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Wetland soils under rice management and seawater intrusion: Characterization and classification

Suelos de humedal bajo manejo de arrozal e intrusión de agua de mar: caracterización y clasificación
Solos de zonas húmidas sob gestão de arrozal e intrusão de água do mar: caraterização e classificação

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ABSTRACT

Wetlands started to gain attention when the scientific community began investigating these resources in the eighties. Water, wildlife, and vegetation attracted most of the interest and funding, whereas soils were relegated from research efforts. Despite this situation, US researchers started developing a specific terminology and methodologies for hydric soils in order to unveil a new soil class that could offer great agricultural and environmental opportunities. In Spain, similar studies are practically nonexistent, and so we carried out a study of wetland soils examining 19 profiles and 133 pits in the Albufera of Valencia, a marsh area cultivated with rice. The aim of this paper was to define the morphology and physico-chemical properties of these hydric soils in order to classify them and to correlate those properties with three topographic variables: distance to the sea, distance to the lagoon and height above the sea level. The soils showed an alluvial character with moderate carbonate content and a high variation in organic matter content due to the management of paddy fields. The proximity to the sea and the different intrusion processes revealed salinity as the most important factor in these soils, which were classified as Entisols and Aridisols.

RESUMEN

Históricamente, el estudio de los humedales ha experimentado una falta de atención específica aunque esta tendencia cambió en los años ochenta cuando la comunidad científica comenzó a investigar sus recursos. Desde entonces se estudiaron el agua, la fauna y la vegetación mientras que los suelos de humedales no han sido ampliamente investigados. Sin embargo, los investigadores estadounidenses comenzaron a desarrollar metodologías y terminología específica para una nueva clase de suelos: los suelos hídricos, que presentan una gran importancia agrícola y ambiental. En España, el desarrollo ha sido prácticamente escaso y para contrarrestar esa situación, el presente trabajo desarrolla un estudio en un humedal con 19 perfiles de suelos y 133 sondeos en la Albufera de Valencia, una zona de marjal donde se cultiva arroz. El objetivo de este trabajo es definir la morfología y las propiedades físicas y químicas de los suelos hídricos con el fin de clasificarlos y correlacionar esas propiedades con tres variables topográficas: la distancia al mar, la distancia a la laguna y la altura sobre el nivel del mar. Como resultado, los suelos del humedal mostraron un carácter aluvial con un contenido de carbonato moderado y una alta variación en el contenido de materia orgánica debido a la gestión de los arrozales. La proximidad al mar y los diferentes procesos de intrusión hicieron de la salinidad el aspecto más importante en estos suelos. Entisoles y Aridisols fueron los dos órdenes de suelos que se encontraron en este humedal.

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RESUMO

As zonas húmidas pantanosas começaram a ser alvo de atenção quando a comunidade científica começou a investigar esses recursos na década de oitenta. Até então, a água, a vida selvagem, e a vegetação tinham atraído a maioria do interesse e do financiamento, enquanto que os solos foram postos de lado pela investigação. Apesar desta situação, os investigadores dos Estados Unidos começaram a desenvolver uma terminologia específica e metodologias para solos hídricos a fim de tentar descobrir uma nova classe de solo que pudesse vir a oferecer grandes oportunidades agrícolas e ambientais. Em Espanha, estudos desta natureza são praticamente inexistentes, pelo que levámos a cabo um estudo dos solos de regiões pantanosas examinando 19 perfis e 133 poços na Albufeira de Valencia, numa área de pântano cultivada com arroz. O objetivo deste trabalho foi definir a morfologia e as propriedades físico-químicas destes solos hídricos a fim de os classificar e correlacionar essas propriedades com três variáveis topográficas: distância ao mar, distância à lagoa e altura acima do nível do mar. Os solos apresentaram um caráter aluvial com conteúdo em carbonatos moderado e uma alta variação no teor de matéria orgânica devido a gestão dos arrozais. A proximidade com o mar e os processos de intrusão diferentes revelaram a salinidade como o factor mais importante nesses solos, que foram classificados como Entissolos e Aridissolos.

KEY WORDS
Soil salinity, hydric soil, paddy soil, aquic regime, Albufera of Valencia, soil organic matter

PALABRAS CLAVE
Salinidad del suelo, suelo hídrico, suelo de arrozal, régimen ácuico, Albufera de Valencia; materia organica del suelo

PALAVRAS-CHAVE
Salinidade do solo, solo hídrico, solo de arrozal, regime aquífero, Albufeira de Valencia, matéria orgânica do solo

1. Introduction

Wetlands occupy an area between 8 and 10 million km^2 and represent around 5-7% of the world's surface (Lehner and Döll 2004; Mitsch and Gosselink 2007). Although society has considered wetlands to be unsanitary areas where diseases and poverty reduce life expectancy, human civilizations have been using them for their own benefit since ancient times (McInnes 2011). The lack of scientific knowledge about wetland resources was reflected in a high level of degradation in the past. The intensive use of pesticides and fertilizers associated with inappropriate agricultural management were the main causes of biodiversity loss (Verhoeven and Setter 2010). The term wetland was first used in USA by Shaw and Fredine (1956) and can be defined as a natural area with three main features: i) water on the surface or close to it (root zone); ii) presence of hydric soils that differ from the surrounding soils, and iii) vegetation adapted to wet conditions (Mitsch and Gosselink 2007). Although water and vegetation were studied early on, soil was the last element to be investigated since it requires a complicated sampling process with a continuous or semi-permanent layer of water on the surface that makes the soil profile description more difficult.

Cowardin et al. (1979) introduced the term "hydric soil" and the National Technical Committee of Hydric Soils (NTCHS) defined it as a soil formed under conditions of saturation, flooding, or ponding during the growing season with anaerobic conditions in the upper part (USDA-NRCS 2010). Several researchers have attempted to determine the time period required for the formation of aquic conditions, but their results have been completely different depending on environmental conditions (Vepraskas et al. 1999; He et al. 2003). It should be noted that flooding situations induced by humans may modify that critical time period because the natural hydric conditions are altered. This action is the most important in rice management and defines the character of hydric soils. The world rice cultivated area is 162 million ha and it occupies 22% of harvested areas (GRiSP 2013; FAO 2014). Asia is the main producer of rice which explains why paddy soils were first investigated in this continent. Kyuma (2004) noted that the first publication about hydric soils in rice fields was the study carried out by Osugi and Takusima (1936), which focused on differences between paddy and non-paddy areas. Most of the related documents on this subject were written in Japanese and so were not accessible to the international scientific community until recently, with the result that knowledge development did not start until the first publication of "Field Indicators of Hydric Soils in the United States" (1996). In the last 30 years the knowledge base about hydric soils has been improved in several relevant topics such as organic matter accumulation (Delaune et al. 2013; Wissing et al. 2014), Climate Global Change implications (Pan et al. 2003), redoximorphic features (Vepraskas and Lindbo 2012), flooding regime consequences (Van den Berg and Loch 2000; Yue-Qin et al. 2009), salinity (Álvarez et al. 2000; Nguyen et al. 2014) and rice management and the soil profile evolution in chronosequences (Kölbl et al. 2014; Huang et al. 2015). In Spain, the list of studies about hydric soils can be reduced to experiments carried out in peatland areas or salt marshes (Álvarez et al. 2000; Álvarez et al. 2001; Gallardo, 2003; Álvarez-Rogel et al. 2007; Martínez et al. 2009; Gimeno-García et al. 2013).

The area of the Albufera of Valencia is not an exception and presents the same lack of information about hydric soil characteristics. The soil forming processes, salt content, soil classification, soil morphology, and so on, have not been investigated systematically. Only a few studies have been conducted in certain parts of the park, for instance the work by Rubio et al. (1998), who analysed the sandy soil area between the beach and the marsh. To fill that lack of knowledge, an exhaustive and detailed study has been carried out with the aim of characterizing and classifying the wetland soils according to environmental factors and rice field management. This paper will also examine the spatial influence of Mediterranean Sea and lagoon on the soil variables under study.

