coastal plain. The geochemical properties found in the studied pedons can be extrapolated to similar mapping units of the region.

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Appendix 1. Values of Eh (mV), Fe^{2+} (ppm), Mn^{2+} (ppm), Moisture (%) and pH for the studied horizons in the Fluvaquent.

	Eh			Fe^{2+}			Mn^{2+}			Moisture			pH		
Date	A	2Cxg	2Cg	A	2Cxg	2Cg	A	2Cxg	2Cg	A	2Cxg	2Cg	A	2Cxg	2Cg
8/Apr/98	323	143	178	0.10	<0.09	81.23	12.12	14.64	58.36	75.55	42.43	35.94	6.4	6.7	6.7
2/Jun/98	336	388	247	1.12	16.47	42.39	7.24	43.38	9.66	80.35	38.89	30.06	6.7	7.0	6.5
6/Jul/98	268	364	362	<0.09	<0.09	4.81	84.08	3.09	19.01	62.52	29.05	28.87	6.5	6.6	7.3
13/Aug/98	352	477	239	<0.09	<0.09	19.87	12.50	4.88	39.73	72.71	29.92	32.13	6.7	7.1	7.1
7/Oct/98	312	344	95	<0.09	<0.09	19.40	7.79	4.61	17.76	118.75	42.12	39.95	6.2	6.3	5.8
10/Nov/98	362	446	132	0.61	<0.09	25.43	11.59	4.68	30.51	103.98	37.12	30.74	6.4	6.2	6.4
15/Dec/98	205	400	180	5.28	0.56	33.03	39.79	7.73	29.86	53.68	30.15	30.00	7.0	6.5	6.8
26/Jan/99	330	396	162	6.90	0.81	61.90	5.90	6.00	25.80	93.85	37.94	50.98	6.3	6.4	6.5
16/Mar/99	406	421	157	0.43	<0.09	52.00	27.40	4.15	64.51	91.47	35.83	64.31	6.7	6.7	6.8
4/May/99	264	308	134	61.32	<0.09	42.13	276.48	3.35	26.24	108.61	38.77	32.60	6.3	7.0	6.8
26/May/99	318	489	202	0.34	0.10	29.00	2.79	<0.09	9.19	48.48	26.20	28.17	6.1	6.7	7.0
22/Jun/99	347	422	211	<0.09	0.10	20.06	2.95	1.77	13.03	67.69	43.58	33.21	6.6	6.9	7.5
19/Jul/99	368	420	173	0.10	<0.09	25.92	2.74	2.73	12.74	48.34	33.98	31.92	6.4	6.7	6.9
31/Aug/99	375	535	128	0.10	0.10	94.00	2.00	1.50	23.10	60.28	30.95	34.30	6.6	7.3	6.5
23/Sep/99	27	-28	356	1.08	0.31	62.87	3.52	0.81	26.60	78.40	32.08	32.24	6.3	6.7	7.1
26/Oct/99	358	438	195	3.41	0.10	60.86	8.53	0.10	11.19	72.09	25.63	28.73	6.5	6.7	6.9
30/Nov/99	327	446	139	0.68	<0.09	71.30	7.89	1.29	20.79	83.93	32.46	34.69	6.5	6.7	6.8
14/Dec/99	397	502	152	1.44	0.10	72.58	6.96	1.34	22.98	49.89	27.06	32.54	7.7	7.2	6.8
26/Jan/00	373	453	155	2.84	1.38	78.68	4.93	12.24	9.87	37.10	29.77	31.41	7.5	6.6	6.8
21/Mar/00	69	-54	232	1.57	1.34	79.45	8.41	10.62	11.20	81.68	27.68	31.97	5.7	5.2	6.5
25/Apr/00	358	373	141	2.80	0.62	75.50	2.92	1.55	10.80	87.92	29.34	26.04	7.7	6.5	6.3
29/May/00	317	405	199	6.75	1.12	88.93	47.50	1.86	24.46	83.22	30.35	28.94	6.9	6.7	6.7
12/Jun/00	297	456	47	0.10	0.10	7.58	6.38	1.11	3.16	46.67	38.38	37.04	6.5	6.8	6.4
13/Jul/00	339	411	349	19.04	0.10	9.13	78.32	0.10	6.44	46.86	25.83	36.10	7.4	6.8	6.7

