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Salinity study of irrigation waters used in rice fields

Estudo da salinidade em águas de irrigação utilizadas na lavoura arrozeira

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ABSTRACT

In Santa Catarina State, Brazil, rice is predominantly cultivated in irrigated systems, and irrigation water is generally collected directly from watercourses. Irrigated rice crops, which are sensitive to water salinity, form the basis of the economy of the Mampituba River Basin region, southern Brazil. This study aimed to assess salinity fluctuations in waters collected from the Mampituba River for irrigation of rice crops during the four seasons of the year. For salinity determination, water samples were collected from six sites along the river course, from the source to the mouth. Three subsamples were collected at each site, with a mean interval of 15 days between collections, beginning in May 2016 and ending in April 2017. Samples were evaluated for electrical conductivity (EC). Assessment of salinity damage was performed in seedlings of rice cultivars 'IRGA 417' and 'EPAGRI 106'. When seedlings reached the S2 stage, they were transplanted into flooded soil at different saline concentrations. EC values ranged from 224 to 20,120 µS cm^{-1} over the experimental period, being higher at sites closer to the sea. The highest salinity values were recorded between November 2016 and January 2017. It was possible to observe an inverse relationship between rainfall and water salinity. Salinity causes damage to rice plants, particularly seedlings. Symptoms include leaf tip chlorosis, leaf curling, and necrosis of old leaves. It is important for rice farmers to understand salt wedge fluctuations within their estuary as well as variations in salinity levels at different sites and times of the year.

KEYWORDS: irrigated rice; leaf damage; electrical conductivity; estuary.

RESUMO

No estado de Santa Catarina predomina na sua totalidade o cultivo de arroz irrigado e a água utilizada para a irrigação destas lavouras em sua maioria são retiradas diretamente de cursos de água. A região da Bacia Hidrográfica do Rio Mampituba tem sua economia baseada no cultivo do arroz irrigado, cujas plantas são sensíveis à salinidade. O presente trabalho objetivou determinar a flutuação de salinidade na água do Rio Mampituba (Sul do Brasil) utilizada para irrigação na lavoura arrozeira durante as quatro estações do ano. Para a determinação da salinidade foram realizadas coletas de água em seis locais no percurso do rio, desde sua nascente até a foz. Em cada local foram coletadas três subamostras de água com intervalo médio de 15 dias iniciado em maio de 2016 e finalizado em abril de 2017 e analisada a condutividade elétrica (CE). A caracterização do dano por salinidade em plântulas de arroz foi realizada nas cultivares IRGA 417 e EPAGRI 106. As plântulas foram transplantadas para solo inundado com diferentes concentrações salinas no estádio S2. A CE ao longo do período avaliado variou de 224 a 20.120 µS cm^{-1} e foi maior nos pontos mais próximos ao mar. Os maiores valores de salinidade foram observados entre os meses de novembro de 2016 e janeiro de 2017. Foi possível observar relação inversa entre a precipitação e a salinidade. A salinidade causa danos as plantas de arroz sendo os principais danos observados em plântulas. Estes danos foram clorose da ponta do limbo foliar, enrolamento foliar e necrose de folhas velhas. É importante que os orizicultores saibam como é a flutuação da cunha salina dentro do estuário, além de quais níveis incidem em cada local e em cada época do ano.

PALAVRAS-CHAVE: arroz irrigado; dano foliar; condutividade elétrica; estuário.

INTRODUCTION

Irrigated rice (*Oryza sativa*) has great socioeconomic importance for municipalities in southern Santa Catarina and northern Rio Grande do Sul States because it can be grown in floodplains that are unsuitable for other crops (SOSBAI 2018). Most rice fields in the Mampituba River Basin region are irrigated with waters from the Mampituba River. The Mampituba River originates in Cambará do Sul and flows toward the South Atlantic Ocean, passing through 18 municipalities, 8 of which are located in Rio Grande do Sul (Torres, Mampituba, Morrinhos do Sul, Dom Pedro de Alcântara, Cambará do Sul, São Francisco de Paula, Três Forquilhas, and Três Cachoeiras) and 10 of which are located in Santa Catarina (Passo De Torres, Praia Grande, São João do Sul, Santa Rosa do Sul, Sombrio, Balneário Gaivota, Balneário Arroio do Silva, Araranguá, Ermo, and Jacinto Machado).

Irrigated rice yields in the Mampituba River Basin amount to 7,715 kg ha^{-1}, although the production potential of cultivars exceeds 10,000 kg ha^{-1} (GIEHL et al. 2021). Such a discrepancy between productive potential and actual yields may be associated with climatic (temperature and rainfall), soil (chemical, physical, and biological characteristics), and phytosanitary (pests and diseases) factors. It is also believed that, in coastal regions, the high salinity levels of irrigation waters, resulting from the mixing of ocean saltwater with river freshwater, may be interfering with the yield of rice crops, given that salt concentrations greater than 0.25% NaCl (about 2000 µS cm^{-1}) are known to cause crop losses of more than 50% (SOSBAI 2018).

Studies in other estuaries in Rio Grande do Sul and Santa Catarina showed that factors such as rainfall, maximum tidal height, relief, and water demand for rice cultivation can positively or negatively influence salt concentrations in rivers such as the Mampituba, and may lead to salinization in areas distant from the coast (DENARDIN et al. 2018). To date, few in-depth studies have been conducted in this or other nearby estuaries; therefore, it is not possible to identify high salinity sites or monitor changes in salt levels in these waters. Variations in salinity index with time of year are also unknown. This information is crucial for rice production in southern Santa Catarina, because many farmers collect water directly from this or nearby estuaries, such as the Araranguá River.

Irrigation with salinized water causes, among other problems, a decrease in tiller emergence, leaf tip burn, and a complete yellowing of leaves. These symptoms are observed in most crops irrigated with water collected from the Mampituba River, and not only in coastal areas (SCHMIDT & VIEIRA FILHO 2017).

This study aimed to assess water salinity levels in the Mampituba River Basin throughout the four seasons of the year and determine which salinity levels cause damage and interfere with the development of irrigated rice seedlings. The main hypothesis was that water salinity fluctuates over the year in the salt wedge of the Mampituba River. Salinity levels in the wedge are higher than 2000 µS cm^{-1}.

MATERIAL AND METHODS

This study consisted of two phases. In the first phase, water samples were collected from the Mampituba River and evaluated for salinity (Experiment 1). In the second phase, a laboratory experiment was conducted to determine the effect of salinity in rice seedlings (Experiment 2).

For Experiment 1, water collection was performed at six sites located along the Mampituba River, encompassing from the source to the mouth, covering a distance of about 70 km (Table 1).

Table 1. Description of water collection sites, with geographic coordinates, elevation, and distance from the mouth of the Mampituba River. IFC, Santa Rosa do Sul campus, SC, 2018.

Collection site	Geographic coordinates		Elevation (m)	Distance from the river mouth (km)
1	29°12′47″S	49°58′14″W	56	36
2	29°14′57″S	49°50′56″W	9	23
3	29°16′22″S	49°50′52″W	6	20
4	29°16′58″S	49°49′22″W	4	17
5	29°17′30″S	49°46′42″W	3	13
6	29°17′47″S	49°44′52″W	2	8

The following criteria were considered for the selection of sampling sites: proximity to the ocean, points of water withdrawal for irrigation of rice crops, connections to other rivers and ponds within the basin, and reports of symptoms compatible with salinity damage in rice fields in previous harvests.

At each sampling site, three subsamples of 300 mL of water were collected between May 2016 and April 2017, with an interval of about 15 days between collections. A general analysis of tide tables was performed for selection of sampling dates. Each collection date was set between one and two days after the high tide in an attempt to standardize sampling procedures. Water aliquots were withdrawn at a depth of 1 m and a distance of at least 1 m from the riverbank. A PET bottle with a hose attached to the bottom was used for water collection. A lead weight was affixed to the hose to keep it underwater and allow determining the depth of sample collection. A second hose, connected to the top of the bottle, was used for suctioning air out, thereby generating a negative pressure that facilitated the entry of water into the bottle.

