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Pedological Studies of Subaqueous Soils as a Contribution to the Protection of Seagrass Meadows in Brazil

Gabriel Nuto Nóbrega[(1)*], **Danilo Jefferson Romero**[(1)], **Xosé Luis Otero**[(2)] and **Tiago Osório Ferreira**[(1)]

[(1)] Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Departamento de Ciência do Solo, Piracicaba, São Paulo, Brasil.
[(2)] Universidade de Santiago de Compostela, Facultade de Bioloxía, Departamento de Edafoloxía e Química Agrícola, Santiago de Compostela, Espanha.

* Corresponding author:
E-mail: nutonobrega@usp.br

ABSTRACT: Seagrass meadows are considered one of the most important and valuable ecosystems on the planet, but also one of the most threatened. Missing knowledge about their existence and their subtidal nature are the main reasons for the lack of information about seagrass soils, especially in Brazil and other tropical areas. This study discussed the paradoxical lack of information about subaqueous soils, with a view to stimulate research on soil properties of seagrass meadows. This short communication provides information about the ecosystem and first descriptions of seagrass soils along the Brazilian Coast, marked by gleyzation, sulfidization, salinization, paludization, solonization, and classified as *Gleissolos tiomórficos*. Pedological studies on these ecosystems provide useful tools for their management, protection, and restoration. Thus, it is fundamental that soil scientists increase their knowledge about subaqueous soils, not only as a contribution to the Brazilian Soil Classification System, but for the conservation of these ecosystems.

Keyword: coastal wetlands, blue carbon, sulfidization, gleization, submerged soils.

INTRODUCTION

Seagrass meadows (or submerged aquatic vegetation) represent complex ecosystems formed by one or more angiosperm species colonizing shallow areas of the oceans and inland waters, associated with fauna and algal epiphytic-cover (Coles et al., 2011; Short et al., 2011; Copertino et al., 2016). This ecosystem can be found in more than 120 countries on all continents, except Antarctica (Spalding et al., 2003, 2010) and covers an estimated 300,000 to 600,00 km^2 around the globe (Duarte et al., 2005; Fourqurean et al., 2012), i.e., the equivalent to twice the area covered by mangroves (Siikamäki et al., 2013).

The total coverage area along the Brazilian coast is still unknown, despite scientific reports indicating the presence of seagrass meadows along the entire coast (Vilanova et al., 2013; Copertino et al., 2016). Only in the lagoon Lagoa dos Patos (state of Rio Grande do Sul), the seagrass meadows cover an area of 120 km^2 (Creed, 2003). Considering the 9,200 km long coastline of Brazil and the innumerous rivers that discharge into the Atlantic Ocean, it is supposed that seagrass ecosystems cover extensive areas in Brazil (Copertino et al., 2016), mostly vegetated by *Halodule wrightii* Ascherson, associated to other Halodule and Halophila species, and *Ruppia maritima* Lipkin (Vilanova et al., 2013).

Seagrasses form extensive vegetated areas at sites where clear waters allow light diffusion through the water column (Short et al., 2007; Brodersen et al., 2015). Generally, the plants of a meadow grow in areas protected from wave action (Phillips et al., 1988; Orth et al., 2006) to a maximum water depth of 90 m (Duarte, 1991; Coles et al., 2009). However, most of the meadows are found in shallow water areas, less than 10 m deep (Grech et al., 2012).

The plants consist of a polyphyletic assemblage of monocots, grouped in 60 known species, 12 genera, and four families (*Cymodoceaceae, Hydrocharitaceae, Posidoniaceae,* and *Zosteraceae*) of the order Alismatales (Les et al., 1997; Orth et al., 2006). These phanerogams have developed a series of ecological, physiological, and morphological adaptations that allow the colonization of completely submerged soils, for example: internal gas transport; epidermal chloroplasts; underwater pollination and dispersion; and absence of stomatal differentiation (Orth et al., 2006; Olsen et al., 2016).