2. Material and Methods

2.1. Study area and soil forming factors

The Albufera of Valencia is a wetland located in Valencia (Spain), 39º 20' N and 0º 21' W (**Figure 1**). It was declared a Natural Park in 1986 and RAMSAR wetland in 1990, and occupies 21,120 ha on a plain that was created by two rivers, the river *Turia* in the northern sector and river *Júcar* in the southern sector. This Natural Park is defined by a freshwater lagoon (2,800 ha) in the center of the flood plain that is separated from the Mediterranean Sea by a sand barrier (3,320 ha). Rice is grown in the marsh area (15,000 ha), and orange trees and some horticultural crops are cultivated in the upland areas. The mean terrain height is 0.5 m above sea level, with a maximum value of 3 m and a minimum of -2.5 m. The average slope is less than 2% since it is located on an alluvial plain.

The climate is warm with an average annual precipitation of 540 mm and temperature of 17.6 ºC. The evapotranspiration is high (around 885 mm) and reveals the semiarid character. Rice is the main crop in marsh areas and controls the water management in the wetland. During the growing season (May to September) and during the autumn-winter period (October to February) water is present as sheet flow on the soil surface. On the contrary, during March, one week in June/July and 10-15 days in September the soil is completely dry and does not present water on its surface because some tasks are implemented (field preparation, rice phenological stages or harvest respectively). In these periods, the water table lies between depths of – 0.15 m and – 0.45 m.

The main geologic materials are quaternary clays, sand, and loamy materials. These have a medium carbonate contents and no coarse elements that reveal the alluvial origin. Soils have been formed in two ways: i) Alluvial sediments: in the past the lagoon occupied more than 30,000 ha and the supplied sediments have gradually reduced the lagoon surface. Thus the soils have been formed by an alluvial natural process; ii) Human action: during the early 1900s, farmers brought soil from the upper areas and deposited it in plots reclaimed from the lagoon. The plots

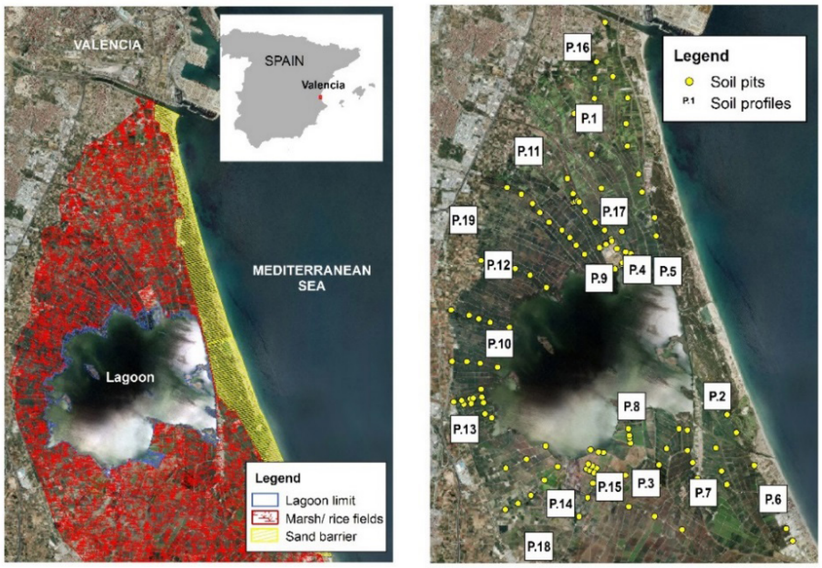


Figure 1. Location of the study area and sampling pits.

were isolated through soil dykes, and afterwards they were filled with non-autochthonous soil until the water was completely eliminated. These new rice fields were called *tancats* and their soil surface was under the lagoon water level.

2.2. Soil sampling and profile description

The geomorphology of the wetland made it impossible to apply classical photointerpretation techniques because the field homogeneity and the uniform geological material defined the entire wetland area as a single homogeneous soil unit. The dual origin of soils and the well-known salinity problems in the lowlands, among other aspects, suggested that some unknown environmental factors could differentiate one area from another. The soil profile locations were defined according to a three-step scheme: i) 133 pits were defined and sampled following a radial design with 17 rows around the lagoon (Figure 1), ii) samples were analysed in the laboratory and the results mapped with GIS and geostatistical techniques, and iii) soil units were defined and soil profiles located.

The radial design of 133 pits in 17 rows was based on the hypothesis that the lagoon might have a considerable influence on soil properties, considering that hydrology is the most important factor in wetlands (Hunter et al. 2008; Mitsch and Gosselink 2007). The distances between the sampled pits and rows were homogeneous, as long as field conditions allowed. The set of pits was georeferenced in three dimensions with GPS equipment using the virtual reference station (VRS) technique. The surveying instrument was a Leica GPS 1200 receiver that supplied the UTM coordinates and most important for this study, the height coordinate or elevation with centimeter accuracy. During the dry field season (March), the soils were sampled approximately each 20 cm with an auger (depending on soil characteristics and horizons: textural changes, structure, soil material, etc.), and a total of 461 samples were described according to Schoeneberger et al. (2012).

Once soil analyses were performed and the maps created, a total of 19 soil profiles were located (**Figure 1**) and opened with the purpose of defining their morphological and hydric properties according to the American Natural

Resources Conservation Service (USDA-NRCS 2010; Schoeneberger et al. 2012). Furthermore, reduced Fe ion was tested for in the field phase using an alpha-alpha-dipyridyl solution (Soil Survey Staff 2014a) and the aquic conditions were registered *in situ*. Soil sampled profiles followed the same procedure as the soil pit samples.

2.3. Laboratory study

Soil samples were air-dried and sieved (2 mm) to remove coarse particles. In that process, several aggregates were saved for further analysis. The analysed parameters were the same for the set of samples, although in soil profiles the principal cations and anions were also analysed.

Carbonate content was measured using a Bernard calcimeter (AENOR 1993) and salinity was determined according to the procedure used by Richards (1954) where the electrical conductivity of saturated paste is determined (EC_e). Organic content was measured by ignition at 400 ºC (Soil Survey Staff 2014b) and the soil organic carbon (SOC) was calculated applying the Van Bemmelen factor. This value could be used to define organic soils which is a taxonomic criterion defined in the Keys to Soil Taxonomy (Soil Survey Staff 2014c). Soil texture was measured by Bouyoucos method (Bouyoucos 1962), but a pretreatment was applied before the texture analysis. Carbonate contents higher than 2%, EC_e greater than 2 dS m^{-1} or samples with high levels of organic matter (OM > 3.5%) can produce interferences in the textural analysis (Soil Survey Staff 2014a). Therefore, carbonate removal was carried out by sodium acetate application, whereas organic matter was removed by the addition of hydrogen peroxide. In sandy samples, a particle-size analysis was performed with several sieves to classify the sand fraction as a function of the particle diameter (mm): very fine (0.05-0.010), fine (0.010-0.25), medium (0.25-0.5), coarse (0.5-1) and very coarse (1-2). Soil colour was determined in both conditions (wet and dry) according to Munsell Soil Charts (Munsell 2000). The fiber volume of organic materials and the decomposition grade were determined by the fiber content (*sapric, hemic,* and *fibric*) and the pyrophosphate colour method respectively (Soil Survey Staff 2014b).

The maximum water content in soil was measured by a gravimetric method. Soil aggregates were deposited on a completely wetted porous surface in a wet ambient. Due to the capillarity forces the air in pores was displaced by water until the aggregate was completely wet. This process lasted more than 48 hours in each sample and after that, the aggregate was weighed and this value was compared with the weight after heating at 105 ºC for 24 hours. Lastly, the n value [$n = (A - 0.2R)/ (L + 3H)$] where A is the percentage of water in the soil in field conditions, R is the percentage of silt + sand, L is the percentage of clay, and H is the percentage of organic matter (Pons and Zonneveld 1965) was calculated in order to determine the degree of subsidence that would occur after draining, which is a taxonomic criterion in Soil Taxonomy (Soil Survey Staff 2014c).

For the estimation of ion concentrations, the soil-water extract was analysed in the soil profiles according to international standards (Soil Survey Staff 2014b): calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^{-}), carbonates (CO_3^{-2}) and bicarbonates (HCO_3^{-}) by titration; potassium (K^{+}) and sodium (Na^{+}) by flame photometry and sulphate (SO_4^{-2}) by turbidimetry. The adjusted Sodium Adsorption Ratio of the soil (SAR) was calculated to assess the soil sodicity (Suárez 1981).

2.4. Taxonomic classification, geostatistical and statistical analysis

Nowadays, World Reference Base for Soil Resources (IUSS Working Group WRB 2014) and the Soil Taxonomy (Soil Survey Staff 1999) are the most important classification systems. The fact that American scientists have published a great deal of public information on hydric soils (list of hydric soils or field indicators with an important feedback to include the newest researches) led us to select the Soil Taxonomy system (Soil Survey Staff 1999). The Keys to soil Taxonomy (Soil Survey Staff 2014c) were used to designate the diagnostic horizons and the type of soil.

The geostatistical analyses were carried out in the working environment of ARCGIS 9.3 (ESRI 2009), using the Bayesian Maximum Entropy method in order to represent the soil attributes. The maps obtained at different depths (0 to 80 cm) were compiled to obtain categorical maps. Those categorical maps defined the soil homogeneous units and the soil classification map. In reference to statistical analyses, data normality was checked by the Shapiro-Wilk test and a correlation analysis with Spearman coefficients was applied for correlating the analysed soil parameters versus three topographic variables: distance to the lagoon (LaD), distance to the seashore (SeD) and height above sea level (SLH). The statistically significant differences were estimated at $p < 0.05$ and $p < 0.001$ levels for each combination.

3. Results

3.1. General soil characteristics

Results showed a moderately calcareous character in all the samples with average values ranging from 35.3 to 36.9% (**Table 1**). The maximum carbonate content value was recorded in the 0-20 cm depth (85.8%) whereas the lowest was registered in 20-40 cm (6.5%). **Figure 2** shows two tendencies in depth distribution. In 44% of pits a somewhat uniform decrease in the carbonate content with depth was found (**Figure 2a**), whereas 56% showed a continuous and irregular variation in depth (**Figure 2b**). No significant differences were found between carbonate content and topographic variables (**Table 2**).

Table 1 provides the experimental pH data. In general, soils were slightly or moderately alkaline (94.5% of samples), 2.3% were classified as neutral and 3.2% as strongly alkaline. The pH showed a positive correlation with SeD ($p < 0.05$).

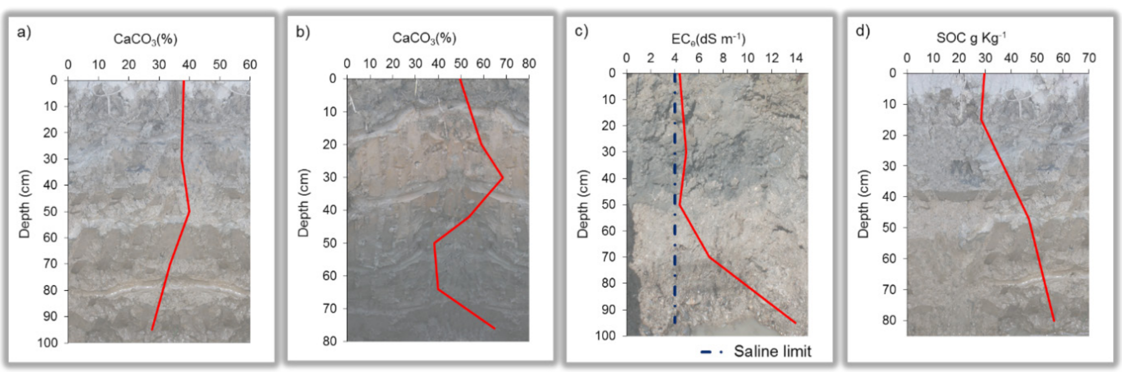


Figure 2. Distribution of soil variables related to depth, carbonates (**a** and **b**), salinity (EC_e) (**c**), and soil organic carbon (SOC) (**d**).

The most striking result that emerged from the data was that of the soil salinity. The majority of samples (79.5%) were saline ($EC_e > 4$ dS m^{-1}), and 7% of those samples were strongly saline ($EC_e > 16$ dS m^{-1}). The average soil salinity was 7.84 dS m^{-1} with the maximum value registered in horizon VII of profile 4 (P.4). The highest recorded value was 55.70 dS m^{-1} at 60 cm. These data revealed the general pattern of soil salinity in the wetland, that is, the salinity increased with depth in all the sampled pits (**Table 1** and **Figure 2c**). The influences of the distances to Mediterranean Sea

(SeD) and to the lagoon (LaD) were statistically tested with the Spearman correlation coefficient ($p < 0.001$). Both variables were negatively correlated with salinity (Table 2). A similar pattern emerged in the relationship between height above sea level (SLH) and salinity, but in this case the correlation coefficient was stronger (0.446; $p < 0.001$). Another interesting feature was the SOC in rice fields. The average values were similar in all the depths (28.5-32.2 g Kg^{-1}), although the maximum values were recorded in the deepest layers (Table 1).

Table 1. Statistical summary of soil characteristics by depth

Depth cm		N	$CaCO_3$ %	pH (H_2O)	ECe dS m^{-1}	SOC g Kg^{-1}	Clay %	Silt %	Sand %	MWC %	n value
0-20	Mean	133	36.87	7.90	6.02	32.20	32.72	38.36	30.49	42.36	0.55
	SD		10.44	0.24	2.99	1.60	11.64	10.26	18.94	11.97	0.43
	Var.		108.97	0.06	8.98	2.56	135.65	105.26	358.85	143.27	0.18
	Min		13.14	7.31	1.16	7.00	0.00	3.20	5.00	8.90	0.00
	Max		85.84	8.77	16.83	120.10	57.00	57.00	96.60	92.32	4.52
20-40	Mean	133	36.46	7.92	7.11	28.5	34.20	37.77	30.05	43.50	0.66
	SD		11.73	0.28	5.18	1.41	12.45	11.39	22.49	16.28	0.31
	Var.		137.82	0.08	26.90	2.21	153.11	134.22	445.67	265.05	0.11
	Min		6.55	7.03	1.03	4.70	2.40	1.50	5.00	11.72	0.00
	Max		84.12	8.79	30.60	119.90	59.00	65.00	96.00	154.08	2.49
40-60	Mean	123	36.36	7.91	8.65	33.2	32.21	36.02	34.98	46.57	0.76
	SD		12.28	0.28	7.18	2.93	13.63	13.81	24.32	35.81	0.80
	Var.		150.98	0.08	51.58	8.64	185.82	190.77	591.64	1282.62	0.64
	Min		11.76	7.03	10.30	1.60	2.50	1.25	0.00	0.00	0.00
	Max		73.05	8.70	40.20	205.60	66.00	60.00	96.70	366.99	5.56
60-80	Mean	72	35.30	7.92	9.59	28.9	28.98	34.24	37.43	49.72	0.89
	SD		12.92	0.31	9.31	2.58	14.14	15.75	25.70	50.05	1.03
	Var.		167.08	0.10	86.78	6.66	200.11	248.07	660.62	2505.02	1.06
	Min		7.52	6.96	1.59	1.00	2.50	0.80	5.00	0.00	0.00
	Max		73.73	8.90	55.70	149.60	67.00	61.00	96.70	405.58	6.41

N: number of samples; SD: standard deviation; Var: variance; Min: minimum; Max: maximum; $CaCO_3$: carbonate content; EC_e: electrical conductivity in saturated paste extract; SOC: soil organic carbon; MWC: maximum water content in soil.

In general, the accumulation of organic matter was found in the topsoil, but the soil profile showed variations in depth. A large number of samples (70%) showed a non-linear increase with depth below tillage layers (Figure 2d), whereas less than a third of pits showed the highest SOC values in the plough layer with a decrease in depth. There were significant correlations between the organic matter content and the spatial location of pits (LaD and SLH). The correlation coefficients showed an inverse relationship (Table 2), so that deeper layers had higher values than topsoil samples. The same behavior was found in the closest points to the lagoon, that is, values in closer areas were greater than soils in farther areas. Distance to the seashore (SeD) revealed a significant correlation with SOC, but the positive coefficient highlighted that the proximity to the sea caused a decrease in the organic carbon content (Table 2).

The outcomes of textural fraction showed that clay loam was the most abundant textural class (30% of samples), followed by silty clay, and clay (16.5% and 12% respectively). Although the sandy textural class only appeared in 4% of samples, the set of textural classes composed of sand, loamy sand and sandy loam included 14.5% of samples. The silt fraction showed a significant correlation ($p < 0.05$) with the three topographic variables, whereas clay did not show any correlation and sand was correlated with SLH (Table 2). This significant correlation was negative, and therefore the deeper layers were sandier that topsoil layers. The abrupt textural changes were located in the deeper horizons, especially in the area near to the sand barrier.

The most frequent colour in dry samples was light brownish gray found in 21.5% of samples (10YR 6/2), although colour data registered a wide variety of Munsell notations. More than 60% of samples were classified as 10YR hue, followed by 2.5Y with a 28%. Where wet conditions were present, the main registered colours were 10YR 5/6 (brown) and 5YR 5/2 (grayish brown). Both categories reached 10% of samples, so in wet conditions the number of different observed colours was higher than in dry conditions. Hue labels were: 10YR (51%), 2.5Y (37%), 7.5YR (6%), 5Y (4%) and 5YR (2%). Aquic conditions were identified in the full set of pits according to the hydric indicators guide and the alpha-alpha-dipyridyl test was used to characterize the redox conditions.

Finally, the maximum water content in soil (MWC) and the n values were correlated, and they showed the same trend as SOC. The values increased with depth and showed mean values between 42.36%-49.72% and 0.55%-0.89%, respectively. Most of samples (77.3%) did not show risk of subsidence, while the remaining showed light-moderate (15.6%) and high risk (7.1%), respectively. Furthermore, the three topographic variables showed statistically significant relationships with the n values (Table 2). The n values showed the highest levels in the upland areas. In the case of MWC, the higher values were registered near the lagoon and in deep horizons.

Table 2. Spearman correlation coefficients between topographic variables and soil characteristics

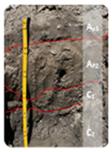
Topographic variables	Variables								
	$CaCO_3$	pH (H_2O)	EC_e	SOC	Clay	Silt	Sand	MWC	n value
Lagoon distance	ns	ns	-0.39**	-0.19**	ns	-0.12*	ns	-0.17**	-0.09*
Seashore distance	ns	0.14*	-0.16**	0.19**	ns	0.14*	ns	ns	-0.16**
Height	ns	ns	-0.45**	-0.21**	ns	-0.21*	-0.18*	-0.18**	-0.10*

$CaCO_3$: carbonate content; EC_e: electrical conductivity in saturated paste extract; SOC: soil organic carbon; MWC: maximum water content in soil. *Significant at level $p < 0.05$; ** Significant at level $p < 0.001$; ns: non significant.

3.2. Soil profile description

The stratification of alluvial and marine sediments was clearly recognizable in the sampling process, and the morphological characteristics were similar in pits and profiles. The pedons showed an A-C type profile, more specifically: Ap_1, Ap_2, C, 2C, 3C (Figures 3 and 4), without any developed B horizon, and a great diversity of calcareous materials that originated from different C horizons. The division

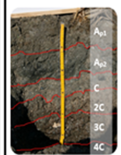
P.1



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	20	7.5YR 4/3	10YR 7/1	BS	CL	W	AVH		Sh/AN	Ma
A_{p2}	22	10YR 4/3	10YR 7/1	BS	SCo	W	AV	PL/M	Sh	Mo
C_1	13	7.5YR 4/2	10YR 5/2	BS	C	W		PL/M	Sh	
C_2	>45	10YR 3/1	10YR 5/2	BS	SCo	W		PL	Sh	

Crop: Rice **Hydric indicators:** F8, F12 **Water-table:** 53 cm
Slope: < 2% **Height (a.s.l):** 0.43 m

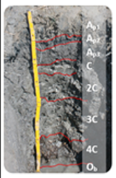
P.2



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	11	10YR 4/2	2.5Y 6/1	BS	SLo	W	AVH	PL	AN	Ma
A_{p2}	10	2.5Y 5/2	2.5Y 6/1	BS	SLo	W	AV			Ma
C	11	7.5YR 5/1	2.5Y 7/1	BS	S	W				Ma
2C	10	2.5Y 6/1	2.5Y 6/1	BS	LS	W		PL	Sh	
3C	18	2.5Y 3/1	2.5Y 6/1	WS	LS				Sh	
4C	>45	2.5YR 3/2	2.5Y 6/1	WS	S					Fi

Crop: Rice **Hydric indicators:** S5, A4 **Water-table:** 39 cm
Slope: < 2% **Height (a.s.l):** -0.05 m

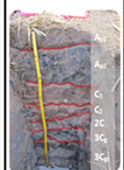
P.3



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	12	2.5Y 4/2	10YR 7/2	BS	SCL	St	AVH	PL	Sh/An	Ma
A_{p2}	3	2.5Y 4/1	2.5Y 6/1	SG	LS	W	AV		Sh/An	Ma
A_{p3}	8	2.5Y 4/1	2.5Y 6/1	SG	S		AV		Sh	
C	13	2.5Y 4/1	2.5Y 6/1	SG	S					
2C	12	2.5Y 3/1	2.5Y 6/1	BS	CL	St			Sh	
3C	23	2.5Y 4/1	2.5Y 7/1	BS	SCo	W		M		
4C	26	5Y 5/1	2.5Y 6/1	BA	SCo	W				
O_b	>47	10YR 2/1	2.5Y 4/1						Sh	He

Crop: Rice **Hydric indicators:** S5, F8 **Water-table:** 30 cm
Slope: < 2% **Height (a.s.l):** 0.13 m

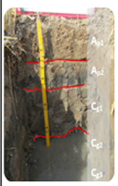
P.4



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	6	2.5Y 4/3	2.5Y 5/3	BS	SCL	Me	AVH	PL	AN	Ma
A_{p2}	15	2.5Y 4/2	10YR 6/2	BS	SCL	St	LV	PL/M		Ma
C_1	12	10YR 4/3	10YR 4/3	BS	SCo	St	LV	PL/M		
C_2	12	10YR 4/2	10YR 7/2	BS	CL	St		PL/M		
2C	6	10YR 5/3	10YR 6/2	BS	SLo	W		M		
$3C_g$	10	5Y 4/1	2.5Y 6/1	SG	SCL	W		RM		
$3C_{g2}$	>41	5Y 6/2	5Y 8/1	BS	CL	W		RM		Ty

Crop: Rice **Hydric indicators:** A8,F8, F15 **Water-table:** 55 cm
Slope: < 2% **Height (a.s.l):** 0.36 m

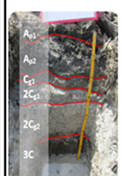
P.5



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	16	10YR 4/2	10YR 6/3	BS	CL	W	AVH	M	AN	Ma
A_{p2}	8	2.5Y 4/2	10YR 6/2	BS	C	St	AV	PL/M		Ma
C_{g1}	19	7.5YR 4/2	10YR 6/2	BS	C	St		Mr		
C_{g2}	10	2.5Y 5/2	10YR 6/2	BA	SCo	Me		Mr		Ty
C_{g3}	>48	2.5Y 6/2	2.5Y 7/1	WS	S			Mr	Sh	

Crop: Rice **Hydric indicators:** F8 **Water-table:** 18 cm
Slope: < 2% **Height (a.s.l):** 0.32 m

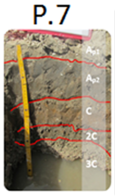
P.6



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	5	2.5Y 4/2	2.5Y 6/2	BS	CL	W	AVH	PL	AN	Ma
A_{p2}	15	7.5YR 4/2	2.5Y 6/2	BS	CL	W	AV	PL	AN	Ma
C_{g1}	7	5Y 4/1	2.5Y 6/2	BS	SCLo	W	LV		Sh	
$2C_{g1}$	5	10YR 7/1	2.5Y 8/1	WS	LS				Sh	
$2C_{g2}$	13	7.5YR 7/1	2.5Y 8/1	WS	LS					
3C	>52	2.5Y 3/1	2.5Y 6/1	WS	LS				Sh	

Crop: Rice **Hydric indicators:** F8, F10, F15 **Water-table:** 25 cm
Slope: < 2% **Height (a.s.l):** 0.19 m

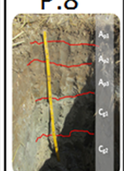
P.7



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	5	7.5YR 4/2	2.5Y 6/2	BS	SCL	St	AVH		An	Ma
A_{p2}	13	7.5YR 4/2	2.5Y 6/2	BS	CL	W	AVH	PL	Sh	Ma
C	8	7.5YR 4/4	10YR 6/3	BS	CL	W	LV	PL	Sh	
2C	6	7.5YR 5/2	10YR 6/3	BS	SCLo	w			Sh	
3C	>58	7.5YR 7/2	10YR 7/2	WS	LS				Sh	

Crop: Rice **Hydric indicators:** F8, F12, F1 **Water-table:** 39 cm
Slope: < 2% **Height (a.s.l):** 0.26 m

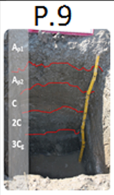
P.8



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	5	10YR 4/3	10YR 6/3	BS	CL	St	AVH		An	Ma
A_{p2}	10	10YR 4/2	10YR 7/2	BS	SCo	W	AV	PL	An/Sh	Ma
A_{p3}	19	10YR 4/2	10YR 6/2	BS	CL	St		PL/M	Sh	Ty
C_{g1}	31	5Y 6/2	5Y 6/2	BS	SCLo	W		Mr	Sh	Ty
C_{g2}	>46	5Y 7/1	5Y 7/1	BS	L	W		Mr		Ty

Crop: Rice **Hydric indicators:** A4, A11, F8, F15 **Water-table:** 53 cm
Slope: < 2% **Height (a.s.l):** -1.28 m

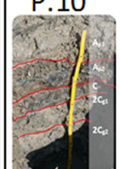
P.9



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	5	7.5YR 4/2	10YR 6/2	BS	SCL	St	AVH	M	An	Mo
A_{p2}	13	7.5YR 4/2	10YR 6/2	BS	SCL	St	AVH	PL	An/Sh	Ma
C	16	7.5YR 4/3	10YR 6/3	BS	SCo	St		PL		Ma
2C	17	5Y 4/1	2.5Y 7/1	BS	SCo	W				
$3C_g$	>45	5Y 6/1	2.5Y 7/1	BS	L	W		Mr		Ty

Crop: Rice **Hydric indicators:** F8, F15 **Water-table:** 16 cm
Slope: < 2% **Height (a.s.l):** -0.49 m

P.10

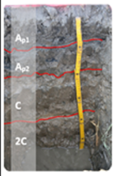


Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	15	10YR 4/2	10YR 6/3	BS	CL	St	AVH	M	An	Ma
A_{p2}	10	10YR 4/2	10YR 6/3	BS	CL	St	AV	PL		Ma
C	7	5Y 4/1	5Y 6/1	BS	CL	St	LV	PL		
$2C_{g1}$	13	7.5YR 5/1	5Y 8/1	BS	CL	W		Mr	Sh	Ty
$2C_{g2}$	>51	10YR 6/1	5Y 7/1	BS	SCo	W		Mr	Sh	Ty

Crop: Rice **Hydric indicators:** F8, F15 **Water-table:** 20 cm
Slope: < 2% **Height (a.s.l):** -0.35 m

Figure 3. Soil profile descriptions (P.1-P.10). Hor: horizons; Thick: thickness; Struc: structure (BS: blocky subangular, SG: simple grain, BA: blocky angular, WS: without structure); Text: texture (S: sand, LS: loamy sand, SLo: sandy loam, SCLo: sandy clay loam, C: clay, SCo: silty clay, SCL: silty clay loam, SL: silty loam, L: loam, CL: clay loam); Coh: dry consistence (St: strong, Me: medium, W: weak); Root: presence of roots (AVH: abundant vertical and horizontal roots, AV: abundant vertical roots, LV: scarce vertical roots); Redox: redoximorphic features (M: redox masses, PL: pore linings, Mr: reduced matrix); Bio: biological presence (An: Annelids, Sh: marine shells); O.M: organic matter (Ma= organic matter associated with the soil mineral matrix, Mo: masses of organic matter, He: medium decomposition grade (Hemist), Ty: presence of plant debris (*Thypa sp.*); Hydric indicators (A4: hydrogen sulfide; A5: stratified layers; A8: muck presence; A.11: depleted below dark surface; S5: sandy redox; F1: loamy mucky mineral; F8: redox depressions; F10: marl; F12: iron-manganese masses; F15: gleyed pores).

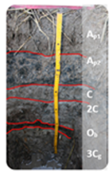
P.11



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	8	10YR 5/3	2.5Y 7/3	BS	SCL	St	AVH		An	Ma
A_{p2}	15	10YR 4/2	10YR 7/3	BS	SCo	St	AV	PL	Sh	Ma
C	20	10YR 5/3	2.5Y 7/3	BS	SCo	St	LV	PL		
2C	>53	10YR 5/3	2.5Y 6/4	BS	SCL	W		PL/M		

Crop: Rice **Hydric indicators:** F8, F15 **Water-table:** 13 cm
Slope: < 2% **Height (a.s.l):** 0.83 m

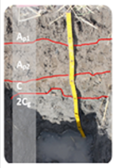
P.12



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	15	10YR 4/2	2.5Y 6/2	BS	L	Me	AVH	PL	An	Ma
A_{p2}	12	10YR 4/2	2.5Y 6/2	BS	L	W	AV	PL	An	Ma
C	8	5Y 4/1	5Y 6/1	BS	L	W	LV		Sh	
2C	10	2.5Y 5/1	5Y 5/6	BS	CL	W				Ty
O_b	9	10YR 2/1	2.5Y 4/2	BS	S	W				He
$3C_g$	>41	2.5Y 5/2	10YR 6/2	BS	SLo	W				

Crop: Rice **Hydric indicators:** F8, F15 **Water-table:** 5 cm
Slope: < 2% **Height (a.s.l):** 0.17 m

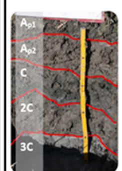
P.13



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	13	10YR 4/2	10YR 6/2	BS	CL	Me	AVH		An	Ma
A_{p2}	15	7.5YR 4/3	10YR 6/2	BS	C	W	LV	PL		
C	17	2.5Y 4/2	10YR 6/2	BS	C	W		M		
$2C_g$	>49	7.5YR 5/1	2.5Y 7/1	BS	C	W			Sh	

Crop: Rice **Hydric indicators:** A11, F8, F15 **Water-table:** 47 cm
Slope: < 2% **Height (a.s.l):** 2.14 m

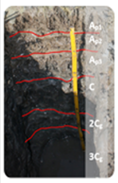
P.14



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	5	7.5YR 5/2	2.5Y 6/2	BS	L	Me	AVH	PL	An	Ma
A_{p2}	14	7.5YR 5/2	2.5Y 7/1	BS	CL	W	AVH	PL		Ma
C	16	2.5Y 4/2	2.5Y 6/2	BS	C	W	LV		Sh	
2C	10	2.5Y 4/2	2.5Y 6/2	BS	C	W			Sh	
3C	>43	5Y 5/1	2.5Y 7/1	BS	SCL	W			Sh	

Crop: Rice **Hydric indicators:** F8, F12, F15 **Water-table:** 53 cm
Slope: < 2% **Height (a.s.l):** 0.43 m

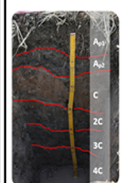
P.15



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	7	10YR 5/3	10YR 6/3	BS	SCo	Me	AVH	PL/M	An	Mo
A_{p2}	7	10YR 4/2	10YR 5/3	BS	C	W	AV	PL	An	Ma
A_{p3}	12	10YR 4/2	10YR 5/3	BS	C	W	LV		Sh	Ty
C	21	10YR 4/1	2.5Y 6/2	BS	SCL	W				Ty
$2C_g$	30	5Y 3/1	5Y 7/1	BS	SL	W		M/Mr	Sh	Ty
$3C_g$	>42	2.5Y 7/1	2.5Y 8/1	BS	SL	W		Mr	Sh	Ty

Crop: Rice **Hydric indicators:** A5, F8, F15 **Water-table:** 35 cm
Slope: < 2% **Height (a.s.l):** 0.19 m

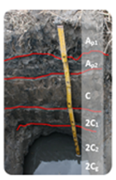
P.16



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	9	10YR 4/2	10YR 5/2	BS	CL	W	AVH		An	Ma
A_{p2}	9	7.5YR 5/4	7.5YR 6/2	BS	C	W	AVH		An/Sh	Ma
C	10	7.5YR 5/4	10YR 7/3	BS	L	W			Sh	
2C	15	5YR 4/1	10YR 6/2	BS	CL	W				
3C	13	7.5YR 4/1	10YR 6/1	BS	C	W		M		Ty
4C	>52	7.5YR 4/1	2.5Y 6/1	WS	S			Mr		Ty