Samples were stored in amber bottles inside Styrofoam boxes and transported to the Laboratory of Chemical Analysis, IFC, Santa Rosa do Sul campus, for determination of electrical conductivity (EC). EC was measured in 300 mL samples by using a conductivity meter (model mCA 150, Lucadema), according to the method described by TEDESCO et al. (1995).

Total Na, K, Ca, and Mg contents were determined at the laboratory of the Institute of Environmental and Technological Research, UNESC (Universidade do Extremo Sul Catarinense), by inductively coupled plasma optical emission spectrometry, according to standard method SMWW 3120 B.

Experiment 2 was conducted at the soil laboratory of IFC, Santa Rosa do Sul campus. The experimental period lasted 22 days. A completely randomized design with four replications was used. Experimental units consisted of plastic trays measuring 0.34 × 0.50 m. Treatments consisted of three saline solutions at different concentrations, as follows: 0 (control), 2000, and 3000 µS cm^{-1}. These salinity levels were chosen on the basis of the tolerance threshold of rice crops (SOSBAI 2018). The cultivars used were ‘IRGA 417’ and ‘EPAGRI 106’, two early cycle varieties purchased from Cooperativa Agroindustrial Cooperja as certified seeds (C2).

Saline solutions were prepared by mixing deionized water and seawater (EC = 95,000 µS cm^{-1}) under agitation. EC was measured using a conductivity meter. First, 1 L of deionized water was added to a beaker. Then, seawater was added until reaching the target EC of each treatment. A trial-and-error method was used to monitor EC values until stabilization.

Each plastic tray was filled with about 5 cm of soil (dystrophic Tb Melanic Gleysol) collected from a site under rice cultivation at IFC, Santa Rosa do Sul campus (29°06′00″S 49°48′21″W, 9 m elevation). Saline solution was added to wet the soil to a muddy consistency. The soil was leveled and more saline was added to a height of 2 cm. Trays were kept at rest for about 24 h for mud stabilization. Then, EC was measured, and, if necessary, more seawater was added and trays were left to rest for a further 24 h. This procedure was repeated until EC values stabilized at the target concentration of each treatment. After stabilization, trays were covered with plastic film to prevent water evaporation and changes in salt concentrations.

Prior to planting, rice seeds were pre-germinated in a biochemical oxygen demand incubator at 24 °C for 5 days. Transplanting was performed when seedlings had the coleoptile and radicle measuring about 15 mm (S2 stage) (COUNCE et al. 2000). Seedlings were arranged in rows spaced about 5 cm apart, with eight seedlings per row and the roots at a depth of 5 to 10 mm. Trays were kept in a protected environment under artificial lighting provided by 80 W incandescent lamps. Each tray was illuminated by a lamp placed at a height of 30 cm from the soil surface.

Seedlings were transplanted on May 22, 2018, and analyzed on June 13, 2018, totaling 22 days of cultivation. During this interval, EC was adjusted every 2 days with a mixture of seawater and deionized water. EC variations during the experimental period did not exceed 200 µS cm^{-1}.

For analysis, plants were harvested and their roots washed with deionized water. Phenological stages were determined using the Counce scale (COUNCE et al. 2000). Plants were photographed to facilitate the description of salinity effects.

Shoots and roots were separated at the coleoptile node and subjected to dry weight determination. Shoot and root samples were placed separately in paper bags, dried in a forced-air oven at 60 °C to constant weight (72 h), and weighed (PARAIZO et al. 2021).

Data were subjected to analysis of variance followed by Tukey’s test at the 5% significance level using Assistat software (SILVA & AZEVEDO 2016).

