University of São Paulo
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Pedogenesis and geochemistry of saltmarsh soils from the Brazilian coast

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Thesis presented to obtain the degree of Doctor in Science. Area: Soil and Plant Nutrition

Piracicaba
2019

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RESUMO

Pedogênese e Geoquímica de solos de marisma da costa brasileira

As marismas são ecossistemas de transição entre a terra seca e os ambientes costeiros e tem características de ambos. Além disso, sua biota é adaptada para períodos de anaerobiose com saturação da água e alterações na salinidade. Além disso, são responsáveis por vários serviços ecossistêmicos, direto ou indiretamente associados aos solos. Apesar do aumento das pesquisas sobre o assunto, os solos de marismas ainda são pouco estudados no mundo, e não existem estudos no Brasil que descrevam a morfologia e classificação desses solos. Para isso, é necessário (1) analisar os estudos de marismas no mundo e suas relações com o solo; (2) avaliar as características morfológicas, químicas e físicas desses solos no Brasil; (3) Relacionar a geoquímica do ferro aos processos pedogenéticos nesses solos; (4) Discuta a relação entre a dinâmica do ferro na transição entre manguezais e marismas em clima tropical. Para isso, foram analisadas duas regiões contrastantes de marismas no Brasil (clima tropical e subtropical). Análises químicas (cátions, pH, Eh, C.E.), tamanho de partícula e análises sequenciais de ferro foram realizadas em ambas as áreas. Assim, as publicações de marismas estão mais relacionadas ao uso da terminologia de “sedimentos” do que “solo”, com 794 (65%) e 437 (35%) publicações, respectivamente. No entanto, o solo de Bragança foi classificado como Gleissolo Tiomórfico órtico sódico, e os solos de Laguna foram Gleissolo Tiomórfico órtico sódico e Gleissolo Tiomórfico órtico típico. Suas diferenças foram relacionadas ao maior teor de ferro no Pará que o de Santa Cataria, e às formas de ferro, onde no Pará são mais óxidos (baixa e alta cristalinidade), e em Santa Catarina está na forma de sulfeto. Os processos relacionados ao ferro de sulfurização e sulfidização foram observados no Pará e Santa Catarina, respectivamente. Em Bragança, os solos das marismas se diferem dos manguezais devido à elevação das marismas, o que reduziu a inundação e favoreceu a oxidação da pirita (processo de sulfurização), enquanto no manguezal parte do ferro é retida como pirita (sulfidização), pela presença de matéria orgânica e sulfetos.

Palavras-chave: Solos de áreas úmidas costeiras, Pedologia, Processos pedogenéticos

ABSTRACT

Pedogenesis and geochemistry of saltmarsh soils from the Brazilian coast

Saltmarshes are transitional ecosystems between dry land and coastal environments and have characteristics of both environments. Also, their biota is adapted for periods of anaerobiosis with water saturation and changes in salinity. Furthermore are responsible for several ecosystem services directly or indirectly associated with soils. Despite the increase in research on the subject, the saltmarshes soils are still poorly studied in the world, and there are no studies in Brazil that describe the morphology and classification of these soils. For that, it is necessary (1) to analyze the studies of saltmarshes in the world and their relations with the soil; (2) to evaluate the morphological, chemical and physical characteristics of these soils in Brazil; (3) Relate the geochemistry of iron to the pedogenetic processes in these soils; (4) Discuss the relationship between iron dynamics in a transition between mangroves and saltmarshes in a tropical climate. For this, two contrasting regions of salt marshes in Brazil (tropical and subtropical climate) were analyzed. Chemical analyzes (cations, pH, Eh, C.E.), particle size and sequential iron analyzes were performed in both areas. Thus, saltmarsh publications are more related to the use of the terminology of “sediment” than “soil”, with 794 (65%) and 437 (35%) publications respectively. However, Bragança saltmarsh soil was classified as Gleissolo Tiomórfico órtico sódico, and Laguna soils were Gleissolo Tiomórfico órtico sódico and Gleissolo Tiomórfico órtico típico. Their differences were related to the higher iron content on Pará than Santa Catarina, and to the iron forms, wherein Para it is more oxide forms (low and high crystallinity), and in Santa Catarina is in sulphate form. The iron-related processes of sulfuricization and sulfidization were observed in Pará and Santa Catarina respectively. In Bragança the saltmarsh soils differ from mangroves due to the elevation of saltmarsh, which reduced the inundation and has favoured to pyrite oxidation (sulfuricization process), while in mangrove soil portion of iron is retained as pyrite, once organic matter and sulphates are available.

Keywords: Coastal wetland soil, Pedology, Pedogenetic process

INTRODUCTION

Saltmarshes are responsible for providing a great variety of ecosystem services (Barbier et al., 2011). Recent studies have highlighted their abilities to act as an efficient sink for CO2 (Beaumont et al., 2014; Chmura et al., 2003), metals (Williams et al., 1994) and an important ecosystem to the maintenance of biodiversity (Deegan et al., 2002; Greenberg et al., 2014). These functions are, to some extent, directly or indirectly related to their soils. One example of the importance of saltmarsh soils in providing ecosystem services is the fact that the largest organic carbon pool in coastal ecosystems lies buried belowground, which contain more organic carbon than the aboveground biomass (Grimsditch et al., 2013; Kauffman et al., 2018).