Crop: Rice **Hydric indicators:** F8, F15 **Water-table:** 47 cm
Slope: < 2% **Height (a.s.l):** 0.72 m

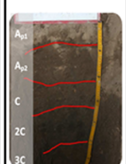
P.17



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	11	7.5YR 4/2	2.5Y 6/2	BS	SCL	W	AVH	PL/M	An	Ma
A_{p2}	7	7.5YR 4/2	2.5Y 6/2	BS	SCo	W	AVH	PL/M	An	Ma
C	16	10YR 4/3	10YR 6/2	BS	SCo	W	LV		Sh	
$2C_1$	13	5YR 4/1	10YR 6/3	BS	C	W				Ty
$2C_2$	20	10YR 5/1	10YR 6/3	BS	SCo	W				
$2C_g$	>39	5Y 5/1	2.5Y 6/2	WS	S			Mr	Sh	

Crop: Rice **Hydric indicators:** F8, F15 **Water-table:** 43 cm
Slope: < 2% **Height (a.s.l):** -0.36 m

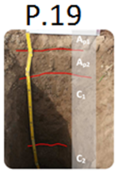
P.18



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	8	7.5YR 3/3	10YR 5/4	BS	CL	W	AV		An	
A_{p2}	16	5YR 4/3	10YR 6/2	BS	CL	W	AV		An	
C	10	7.5YR 4/3	10YR 6/3	BS	SCLo	W	LV			
2C	35	10YR 4/3	10YR 6/3	BS	CL	W				
3C	>30	7.5YR 4/3	10YR 6/2	BS	CL	W				

Crop: Orange **Hydric indicators:** **Water-table:**
Slope: < 5% **Height (a.s.l):** 2.54 m

P.19



Hor.	Thick. (cm)	Color Wet	Color Dry	Struc	Text	Coh.	Root	Redox	Bio	O.M
A_{p1}	10	7.5YR 3/4	10YR 5/4	BS	CL	W	AV		An	
A_{p2}	13	7.5YR 4/4	10YR 5/3	BS	CL	W	AV		An	
C	44	7.5YR 4/4	10YR 5/3	BS	CL	W				
2C	>27	5YR 4/6	7.5YR 5/4	BS	CL	W				

Crop: Com **Hydric indicators:** **Water-table:**
Slope: < 5% **Height (a.s.l):** 2.85 m

Figure 4. Soil profile descriptions (P.11-P.19). Abbreviations equal to Figure 3.

into horizons was made by differences in texture, structure, colour, organic matter and material consistence. The epipedons were differentiated by the presence of roots and wildlife distribution, whereas the endopedons were identified by the presence of organic horizons or gleyed materials (Figure 5a). Gleyzation process was clearly visible in the deeper horizons with a continuous water table (Cg) or in pits and profiles near the lagoon. In that regard, the aquic conditions were not identified in 2 of 19 profiles (P.18 and P.19) located in maize fields and orange tree orchards at 2.54 and 2.84 m above the sea respectively. The redoximorphic features were identified in 17 profiles with red and brownish colours (oxidized state). Redox concentrations were described as masses and pore linings, especially in the upper horizons (Figures 5b and 5c).

In spite of the fact that the decomposition rate should be slower due to the hydromorphic character in the wetland, it is worth mentioning that only 2% of samples were categorized as organic material. With that classification, two types of diagnostic horizons were identified in profiles: ochric epipedons and salic horizon, whereas two buried organic horizons were found in profiles P.3 and P.12. In the topsoil (Ap horizons), there was a plough layer of 20-30 cm with roots and wildlife (annelids) that improved soil physical properties such as porosity. Although topsoil was essentially mineral, in the majority of pits and profiles, there were many organic matter masses that were mixed into the soil matrix (Figure 5d).

The water table (Figure 5e) was recorded in 17 profiles at depths between 3 and 65 cm. It was always fluctuating throughout the year and a pump was required to remove water and describe the soil profiles. This fact was a problem in P.5 because there was a layer of marine shells and sand that complicated the soil description due to the high soil hydraulic conductivity. The existence of shells and other marine elements is shown in Figure 5f and showed an increased presence with depth.

As mentioned in the previous section, the soil chemical and physical characteristics showed a general view of wetland soils and can be accepted as a common description of soil profile characteristics. In addition, specific analyses were done to determine the concentration of cations and anions. Table 3 shows that Cl^- and Na^+ registered the highest average values followed by SO_4^{-2}, Ca^{+2} and Mg^{+2}. The high value of the variance denoted its variable character, which was reflected in the relationship between the ion concentration and the topographic variables (Table 4).

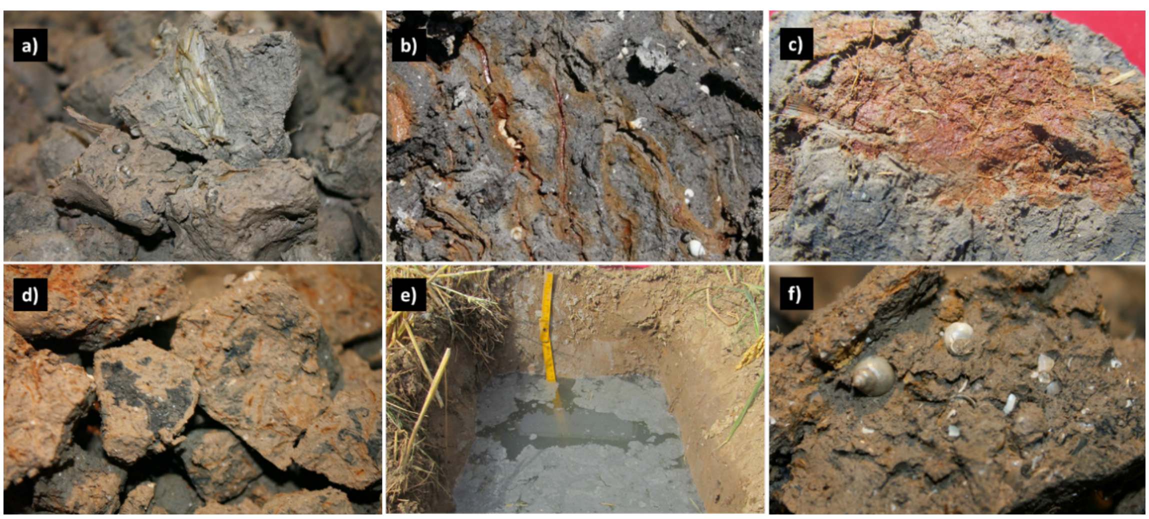


Figure 5. Profile description characteristics: **a)** gleyed material; **b)** redox features: pore lining; **c)** redox features: oxidation mass; **d)** organic masses in a mineral soil matrix; **e)** water table identification; **f)** marine shells in soil matrix.

Table 3. Statistical summary of anions and cations concentration in soil profiles

	SAR	Na^+	K^+	Ca^{+2}	Mg^{+2}	SO_4^{-2}	Cl^-	HCO_3^-
		meq l^{-1}						
Average	8.27	42.55	1.28	27.72	16.86	38.02	49.5	0.93
Stand. dev.	7.44	58.26	0.97	19.67	17.5	25.23	71.38	0.34
Variance	55.49	3395.23	0.95	387.21	306.32	636.86	5096.48	0.12
Min.	1.08	1.9	0	1.38	0.98	1.88	1.69	0.2
Max.	45.23	468.74	6	102	143.8	120.01	608.45	1.96

EC_e: electrical conductivity in saturated paste extract; SAR: sodium adsorption ratio.

Table 4. Spearman correlation coefficients between topographic variables and cation/anion concentrations

Parameters		Na^+	K^+	Ca^{+2}	Mg^{+2}	SO_4^{-2}	Cl^-	HCO_3^-
Topographic	Lagoon distance (LaD)	-0.69**	-0.32**	-0.29**	-0.48**	-0.39**	-0.65**	ns
	Seashore distance (SeD)	-0.21*	ns	-0.38**	ns	-0.23*	-0.25*	-0.37**
	Height (HSL)	-0.43**	-0.46**	-0.35**	-0.39**	-0.47**	-0.37**	ns

*Significant at level p < 0.05; ** Significant at level p < 0.001; ns: not significant.