Several studies consider these ecosystems as worldwide most productive (Duarte and Chiscano, 1999; Olsen et al., 2016), mainly for their role as basis of many food webs, providing nutrients (mainly N and P) and biomass for other parts of the ocean (Short et al., 2011). Thus, seagrass meadows interact with other adjacent coastal ecosystems, contributing to the maintenance and diversity of the surrounding ecological systems (e.g., mangroves, salt marshes, and coral reefs) (Short et al., 2006, 2007). Compared to other ecosystems, the economic value of seagrass meadows is one of the highest (dollars per ha) (Costanza et al., 1997; Barbier et al., 2011), estimated at US$ 28,000 ha^{-1} yr^{-1} in 2010 (Costanza et al., 2014). More recently, seagrasses and other coastal wetland soils were recognized as key drivers of carbon concentration reduction in the atmosphere and mitigators of global warming effects (Chmura et al., 2003; Mcleod et al., 2011; Chmura, 2013; Grimsditch et al., 2013).

Since these ecosystems are submerged, environmental impacts on their areas have been neglected (Waycott et al., 2009; Gladstone and Courtenay, 2014). Globally, about 30 % of seagrass meadows were lost in the last 50 years, at a higher rate than that reported for other ecosystems (e.g., tropical rainforest) (Waycott et al., 2009; Siikamäki et al., 2013). The expansion of cities and industries associated with unsustainable fishing practices have been cited as the most relevant threats to seagrass meadows (Waycott et al., 2009). In addition, the submerged nature of the seagrass meadows and apparently low species diversity disenchant the general public interest and support (Duarte et al., 2008; Randall Hughes et al., 2009).

Regardless of the great importance of seagrass meadows and the demand for restorative practices, the lack of knowledge about the underlying soils hampers the implementation of many potentially successful restoration and management practices (York et al., 2016). Thus, pedological studies of seagrass meadow soils may provide useful tools for the management and protection of these ecosystems by deepening the understanding of inter-relationships between soils and seagrasses and of the genesis of edaphic properties that influence seagrass persistence and susceptibility to environmental stressors. Thus, it is crucial that soil scientists increase their knowledge on subaqueous soils and their functioning.

This this research highlights the paradoxical lack of information about seagrass meadows and the underlying subaqueous soils, with a view to motivate studies on their properties and local/regional variations; to contribute to the Brazilian Soil Classification System (SiBCS), and to promote the protection and management of these ecosystems.

Seagrass meadows and subaqueous soils in Brazil

For the Soil Taxonomy system, the water can be considered as a possible upper limit of the soil, if it allows the growth of rooted plants (Soil Survey Staff, 2014). Thus, the recognition of the substrates of seagrass meadows as soils by the Soil Taxonomy system led to the creation of the taxa "Wassents" and "Wassists" to better suit Entisols and Histosols, with positive water potential (Soil Survey Staff, 2014), since these soils differ significantly from the subaerial soils classified as Aquents or other Histosol (Rabenhorst and Stolt, 2012).

Similarly, for the World Reference Base for Soil Resources, the water column can also be considered as possible upper soil limit, however, restricted to sites with water columns lower than two meters (WRB, 2015). The principal qualifiers "*tidalic*" and "*subaquatic*" were created to discriminate some soil orders (e.g., Histosols, Technosols, Cryosols, Leptosols, Solonchaks, Gleysols, Arenosols, and Fluvisols) which are permanently flooded (subaquatic) or only flooded by tidewater at mean high tide, but not flooded at mean low tide (tidalic) (WRB, 2015). However, the characterization of subaquatic soils is still poorly defined by the WRB-FAO system, since the definition of the qualifier explicitly determines a maximum water column height of two meters during low tide and it is known that seagrasses can commonly be found in deeper water areas (Duarte, 1991).

On the other hand, for the Brazilian Soil Classification System (Santos et al., 2013a), only the atmosphere can be considered the upper limit of soils. Except for the definition of the upper limit, the seagrass meadow soils fit perfectly in the soil definition used by the SiBCS (Santos et al., 2013a). In fact, all pedogenetic processes (addition, loss, translocation, and transformation) were identified in seagrass meadows worldwide, including in Brazil, for example: the addition of organic matter and biogenic calcium carbonate; loss of metals and organic matter; translocation of soil particles due to bioturbation; and transformation of organic substances, Fe, and S forms (Table 1) (Demas and Rabenhorst, 1999; Osher and Flannagan, 2007; Rabenhorst and Stolt, 2012; Serrano et al., 2012; Ferronato et al., 2016; Vittori Antisari et al., 2016; Nóbrega, 2017).

To our knowledge, only one study was published about Brazilian seagrass meadows soils. The occurrence of subaqueous soils along the Abrolhos archipelago was mentioned in a paper on soil phosphatization and landscape evolution (Schaefer et al., 2010). However, no pedological study, providing the morphological description, properties, and classification of seagrass soils of the Brazilian coast was published so far. Thus, to fill this gap of basic information and to stimulate the update of the SiBCS, two soil profiles from different coast compartments were studied to contribute with a first approach addressing the variability of seagrass soils of Brazil. Soil profiles were sampled on the semiarid coast in the Northeast (state of Ceará; predominantly vegetated with *Halodule spp*.) and the quaternary coast in the South (Lagoa dos Patos - RS; mostly vegetated by *Ruppia*

maritima; Figure 1), and described according to Santos et al. (2013b). On the semiarid coast of northeastern Brazil, seagrass soil was collected at a water depth of 1.8 m [water depth corrected to a mean water level 1.71 m; Marinha do Brasil (2017)], whereas on the quaternary coast in the South, soil under seagrass was collected at a water depth of 1.3 m [corrected to a mean water level of 0.68 m; Marinha do Brasil (2017)].

Table 1. Morphological properties and grain size composition of subaqueous soils of Brazilian seagrass meadows

Horizon	Depth	Matriz[1]	Mottle[3]	Struc[4]	Plast[5]	Stick[6]	Sand	Silt	Clay	Text[7]	Bound[8]
	m						——— % ———				
NE - *Gleissolo Tiomórfico Órtico sálico solódico neofluvissólico*[*] (SiBCS) / Fluventic Sulfiwassent (Soil Taxonomy) / Fluvic Subaquatic Solonchak (Hypersalic, Protosodic, Hypersulfidic, Loamic) (WRB-FAO)											
Agjz	0.00-0.10	5GY 3/1, 10YR 3/1[2]		MA	PL	SST	66	14	20	SCL/SL	GS
CAgjz	0.10-0.26	5G 4/1		MA	PL	SST	60	15	25	SCL	CS
Cgjz1	0.26-0.37	5GY 4/1		MA	SPL	NST	78	6	16	SL	AS
Cgjz2	0.37-0.56	10Y 4/1		MA	NPL	NST	82	6	12	SL	DS
2Cgjz3	0.56-0.84	5GY 4/1		SG	SPL	SST	80	2	18	SL	CS
3Cgjnz	0.84-1.14[+]	10B 4/1		MA	VPL	ST	48	12	40	SC	
S - *Gleissolo Tiomórfico Órtico sódico salino*[*] (SiBCS) / Fluventic Sulfiwassent (Soil Taxonomy) / and Fluvic Subaquatic Gleysol (Protosalic, Sodic, Hypersulfidic, Loamic) (WRB-FAO)											
Agj	0.00-0.6	N 2.5, 10Y 3/1 [2]		MA	SPL	SST	85	5	10	LS	CW
ACgj	0.06-0.13	2.5Y 5/1	7,5YR 4/4 CVD N 2,5/ VVD	MA	NPL	NST	91	4	5	S	CW
CAgjn1	0.13-0.30	2.5Y 4/1		MA	SPL	SST	69	11	20	SCL/SL	GS
CAgjn2	0.30-0.44	N 4		MA	SPL	SST	80	4	16	SL	GS
Cgjz	0.44-0.70	N 5		MA	SPL	SST	81	4	15	SL	GS
2Cgjnz	0.70-0.93	N 3		MA	PL	ST	50	20	30	SCL	CB
2Cgjnz/ 2Cgjn	0.93-1.06	5B 3/1, N 3[2]		MA	PL	ST	80	5	15	SL	CS
2Cgjn	1.06-1.11	5B 3/1		MA	VPL	VST	26	4	70	C	

[1] Matriz colour. [2] Variegated. [3] CVD: common, very fine, distinct; VVD: very few, very fine, distinct. [4] Structure: MA = massive; SG = single grain. [5] Plasticity: NPL = non-plastic; SPL = slightly plastic; PL = plastic; and VPL = very plastic. [6] Stickness: NST = non-sticky; SST = slightly sticky; ST = sticky; and VST = very sticky. [7] Texture: SCL = sandy clay loam; SL = Sandy loam; SC = Sandy clay; LS = Loamy sand; S = Sand; and C = Clay. [8] Boundary: GS = gradual smooth; CS = clear smooth; AS = abrupt smooth; DS = diffuse smooth; CW = clear wavy; and CB = clear broken (discontinuous). [*] the terms *neofluvissólico* and *salino* were included to better classify the soils of the NE and S coast, respectively.
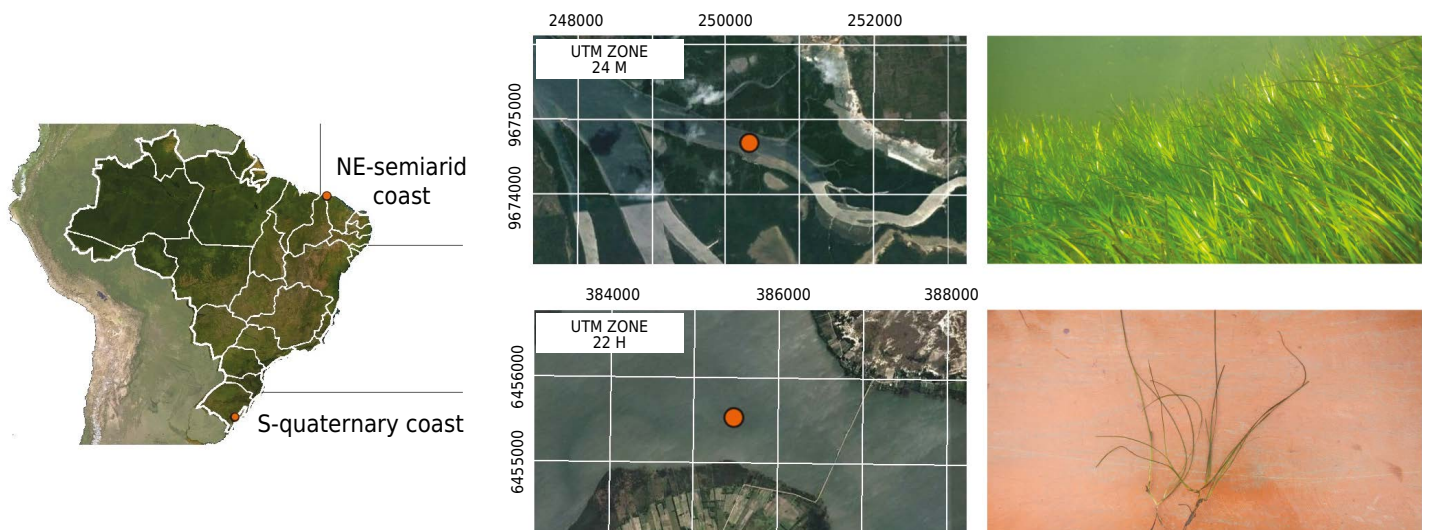

Figure 1. Subaqueous soil sampling locations.

These subaqueous soils were sampled using samplers attached to transparent tubes for sampling and visual confirmation of the partially disturbed samples (Figure 2). The tubes were pushed into the soil with a remote hammering system and a watertight valve prevented sample loss when pulling the sample out of the soil/water (Figure 2). After sampling, the tubes were sealed with rubber caps, transported in vertical position to the laboratory, where the samples were removed from the tubes. According to Erich et al. (2010), the two sampling techniques - vibracoring for deeper waters and sealed rigid tubes for shallower areas - can also be used for soil profile collection and description.

After soil description, subsamples of each soil horizon were taken and washed with ethanol (60 %) to remove soluble salts, until a silver nitrate test indicated absence of the chloride ion (Sumner and Miller, 1996; Claessen, 1997). Then the soil samples were dried, ground, and sieved to determine exchangeable cations, calcium carbonate equivalent (CCE), and grain size composition, using the soil classification methods proposed for SiBCS (Claessen, 1997; Santos et al., 2013a,b). Additionally, subsamples of soil horizons were taken and frozen until posterior analysis of total organic carbon (TOC), total nitrogen (TN), and Fe fractionation. Total organic C was quantified using an elemental analyzer, after removal of inorganic C with HCl 1 mol L^{-1} (Howard et al., 2014), whereas TN was quantified in untreated samples using an elemental analyzer. Iron was fractionated using the method proposed by Lord III (1982), obtaining two operationally distinct fractions: Fe-oxyhydroxides (Oxy-Fe) and pyrite (Py-Fe), which allowed the determination of the degree of pyritization [DOP = (Py-Fe × 100)/(Py-Fe + Oxy-Fe)] (Berner, 1970). The total potential acidity (pH$_{OXI}$) was determined measuring the pH after sample oxidation by H_2O_2 (Konsten et al. 1988).

The collected soils differed significantly regarding the morphological, chemical, and physical properties (Table 1 and 2). For both profiles, as a consequence of the characteristic waterlogging, the most significant processes were gleyzation and sulfidization, resulting in soils with low chromas (or neutral colors), but also dark and very dark gray colors, indicating sulfide accumulation (Table 2 and Figure 3). As a result of the intense sulfidization, a high percentage of the iron was incorporated into sulfides [degree of pyritization >50 %; e.g., percentage of Fe incorporated into pyrite; for further details, please see Berner (1970)]. However, due to oxidation promoted by the plant rhizosphere, brown Fe mottles can occur, evidencing oxidation of Fe sulfides and thus, the onset of sulfurization (Figure 3).
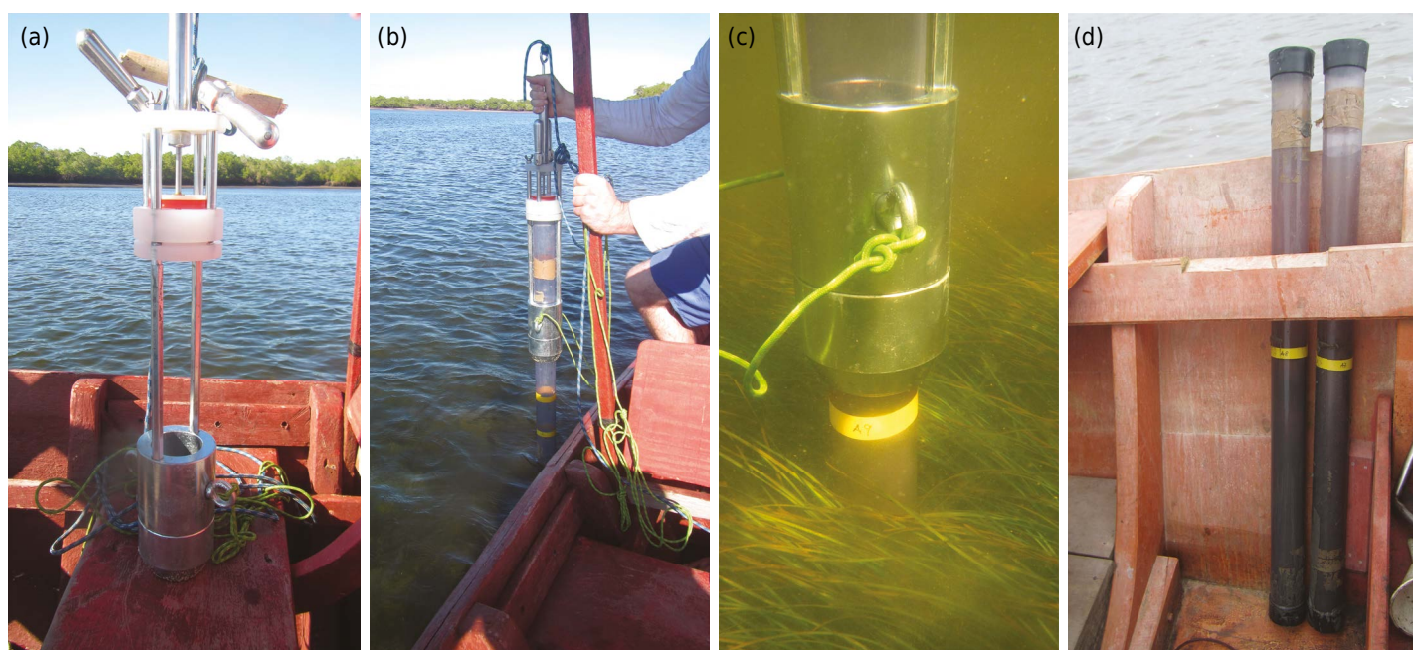

Figure 2. Subaqueous soil sampling procedure. Overall view of the soil sampler used (a) and onboard launch (b). Close view of the remote hammering system (c) and collected soil samples (d).

Figure 3. Subaqueous soil profile of the semiarid coast in the Northeast (a) and the Quaternary coast in the South of Brazil (b). In details, the variegated colors of the Agjz horizon (0.00-0.10 m) (c); broken seashells within a sandy texture matrix (2Cgjz horizon; 0.56-0.84 m) (d); whole seashells within a clayey matrix (horizon 3Cgjnz, 0.84-1.14⁺ m) (e), from the NE semiarid coast; surface soil horizon Agj (0.00-0.06 m) (f); mottles from sulfide production (black) and iron oxidation (brown) (ACgj horizon, 0.06-0.13 m) (g), and rhizospheric oxidation resulting in Fe oxyhydroxide precipitation (ACgj horizon, 0.06-0.13 m) (h) from the Quaternary coast in the South.

The accumulation of oxidizable Fe and S material induced strongly acidic conditions when the soil material was oxidized (Table 1), characterizing the presence of *hypersulfidic material* (WRB, 2015). This acidification due to oxidation was less significant in soil horizons with higher amounts of seashells, and higher amount of calcium carbonate equivalent (CCE), which can buffer the acidification process (*hyposulfidic material*) (WRB, 2015) (Figure 3 and Table 1). Attention should be paid to the CCE and seashells since they are not considered in definition of a "*Horizonte Cálcico*", used by the SiBCS (Santos et al., 2013a), conditioning the presence of secondary calcium carbonates. Moreover, the presence of biogenic calcium carbonate does not match the definition of subordinate properties for the presence of carbonates (k) or accumulation of secondary calcium carbonate (k̄) in the Brazilian System of Soils Classification (Santos et al., 2013b). Thus, the presence of biogenic carbonate should be considered in future modifications of SiBCS, since it strongly affects the acidity neutralizing potential and reflects the influence of biota on soil formation.

Soil textures with predominance of sand (Table 2) usually indicate a higher hydrodynamic in these ecosystems. Additionally, the variation in particle-size distribution within the soil profiles (presence of fluvic material) (WRB, 2015) may also result from changes in hydrodynamics through the evolution of the soil profiles.

Table 2. Chemical properties of seagrass meadow soils of Brazilian Coast

Horizon	Depth	pH Field	pH Oxi[1]	Eh	EC	TOC	TN	CCE	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	CEC	V	ESP	P	Oxy-Fe[2]	Py-Fe[3]	DOP
	m			mV	dS m^{-1}		%					cmol$_c$ kg^{-1}						%	mg kg^{-1}	µmol g^{-1}		%
NE - *Gleissolo Tiomórfico Órtico sálico solódico neofluvissólico** (SiBCS) / Fluventic Sulfiwassent (Soil Taxonomy) / Fluvic Subaquatic Solonchak (Hypersalic, Protosodic, Hypersulfidic, Loamic) (WRB-FAO)																						
Agjz	0.00-0.10	6.78	4.92	-36	42	3.5	0.3	2.9	0.3	0.6	8.3	1.7	<0.01	3.4	10.9	14.3	76	2	16	47.8	126.7	71
CAgjz	0.10-0.26	7.14	2.89	+34	42	1.8	0.1	2.0	0.1	0.3	1.8	2.6	<0.01	2.8	4.8	7.6	63	1	15	23.6	52.6	67
Cgjz1	0.26-0.37	7.06	2.76	+4	45	1.2	0.1	2.3	0.1	0.1	2.0	1.0	<0.01	1.6	3.1	4.7	66	1	8	14.3	44.7	66
Cgjz2	0.37-0.56	6.85	6.14	+32	45	3.2	0.1	13.8	0.1	0.2	7.2	2.4	<0.01	0.4	9.9	10.3	96	1	18	23.8	14.4	48
2Cgjz3	0.56-0.84	6.88	6.96	+222	45	2.9	0.1	14.6	0.1	0.2	9.8	3.0	<0.01	0.3	13.1	13.4	98	1	16	31.3	152.0	75
3Cgjnz	0.84-1.14$^+$	6.80	2.90	+169	52	2.5	0.1	42.	3.2	2.1	9.7	7.5	<0.01	1.5	22.5	24.0	94	13	27	31.5	176.9	83
S - *Gleissolo Tiomórfico Órtico sódico salino** (SiBCS) / Fluventic Sulfiwassent (Soil Taxonomy) / and Fluvic Subaquatic Gleysol (Protosalic, Sodic, Hypersulfidic, Loamic) (WRB-FAO)																						
Agj	0.00-0.06	7.72	2.99	+269	3	0.6	0.2	1.9	0.1	0.2	0.9	1.2	<0.01	1.3	2.3	3.6	64	<1	27	13.2	0.7	5
ACgj	0.06-0.13	7.14	2.45	+294	3	0.5	0.2	1.7	0.1	0.1	0.4	0.9	<0.01	0.9	1.4	2.3	61	1	18	10.8	19.2	55
CAgjn1	0.13-0.30	6.98	2.28	+366	2	0.6	0.2	1.7	0.8	0.4	1.3	4.7	2.8	5	7.2	12.2	59	7	27	16.1	53.1	76
CAgjn2	0.30-0.44	7.93	2.47	+94	3	0.6	0.2	1.8	0.5	0.4	0.9	2.8	1.7	3.9	4.6	8.5	54	6	33	13.5	26.8	63
Cgjz	0.44-0.70	7.84	2.65	-36	4	0.6	0.2	1.7	0.1	0.3	0.5	1.7	1.1	2.2	2.6	4.8	54	2	24	10.5	16.5	60
2Cgjnz	0.70-0.93	7.84	2.87	+38	5	0.4	0.2	1.7	4.6	2.4	5.4	8.6	<0.01	0.4	21.0	21.4	98	22	101	15.1	22.1	59
2Cgjnz/ 2Cgjn	0.93-1.06	7.73	3.30	+39	4	0.5	0.2	1.8	4.5	2.7	6.2	8.4	<0.01	0.1	21.8	21.9	99	22	78	15.2	16.9	45
2Cgjn	1.06-1.11	7.58	2.83	+40	2	0.8	0.2	1.8	4.4	2.7	9.3	10.1	<0.01	0.2	26.5	26.7	99	16	93	49.0	24.2	66