Appendix 2. Values of Eh (mV), Fe^{2+} (ppm), Mn^{2+} (ppm), Moisture (%) and pH of the Natraquert horizons (Eh and pH measured only in A and Bssg1 horizons).

	Eh		Fe^{2+}					Mn^{2+}					Moisture					pH	
Date	A	Bssg1	A	Bssg1	Bssg2	Bssg3	2Cg	A	Bssg1	Bssg2	Bssg3	2Cg	A	Bssg1	Bssg2	Bssg3	2Cg	A	Bssg1
8/Apr/98	253	540	<0.09	<0.09	<0.09	2.15	2.60	55.97	196.79	28.14	13.72	6.06	99.72	60.90	80.26	81.42	41.94	7.0	8.8
2/Jun/98	215	395	11.43	<0.09	<0.09	<0.09	<0.09	177.19	105.22	29.75	7.50	6.46	87.78	75.35	80.55	79.07	48.09	7.2	7.5
6/Jul/98	313	404	<0.09	0.10	<0.09	<0.09	<0.09	91.09	89.94	9.14	3.04	12.63	84.40	60.20	73.10	79.80	51.00	7.3	7.8
13/Aug/98	243	313	1.42	0.10	0.10	<0.09	<0.09	99.46	97.19	8.31	3.12	6.91	59.00	60.00	80.00	79.00	48.00	7.0	7.5
7/Oct/98	316	442	5.57	<0.09	<0.09	<0.09	<0.09	141.24	93.96	14.88	22.70	5.74	70.42	66.80	87.15	100.00	47.92	7.9	7.9
10/Nov/98	320	470	0.52	1.28	0.64	<0.09	0.10	28.31	75.28	8.99	3.99	9.94	70.10	68.70	75.93	67.63	47.13	7.7	8.1
15/Dec/98	298	423	0.76	0.10	0.10	0.44	0.10	27.18	50.26	40.97	5.53	4.99	70.57	58.64	74.12	77.88	55.76	7.5	8.3
26/Jan/99	294	473	<0.09	<0.09	<0.09	1.36	1.82	162.30	119.13	4.80	3.90	8.90	82.75	63.20	88.20	72.95	51.12	8.3	8.6
16/Mar/99	447	416	0.10	0.75	0.54	0.01	<0.09	37.10	44.70	7.40	7.50	8.86	56.94	57.85	79.63	79.76	42.54	8.4	7.9
4/May/99	326	392	0.10	0.10	0.43	0.41	1.58	85.12	133.24	21.43	23.67	8.33	67.74	58.08	85.22	83.74	53.87	8.5	7.3
26/May/99	343	499	0.43	1.39	0.37	1.83	<0.09	15.43	160.35	6.04	6.10	5.70	77.64	60.27	74.85	86.10	47.17	8.2	8.4
22/Jun/99	324	434	0.10	0.10	0.55	0.01	<0.09	5.71	27.70	10.26	5.98	4.57	90.45	70.92	81.12	71.62	46.60	7.9	7.5
19/Jul/99	297	479	<0.09	0.50	<0.09	<0.09	<0.09	36.07	31.85	3.72	1.79	2.53	89.08	78.02	79.85	99.03	46.39	7.7	8.0
31/Aug/99	285	471	9.40	1.50	2.50	2.80	1.90	97.10	52.91	22.59	9.56	10.78	81.04	83.04	86.31	74.02	44.26	7.8	8.4
23/Sep/99	340	475	0.89	8.63	0.74	0.50	0.68	27.69	73.96	12.74	15.51	0.90	82.53	76.40	82.51	64.26	44.58	8.3	8.4
26/Oct/99	342	415	2.79	5.78	5.33	2.13	<0.09	171.41	84.13	28.93	26.33	6.54	55.84	59.56	70.96	70.36	52.66	8.6	7.9
30/Nov/99	386	494	0.70	<0.09	0.10	0.10	<0.09	39.67	49.71	21.87	6.88	8.58	63.26	64.35	75.18	58.37	50.76	8.4	8.1
14/Dec/99	475	529	0.36	0.10	0.10	0.43	0.10	12.33	37.53	5.26	13.09	2.91	47.77	45.26	66.41	78.80	39.24	8.4	8.8
26/Jan/00	423	498	0.10	<0.09	0.55	<0.09	0.10	46.17	69.27	6.92	5.61	14.65	40.04	41.31	48.01	59.70	45.84	8.5	8.5
21/Mar/00	401	508	0.51	0.10	0.10	<0.09	<0.09	9.49	46.41	1.94	1.98	2.94	50.12	40.06	50.45	61.81	32.92	8.2	8.6
25/Apr/00	328	418	1.09	0.10	0.10	<0.09	<0.09	68.38	113.78	16.11	3.28	3.82	76.72	52.13	64.23	69.04	42.17	8.0	7.9
29/May/00	229	379	1.69	1.00	1.02	0.62	1.15	122.52	89.25	14.05	3.13	3.64	95.28	47.22	51.59	85.32	44.82	7.0	7.5
12/Jun/00	247	346	3.65	1.71	<0.09	<0.09	<0.09	144.33	389.19	3.39	1.39	1.64	86.93	68.80	75.07	68.87	46.47	7.3	7.4
13/Jul/00	262	393	0.10	<0.09	<0.09	<0.09	0.10	31.14	22.86	3.56	3.06	1.33	108.38	76.90	87.95	82.21	47.81	7.3	7.8

