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Salt-affected soils of the coastal plains in Rio Grande do Sul, Brazil

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ABSTRACT

In Rio Grande do Sul (RS) State, Brazil, the soils are not prone to salinization due to the large amounts of rainfall, which are sufficient to leach the soluble salts. However, flooded rice crops grown in the coastal plains of RS may be affected by soil salinity, once the soils in this region are formed by marine, fluvial-lacustrine sediments. The use of water for irrigation of crops from sources connected with the Atlantic Ocean, especially Patos Lagoon, can lead to deposition of excessive amounts of sodium in the soil, especially in southern portion, by the proximity to channel linking the lagoon to the sea. This study aimed to map the occurrence of salt-affected soils in the coastal plains of RS State, Brazil. The study was performed in three regions: Internal Coastal Plain (ICP), External Coastal Plain (ECP) to Patos Lagoon and North Shore. 766 georreferenced soil samples were collected and levels of exchangeable sodium, exchangeable sodium percentage (ESP) and electrical conductivity (EC) of saturated extract (ECse) were analyzed. The resulting analytical data of the sampling points were submitted to a descriptive statistic and used to generate maps aiming to depict the continuous spatial variation of each measured variable. Most of soil samples showed indicators of low soil salinity, especially in most of the ICP and North Shore. The soils most affected are concentrated in regions overlapping the paleochannels sub-surface previously identified in the sub-surface of the ECP and in areas closer to links between sources of freshwater and sea. In the ICP, the salinity problem was restricted to only some areas due to the use of saline water from Patos Lagoon.

1. Introduction

According to the FAO, the yearly global rice production is currently 750 million tonnes. The Asian continent is responsible for 90% of this production, followed by 5% from the American continents. In America, Brazil is highlighted as one of the major producers, with 1.3% of global rice production, generating approximately 12 million tonnes per year (FAOSTAT, 2013). Brazilian rice production is mostly irrigated (86.3%), and RS is the state with the highest production, exceeding 8 million tonnes (Embrapa Arroz e Feijão, 2015). This production is concentrated in five regions of the state that represent an area of 1.1 million ha. The ICP and ECP of RS are responsible for 25% of Brazilian rice production and are the regions with the greatest water availability (IRGA, 2018). These regions are situated on the southern coast of Brazil, which is dominated by lagoons separated from the Atlantic Ocean by only a thin sandy barrier that acts as an obstacle to the superficial flux of freshwater (Machado et al., 2008).

In general, the soils of RS State are not prone to salinization due to the large amounts of rainfall, which are sufficient to leach the soluble salts, such as sodium chloride (NaCl). However, in irrigated rice fields on the coastal plains of RS State, where the soils are formed by marine and fluvial-lacustrine sediments (Villwock and Tomazelli, 1995), soil salinity problems frequently occur because irrigation is performed with low quality water (i.e., water with a high content of salts). The soil salinity and sodicity of this region is attributed mainly to the irrigation of rice with saline water from coastal rivers and from Patos Lagoon. Patos Lagoon is the main water source for irrigation of rice fields and is a body of shallow water connected to the adjacent ocean (Atlantic Ocean) through a channel 22-km-long, 2-km-wide and 12-m-deep, on average (Kjerfve, 1986).

In the winter, the passage of frontal systems causes an increase in the frequency of south quadrant winds (Moller Jr. et al., 1996), which generates a water gradient between Patos Lagoon and the Atlantic Ocean, with a lower water level in Patos Lagoon. The established gradient is responsible for "pumping" the water of the Atlantic Ocean to the interior of Patos Lagoon, increasing its salinity (Castelão et al., 2003) mainly in its southern and estuarine portions, which occupy approximately 10% of the total surface of the lagoon. Salinization of Patos Lagoon frequently occurs in January and February, which corresponds to

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the reproductive stage of the rice crop (Marcolin et al., 2005; SOSBAI, 2016). Salt accumulation in the soil can damage the rice yield due to the high sensitivity of rice to salt stress (Khatun and Flowers, 1995; Gao et al., 2007; Fraga et al., 2010). When monitoring different local water catchments from Patos Lagoon for rice irrigation, Fraga et al. (2007) verified a large range of EC values: from 0.5 to >6 dS m^{-1}. Many of the measured values were considerably above the threshold values for irrigated rice (Ayers and Westcot, 1985).

Salt transport to the subsurface is a frequent phenomenon when an aquifer connects with surface water through permeable sediments (Burnett and Dulaiova, 2003), as occurs in the case of the ECP in RS, Brazil. Windom and Niencheski (2003) suggested that a significant amount of such water goes to the sea through an aquifer, mixing the fresh water from Patos Lagoon with saline water from the Atlantic Ocean. This underground mixture tends to be discharged into the Atlantic Ocean, especially after significant rain events that increase the level of Patos Lagoon (Machado et al., 2008). However, the quantity of reverse flow of this mixture, returning to Patos Lagoon, is still unknown. This reverse flow event may be observed in seasons with low rainfall in the headwaters of the main tributary rivers of Patos Lagoon, as in years of La Niña phenomena. In this way, Patos Lagoon can become a potential source of salt intrusion in coastal soils and many irrigated rice fields.

The dimension of this area and the salinity level of salt-affected soils are still unknown (Marcolin et al., 2005). However, it is known that salinity tends to occur in lowland soils adjacent to the southern portion of Patos Lagoon. The proximity of this region to the Atlantic Ocean and to the mouths of rivers that connect to the Atlantic Ocean (e.g., Tramandaí River and São Gonçalo Channel) confirms the occurrence of soils with sodic or solodic character (Pinto et al., 2004).