[1] pH values recorded after sample oxidation with H_2O_2. [2] Iron associated to oxyhydroxides. [3] Iron associated to pyrite. Eh = redox potential; EC = electrical conductivity; TOC = total organic carbon; TN = total nitrogen; CCE = calcium carbonate equivalent; SB = sum of bases; CEC = cation exchange capacity; V = base saturation; ESP = exchangeable sodium percentage; DOP = degree of pyritization. * The terms *neofluvissólico* and *salino* were included to better classify the soils of the NE and S coast, respectively. Soil samples (after the removal of soluble salts) were analyzed according to the methods proposed by Claessen (1997) and Santos et al. (2013a,b). Total organic carbon was obtained by elemental analyzer after samples acidification; total nitrogen was obtained by elemental analyzer using untreated samples (Howard et al., 2014). Iron fractions (i.e., Oxy-Fe and Py-Fe) were obtained according to Lord III (1982).

The soils also differed considerably with regard to the salinization process, with much higher electrical conductivity in the soils of the semiarid coast ($\approx$ 45 dS m^{-1}) compared to the Quaternary soils on the southern coast ($\approx$ 3 dS m^{-1}) evidencing that the salinization processes may occur at very contrasting intensities, regardless of the constant tidal influence on these soils. Additionally, the effects of seawater conditioned the occurrence of solonization/solodization processes, especially in the deeper layers of the S coast soils (Table 2). Besides, due to the significant seasonal variations in the water properties (e.g., salinity, temperature, nitrogen, and phosphorous) of the Lagoa dos Patos (Lanari and Copertino, 2016), it is expected that the salinization and solonization processes at this site also vary throughout the year. Thus, further studies are required to comprehend how relevant seasonal variations are for subaqueous soils.

Another difference between the two soil types is related to the intensity of paludization, i.e., the accumulation of organic C under anaerobic conditions. For the seagrass soil on the semiarid coast, C accumulation was significantly higher than that of the lagoon Lagoa dos Patos. These preliminary results evidenced paludization, since the climatic conditions may have been predominated by the local biogeochemical conditions. Additionally, the higher plant biomass on the NE coast (Figure 1), which resulted in a higher C input, should be emphasized. Paludization is probably the most studied pedogenic process in seagrass soils, due to the important role these ecosystems play for atmospheric CO_2 sequestration (Fourqurean et al., 2012). In fact, seagrass meadows and other coastal wetlands have been highlighted as the most important ecosystems for C sequestration, particularly into the soils, which inspired the designation Blue Carbon sinks (Nellemann et al., 2009) and stimulated studies regarding C accumulation in these ecosystems.