RESULTS AND DISCUSSION

EC ranged from 224 µS cm^{-1} to 20,120 µS cm^{-1} at sites 1 to 6 over the 1-year evaluation period. The highest salinity values were recorded between November and January (Figure 1). There was an inverse relationship between rainfall and salinity; that is, EC increased with decreasing rainfall. This finding can be attributed to the intrusion of seawater along the estuary. It can be estimated that the salt wedge extended up to 10-13 km from the sea. This value, however, may vary, given that it was not possible to determine the exact extent of sea wedge intrusion during collection because collection sites were located 5-7 km apart from each other. Previous studies observed high salinity values (>2000 µS cm^{-1}) in estuaries at 5 km from the sea; an EC of 2000 µS cm^{-1} is the tolerance threshold of irrigated rice (D'AQUINO 2011, COUCEIRO et al. 2021).

Water samples with an EC of 5860 µS cm^{-1} and a pH of 6.7 were shown to contain the following salt composition: 987.5 mg L^{-1} Na, 47.76 mg L^{-1} K, 39.5 mg L^{-1} Ca, and 101.12 mg L^{-1} Mg. Na was the element with the highest concentration in the evaluated samples, responsible for the increase in salinity which resulted in chlorosis in rice plants. In another estuary, Na was identified as the main salt responsible for the increase in the EC of water used for irrigation; this correlation was used to indirectly estimate exchangeable sodium percentage (Na saturation), which is the most accurate method for identifying the salt saturation limit of a given soil (CARMONA et al. 2011, DENARDIN et al. 2018).

Between August and January, despite the frequent rainfall, there was an increase in EC values and presence of salinity at collection sites 3 to 6. This behavior might be associated with increased withdrawal of water for rice irrigation. The highest EC values and salinity occurrence were recorded from the second half of November to the first half of January (Figure 1). Salt wedge intrusion is related to rice cultivation, because EC levels are more pronounced in irrigated rice fields at the beginning of soil preparation, which is traditionally performed after the second half of August. During this period, there is greater water withdrawal from the estuary, and reduced precipitation contributes to increasing EC across collection sites. Such a scenario is accentuated in the spring, from the first half of November onward, because the increase in evapotranspiration of crops increases their water demand.

