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Saline water irrigation in semiarid region: I – effects on soil chemical properties

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Abstract

The use of saline water for crop irrigation is a commonly adopted practice among the farmers in the semiarid regions around the world, but the magnitude of soil salinization resulting from the use of these waters is currently insufficiently understood. This work aims to evaluate the chemical attribute changes of two Fluvisols cultivated with onion and subjected to irrigation with increasing levels of salinity, expressed by electrical conductivity (EC) and sodium adsorption ratio (SAR). Sandy loam and silty clay loam soils were irrigated with three different levels of saline waters with electrical conductivity (EC - 200, 700 and 2,000 µS cm^{-1}) and six levels of sodium adsorption ratio (SAR - 0, 5, 10, 15, 20 and 25 $(mmol_c\ L^{-1})^{0.5}$). Thus, the experiment consisted of a complete factorial arrangement 2 x 3 x 6 (two soils, three EC levels and six SAR levels), in four replicates. The soils were cultivated with onion and pH levels of the soil were measured at 90 days after transplanting, as were the contents of exchangeable and soluble cations. ESP and SAR values were then calculated. This study revealed that the use of water with salinity at or above 700 µS cm^{-1} is capable of promoting changes in the chemical properties of soils and the continuous use of irrigation water with high EC and high SAR values may promote salinization and sodification of Fluvisols in a semiarid environment. These changes were found to be more severe in silty clay loam soils than in sandy loam soils.

Keywords: Salt stress; soil salinity; soil degradation; *Allium cepa*; water quality.

Introduction

Growing food demand has made irrigation use imperative throughout the world, especially in semiarid regions, where water deficiency occurs during most of the year. In these areas, the viability of agricultural production, in terms of yield and quality, is dependent on irrigation (Viana et al., 2001). However, one of the most important aspects of successful irrigation as an agricultural practice is the quality of irrigation water, especially in arid and semiarid regions where there may be increased concentrations of salts and soil degradation, which can, in turn, limit production or preclude it altogether.

Saline water is used to irrigate croplands in different parts of the world, especially in arid and semiarid regions, which occupy 41% of the global land surface, with poor water quantity and quality (Huang et al., 2010). In these regions, the limited rainfall is not sufficient to leach out salts from the root zone, which leads salt from the irrigation water to accumulate in the soil and affect the soil properties. Literature shows that the concentration of sodium, calcium and magnesium ions in soil layers can affect the dispersion of clay particles (Shainberg et al., 1981a,b), the soil hydraulic conductivity (Shainberg and Letey, 1983), soil pores (Pupisky and Shainberg, 1979), soil aggregate stability and the formation of soil crusts (Tedeschi and Dell' Aquila, 2005). In addition, irrational human activities, such as poor agricultural management, flood irrigation and so on, also aggravate salinization, due to ineffective control of the accumulation of salts in soil. Therefore, salinity increases in extensive portions of irrigated lands, which become degraded by salinization (Shrivastava and Kumar, 2015).

For sustaining the existing croplands and guaranteeing subsistence, local farmers have to exploit the groundwater with high salinity to irrigate croplands, which leads to salt accumulation in the soil under strong evaporation (Wang and Cui, 2004), but soil salinization is related not only to the quality of the irrigation water. It also depends on the physical-chemical characteristics of the soil in its natural state and the management techniques utilized (Tedeshi and Menenti 2002a,b). Increased salinity is common in irrigated areas where management techniques do not take into consideration the adequate application of water or conservation of the productive capacity of the soils, associated with the absence of an efficient drainage system, or where fertilizer use is excessive (Silva Filho et al., 2000).

Within the irrigated perimeter Cachoeira II, located in the municipality of Serra Talhada-PE, in the semiarid region of Brazil, well water is commonly used in the irrigation of crops by local farmers. These waters, in most cases, are of a lower quality due to having higher salt contents, especially in drier periods of the year, according to Fernandes et al., 2009. These same authors also concluded in their research that the soils of the irrigated perimeter show a susceptibility to the processes of degradation by salinization and sodification, making it necessary to monitor these properties when irrigated with saline waters.

This practice adopted by farmers in the region, over many years, has a substantial environmental impact with regard to the degradation of the soils by the contribution of salts, rendering them unproductive and affecting the development of crops. In this context, it is necessary to evaluate the potential of these waters to salinize / sodify the soils, in order to avoid such degradation in the future, allowing their long-term continued utilization, with minimal environmental disturbance. The aim of this work was to study the effects of saline water irrigation on soil properties of two Fluvisols from semiarid region cultivated with onion. Our intention is to promote a better understanding of how soil properties are affected when using saline water to irrigate arid croplands, to mitigate the negative impact of saline irrigation by implementing appropriate management of saline water and soil.

Results and Discussion

EC and Soil factors had a more significant effect on soil pH values, soluble and exchangeable element contents, electrical conductivity of saturation extract (EC), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) of soils (Tables 3 and 4). However, because the interactions were significant only for some of these variables, the effects of the EC and Soil factors were evaluated. In the case of the SAR, although it also exerted a significant primary effect on these variables, the SAR x EC significant interaction allowed for the adjustment of regression equations for salinity variables.

Effects of saline irrigation on soluble complex

EC values increased proportionally to the salinity of the irrigation water (Table 5), reflecting the potential of the waters to salinize the soil. Irrigation water of EC 2,000 µS cm^{-1} promoted a higher elevation in soil EC (4.88 dS m^{-1}), making the soil saline according to the classification proposed by the Richards (1954). Several studies in existing literature have reported the proportional increase of soil salinity due to salt concentration in irrigation water (Alsadon et al., 2013; Liu et al., 2016; Abu-Alrub et al., 2018;), confirming the contribution of salts to the soil via irrigation water and agreeing with the results obtained in this study, differing according to soil type and salinity of water used in each specific case study. However, there is a general agreement on the salinizing potential of irrigation waters.

The levels of soluble cations and soluble chlorides were also elevated with the increasing irrigation water salinity, where Na^+ was predominant in relation to the other cations, regardless of irrigation water salinity (Table 5). The increase in Mg^{2+} and K^+ contents in the saturation extract could be related to the displacement of these from the exchange complex by the Na^+ and Ca^{2+} ions provided by the irrigation salt water. SAR values also increased as a function of irrigation water salinity, as a result of the addition of this element by irrigation water. Similar results were obtained by Singh et al. (1992), who also observed higher SAR values persisting in sandy loam soils cultivated with pearl-millet and wheat, irrigated with higher SAR and EC waters.

The values of soil EC were higher in the silty clay loam soil than in the sandy loam soil due to the higher retention of salts in its finer textured soil, which is evidenced by the Ca^{2+}, Na^+ and Cl^- soluble contents, which were also higher in this soil (Table 5). The K^+ was the only element that presented higher levels in the sandy loam soil, due to the higher content observed in natural conditions in this soil (Table 2). The predominance of Na^+ and Ca^{2+} ions can be attributed to the use of water prepared with NaCl and $CaCl_2$ salts, which is confirmed by the high Cl^- values in the saturation extract.

The higher potential for ion retention in the silty clay loam soil exerted a less detrimental effect with respect to soil SAR, due to the fact that this soil presented higher soluble Ca^{2+} and Mg^{2+} contents, reflecting lower values of SAR in this soil in relation to sandy loam soil (Table 5). This soil's ability to retain a higher Ca^{2+} content in relation to sandy loam soil may indicate a greater possibility of using this soil irrigated with Na^+ rich saline waters, since Ca^{2+} has a flocculating effect, tending to inhibit the undesirable effects of Na^+.

Effects of saline irrigation on exchange complex

In analyzing the soil exchange complex (Table 6), we observed a reduction in pH values of the soil with increasing irrigation water salinity, which was likely due to the use of Cl^- salts, replacing basic anions such as CO_3^{2-} and HCO_3^-. According to Weill and Brady (2016), the decreasing soil pH values with the application of saline water can be attributed to the addition of $CaCl_2$ to the soil via irrigation water, resulting in an increase in the concentration of H^+ ions in the soil solution. However, soil pH values remained too high for the development of most cultivated plants, which may lead to the unavailability of some micronutrients.

The highest levels of exchangeable Ca^{2+} were obtained in soils irrigated with water of CE 700 µS cm^{-1}, although higher values were expected for soils irrigated with water of higher EC (Table 6). In relation to Mg^{2+} and K^+, a reduction was observed in its contents with the increase of salinity of irrigation water, due to the competition of Ca^{2+} and Na^+ by the soil exchange complex. Tavakkoli et al. (2010), in a field study, also verified a reduction in Mg^{2+} levels with increasing irrigation water salinity in a NaCl-treated sandy loam red Chromosol, from Roseworthy - South Australia. Levels of exchangeable Na^+ and, consequently, ESP both increased with elevated salinity of irrigation water (Table 6). Minhas et al. (2007), working with different levels of irrigation water salinity in soil cultivated with paddy-wheat crops also verified an increase in the Na^+ content with increasing salinity of the applied irrigation water. Mahdy (2011), studying the application of percolation solutions with increasing values of EC in soils observed that the increase in EC (3.35 to 15.53 dS m^{-1}) and SAR (5.29-8.42 $mmol_c$ L^{-1}) of the percolation solutions also increased the exchangeable sodium and the exchangeable sodium percentage (ESP) of the studied soils.

It is possible that this process will promote Mg^{2+} and K^+ deficiency with the continuous use of this type of irrigation water, especially when these waters are rich in ions such as Ca^{2+} and Na^+, as in the case of waters commonly found in

Table 1. Physical attributes of the two Fluvisols (0-20 cm) used in the experiment.

Soil texture	Sand	Silt	Clay	WDC[1]	FI[2]	DI[3]	BD[4]	PD[5]	TP[6]	K_0[7]
	$g\ kg^{-1}$				%		$g\ cm^{-3}$		%	$cm\ h^{-1}$
Sandy loam	546.8	220.0	233.2	169.6	27.27	72.73	1.34	2.50	46	3.89
Silty clay loam	191.6	420.0	388.4	289.6	25.44	74.56	1.21	2.70	55	0.33

[1]WDC: Water Dispersible Clay; [2]FI: Flocculation Index; [3]DI: Dispersion Index; [4]BD: Bulk Density; [5]PD: Particle Density; [6]TP: Total Porosity; [7]K_0: Saturated Hydraulic Conductivity.

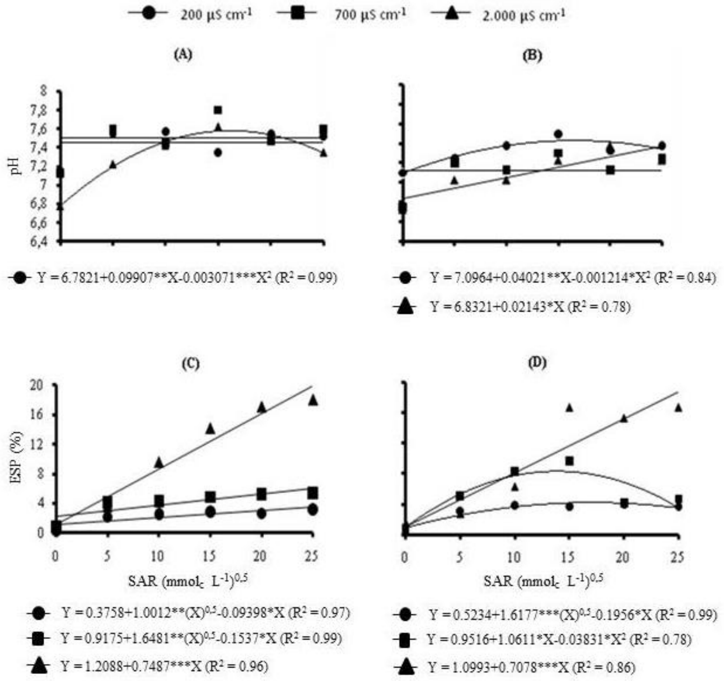

Fig 1. Soil pH values of the sandy loam (A) and silty clay loam (B) soils and values of exchangeable sodium percentage (ESP) of the sandy loam (C) and silty clay loam (D) soils as a function of the sodium adsorption ratio of irrigation water (SAR) at the EC values of CE 200, 700 and 2,000 µS cm^{-1} (*, **, *** - significant at 5, 1 and 0.1% probability, respectively).

Table 2. Chemical attributes of the two Fluvisols (0-20 cm) used in the experiment.

Attribute	Soil texture	
	Sandy loam	Silty clay loam
Exchangeable complex		
pH (1:2.5 – soil:water)	7.3	7.1
Ca^{2+} ($cmol_c\ dm^{-3}$)	7.43	8.54
Mg^{2+} ($cmol_c\ dm^{-3}$)	2.17	3.23
Na^{+} ($cmol_c\ dm^{-3}$)	0.07	0.30
K^{+} ($cmol_c\ dm^{-3}$)	0.57	0.49
CEC[1] ($cmol_c\ dm^{-3}$)	11.63	15.86
ESP[2] (%)	0.60	1.89
P_{Bray-1}[3] ($mg\ dm^{-3}$)	43.75	23.66
Soluble complex		
pH	8.3	7.4
EC[4] ($dS\ m^{-1}$)	0.86	0.85
Ca^{2+} ($mmol_c\ L^{-1}$)	3.73	5.12
Mg^{2+} ($mmol_c\ L^{-1}$)	2.89	3.70
Na^{+} ($mmol_c\ L^{-1}$)	1.97	2.46
K^{+} ($mmol_c\ L^{-1}$)	1.42	0.61
Cl^{-} ($mmol_c\ L^{-1}$)	3.00	3.00
HCO_3^{-} ($mmol_c\ L^{-1}$)	2.16	1.76
CO_3^{2-} ($mmol_c\ L^{-1}$)	1.20	0.00
SAR[5] ($(mmol_c\ L^{-1})^{0,5}$)	1.08	1.17

[1]CEC: Cation Exchange Capacity; [2]ESP: Exchangeable Sodium Percentage; [3]P_{Bray-1}: Phosphorous extracted by Bray-1; [4]EC: Electrical Conductivity; [5]SAR: Sodium Adsorption Ratio.

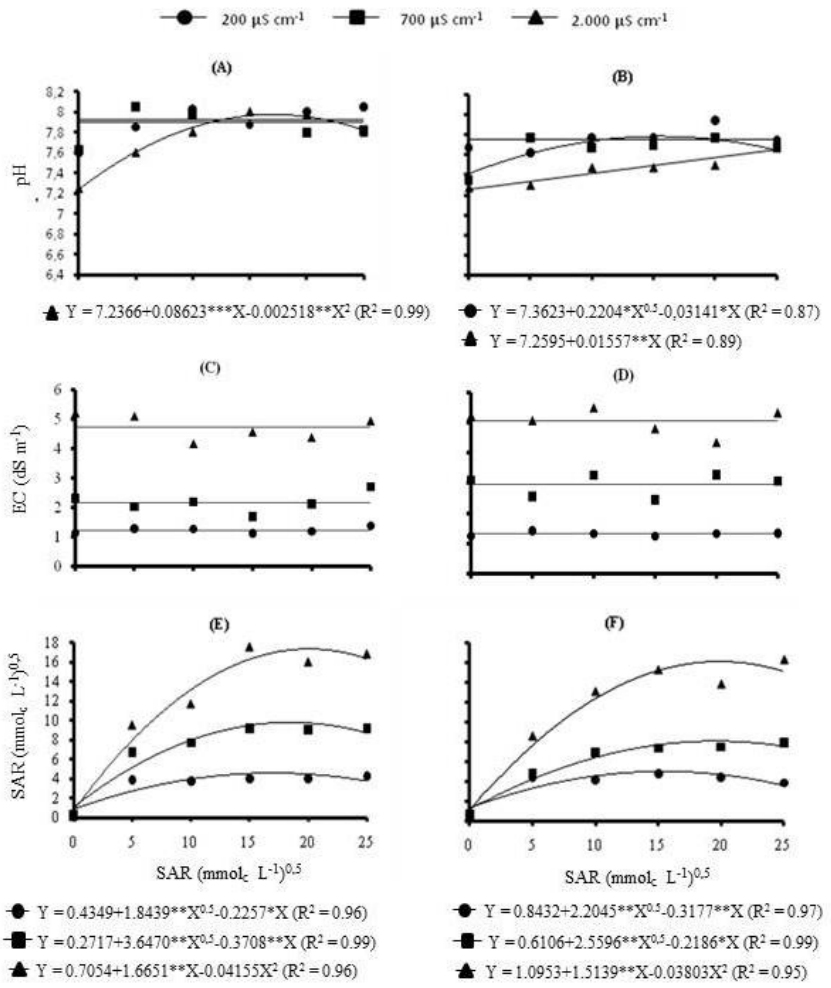

Fig 2. Saturation extract pH values of the sandy loam (A) and silty clay loam (B) soils; electrical conductivity (EC) values of the sandy loam (C) and silty clay loam (D) soils and sodium adsorption ratio (SAR) of the sandy loam (E) and silty clay loam (F) soils as a function of the sodium adsorption ratio of irrigation water (SAR) at the EC values of CE 200, 700 and 2,000 µS cm^{-1} (*, **, *** - significant at 5, 1 and 0.1% probability, respectively).

Table 3. Summary of the variance analysis of the evaluated elements in the soluble complex (saturation extract) and in the exchangeable complex of the soils.

Sources of variation	DF[1]	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-
				Soluble Complex		
Soil	1	27.14^{***}	1.66^{ns}	5.19^{*}	40.09^{***}	10.23^{**}
EC	2	123.39^{***}	16.18^{***}	455.24^{***}	9.92^{***}	436.17^{***}
SAR	5	74.20^{***}	12.69^{***}	105.05^{***}	3.94^{**}	3.36^{**}
SAR*EC	10	15.43^{***}	0.79^{ns}	21.81^{***}	0.77^{ns}	1.88^{ns}
SAR*Soil	5	2.51^{*}	0.77^{ns}	1.70^{ns}	2.54^{*}	1.52^{ns}
EC*Soil	2	16.21^{***}	6.03^{**}	1.74^{ns}	0.35^{ns}	1.76^{ns}
SAR*EC*Soil	10	1.63^{ns}	0.79^{ns}	1.48^{ns}	0.78^{ns}	1.60^{ns}
				Exchangeable Complex		
Soil	1	792.22^{***}	2069.09^{***}	54.54^{***}	1.13^{ns}	-
EC	2	8.66^{**}	173.27^{***}	105.02^{***}	11.88^{***}	-
SAR	5	23.96^{***}	13.47^{***}	52.20^{***}	0.34^{ns}	-
SAR*EC	10	8.69^{***}	4.78^{***}	13.20^{***}	2.80^{**}	-
SAR*Soil	5	1.24^{ns}	0.35^{ns}	3.22^{**}	3.31^{**}	-
EC*Soil	2	2.84^{ns}	9.35^{**}	8.31^{**}	21.83^{***}	-
SAR*EC*Soil	10	2.03^{ns}	1.12^{ns}	1.14^{ns}	1.74^{ns}	-

[1] Degree of Freedom. *, ** and ***: Significant at 5, 1 and 0.1% probability, respectively. ^{ns}: non-significant.

Table 4. Summary of the analysis of variable variance - electrical conductivity of the saturation extract (EC), sodium adsorption ratio.

Sources of variation	DF^1	pH	EC	SAR	pH	ESP
Soil	1	1.05^{ns}	12.94***	42.47***	120.77***	1.91^{ns}
EC	2	0.98^{ns}	360.79***	392.14***	21.73***	159.84***
SAR	5	1.33^{ns}	1.66^{ns}	726.97***	48.00***	54.37***
SAR*EC	10	0.92^{ns}	1.04^{ns}	50.49***	4.42***	22.33***
SAR*Soil	5	1.23^{ns}	0.67^{ns}	11.53***	1.09^{ns}	1.85^{ns}
EC*Soil	2	1.79^{ns}	3.29*	44.65***	11.36***	2.61^{ns}
SAR*EC*Soil	10	1.10^{ns}	0.49^{ns}	3.20**	2.40^{ns}	1.39^{ns}

(SAR), soil pH and exchangeable sodium percentage (ESP).^{1}Degree of Freedom. *, ** and ***: Significant at 5, 1 e 0,1% probability, respectively. ^{ns}: non-significant.

Table 5. pH, electrical conductivity (EC), calcium, magnesium, sodium, potassium, chloride content and sodium adsorption ratio values (SAR) in the saturation extract as a function of the electrical conductivity of irrigation water and soil texture at the end of the onion cycle.

Treatment	pH	EC (dS m^{-1})	Ca^{2+}	Mg^{2+} ——(mmol$_c$ L^{-1})——	Na$^+$	K$^+$	Cl$^-$	SAR (mmol$_c$ L^{-1})$^{0.5}$
EC (µS cm^{-1})								
200	7.66 A	1.27 C	3.83 C	1.87 C	5.73 C	0.59 B	7.87 C	3.57 C
700	7.79 A	2.56 B	5.69 B	2.14 B	11.42 B	0.85 A	19.60 B	6.45 B
2.000	7.60 A	4.88 A	8.55 A	2.53 A	25.36 A	0.93 A	40.58 A	11.65 A
CV (%)	9.08	22.98	24.58	26.23	22.41	49.55	23.23	14.82
Soil								
Sandy loam	7.74 A	2.71 B	5.39 B	2.12 A	13.25 B	0.99 A	21.22 B	7.47 A
Silty clay loam	7.62 A	3.11 A	6.67 A	2.24 A	14.42 A	0.58 B	24.15 A	6.98 B
CV (%)	9.08	22.98	24.58	26.23	22.41	49.55	24.23	14.82

*Means followed by the same letter in the columns do not differ among themselves by Skott Knott test (p<0.05). *CV = Coefficient of Variation.

Table 6. Soil pH values, exchangeable calcium, magnesium, sodium and potassium contents and exchangeable sodium percentage values (ESP) in the soil – exchangeable complex - as a function of the electrical conductivity of the irrigation water (EC) and soil texture, at the end of onion cycle.

Treatment	pH	Ca^{2+}	Mg^{2+} ——(cmol$_c$ dm^{-3})——	Na$^+$	K$^+$	ESP (%)
EC (µS cm^{-1})						
200	7.38 A	10.89 B	3.42 A	0.38 C	0.41 A	2.73 C
700	7.32 B	11.27 A	3.17 B	0.67 B	0.38 B	4.79 B
2.000	7.21 C	10.64 B	2.67 C	1.40 A	0.35 C	10.26 A
CV (%)	1.82	6.76	6.55	37.50	17.42	35.97
Soil						
Sandy loam	7.43 A	9.20 B	2.33 B	0.66 B	0.39 A	5.68 A
Silty clay loam	7.18 B	12.67 A	3.86 A	0.98 A	0.38 A	6.17 A
CV (%)	1.82	6.76	6.55	37.50	17.42	35.97

*Means followed by the same letter in the columns do not differ among themselves by Skott Knott test (p<0.05). *CV = Coefficient of Variation.

the semiarid region of Brazil. A consequence of the use of these waters highlighted by Grattan and Grieve (1992) is magnesium deficiency, which can be induced in plants stressed by salts, which reduces plant growth by changing the Ca^{2+}/Mg^{2+} ratio, leading to a reduction in the ratio of photosynthesis and decline in water use efficiency. In this work, the increase of Ca^{2+} and Na^+ contents in irrigation water also promoted reductions in K^+ and Mg^{2+} contents (Table 6). Although the use of more saline water promoted an increase in ESP, the values of this water did not reach the 15% level (Table 6) necessary to classify it as a sodic soil, according to the classification proposed by Richards (1954). However, for local conditions, these increases in exchangeable Na^+ and ESP may already represent adverse effects on the soil, according to Miranda et al. (2018), which report risks of sodification and impairment of the physical properties of similar soils with values lower than those detected in this study. Comparing the soils, we observed that the pH was higher in the sandy loam soil, which can be explained by the presence of higher carbonate and bicarbonate contents under natural conditions (Table 2). The exchangeable cation contents were higher in the silty clay loam due to a higher ion retention potential in relation to the sandy loam soil. In both soils, the highest cation contents were Ca^{2+}, followed by Mg^{2+}, Na^+ and K^+ (Table 6). In other words, the use of these waters promoted an increase in Na^+ in relation to K^+, differentiating this composition from the exchange complex in relation to the soils prior to the addition of irrigation with saline water (Table 2). ESP values also increased in relation to the initial condition despite not reaching the 15% ESP limit value necessary to classify it as a sodic soil (Richards, 1954) during the onion cycle, the continuous use of these waters over cycles may promote the elevation of ESP at this level, or even overcome it, making these soils unfit for cultivation.

Effects of Sodium Adsorption Ratio on saline variables

In the model adjustment for the soil salinity variables as a function of SAR of irrigation water, significant models were selected, mainly for the highest EC water (2,000 µS cm^{-1}). pH values in sandy loam soil were adjusted to a rising quadratic equation with the elevation of SAR of irrigation water of higher EC, but for the other waters, SAR elevation did not promote soil pH responses (Figure 1A). In soil with silty clay loam texture it was not possible to adjust equations for EC waters of 700 µS cm^{-1} (Figure 1B). When it was possible to adjust regression equations, SAR of irrigation water increased pH values in both soils. Coleman and Mehlich (1957) stated that Na^+ tends to raise soil pH because this ion become hydrolyzed upon contact with water, , releasing OH^- and consecuently raising soil pH.

For the ESP variable, it was possible to adjust equations in both soils as well as for the three values of EC of water irrigation (Figures 1C and 1D). With the increase of SAR, ESP values increased significantly, indicating a higher saturation of the soil exchange complex with the Na^+ ion. A similar behavior was observed in ESP growth in waters of EC 200 and 700 µS cm^{-1}, which did not occur in the water with EC of 2000 µS cm^{-1}. In this case, the ESP increase was more pronounced in relation to the other saline waters, proving a more damaging effect of the use of more saline waters and higher SAR values, which can trigger physical problems in the soil (Jalali and Ranjbar, 2009; Chaganti et al., 2015; Dang et al., 2018).

The pH of the saturation extract was also evaluated as a function of the SAR treatments used and the behavior of this variable was very similar to that of the soil pH (Figures 2A and B). In the sandy loam soil, the effect of SAR on the pH of the saturation extract was only observed for the water with the highest salt content (2,000 µS cm^{-1}); and in the silty clay loam soil, equations for EC of 700 and 2,000 µS cm^{-1} were adjusted, indicating that in this soil even a small increase in the salinity of the irrigation water had an effect on the pH of the saturation extract, which did not occur in sandy loam soil (Figures 2A and 2B). The EC values of both soils were similar, without variation as a function of SAR of the saline irrigation water (Figures 2C and 2D).

Both the SAR of saturation extract (Figures 2E and 2F) and ESP values (Figures 1C and 1D) were strongly influenced by increasing the proportion of sodium in irrigation waters. With respect to soil SAR, significant regression equations were adjusted for the waters in the three EC values evaluated, indicating an increase in SAR values of soils with increasing SAR of irrigation water (Figures 2E and 2F).

The obtained results, in which the pH of the soil and the pH of the saturation extract were not influenced by the SAR of irrigation water, were predicted, since chloride salts were used and they are neutral reaction anion that does not promote substantial changes in pH. However, the SAR of the saturation extract and soil ESP are variables directly related to the Na^+ content in the solution and in the soil exchange complex, respectively, being heavily influenced by the SAR of the applied irrigation water. The increases in soil SAR values increased with the salinity of irrigation water.

Materials and methods

Description of the experimental area

We collected two soils from the superficial layer (0-20 cm) in the Irrigated Perimeter Cachoeira II, Serra Talhada-PE, in the semiarid region of Brazil. Two Fluvisols were selected due its being representative in the Irrigated Perimeter. These soils were non-saline and non-sodic, one of the textural class sandy loam and the other silty clay loam. The soils were air-dried and sieved in a 2 mm mesh for physical and chemical characterization analyzes (Tables 1 and 2); and again in 4 mm mesh for the assembly of the experiment.

Experimental design and description of treatments

The experiment was conducted in a greenhouse at the Agronomy Department of the Federal Rural University of Pernambuco, Brazil. The soils were irrigated with water at three values of electrical conductivity (EC) and six levels of sodium adsorption ratio (SAR), combined as salinity treatments. Thus, the experiment consisted of a complete factorial arrangement 2 x 3 x 6 (two soils, three EC levels and six SAR levels), in four replicates, totaling 144 experimental units. The experimental design was randomized blocks, with one replicate per block.

Irrigation waters with different salinities were prepared in the laboratory to represent the mean salinity of that found in the water sources used in the irrigated perimeter, according to Fernandes et al. (2009), with electrical conductivities of irrigation water (EC) of 200, 700 and 2,000 µS cm^{-1} and SAR of 0, 5, 10, 15, 20 and 25 $(mmol_c\ L^{-1})^{0.5}$, totaling 18 types of water. These irrigation waters were elaborated from the salts NaCl and $CaCl_2.2H_2O$.

The soils were homogenized and packed in polyethylene pots with 6.5 kg of soil, which had been saturated with the respective salt water. Irrigation was performed with a water blade above to the soil retention capacity, providing leaching, performed manually, on alternate days.

Onion seedlings of the Vale Ouro IPA 11 cultivar were sown in trays with commercial substrate and transplanted to the pots at 30 days growth. At the time of transplanting, fertilization was carried out in all treatments, to meet the needs of the crop, according to the chemical analyzes of the soils and the nutritional requirements of the onion, according to the Recommendation Bulletin of Corrective and Fertilizers of the State of Pernambuco (IPA, 2008). Phosphate fertilization was implanted at a depth of 10 cm, using triple superphosphate (45 kg ha^{-1} of P_2O_5) as the source of P, potassium sulphate (45 kg ha^{-1} K_2O) as potassium source, and nitrogen in the form of urea (45 kg ha^{-1} of N), with the values adjusted to the soil volume of the vessels. Micronutrients were supplied by the "Fertilizer Base" leaf fertilizer, by foliar spray recommended for onion cultivation, in a ratio of 200 mL of the product to 100 L of water. The soils began to be irrigated with the respective saline waters at time of seedling transplantation.

Soil measurements

The soil samples were collected at 90 days after transplanting. Soil pH was measured in the water (1:2.5), and the contents of the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were extracted with ammonium acetate. Ca^{2+} and Mg^{2+} were measured by atomic absorption spectrophotometry and Na^+ and K^+ were measured by flame photometry. Finally, ESP was calculated according to Richards (1954). (Eq 1).

Eq 1. $ESP\ (\%) = 100\ \frac{Na^+}{CEC}$, where CEC is the cation exchange capacity.

The soil saturation extract was prepared as to measure pH, EC, the soluble cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), measured in the same way as the exchangeable cations and Cl^- soluble anions by volumetry. The SAR was calculated according to Richards (1954) (Eq 2).

Eq 2. $$SAR\ (mmol_c\ L^{-1})^{0.5} = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}.$$

Statistical analysis

Data were submitted to variance analysis and Scott Knott's mean test at a 5% probability level for comparison of means between EC and Soil treatments. Regression equations were also adjusted according to the result of the dependent variables obtained as a function of the applied SAR treatments, in order to obtain estimates of soil composition with the use of irrigation water with different SAR values.

Conclusion

Irrigation with increasing water salinity (EC) resulted in increased levels of exchangeable Na^+, values of EC, SAR and ESP of soils; however, increasing SAR of irrigation water promoted an increase in ESP and SAR values of the evaluated soils. This study revealed that the use of water with salinity above 700 µS cm^{-1} is sufficient to promote changes in the chemical properties of soils and that the continuous use of irrigation water with EC and SAR values than this have the potential to promote salinization and sodification of Fluvisols in a semiarid environment. These changes were more severe in silty clay loam soils, which have a higher salt retention capacity.

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References

Abu-Alrub I, Marcum KB, Kabir N, Aran A, Hammadi MA (2018) Productivity and nutritional value of four forage grass cultivars compared to Rhodes grass irrigated with saline water. Aust J Crop Sci. 12 (02): 203-209.

Alsadon A, Sadder M, Wahb-Allah M (2013) Responsive gene screening and exploration of genotypes responses to salinity tolerance in tomato. Aust J Crop Sci. 7 (9): 1383-1395.

Chaganti VN, Crohn DM, Simunek J (2015) Leaching and reclamation of a biochar and compost amended saline–sodic soil with moderate SAR reclaimed water. Agr Water Manage. 158: 255-265.

Coleman NT, Mehlich A (1957) The chemistry of soil pH. In: Stefferad A (ed) Soil: The yearbook of agriculture, 1st edn. United States Department of Agriculture, Washington.

Dang A, Bennett JM, Marchuk A, Marchuk S, Biggs AJW, Raine SR (2018) Validating laboratory assessment of threshold electrolyte concentration for fields irrigated with marginal quality saline-sodic water. Agr Water Manage. 205: 21-29.

Fernandes JG, Freire MBGS, Cunha JC, Galvíncio JD, Correa MM, Santos PR (2009) Qualidade físico-química das águas utilizadas no Perímetro Irrigado Cachoeira II, Serra Talhada, Pernambuco. Revista Brasileira de Ciências Agrárias. 4 (1): 27-34.

Grattan SR, Grieve CM (1992) Mineral nutrient acquisition and growth response of plants grown in saline environments. Agr Ecosyst Environ. 38 (4): 275-300.

Huang CH, Xue X, Wang T, De Mascellis R, Mele G, You QG, Peng F, Tedeschi A (2010) Effects of saline water irrigation on soil properties in northwest China. Environ Earth Sci. 63 (4): 701-708.

IPA – Instituto Agronômico de Pernambuco (2008) Recomendações de adubação para o estado de Pernambuco, 2nd edn. IPA, Recife.

Jalali M, Ranjbar F (2009) Effects of sodic water on soil sodicity and nutrient leaching in poultry and sheep manure amended soils. Geoderma. 153: 194-204.

Liu X, Feike T, Chen S, Shao L, Sun H, Zhang X (2016) Effects of saline irrigation on soil salt accumulation and grain yield in the winter wheat-summer maize double cropping system in the low plain of North China. J Integr Agr. 15 (12): 2886-2898.

Mahdy AM (2011) Soil properties and wheat growth and nutrients as affected by compost amendment under saline water irrigation. Pedosphere. 21 (6): 773-781.

Minhas PS, Dubey SK, Sharma DR (2007) Effects on soil and paddy–wheat crops irrigated with waters containing residual alkalinity. Soil Use Manage. 23: 254-261.

Miranda MFA, Freire MBGS, Almeida BG, Freire AG, Freire FJ, Pessoa LGM (2018) Improvement of degraded physical attributes of a saline-sodic soil as influenced by phytoremediation and soil conditioners. Arch Agron Soil Sci. 64: 1-15.

Pupisky H, Shainberg I (1979) Salt effects on the hydraulic conductivity of a sandy soil. Soil Sci Soc Am J. 43: 429–433.

Richards LA (1954) Diagnosis and improvement of saline and alkali soils, USDA Agricultural Handbook 60, US Department of Agriculture, Washington.

Shainberg I, Letey J (1983) Response of soils to sodic and saline conditions. Hilgardia. 52 (2): 1–5.

Shainberg I, Rhoades JD, Prather RJ, (1981a) Effect of low electrolyte concentration on clay dispersion and hydraulic conductivity of a sodic soil. Soil Sci Soc Am J. 45: 273–277.

Shainberg I, Rhoades JD, Prather RJ (1981b) Effect of mineral weathering on clay dispersion and hydraulic conductivity of sodic soils. Soil Sci Soc Am J. 45: 287–291.

Shrivastava P, Kumar R (2015) Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi J Biol Sci. 22: 123-131.

Silva Filho SB, Cavalcante LF, Oliveira FA, Lima EM, Costa JRM (2000) Monitoramento da qualidade da água e acúmulo de sais no solo pela irrigação. Irriga. 5 (2): 112-115.

Singh RB, Minhas PS, Chauhan CPS, Gupta RK (1992) Effect of high salinity and SAR waters on salinization, sodification and yields of pearl-millet and wheat. Agr Water Manage. 21: 93-105.

Tavakkoli E, Rengasamy P, McDonald GK (2010) High concentrations of Na^+ and Cl^- ions in soil solution have simultaneous detrimental effects on growth of faba bean under salinity stress. J Exp Bot. 61 (15): 4449-4459.

Tedeschi A, Dell' Aquila R (2005) Effects of irrigation with saline waters, at different concentrations on soil physical and chemical characteristics. Agr Water Manage. 77: 308–322.

Tedeschi A, Menenti M (2002a) Indicators of the seasonal cycle of total dissolved and adsorbed salts under irrigation. Water Resour Manage. 16 (2): 89–103.

Tedeschi A, Menenti M (2002b) Simulation studies of long term saline water use: model validation and evaluation of schedules. Agr Water Manage. 54: 123–157.

Viana SBA, Rodrigues LN, Fernandes PD, Gheyi, HR (2001) Produção de alface em condições de salinidade a partir de mudas produzidas com e sem estresse salino. Rev Bras Eng Agr Amb. 5 (1): 60-66.

Wang B, Cui XH (2004) Researches on laws of water balance at transitional zone between oasis and desert in Minqin. Acta Ecologica Sinica. 24 (2): 235–240.

Weil RR, Brady NC (2016) The Nature and Properties of soils, 15th edn. Pearson, Boston.