Ion concentration was related to topographic location, because LaD and SLH showed the same trend with different grade of correlation. On one hand, distance to the lagoon (LaD) showed statistically significant correlations with all the ions, except with the bicarbonates. The correlation coefficients showed strong relationship (values > 0.5) in the cases of Na^+ and Cl^-, and weaker relationships with the other ions in the following decreasing order: $Mg^{+2} > SO_4^{-2} > K^+ > Ca^{+2}$, although p-values were all below 0.001. On the other hand, height registered the same p-value but the correlation coefficients showed moderate correlations (values between 0.35 and 0.47). As regards SeD, Na^+, Ca^{+2}, SO_4^{-2}, Cl^- and HCO_3^- statistically significant correlations were found (Table 4), whereas Mg^{+2} and K^+ did not show that correlation. The combination of SAR and EC_e values allowed the classification of soil profiles with respect to salinization and sodification risk. In that regard, 21% of studied samples were classified as normal, 26% as a saline-sodic and over half of soil profiles were defined as saline (53%). Moreover, the correlation analysis between the entire set of variables and EC_e (except bicarbonates and carbonates) denoted a high statistical significance $p < 0.001$ with strong coefficients (values higher than 0.60). The same trend was recorded between cations and anions. Cl^- and Na^+ showed the highest correlation coefficient (0.96), while the other coefficients were Ca^{+2} and SO_4^{-2} (0.86), Mg^{+2} and SO_4^{-2} (0.72) and K^+ and Cl^- (0.66).

3.3. Soil classification

The soil profile development characteristics were such that no diagnostic horizons were observed in soil profiles, except in P.4 where a salic horizon was detected. It is for this reason that the great majority of soils under study were classified as Entisols. Only P.4 was classified as Aridisol given the high levels of salinity. In this profile a salic horizon within 100 cm from soil surface was

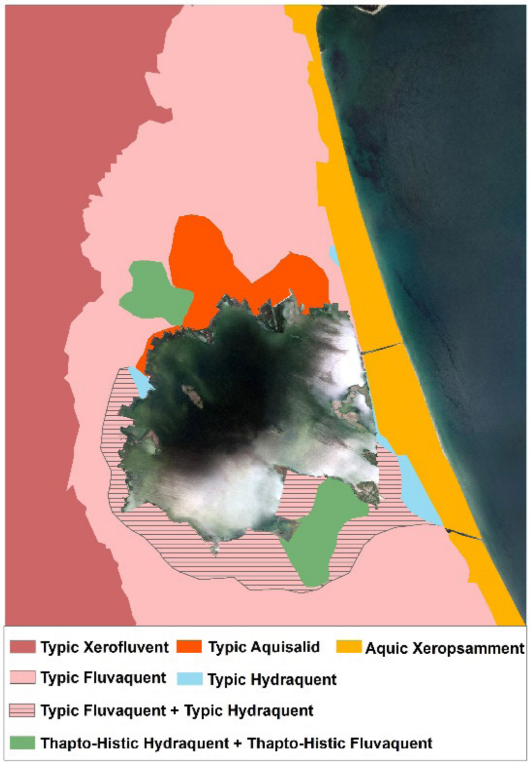


Figure 6. Soil classification map.

found. The condition of anthric saturation gave a classification of Aquisalid, and the absence of a gypsic or calcic horizon led us to catalogue this soil within the subgroup Typic Aquisalid.

In the case of Entisols, the two profiles that did not show aquic conditions (P.18 and P.19) were classified as Typic Xerofluvent because there was an irregular decrease in organic carbon content and the moisture regime was xeric. Profiles P.1, P.5, P.6, P.7, P.9, P.10, P.11, P.12, P.13, P.14, P.16 and P.17 were classified as Typic Fluvaquent because they had variations in the organic carbon content but other diagnostic characteristics had not been sufficiently developed to classify them in other subgroups. In the opposite case, profiles P.2, P.3, P.8 and P.15 were classified as Typic Hydraquent because n values and clay contents were higher than 0.7 and 8% respectively. P.3 was classified at the subgroup level as Thapto-histic Hydraquent because it showed an organic horizon at the depth of 73 cm, with thickness greater than 20 cm. Note that the existence of buried organic layers in another soil profile (P.12) did not satisfy the thickness requirements, so the profile could not be classified as Thapto-histic.

Figure 6 shows the soil classification map. The Aridisol order was located near the north shore of the lagoon, due to the high level of salinity in soils. In reference to Entisol order, the Typic Xerofluvent subgroup was located in the upland area where the aquic conditions could not be described, whereas the Typic Fluvaquent was located in the marsh area. In the southern part, there was an association between the Typic Fluvaquent and Typic Hydraquent that reflected the variability of soil materials. The last subgroup was the Thapto-Histic Hydraquent. It was located in areas where an organic horizon has been buried and was associated with the Thapto-Histic Fluvaquent, where the n condition was not recorded.

4. Discussion

Wetland soils under rice management are specific anthropogenic soils where human management has considerable influence in the soil profile development (Huang et al. 2015). The hydromorphic features needed to identify the saturation and anaerobic conditions are artificially altered by water management and therefore soil properties can be modified by this fact. The results of Zhang et al. (2013) reinforce this idea. They concluded that drying and flooding cycles in rice fields influenced the modification of the soil topographic and chemical properties, since these could not be attributed solely to the intrinsic properties of site conditions. Wissing et al. (2014), Kölbl et al. (2014) and Huang et al. (2015), highlighted that paddy soils suffered several important processes including desalinization and plough pan formation; decalcification and organic matter accumulation, and iron oxides formation or redistribution. They revealed that the time interval necessary to develop those attributes could be longer than 700 years for iron oxide distribution and redoximorphic features. In that sense, if we take into account that the Albufera of Valencia has been cultivated since the 8th century, all those features should be recognized in soil profiles. Conversely, the geomorphological location generates a cyclic input of materials that did not allow full soil profile development.

Decalcification or decarbonation are processes induced by periodic waterlogging (Van den Berg and Loch 2000). However, soil profile data showed either a carbonate increase with depth or an irregular increase (**Figure 3a** and **3b**). Kölb et al. (2014) and Wissing et al. (2014) demonstrated that rice management accelerates carbonate removal. Nevertheless, Chen et al. (2011) related that fact to the intrinsic soil behavior and Wissing et al. (2014) revealed that the insensitivity and the accelerated decalcification processes were still unclear in relation to paddy soil pedogenesis. In this wetland, this situation was not demonstrated because, as stated above, the overlying basin is calcareous and each year alluvial materials are deposited on soils after extreme rainfall episodes. Therefore, the decalcification process experiences new inputs each year due to the natural sedimentation process. Regarding carbonate content, Kyuma (2004) concluded that soil chemical properties are generally governed by the nature of sediments because soils in a floodplain do not have sufficient time to mature. This situation could explain why carbonates did not follow a depletion curve with depth. According to Vepraskas et al. (1999) the carbonate distribution was influenced by hydrology since the presence of water enabled the process of decarbonation. In a flood situation, calcite is transformed into bicarbonate and calcium. The latter appeared with higher concentrations in surface samples than in deeper layers, demonstrating the negative correlation with height (**Table 4**). The non-relationship between SLH and LaD with respect to carbonate content revealed a homogeneous banded distribution along the wetland. Only an influence with respect to the seashore was detected, so that areas near the limestone locations presented higher values than areas near the sea. In wetlands, soils with alkaline pH values tended to neutral values (Vepraskas and Faulkner 2001; Kyuma, 2004). This situation reflected the calcareous material influence and the correlation between them. In relation to pH, Vepraskas et al. (1999) concluded that soils containing carbonates with pH > 7 can be problematic for determining the redoximorphic features because the development rate is slower than in acid soils. The redox concentrations showed the hydric character of soils, and gley hues in the reduced matrix areas were commonly described. The aquic conditions were registered in soil samples with several hydric indicators (USDA-NRCS 2010): redox depletions, redox concretions, presence of H_2S (rotten egg smell), iron-manganese masses, mucky material, gleyzation processes, presence of a water table, and so on, and suggests problems in recognizing those features did not exist during that study.