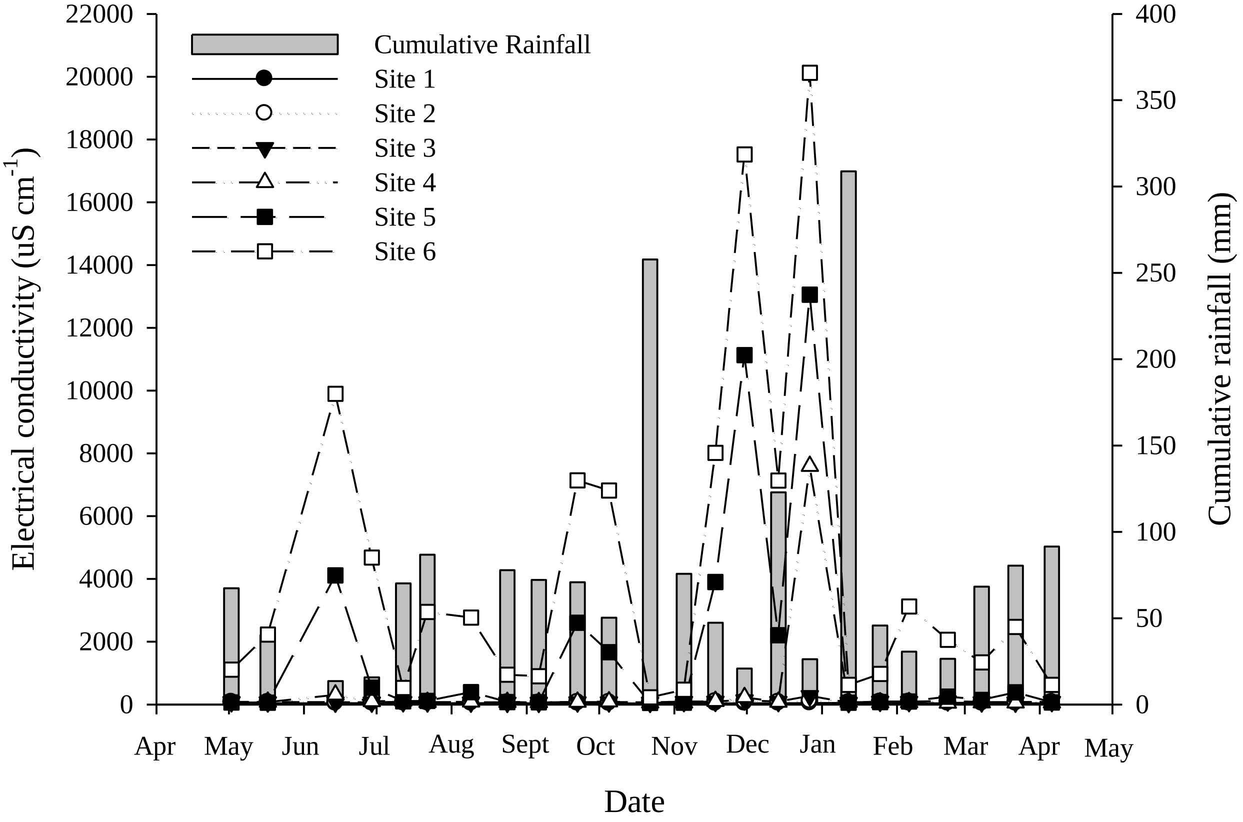

Figure 1. Variation in electrical conductivity of the main tributary of the Mampituba River at six different sites and cumulative rainfall from February 5, 2016, to June 4, 2017 (15-day intervals). IFC, Santa Rosa do Sul campus, SC, 2018.

The EC of the Mampituba River fluctuated throughout the year, mainly stemming from changes in rainfall and water withdrawal for irrigation. Although the watershed has a well-distributed water regime, periods of 15 days or more without rain are common throughout the year. The region has few reservoirs for agricultural use; thus, there is a large demand for water from the Mampituba River. Water is withdrawn from Praia Grande, Santa Catarina State, to the river's mouth, in Torres, Rio Grande do Sul State. ALTHOFF (2002) observed a similar fluctuation in salinity levels in the Araranguá River Basin. The author sampled water near the mouth and in a region with high water demand for irrigation: EC levels of about 5000 µS cm^{-1} were observed from September 1990 to March 1991.

Variation in EC levels is mainly due to the evaporative demand of crops, which are irrigated with estuary water. The high water demand of rice crops is attributed to the fact that water is distributed over a large area, causing a reduction in blade height and potentiating evaporation. Evaporation reduces the freshwater column of the estuary, promoting tide elevation and salt wedge intrusion, consequently affecting cultivated areas. Another factor that aggravates this problem is the fact that there is no other source of water for crop irrigation in the study region.

Damage to the leaf blade was observed in rice 'IRGA 417' and 'EPAGRI 106' as a result of exposure to the highest saline concentration (3000 µS cm^{-1}) compared with the control (Figures 2A, B, E, and F; Figures 3A, C, and D). Plants exposed to 2000 µS cm^{-1} had similar growth and development patterns to the control (Figures 2C and D), showing mild necrosis in the leaf blade and senescence of, mainly, the first expanded leaf (Figure 3B). The salinity tolerance of the studied rice cultivars is 2000 µS cm^{-1} (KOSH et al. 2016, SOSBAI 2018).

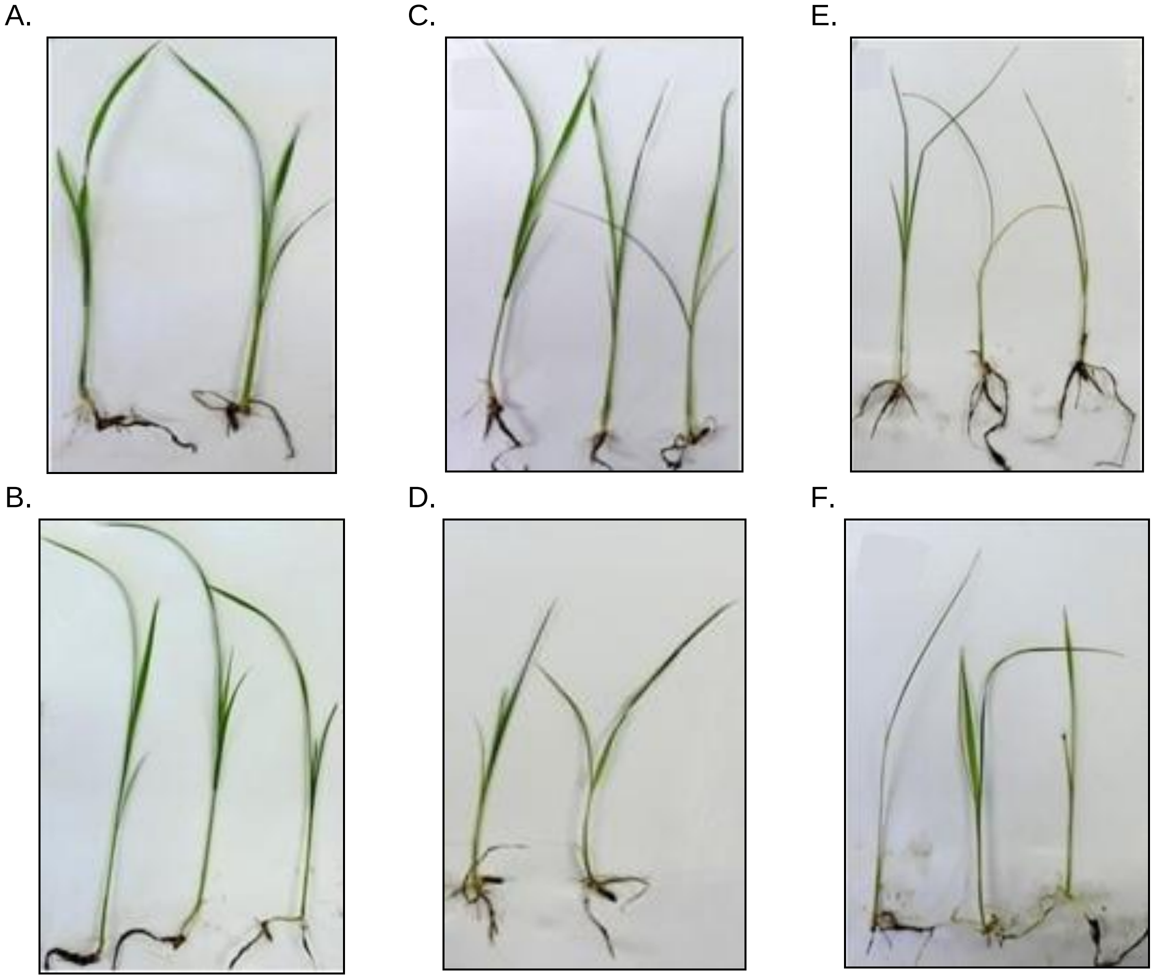

Figure 2. Growth and development pattern of rice 'IRGA 417' and 'EPAGRI 106' subjected to different saline concentrations. Treatments were as follows: control (0 µS cm^{-1}) for 'IRGA 417' (A) and 'EPAGRI 106' (B); 2000 µS cm^{-1} for 'IRGA 417' (C) and 'EPAGRI 106' (D); and 3000 µS cm^{-1} for 'IRGA 417' (E) and 'EPAGRI 106' (F). IFC, Santa Rosa do Sul campus, SC, 2018.

The results of the current study were similar to those reported by SCHMIDT & VIEIRA FILHO (2017), who subjected seedlings of several rice cultivars to saline stress (EC = 2000 µS cm^{-1}). The authors observed that plant growth was higher at 40 days in the experimental group than in the control. Such a result occurred because, at low concentrations, Na stimulates cell expansion, promotes tissue growth, and replaces K in osmotic adjustment in cells. Like K, Na is a highly hygroscopic ion, favoring water absorption by plants

(PARIHAR et al. 2015). Differences in growth patterns between rice plants subjected to the same saline concentration (Figure 2) might be associated with the atypical temperature during the crop cycle (about 20 °C) and the use of artificial lighting, which might have caused etiolation because of competition for light.