The soils were classified as Fluventic Sulfiwassent, according to the Soil Taxonomy; Fluvic Subaquatic Solonchak (Hypersalic, Protosodic, Hypersulfidic, Loamic) and Fluvic Subaquatic Gleysol (Protosalic, Sodic, Hypersulfidic, Loamic) according to the FAO-WRB system.

In general, the soils had a moderately adequate classification according to the SiBCS, being classified as *Gleissolo Tiomórfico* Órtico *sálico solódico* (NE-Semiarid coast) and *Gleissolo Tiomórfico* Órtico *sódico* (S-Quaternary Coast). For a better fitting of subaqueous soils in the SiBCS, a suborder for the *Gleissolos* soil order should be created, similar to the tidalic and subaquatic classifiers used by WRB-FAO, as well as criteria for the definition of a property analogous to hyposulfidic material. Additionally, new subgroups consisting of *Gleissolos Tiomórficos* Órtico *sálico solódico* **neofluvissólico** and *Gleissolos Tiomórficos* Órtico *sódico* **salino** could be created to detail the classification of seagrass soils of Brazil.

The pedological approach to these soils makes, among other aspects, their description and consistent mapping based on the pedogenetic similarities possible. In fact, many studies have been conducted to map subaqueous soils, mostly in estuarine environments (Demas and Rabenhorst, 1999; Bradley and Stolt, 2003, 2006; Erich and Drohan, 2012; Vittori Antisari et al., 2016). The study of subaqueous soils from the viewpoint of pedology paves the way for the management of these areas based on measurable physical and chemical soil processes, in the future, similarly to that used in subaerial soils. Research along this line will contribute to the establishment of thresholds to define subaqueous soil quality classes, which will in turn provide guidance for management practices (Demas and Rabenhorst, 1999, 2001; Erich and Drohan, 2012). Subaqueous soil maps could guide the identification of areas most indicated for dredging, for mollusk, and shellfish cultivation, but could also provide new insights on the main factors controlling the genesis of seagrass soils (Grech et al., 2012; Gladstone and Courtenay, 2014; York et al., 2016). Therefore, the use of the methods and procedures commonly used in soil genesis studies can significantly contribute to a more detailed and precise knowledge about processes and properties of seagrass soils and increase the chances of success of initiatives for restoration and protection.

For the Brazilian soil science community, including subaqueous soils as a potential study object would not only help to develop the soil classification system and the theoretical models used for soil genesis, but would also open new study fields of nitrogen-fixing and phosphate-solubilizing bacteria for soil microbiologists (Vazquez et al., 2000; Welsh, 2000), for soil chemistry and organic matter analyses (York et al., 2016), as well as other co-related soil science disciplines.

The comprehension of the pedogenetic processes may help to understand the ecological functions of seagrass meadows. Moreover, the studies of seagrass soils may be considered a future frontline of Brazilian soil science, as a new study object for soil chemistry, microbiology, and organic matter scientists, but also a useful tool for the conservation, restoration, and comprehension of ecological services provided by these ecosystems. Thus, it is fundamental that soil scientists increase their knowledge on subaqueous soils and their variations, not only to update and contribute to Soil Classification Systems (e.g., SiBCS, WRB-FAO, and Soil Taxonomy) but more importantly, to contribute to the protection of these endangered ecosystems.

CONCLUSIONS

According to the Brazilian Soil Classification Systems, the natural body formed by pedogenetic processes (mainly: gleyzation, sulfidization, salinization, paludization, and solonization and classified as *Gleissolos tiomórficos*) and that supports the life of rooted seagrass plants is not considered a soil, since the present soil definition a water column cannot be considered an upper limit of a soil.

The criteria related to the presence of calcium carbonate in the SiBCS (e.g., *Horizonte Cálcico;* and the subordinate characteristics k and k̄), should be re-defined, since the presence of seashells is not taken into account, which are important to control the acidification generated by the oxidation of sulfidic material; and properties should be created that describe the frequency of flooding and the occurrence of hyposulfidic material.

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