It is underestimated there is 5,500,000 ha of saltmarsh worldwide (Mcowen et al., 2017), mainly in North America and Europe. Duarte et al. (2008) estimate a worldwide area of 140 Mha of saltmarshes, been the largest coastal wetland, while seagrasses (18 Mha) and mangroves (15 Mha) cover smaller areas. Despite its widespread occurrence, saltmarshes are being rapidly degraded around the world; losses are between 25% and 50% of their global historical coverage (Crooks et al. 2011, Duarte et al. 2008). In response to degradation, saltmarshes may lose their ability to act as sinks for metals or C but instead may be a source.

To understand that saltmarshes soils are essential to maintain their ecological services, it is pivotal to understand how these soils function, with respect to its formation, overall characteristics, chemical elements dynamics and behaviour to assess its responses under different stress situations (Kelleway et al., 2017). For this reason, studies about soil genesis (pedogenesis), soil formation, soil morphology and also pedology (the study of soil) are important.

Saltmarshes are coastal wetlands formed mainly by herbaceous vegetation and shrubs under the influence of saline or brackish water. Saltmarshes differ from mangrove forests mainly by the absence of trees (Adam, 1990). Both, mangroves forests and saltmarshes grasslands can occur at similar physiographic positions, however, each ecosystem has its optimum development under different climate regimes; temperate and sub-tropical climate usually favour saltmarshes; and sub-tropical to tropical climates mangroves (Perillo et al. 2009).

As mangroves, saltmarshes are transitional ecosystems located between drylands and the ocean, which present a biota adapted to long periods of water saturation, anoxic soil and salinity (Adam, 1990).

Saltmarshes have a high primary production both in the aboveground and belowground (Perillo et al. 2009). The higher production associated with the anaerobic environment (water-saturated), slows the rate of organic matter decomposition, promoting the accumulation of high contents of organic matter in its soils (i.e. paludization process). Hence, saltmarshes are an effective ecosystem in promoting carbon sequestration. Thus, when this ecosystem is impacted (e.g. land-use change), it may work as sources for CO_2 due to the increase in organic matter decomposition (Howard et al., 2014).

In response to the tidal action, saltmarshes soils are subjected to a redox-oscillating environment where different respiration processes act in an alternating fashion (anaerobic and aerobic respiration). Following the thermodynamic sequence, after oxygen (O_2), nitrate (NO_3^-) is the most avid electron acceptor, being reduced to nitrite (NO_2^-). Subsequently, manganese and iron oxides are used and then, sulphate is reduced to sulphite (Reddy et al., 1986).

The iron oxides (Hematite Fe_2O_3 and Goethite FeOOH) are the main pigmenting agent in soils. Iron reduction in oxygen-depleted environments drastically increases its solubility and produces low chroma and values colours in response to a process called gleyzation. Oxic microenvironments within the soil (produced by root and fauna activity) may favour the reoxidation of Fe producing mottled patterns with reddish or yellowish colours (redoximorphic features).

Under anoxic conditions ($Eh < 0$ mV) sulphate reduction may be the main organic matter decomposition pathway (Baas Beccking and Moore, 1961; Connel and Patrick, 1969). In saltmarshes, sulphate is maintained by seawater, which allows the formation of both mono and di iron sulphites (mackinawite and pyrite). The formation of pyrite is called sulfidization (Fanning and Fanning, 1989; Ferreira et al., 2007). This process alters several chemical and morphologic properties (Griffin and Rabenhorst, 1989).

Sulfidization can contribute to the unavailability of potentially toxic metals by the coprecipitation of these metals with pyrite (Otero et al., 2000). Moreover, pyrite oxidation produces sulfuric acid, which can decrease soil pH to values as lower than 3.0 triggering the sulfuricization process (Fanning et al., 2017).

Despite the recent recognition of coastal wetland soils for several key ecosystem services (e.g. carbon sequestration and contaminant immobilization), pedological studies are still scarce in some of these environments. Saltmarsh soils have been mostly studied in temperate countries despite the fact that these ecosystems cover vast areas of tropical coastlines.

Thus, the present study aimed to:

1. Assess the pedological studies on saltmarshes worldwide;
2. Assess the main chemical and morphological characteristics of saltmarshes soils from Brazil;
3. Identify the iron dynamic related to pedogenetic processes active in these soils;
4. Study iron and sulphur geochemistry in tropical and subtropical saltmarsh soils.

FINAL CONSIDERATIONS

Saltmarsh publications are more related to the use of the terminology of "sediment" than "soil", with 794 (65%) and 437 (35%) publications respectively. However, it has given attention to the soil as a key factor in providing different kinds of ecosystem services . In this way, it is expected more studies using the term soil to refer to coastal wetland substrates in the next years.

Morphologically, Bragança saltmarsh soil and Laguna saltmarshes soils are distinct, mainly by depth, particle size distribution, soil mineralogy, pH and iron contents. In addition, these soils were classified as Gleissolo Tiomórfico órtico sódico in Bragança, and Laguna soils were Gleissolo Tiomórfico órtico sódico and Gleissolo Tiomórfico órtico típico.

Furthermore, the differences between tropical and subtropical soils were related to the higher iron contents at Pará than Santa Catarina, and to the iron forms, with iron oxides prevailing in Pará (poorly crystalline iron oxides), and Fe – S forms in Santa Catarina, evidencing the iron-related processes of sulfuricization and sulfidization.

Contrasting tropical saltmarsh soils with mangroves in Pará, saltmarshes occupied a slightly more elevated terrain, which reduced the inundation and has favoured to pyrite oxidation (sulfuricization process), while mangrove soils were mainly marked by the sulfidization process;

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