Appendix 3. External factors (Flood, WTD: water-table depth and RET: real evapotranspiration) considered in the statistical correlations.

	Fluvaquent			Natraquert	
Date	Flood [1]	WTD (m)	RET x 7 [2] (mm)	WTD (m)	RET x 15 [2] (mm)
8/Apr/98	0	no data	14	1.10	29
2/Jun/98	no data	no data	7	1.15	17
6/Jul/98	26	0.35	6	1.20	14
13/Aug/98	2	0.45	5	1.10	13
7/Oct/98	20	0.16	13	1.00	25
10/Nov/98	18	0.50	16	1.10	32
15/Dec/98	2	0.40	20	1.80	25
26/Jan/99	17	0.25	27	1.80	49
16/Mar/99	5	0.45	17	1.20	39
4/May/99	7	0.25	13	1.00	27
26/May/99	9	0.45	6	0.95	14
22/Jun/99	36	0.45	7	1.00	15
19/Jul/99	5	0.40	4	1.00	9
31/Aug/99	9	0.30	9	1.00	18
23/Sep/99	4	0.82	13	1.10	23
26/Oct/99	27	0.90	20	1.14	37
30/Nov/99	1	0.25	22	1.50	48
14/Dec/99	9	0.45	22	1.20	46
26/Jan/00	3	0.35	20	1.30	45
21/Mar/00	4	0.45	14	1.80	29
25/Apr/00	39	0.60	12	1.80	25
29/May/00	6	0.33	9	1.20	17
12/Jun/00	20	0.45	8	1.15	16
13/Jul/00	no data	0.40	3	1.05	11

[1] Number of days elapsed since the last flood
[2] Real evapotranspiration accumulated in the 7 (Fluvaquent) and 15 (Natraquert) days previous to each measurement. Data supplied by Chair of Hydrogeology (Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata)