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QUALITY OF WATER DRAINAGE IN THE NORTHEAST REGION OF BRAZIL USING ELECTRICAL CONDUCTIVIY AND SODIUM ADSORPTION RATIO

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1 ABSTRACT

Water and soil salinity are major concerns in irrigated agriculture, and electrical conductivity must be taken into consideration when planning irrigation. The Jacaré-Curituba irrigated perimeter, located in the municipality of Poço Redondo, state of Sergipe, Northeast Brazil, lies in a semi-arid region and has the characteristic of being geared toward family farming. Thus, this work had as objective to evaluate the electrical conductivity (EC) of the water and the sodium adsorption ratio (SAR) of the drainage water of a saline soil recovery area in field conditions. The field experiment was conducted in saline-sodium soil in irrigated plots, and the experimental design was completely randomized, with nine water sampling points and three replications. The collection points were as follows: drainage channel input (CDI), drainage channel outlet (CDO), lateral drains for each plot (D1, D2, D3, D4, D5, D6) and useful water for irrigation (IW), with six water sampling campaigns being performed. The induced results showed that drain water has a much high risk of causing salinity.

Keywords: irrigated perimeter, salinity, semi-arid, irrigated agriculture.

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2 RESUMO

A salinidade do solo e da água é uma grande preocupação na agricultura irrigada, sendo que a condutividade elétrica deve ser considerada no planejamento da irrigação. O perímetro irrigado

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Jacaré-Curituba localizado no município de Poço Redondo, estado de Sergipe, Nordeste do Brasil, se situa na região semiárida e tem como característica ser voltado para agricultura familiar. Assim, o presente trabalho teve como objetivo avaliar a condutividade elétrica da água (CE) e a razão de adsorção de sódio (RAS) da água de drenagem de uma área de recuperação de solo salino-sódico em condição de campo. O experimento de campo foi realizado em solo salino-sódico em lotes irrigados, sendo que o delineamento experimental foi inteiramente casualizado, com nove pontos de amostragem de água e três repetições. Os pontos de coleta foram os seguintes: início da entrada do canal de drenagem (CDI), saída do canal de drenagem (CDO), drenos laterais para cada parcela (D1, D2, D3, D4, D5, D6) e água utilizada para irrigação (IW), sendo realizadas seis campanhas de amostragem de água. Os resultados mostraram que a água de drenagem tem um risco alto e muito alto de causar salinidade.

Palavras-chave: perímetro irrigado, salinidade, região semiárida, agricultura irrigada.

3 INTRODUCTION

The semiarid is constituted as a climatic classification, and its concept and delimitation correspond to the following criteria, according to the Sudene Deliberative Council (CONSELHO DELIBERATIVO DA SUDENE, 2017): “Average annual rainfall of 800 mm or less; Thornthwaite aridity index equal to or less than 0.50 and daily percentage of water deficit equal to or greater than 60%, considering all days of the year.” Thus, 1,262 municipalities within the nine states of the northeast region, in addition to the north of Minas Gerais, are part of the semiarid region of Brazil. In the state of Sergipe, specifically, it covers 29 municipalities. The Brazilian Northeast region has the largest semi-arid area of the World with 982,566 Km2 that corresponds to 18% of the country, 53% of the northeast region, reaching 1,113 municipalities and the population of about 22 million inhabitants with the limitation of water resources that impose major challenges to water resources management (BRASIL, 2017; EL GAMMAL, 2016). Irrigated perimeters are essential in the development of Brazilian semi-arid and the public policies have driven the expansion of irrigated areas recently (PONTES et al., 2013).

In irrigation management, a particularly complex environmental issue is the relationship between water quality and quantity at macro (system), meso (intermediate), and micro (plot) levels of drainage. To better understand the spatial and temporal variation of drainage water quality across these nested scales it is necessary to reduce the adverse effects of reusing drainage water on agricultural productivity, natural ecosystems, and human health (EL-AGHA et al., 2020). Salinity is a major concern and is deemed the most important parameter in determining water suitability for agricultural irrigation.

The extent of the salinization of water resources, whether by natural processes or induced by human activities, is not well defined in most countries. The volumes of water affected, and the degree of salinization is usually poorly quantified (STENHOUSE; KIJNE, 2006).

The FAO (Food and Agriculture Organization of the United Nations) classification reported by Ayers and Westcot (BORTOLINI; MAUCIERI; BORIN, 2018) is the most used among the different water quality classifications mentioned by the scientific literature.

Four levels of saline irrigation water have been distinguished: low salinity defined by the electrical conductivity of less than 0.25 dS m^{-1}; medium salinity (0.25 to

0.75 dS m^{-1}); high salinity (0.75 to 2.25 dS m^{-1}), and very high salinity with an electrical conductivity exceeding 2.25 dS m^{-1} (US Salinity Laboratory Staff, 1954). Saline irrigation water is affected not only by the salinity level but also by soil characteristics, irrigation practices such as the type of system and the timing and number of irrigation applications (STENHOUSE; KIJNE, 2006). The main parameters considered important for irrigation are Na, Ca, Mg, Fe, Cl contents, EC_w, and pH value.

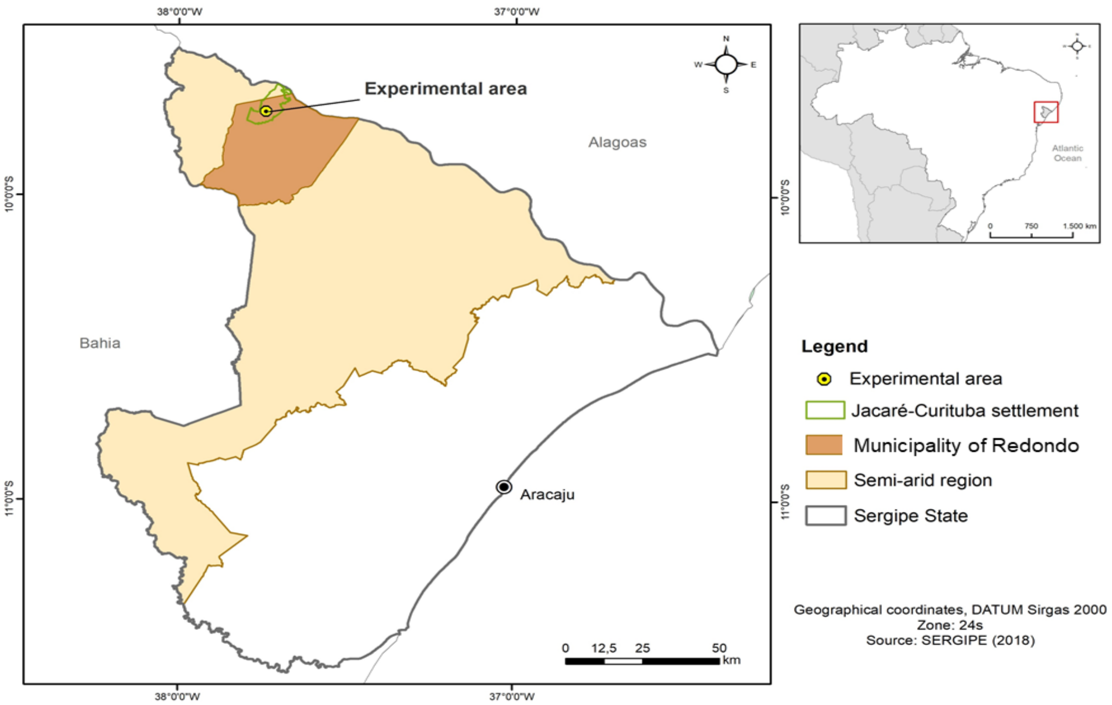
Agricultural wastewater contains high levels of nutrients and salinity that, when drained into water bodies and the soil, result in devastating changes in the quality of these drainage areas (AKRAM et al., 2013).

Drainage system development and management are vital for the humidity and salinity control of lands, particularly in saline lands with shallow groundwater table (POVILAITIS et al., 2015). Drainage water salinity is a major water quality concern for agricultural water management in arid and semi-arid regions. The reuse of drainage water with high salinity affects the sustainability of the irrigation system (EL-AGHA *et al.*, 2020). Thus, the aim of this research was to evaluate the electrical conductivity (EC) of water and sodium adsorption ratio (SAR) of the water drainage from a saline soil recovery area under field condition.

4 MATERIAL AND METHODS

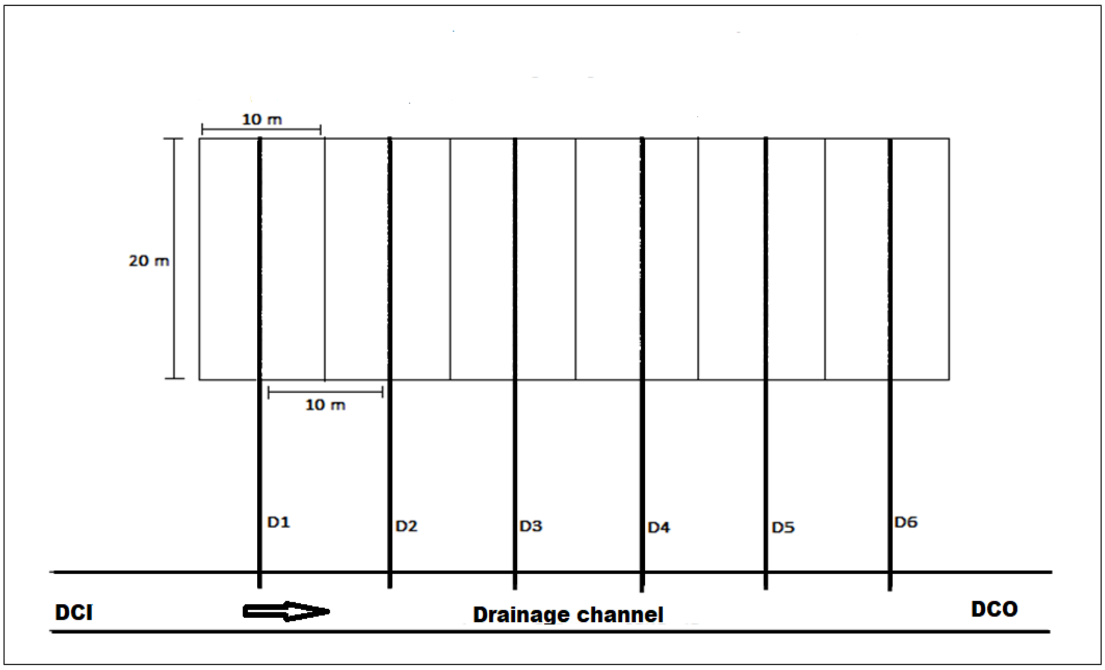
The study was carried out in the area of an experiment to recover a soil affected by salts (saline-sodium) at Jacaré-Curituba irrigated perimeter, semiarid region of Sergipe State (Figure 1). The soil at the experimental site was classified as Salic Sodic Haplic Vertisol, with electrical conductivity of the soil saturation extract of 20.82 dS m^{-1} and exchangeable sodium percentage of 15.99%. More details of the experiment about reduction of saline soil with gypsum associated with manure can be found in Silva et al. (2020).

Figure 1. Experimental site location in Sergipe state, northeast of Brazil



The research design was completely randomized, with nine points of water sampling and three replications. The points were at the drainage channel input (DCI), the drainage channel output (DCO), lateral drains for each plot (D1, D2, D3, D4, D5, D6) and water used for irrigation (IW). Each of them drained a plot of 200 m^2 with a total area of 1.200 m^2 (Figure 2). Six lateral drains were installed at a depth of 0.3 m, in the center of each plot; PVC pipes with diameters of 0.1 m and a blanket for agricultural drainage were used in the drainage system, which were installed under a layer of gravel. The drains were installed at a 0.1% slope up to the secondary drain, which drained into the tributary of the Jacaré River.

Figure 2. Experimental field sketch



In the experimental area, combinations of treatments using agricultural gypsum were applied to reduce the percentage of exchangeable sodium and cattle manure to improve the physical conditions of the soil. Intermittent flood irrigation was used as a salt leaching method. Leaching lasted 36 days between May and June 2019, after complete soil saturation, with daily irrigations during the soil recovery period. More details of the experiment on saline soil recovery with gypsum associated with manure can be found in Silva et al. (2020)

4.1 Water Sampling

During the experiment six water sampling campaigns were carried out from May 17th to June 11th of 2019. Samplings of 2 L of water collected from upstream of the experiment area in the secondary drainage channel; drain water at the outlet of the side drains; water downstream of the experimental area in the secondary drain and irrigation water applied in the experimental plots. The irrigation systems of the Jacaré-Curituba Irrigated Perimeter were supplied with water collected from the São Francisco River.

The collection of drained water was performed using the method described by Holanda et al. (2016). According to the method, the samples were taken and stored properly in a refrigerated manner. The samples were transferred to the laboratory as soon as practicable after collection, typically within few hours.

4.2 Water Analysis

In order to analyze the quality of water drainage samples, Electrical Conductivity (EC) and sodium adsorption rate (SAR) were measured.

At the Soil Remediation Laboratory of the Federal University of Sergipe, the electrical conductivity of water samples was determined using a bench conductivity meter. Measures in field were not possible because the portable device was broken.

To determine the concentrations of sodium, calcium and magnesium, the method developed by the United States Environmental Protection Agency (US EPA) was followed, for the determination of inorganic ions in water by ion chromatography, using the ion chromatograph of the DIONEX brand, model ICS - 3000, at the Technology and Environmental Monitoring Laboratory of the Federal University of Sergipe. SAR calculation following below Equations 1, 2, e 3.

$$SAR = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}} \quad (1)$$

$$SAR_{adj1} = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}} \times [1 + (8.4 - pHc)] \quad (2)$$

$$SAR_{adj2} = \frac{Na}{\sqrt{\frac{(Ca^{o}+Mg)}{2}}} \quad (3)$$

Where:
Na - Sodium concentration, mmolc L^{-1};
Ca - Calcium concentration, mmolc L^{-1};
Ca^{o} - Calcium concentration in water adjusted by relation HCO_3^-/Ca (mmolc L^{-1}) e CEa (dS m^{-1});
Mg - Magnesium concentration, mmolc L^{-1}, and
pHc - theoretical pH that the water would have if it were in equilibrium with $CaCO_3$.

In Equation 2, more detail about pHc can be seen in Bower *et al.* (1965) that propose the Langelier saturation index. Positive values of the index indicate that $CaCO_3$ will precipitate from the water whereas negative values indicate that the water dissolves $CaCO_3$.

In this research analysis of variance (ANOVA) test was carried out to detect the temporal variation of the water quality parameters.

Tukey's test measures the differences between means of each treatment (the means of water quality variables samples of each date collection for all period of the experiment) to the means of all possible treatment; that is, it concomitantly put in practice to the group of all paired comparisons and identifies any difference between two means that is greater than the expected standard error. In this work Tukey’s Test is applied to formally test whether the difference between a pair of groups (different months all years) is statistically significant.

5 RESULTS AND DISCUSSION

The ANOVAs indicated that water electric conductivity (EC) varied significantly between sampling dates ($P<0.001$) and significant differences were observed between the points of sampling. Water Electric conductivity (EC) measured in the sixth drain, the channel drainage and water irrigation ranged between 11.73 dS m^{-}

[1] and 0.06 dS m^{-1} with the highest average recorded at the D5 (Table 1).

Table 1. Medium values of electric conductivity (dS m^{-1}) of water drainage in 2019

	Sampling points								
WC	**IW**	**DCI**	**DCO**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
05-17	0.06 Aa	1.79 Ab	2.30 Ab	7.64 Cd	10.43 CDe	3.06 Ab	5.47 Bc	11.73 Ce	5.92 Dc
SD	0.01	0.00	0.01	0.03	0.01	0.03	0.05	0.01	0.01
05-20	0.07 Aa	1.82 Ab	1.91 Ab	8.31 Cd	11.51 De	5.53 Bc	5.58 Bc	8.19 Bd	2.11 Ab
SD	0.01	0.01	0.01	0.03	0.28	0.08	0.27	0.10	0.03
05-27	0.09 Aa	2.12 Ab	2.57 Ab	3.01 Abc	7.04 Be	3.05 Abc	5.63 Bd	6.94 Bde	4.15 Cc
SD	0.00	0.01	0.01	0.01	0.29	0.07	0.24	0.09	0.02
05-30	0.10 Aa	2.62 Ab	2.73 Ab	4.32 Bc	4.47 Ac	4.35 Bc	2.24 Ab	2.56 Ab	2.82 ABb
SD	0.00	0.00	0.01	0.02	0.02	0.08	0.08	0.02	0.03
06-03	0.10 Aa	2.69 Abc	2.83 Abc	2.01 Ab	7.30 Be	6.85 Cde	5.81 Bd	7.20 Bde	3.78 BCc
SD	0.01	0.01	0.97	0.17	0.02	0.19	0.38	0.07	2,71
06-11	0.10 Aa	2.59 Ab	2.79 Ab	3.22 ABbc	9.92 Cf	11.67 Dg	5.69 Bd	8.15 Be	4.58 Ccd
SD	0.01	0.01	0.97	0.16	0.05	0.17	0.33	0.08	2.80
Min	0.06	1.79	1.91	2.01	4.47	3.05	2.24	2.56	2.11
Max	0.10	2,69	2.83	8.31	11.51	11.67	5.81	11.73	5.92
SD	0.02	0.41	0.36	2.61	2.63	3.25	1.39	2.95	1.34

WC = water collection times; IW = water used for irrigation; DCI = Drainage channel input; DCO = drainage channel output; D1, D2, D3, D4, D5, D6 = lateral drains for each plot.
Minimum value (Min); Maximum value (Max); Standard deviation (SD).
Equal capital letters in the columns and lower case letters in the row do not differ statistically at the 5% probability level by the Tukey test. The significance of the interaction was less than 0.1%.
The coefficient of variation for an interaction of 12.08%.

Gabr (2018) assessing irrigation water quality (agriculture drainage wastewater), soil drainage, and soil salinity found values of EC minimum of 2.28 dS m^{-1}, maximum 16.0 dS m^{-1} and the median 4.24 dS m^{-1}, values superior to those found in this study.

Cavalcante et al. (2010) observed that, in an experiment of the potential of nitrate leaching and the level of electrical conductivity of the drainage water with synthetic effluent similar to the domestic effluents, even with irrigation solutions with conductivity less than 2 dS m^{-1}, as the specification of each treatment, the drained and leached water can reach levels close to 9 dS m^{-1}, deserving special attention in its management, such as better agricultural drainage from the soil. While Ferreira et al. (2006) studying the effects of leaching of four salinity levels of irrigation water of an alluvial soil in an area abandoned by salinity problems observed that the value of the electrical conductivity of the effluent increased with the leaching water depth to the water depth equivalent to a volume of pores. At that point, the maximum electrical conductivity of the effluent reached 13.2 dS m^{-1}, and it started to decrease from then on. This happened because there was displacement of the salts that were initially concentrated on the soil surface.

EC in this research in D3 increased showing the similar behavior as the authors cited previously, but under field condition and in an area larger than the authors' experiment. According to Silva *et al*. (2020) that evaluated the effect of different amounts of agricultural gypsum and cow manure associated with an artificial drainage system and salt leaching in a soil classified as saline and sodic soil in an experiment field at the Jacaré-Cutituba district perimeter the highest EC values for treatments with gypsum can been explained by the salt concentration that was not leaching and not incorporated to soil, also probably due to elevated cations and anions concentration affecting calcium solubility. This fact can help understand the behavior of the EC.

Refaey, Amer and Gaber (2020) reported when evaluated the improving drainage water quality that drain salinity usually increases downstream as the drain receives inflows from open and tile drains. In this research EC in DCO had slightly variation and kept a maximum value of 2.83 dS m^{-1} an important fact to irrigation sustainability.

During the experiment in D3, the last water sampling collected showed an increase of the EC instead of a decrease. According to Lucas *et al*. (2019) it should be drawn attention that irrigated areas of Jacaré-Curituba the salinity is a risk and is building up gradually as the irrigation practices are continuing. Increasing salinity threat in the soils at this pace will cause toxicity and eventually will impair the growth of irrigated crops.

The SAR is a good indicator of the sodium hazard in soil and water and the statistics for this parameter is shown in Table 2. ANOVAs indicated that SAR varied significantly between sampling dates ($P<0.001$) and significant differences were observed between the points of sampling. sodium adsorption rate (SAR) measured in the sixth drain, the channel drainage and water irrigation ranged between 3.33 $mmol_c$ L^{-1} and 24.19 $mmol_c$ L^{-1} with the highest average recorded at the D5.

Table 2. Medium values of sodium adsorption rate (mmol$_c$ L^{-1}) of water drainage

	Sampling points								
WC	**IW**	**DCI**	**DCO**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
	3.33	8.74	9.65	10.72	10.70	8.63	15.60	20.66	16.67
05-17	Aa	Ab	Ab	Bb	BCb	Ab	Bc	Cd	Ccd
SD	0.63	0.80	0.46	0.06	0.13	0.09	0.55	0.05	0.07
	3.93	8.76	8.63	10.62	11.78	9.43	23.55	24.19	12.13
05-20	Aa	Ab	Ab	Bb	Cb	Ab	Cc	Cc	Bb
SD	0.67	0.74	0.61	0.05	0.36	0.06	0.45	0.10	0.38
	3.77	8.35	8.39	7.52	6.96[a]	5.97	12.66	14.15	10.45
05-27	Aa	Abcd	Abcd	ABabc	Babc	Aab	ABde	Be	ABcde
SD	0.68	0.70	0.18	0.04	0.36	0.06	0.52	0.18	0.34
	4.25	8.90	8.46	7.16	6.39	6.80	9.78	9.28	10.05
05-30	Aa	Ab	Aab	ABab	Aab	Aab	Ab	Ab	ABb
SD	0.55	0.28	0.19	0.04	0.10	0.12	0.01	0.27	0.31
	4.75	8.37	8.12	5.75	7.56	7.08	13.81	10.94	8.97
06-03	Aa	Aab	Aab	Aa	ABab	Aab	Bc	ABbc	ABab
SD	0.67	0.35	2.61	0.17	0.28	1.08	0.11	0.33	0.22
	4.19	8.40	8.43	5.37	8.27	8.96	12.53	12.76	8.04
06-11	Aa	Aabcd	Aabcd	Aab	ABCabc	Abcd	ABcd	ABd	Aab
SD	0.74	0.53	2.67	0.24	0.37	0.88	0.15	0.35	0.23
Min	3.33	8.35	8.12	5.37	6.39	5.97	13.77	9.28	8.04
Max	4.75	8.9	9.65	10.72	11.78	9.43	9.78	24.19	16.67
SD	0.48	0.24	0.53	2.33	2.16	1.38	4.75	5.84	3.08

WC = water collection times; IW = water used for irrigation; DCI = Drainage channel input; DCO = drainage channel output; D1, D2, D3, D4, D5, D6 = lateral drains for each plot.
Minimum value (Min); Maximum value (Max); Standard deviation (SD).
Equal capital letters in the columns and lower case letters in the row do not differ statistically at the 5% probability level by the Tukey test. The significance of the interaction was less than 0.1%.
The coefficient of variation for an interaction of 17.56%.

Statistical analyses ANOVA for SAR$_{adj1}$ significantly indicated variation between sampling dates (P<0.001) and significant differences were observed between the points of sampling. SAR$_{adj1}$ measured in the sixth drain, the channel drainage and water irrigation ranged between 4.08 mmol$_c$ L^{-1} and 71.10 mmol$_c$ L^{-1} with the highest average recorded at the D5 (Table 3).

Table 3. Medium values of adjusted sodium adsorption Rate (RAS_{adj1}, $mmol_c\ L^{-1}$) of water drainage in 2019

WC	IW	DCI	DCO	D1	D2	D3	D4	D5	D6
	Sampling points								
05-17	5.33 Aa	23.59 Ab	27.35 Ab	33.17 Cbcd	31.05 BCbc	21.59 ABb	43.68 Bcd	59.91 Ce	46.13 Bd
SD	0.34	1.33	0.53	0.15	0.34	0.22	1.53	0.15	0.18
05-20	4.98 Aa	23.66 Abc	22.45 Ab	27.55 BCbc	36.08 Cc	29.24 Bbc	68.69 Cd	71.10 Cd	20.96 Ab
SD	0.42	1.52	0.98	0.15	0.95	0.15	2.63	0.23	1.01
05-27	4.08 Aa	21.70 Abc	22.66 Abc	15.30 ABab	19.25 ABb	14.34 Aab	33.34 Bcd	40.57 Bd	25.08 Abc
SD	0.48	1.42	1.05	0.10	0.94	0.16	2.99	0.29	0.91
05-30	4.99 Aa	23.13 Ab	22.56 Ab	18.18 ABab	17.24 Aab	17.69 ABab	16.63 Aab	17.63 Aab	21.77 Ab
SD	0.71	0.96	0.85	0.12	0.27	0.32	0.03	0.78	0.85
06-03	5.00 Aa	21.75 Abcd	21.92 Abcd	15.07 Aab	21.91 ABbcd	20.78 ABbc	34.83 Bd	29.54 ABcd	20.64 Abc
SD	0.64	0.50	10.71	0.96	0.72	3.99	0.20	0.89	1.68
06-11	4.62 A	21.83 A	22.75 A	12.89 A	23.98 ABC	27.17 B	33.04 B	34.89 B	21.16 A
SD	1.08	0.18	10.75	1.13	0.97	3.29	0.19	0.95	1.97
Min	4.08	21.7	21.92	12.89	17.24	14.34	16.63	17.63	20.64
Max	5.33	23.66	27.35	33.17	36.08	29.24	68.69	71.1	46.13
SD	0.43	0.95	2.01	8.12	7.26	5.62	17.24	19.84	10.02

WC = water collection times IW = water used for irrigation; DCI = Drainage channel input; DCO = drainage channel output; D1, D2, D3, D4, D5, D6 = lateral drains for each plot. Minimum value (Min); Maximum value (Max); Standard deviation (SD). Equal capital letters in the columns and lower case letters in the row do not differ statistically at the 5% probability level by the Tukey test.
The significance of the interaction was less than 0.1%.
The coefficient of variation for an interaction of 20.84%.

The statistics for the results of SAR_{adj2} are shown in Table 4. ANOVA significantly indicated variation between sampling dates ($P<0.001$) and significant differences were observed between the points of sampling. SAR_{adj2} measured in the sixth drain, the channel drainage and water irrigation ranged between 3.09 $mmol_c\ L^{-1}$ and 19.01 $mmol_c\ L^{-1}$ with the highest average recorded at the D5.

Table 4. Medium values of adjusted sodium adsorption rate (RAS_{adj2}, $mmol_c\ L^{-1}$) of water drainage in 2019

WC	Sampling points								
	IW	**DCI**	**DCO**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
05-17	3.09 Aa	7.55 Ab	8.16 Ab	11.63 Bc	12.00 Cc	7.99 ABb	12.20 Bc	18.01 Cd	12.99 Bc
SD	0.16	0.43	0.20	0.07	0.08	0.09	0.28	0.01	0.05
05-20	5.32 Aa	7.57 Ab	7.50 Ab	11.43 Bcd	13.74 Cd	9.72 Bbc	16.84 Ce	19.01 Ce	7.74 Ab
SD	0.49	0.42	0.29	0.03	0.34	0.06	0.33	0.07	0.24
05-27	3.52A a	7.05 Ab	7.27 Ab	6.76 Ab	7.50 ABbc	5.94 Abc	10.21 Bcd	11.78 Bd	8.39 Abc
SD	0.49	0.41	0.13	0.01	0.34	0.03	0.38	0.08	0.21
05-30	3.99A a	7.61 Ab	7.40A b	7.28 Ab	6.67 Ab	6.97 Ab	6.88 Ab	7.01 Ab	7.45 Ab
SD	0.40	0.41	0.15	0.09	0.05	0.07	0.01	0.16	0.19
06-03	3.74A a	7.28 Ab	7.25A b	5.39 Abc	8.17 ABbcd	7.76 ABbcd	10.43 Bd	10.10 Bcd	7.52 Abc
SD	0.45	0.24	2.26	0.28	0.16	0.66	0.12	0.19	1.23
06-11	3.37 Aa	7.30 Abc	7.47 Abcd	5.68 Aab	9.34 Bcdef	10.25 Bdef	10.29 Bef	11.64 Bf	7.78 Abcde
SD	0.46	0.26	2.30	0.35	0.25	0.54	0.14	0.20	1.25
Min	3.09	7.05	7.25	5.39	6.67	5.94	6.88	7.01	7.45
Max	5.32	7.61	8.16	11.63	13.74	10.25	16.84	19.01	12.99
SD	0.79	0.22	0.34	2.80	2.76	1.63	3.28	4.67	2.15

WC = water collection times; IW = water used for irrigation; DCI = Drainage channel input; DCO = drainage channel output; D1, D2, D3, D4, D5, D6 = lateral drains for each plot.
Minimum value (Min); Maximum value (Max); Standard deviation (SD).
Equal capital letters in the columns and lower case letters in the row do not differ statistically at the 5% probability level by the Tukey test. The significance of the interaction was less than 0.1%.
The coefficient of variation for an interaction of 12.66%.

The SAR is one of the most reliable parameter used to determine the water quality for irrigation related to sodium concentration in water and its effects on soil. Results presented in this work agree with Maia, Morais and Oliveira (1998a, 1998b) that found RAS < RAS_{adj2} < RAS_{adj1} for a set of water samples.

The irrigation water classified by CE and SAR, SAR_{adj1} and SAR_{adj2} is shown in Table 5. It is observed that for irrigation water the risk of salinity is low during the entire period of the experiment, while for SAR_{adj1} water presents a risk ranging from medium to very high, whereas SAR_{adj2} the risk varied from low to medium during the study period. For the other points, the risk was high and very high for SAR, SAR_{adj1} and SAR_{adj2}.

Table 5. Water drainage classification

		Sampling points								
		IW	**DCI**	**DCO**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
SAR	**05-17**	C_1S_1	C_3S_1	C_4S_1	C_4S_2	C_4S_2	C_4S_1	C_4S_2	C_4S_3	C_4S_2
	05-20	C_1S_1	C_3S_1	C_3S_1	C_4S_2	C_4S_2	C_4S_1	C_4S_3	C_4S_3	C_3S_2
	05-27	C_1S_1	C_3S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_2	C_4S_2	C_4S_2
	05-30	C_1S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_2
	06-03	C_1S_1	C_4S_1	C_4S_1	C_3S_1	C_4S_1	C_4S_1	C_4S_2	C_4S_2	C_4S_1
	06-11	C_1S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_2	C_4S_2	C_4S_1
$SAR_{adj\,1}$	**05-17**	C_1S_4	C_3S_4	C_4S_3	C_4S_4	C_4S_4	C_4S_4	C_4S_4	C_4S_3	C_4S_1
	05-20	C_1S_4	C_3S_4	C_3S_4	C_4S_4	C_4S_4	C_4S_3	C_4S_3	C_4S_3	C_3S_1
	05-27	C_1S_2	C_3S_3	C_4S_2	C_4S_4	C_4S_4	C_4S_3	C_4S_3	C_4S_3	C_4S_1
	05-30	C_1S_3	C_4S_2	C_4S_2	C_4S_2	C_4S_2	C_4S_3	C_4S_3	C_4S_3	C_4S_1
	06-03	C_1S_2	C_4S_3	C_4S_3	C_3S_4	C_4S_4	C_4S_3	C_4S_3	C_4S_3	C_4S_1
	06-11	C_1S_2	C_4S_3	C_4S_4	C_4S_4	C_4S_4	C_4S_3	C_4S_3	C_4S_3	C_4S_1
$SAR_{adj\,2}$	**05-17**	C_1S_2	C_3S_2	C_4S_1	C_4S_2	C_4S_3	C_4S_2	C_4S_1	C_4S_1	C_4S_1
	05-20	C_1S_2	C_3S_2	C_3S_1	C_4S_2	C_4S_3	C_4S_1	C_4S_1	C_4S_1	C_3S_1
	05-27	C_1S_1	C_3S_1	C_4S_1	C_4S_2	C_4S_2	C_4S_1	C_4S_1	C_4S_1	C_4S_1
	05-30	C_1S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1	C_4S_1
	06-03	C_1S_1	C_4S_1	C_4S_1	C_3S_2	C_4S_2	C_4S_1	C_4S_1	C_4S_1	C_4S_1
	06-11	C_1S_1	C_4S_1	C_4S_2	C_4S_2	C_4S_2	C_4S_1	C_4S_1	C_4S_1	C_4S_1

IW = water used for irrigation; DCI = Drainage channel input; DCO = drainage channel output; D1, D2, D3, D4, D5, D6 = lateral drains for each plot. Water sampling collected in 2019.

El-Agha *et al*. (2020) argue that the drainage water salinity in the collectors of the subsurface system varied widely in depth, space, and time, which among others reflect soil heterogeneity, but also how soil salinity increases dramatically when the subsurface drainage is clogged up and not working. The Jacaré-Curituba irrigated perimeter needs subsurface drainage to enhance the irrigated agriculture because the point DCI water drainage showed high to very high risk of salinization.

Sales *et al.* (2020) reported that the salt content in the water is assessed by means of electrical conductivity (EC), and found results ranging from 0.007 dS m^{-1} to 3.97 dS m^{-1} in the catchment dam for irrigation in the perimeter and in the stream that crosses the Jacaré-Curituba settlement, the same region of the experiment. The authors further argue that this pattern of increase found between the dam and the control point occurs both in the rainy and dry periods. In the classification of irrigation water there was variation between classes C_1S_1 (low risk of salinity and sodicity) in the dam to C_4S_3 (very high risk of salinity and strong risk of sodicity) in the control point.

Sodicity, when evaluated by the sodium adsorption ratio or exchangeable sodium percentage, is basically a soil problem. Sodic soils demonstrate structural problems originated by certain physical processes (slaking, swelling, and dispersion of clay) and surface crusting that affect erosion, seedling emergence, root penetration, tillage operations, water and air movement, and plant-available water-holding capacity (QADIR *et al*., 2007)

Drainage water salinity is a major water quality concern for agricultural water management in semi-arid areas like the Northeast of Brazil. The reuse of drainage water with high salinity affects the sustainability of the irrigation system.

Many factors influence the salt concentration in drains, such as the quantity and quality of irrigation water, type of soil, and type of crop (EL-AGHA *et al*., 2020).

Drainage water salinity is one of the main environmental challenges for the reuse strategy (EL-AGHA *et al*., 2020). Egypt applies an approximately 5 billion cubic meters of drainage water for irrigation in the Nile Delta, combining drainage water with freshwater. Whereas, farmers at the tail ends of irrigation schemes reuse an approximately 2.8 billion cubic meters of drainage water unofficially (QADIR *et al*., 2007), but this is not the case in Brazil. Although experiments with salinity water are done in small scale in greenhouses and the salinity water is mixed in laboratories such as the work of Diniz *et al*. (2021).

According to Qadir *et al*. (2007) drainage water has the potential for reusing since the high salt content of the effluent drainage water is reduced. Drainage water can be reused if it is blended with freshwater or used to irrigate salt-tolerant crops. Regarding the point DCO, after collecting the water drainage from salt-affected soil in Jacaré-Curituba, it can be reused for irrigation if mixed with fresh water. However, it is recommended to drain the area and to correctly manage water and soil to prevent the problem.

6 CONCLUSION

The results of this study confirmed that the water drainage from a salt-affected soil has very high potential to increase soil salinity at the irrigated perimeter of Jacaré-Curituba. Irrigation water management, such as, well designed irrigation projects and agronomic techniques, can play an important role in controlling the salinity and pollution levels in drains and reused water drainage should be mainly considered in semi-arid region of Northeast Brazil.

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