Salinity tolerance is mainly determined by the exchangeable sodium percentage (Na saturation), a parameter that varies according to soil type and Na content (CARMONA et al. 2011, DENARDIN et al. 2018). In greenhouse assays, only 20% of plants irrigated with water with an EC of 3000 μS cm^{-1} survived, showing reduced growth (KRISHNAMURTHY et al. 2016). Field experiments conducted in a protected environment revealed that rice is sensitive to salinity, especially during the initial stages of growth; an EC of 1900 μS cm^{-1} is sufficient to affect plant growth and development (KRISHNAMURTHY et al. 2016, MUKHOPADHYAY et al. 2021).

The main plant damage observed was leaf tip chlorosis, which over time evolved into full chlorosis, ultimately resulting in total leaf necrosis (Figures 3B, C, and D). In plants subjected to saline stress, only leaves undergoing early development (lacking the collar region) did not show damage, being similar to leaves of control plants (Figure 3A). Leaf curling was observed in younger and older leaves, the latter of which also showed chlorosis, resulting in rupture of the leaf blade (Figure 3D). The main defects observed were total chlorosis of old leaves, intense leaf curling in younger and developing leaves, and a yellowish-green to yellow color (Figures 3B and C). Saline stress alters the ionic composition of stroma, modifying surface charges in the thylakoid membrane; moreover, the effects of Na itself further contribute to membrane disorganization (KHARE et al. 2015), causing damage to all photosystem components, possibly inhibiting photosynthesis and reducing the production of sugars and energy. Consequently, the aerial part of plants subjected to saline stress shows reduced or halted growth (SCHMIDT & VIEIRA FILHO 2017).