In this context, the survey of areas with salt-affected soils is a real and important demand to identify the scale of the problem in this indispensable Brazilian rice-producing region. The identification of such areas is also important to establish action strategies to minimize or correct the problem. Thus, the objective of the present study was to map the occurrence of salt-affected soils in the coastal plains of RS State, Brazil.

2. Materials and methods

The study was performed in three regions of RS State, Brazil: (i) ICP (Camaquã, Rio Grande, Arambaré, Tapes and Pelotas municipalities); (ii) ECP (Mostardas, Viamão and Palmares do Sul municipalities); and (iii) North Shore (Santo Antônio da Patrulha, Osório and Torres municipalities) (Fig. 1). The region of the coastal plains and the North Shore is formed by sedimentary deposits. The soils commonly found in the region were formed from sediments of marine and fluvial-lacustrine origin (Villwock and Tomazelli, 1995) and, therefore, are almost all characterized as sandy soils, being mainly represented by planosols, gleysols, arenosols and plinthosols (Streck et al., 2018). In addition to the sandy texture, most of the soils have a low organic matter content, resulting in a low cation exchange capacity (CEC) (Pinto et al., 2004).

The evaluation period was from July 2008 to August 2009. In total, 766 soil samples were collected from the 0–20 cm layer, with an auger, in areas with current soybean or pasture cultivation but with a recent history of rice cropping with irrigation from Patos Lagoon. The areas were chosen based on previous information from field technicians of Riograndense Rice Institute (IRGA) and rice farmers. The sampling density was 0.08 and 10 observations km^{-2} (low intensity recognition survey) in areas without and with historic knowledge of a soil salinity and sodicity problem, respectively. All the soil samplings were geo-referenced with GPS devices and composed of three sub-samples.

The following analyses were performed on all soil samples: ECse, levels of exchangeable Ca^{2+}, Mg^{2+} and Al^{3+} extracted by 1.0 M KCl (soil:extractant ratio 1:20) and levels of exchangeable Na^{+} and K^{+} extracted by Mehlich 1 (Tedesco et al., 1995). Exchangeable Al^{3+} in KCl extract was determined by titrating with 0.0125 M NaOH solution; Ca^{2+} and Mg^{2+} were determined in an atomic absorption

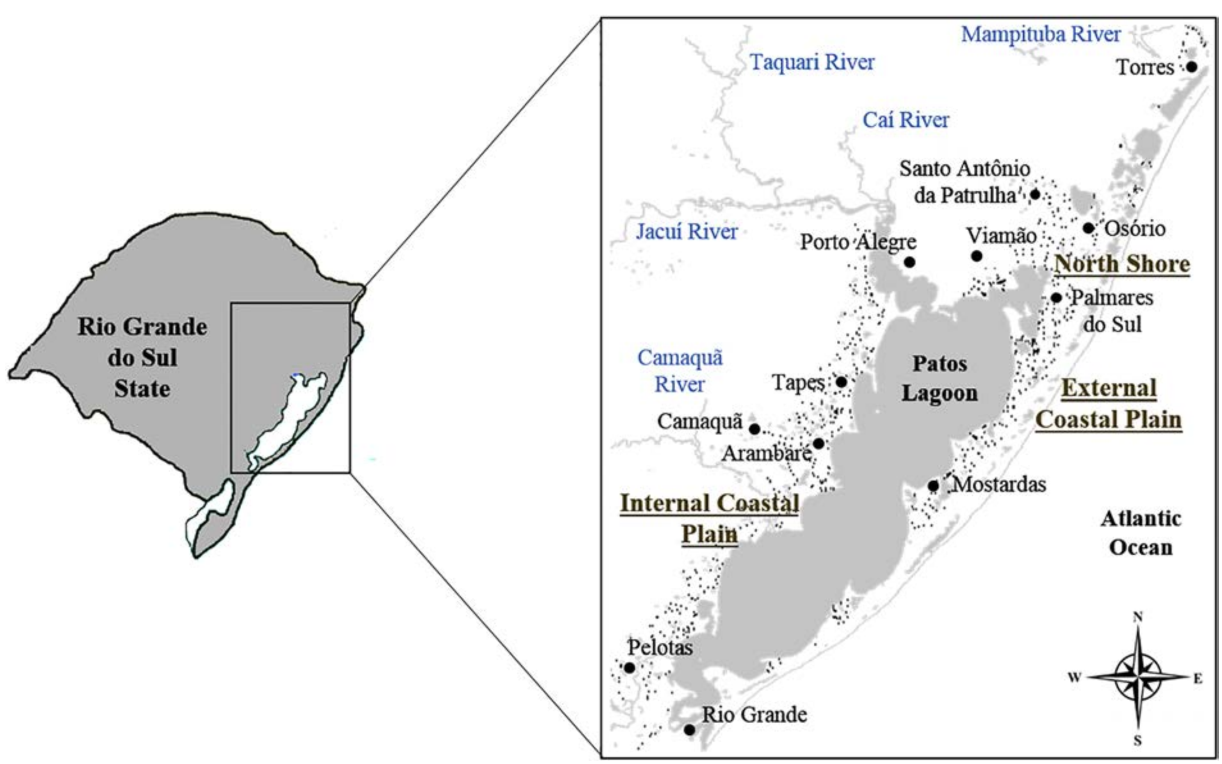

Fig. 1. Location of the study area in the Rio Grande do Sul State, with the indication of the main municipalities around the region of Costal Plains and rivers that flow into Patos Lagoon. The small black spots represent the site of soil sampling in the Internal and External Coastal Plains and North Shore of Rio Grande do Sul State, Brazil.