SOC values in the Albufera of Valencia soils were around 30 g kg^{-1}. Hydric soils with continuous waterlogging showed higher values of SOC than non-hydric or alternate drying-waterlogging soils (Yue-Qin et al. 2009), although there are studies that could not find that trend (Hanke et al. 2013). A wetland soil could reach a wide range of organic carbon values; for instance, Delaune et al. (2013) registered values between 541 and 793 g kg^{-1} in Histosols. However, the hydric soils in rice areas do not usually register those values. In this study, the average value recorded in the topsoil (28.5 g Kg^{-1}) was in concordance with the results obtained in other world areas. Pan et al. (2003) reported a value of 16.58 g kg^{-1} in China, whereas the same author with other researchers (Pan et al. 2008) registered contents of SOC in topsoil between 10.55 and 25.94 g kg^{-1}. In addition, Shirato (2005) registered a content of 29 g kg^{-1} in Japan. These values corroborated the data of Kirk (2004) who explained that rice soils do not show high organic carbon contents. It has been assumed that during anaerobic conditions the rate of organic matter decomposition is slower (Wu 2011) and thus there is an accumulation of organic matter in the soil profile. However, Kögel-Knabner et al. (2010) and Cui et al. (2014) clarified that the amount of organic input after the harvest (rice straw) is the main reason for the high values in the topsoil in relation to the normal content of hydric soils.

Regarding soil depth distribution, the results showed a high value in topsoils, a decrease in intermediate layers, and a subsequent increase in deeper layers. This situation is related to natural and anthropogenic processes of rice field formation in the area. The addition of soil from upland areas by farmers with the aim of reclaiming land from the lagoon caused the burial of the natural vegetation. In these areas, dense ancient vegetation was covered with soil and an accumulation of organic matter due to the anaerobic conditions was generated by the presence of a continuous water table. This situation explains the maximum value reached in deep layers: 205.60 g kg^{-1}. However, these data are far-removed from the data registered by Delaune et al. (2013) in an organic layer. There are several possible explanations for this result: i) the nature of the vegetation, specifically its high organic carbon content or current degree of decomposition, and ii) the highest level of EC_e that could affect the decomposition rate. In this case, the organic matter decomposition is difficult in saline soils due to the low microbiological activity (Rhao and Pathak 1996; Vepraskas and Lindbo 2012). In the Albufera of Valencia, 79.5% of soil samples were considered saline with an average value of 6.02 dS m^{-1} (two units above the limit of saline soils: 4 dS m^{-1}). In a similar topographic situation (marsh area in the same region), Gimeno-García et al. (2013) registered values of EC_e between 0.3 and 25.4 dS m^{-1} and they explained the high soil salinity values due to the water table fluctuation and the influence of seawater intrusion near the seashore. It is clear that the Albufera of Valencia shows a soil salinization problem, although the percentage of saline samples was lower (74.8%) in the topsoil. *A priori*, such high salinity values would not be recommended for rice cultivation according to Ayers and Wescot (1985), who concluded that an EC_e higher than 3 dS m^{-1} reduced rice yield. Anyway, there were two factors which could explain the high salinity values in soil samples. Firstly, the sampling process was conducted during the preparation of the rice fields. At that time, there was no water in the first 20 cm of soil and the weather conditions showed an increase of evapotranspiration data versus rainfall. That combination may contribute to accelerate salt precipitation process in topsoil due to the capillary rise of water table (Seeboonruang 2013). Secondly, the free water layer on the soil surface during the growing season dilutes and leaches salts to deeper soil layers.

EC_e values were higher in the lower altitude areas and those nearest to the lagoon. According to Nguyen et al. (2014) and Akramkhanov et al. (2011), differences in height or landform registered large differences in soil salinity levels. In the Albufera of Valencia, these areas are called *tancats* and soil surface is under the lagoon water level. Antonelli et al. (2008) concluded that micro-topography and geomorphology play an important role in salinity distributions because the accumulated salt is in the most depressed areas (marsh or floodplains). Yu et al. (2014) compared soil salinity at different landforms on coastal Yellow River Delta in China and concluded that the highest EC_e was in the deepest area. In that sense, the combination of the deeper areas and the seawater intrusion demonstrated by Moreno

(2013) during three yearly rice campaigns explained the high values of soil salinity in the area surrounding the lagoon. The EC average value of water table during these years was 7.25 dS m^{-1}, with a maximum value of 46.21 dS m^{-1} on the north side of the lagoon in June. This point was precisely located in the area and was classified as Aridisol. Therefore a subsurface seawater flow affected the deeper soil layers and contributed considerably to soil salinization. These results agree with those of Álvarez-Rogel et al. (2007), who explained that marine intrusion caused soil salinization and it was caused by the saline water table.

Another result that reinforces that statement is the significant positive correlation between the distance to the seashore (SeD) and the EC_e. The high correlation between Na^+ and Cl^- and their high concentration revealed that the most important salt in the soil extract was NaCl. The high degree of correlation suggested either a common origin or similar geochemical behavior: seawater (Gimeno- García et al. 2013). Samples with high salinity levels also showed an increase in Na^+ and Cl^- ions, as has been noted in studies carried out in the Mediterranean area by Álvarez et al. (2001). The concentration of other ions (SO_4^{-2}, Ca^{+2} and Mg^{+2}) also showed a significant correlation with EC_e, and these are the major species in seawater composition as well. This situation should be controlled and monitored because it might lead to modifications in the vegetation according to salinity tolerance levels. This same situation was reported by Álvarez-Rogel et al. (2007) for a Mediterranean coastal marsh, where vegetation changed according to salinity levels.

With respect to n values and maximum water content in soil (MWC), the correlation between the data and the topographic variables could be explained by the presence of organic materials near the lagoon and in the deeper horizons. It is well known that organic materials can store an abundant amount of water because they are more porous than mineral materials (Collins and Kuehl 2001), so the n values and the maximum water content (MWC) of these soils were higher than the other soil samples. The relationship between the n value and the distance to the seashore (SeD) could be explained by the more sandy soils near the seashore, and in that area the n values showed the lowest results.

In reference to soil classification, soils were not defined as subaqueous because they did not reach the positive water potential during 21 hours/day. Two orders were chosen according to soil development: four subgroups of Entisols, and the unusual case of the Aridisol order. Boettinger (1997) defined the Aquisalids as wet saline soils that were periodically saturated, located in semiarid regions and in floodplains, lagoon plains or beaches with a fluctuating water table, and presented salt accumulations.

Bockheim and Hartemink (2013) conducted a study of Salids in USA where they described 13 pedons with a salic horizon and concluded that soils with a salic horizon occurred on gentle slopes (0-3%) with an alluvial origin (59%) or lacustrine and marine deposits (28%). In a literature review, they described the case of 44 pedons around the world (23 in Spain) with a maximum EC_e value of 53.9 dS m^{-1} (Spanish case). With the salic horizon found in this study another new case could be added to this list with the highest value registered (55.7 dS m^{-1}).

As for map design, it was necessary to create several associations to explain and represent the variety of soils in the area. Thapto-Histic Hydraquents were associated with Thapto-Histic Fluvaquents, because there was a buried organic layer in two different situations: areas that did not reach the n-value condition and areas that reached this condition and could be classified as “Hydra”. The same circumstances were met in the association of Typic Fluvaquents and Typic Hydraquents.

5. Conclusions

The soils of the Albufera of Valencia are moderately calcareous, with a medium organic matter content and high degree of salinity. The alluvial soil character is reflected in the variation of carbonates in depth. Likewise, rice management clearly affects the contribution of organic material in the soil profile. The high salinity of the soil and the relationships with topographic variables reflect a clear influence of groundwater since the source material is not saline. There is a subsurface flow from the Mediterranean Sea that varies depending on the presence of surface water and the irrigation demands. This flow produces a salinization of soil horizons in depth. Therefore topographic position, rice management, and water table fluctuation were responsible of soil pedogenesis in the wetland.

Entisols, with poor profile development, and Aridisols, with a salic horizon, are the two soil orders found in the area.

The annual content variations in SOC and EC_e should be monitored in order to understand the normal soil and water behavior in the wetland. This will be necessary in the future for controlling soil salinization processes and organic carbon losses.

Finally, the classical photointerpretation technique was not suitable for defining soil units in this kind of natural environment. The approach based on geostatistical analysis of soil survey data circumvented that disadvantage and allowed the characterisation and classification of wetland soils.

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