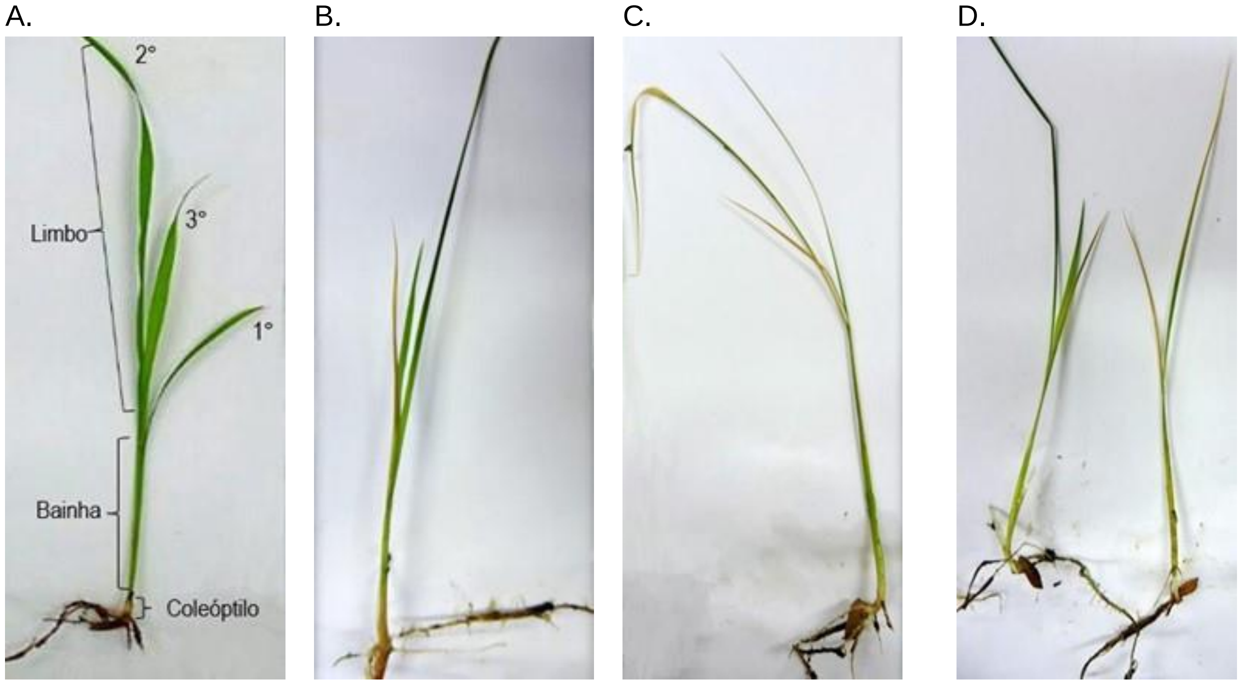

Figure 3. Major salinity-induced damage in rice plants after 22 days of cultivation. Control plant without damage to leaf structures, showing coleoptile, sheath, and leaf blade (A), leaf necrosis and curling of the first leaf (B), necrosis on all leaves (C), and burnt leaf tips and leaf curl (D). IFC, Santa Rosa do Sul campus, SC, 2018.

Cultivars differed in phenological stage (COUNCE et al. 2000) (Table 2), a characteristic associated with the genetic variation of materials during seedling establishment, even though both cultivars are classified as early maturation. Leaf development did not differ significantly between treatments within a cultivar.

Shoot and root dry weights did not differ significantly between treatments or cultivars, indicating that the evaluation period was not long enough to detect variations in leaf emission or biomass accumulation (Table 2). The short cultivation period (22 days) and unfavorable environmental conditions (temperature and lighting) might have contributed to these results. In the 22 days of cultivation, it was possible to observe severe visual damage but not to detect changes in shoot or root weight, given that most of the energy and nutrient supply is obtained from the seed at this stage (SOSBAI 2018).

Variations in EC and, consequently, salinity levels were observed during the four seasons of the 2016/2017 crop year. Long-term studies are needed to more accurately determine the salinity levels and salt wedge intrusion of the studied estuary. It is also necessary to periodically monitor the salinity of irrigation water collected from the river. Currently, farmers use unsophisticated and imprecise methods to detect the presence of salt in water.

Table 2. Phenological stage (number of leaves with collar), shoot dry weight (SDW), and root dry weight (RDW) of rice 'IRGA 417' and 'EPAGRI 106' subjected to different saline concentrations after 22 days of cultivation in a protected environment. IFC, Santa Rosa do Sul campus, SC, 2018.

Treatment	Phenological stage[1]		SFW (mg)		RFW (mg)	
	IRGA 417	EPAGRI 106	IRGA 417	EPAGRI 106	IRGA 417	EPAGRI 106
Control	2.50 ^{ns}	2.40 ^{ns}	12.96 ^{ns}	14.25 ^{ns}	30.08 ^{ns}	29.42 ^{ns}
2000 µS cm^{-1}	2.6	2.4	13.87	13.25	25.01	21.91
3000 µS cm^{-1}	2.5	2.3	13.58	13.5	24.83	24.88
Mean	2.56 a	2.4 b	13.46 a	13.68 a	26.63 a	25.39 a
CV (%)	4.47		9.91		21.33	

(^{ns}), not significant; CV, coefficient of variation. Means in a row followed by the same letter do not differ from each other by Tukey's test at the 5% probability level. [1] Phenological stage was assessed according to the scale proposed by COUNCE et al. (2000).

CONCLUSION

Salinity varies dynamically in the Mampituba River, ranging from 224 µS cm^{-1} to 20,120 µS cm^{-1} throughout the year.

EC levels of 2000-3000 µS cm^{-1} cause chlorosis, leaf curling, and necrosis of old leaves, interfering with the development of irrigated rice seedlings.

The results underscore that farmers need to measure salinity directly to avoid irrigating rice crops with saline water.

It was possible to gain insight into the fluctuation of the salt wedge in the studied estuary, but further research is needed in the current and other estuaries to monitor the behavior of the salt wedge in years with rainfall levels below and above the average.

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