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SOIL SUSCEPTIBILITY TO SALINITY AND SODICITY IN SORGHUM AREAS UNDER ABIOTIC STRESS

SUSCEPTIBILIDADE DO SOLO À SALINIDADE E SODICIDADE EM ÁREAS DE SORGO SOB ESTRESSES ABIÓTICOS

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ABSTRACT: Sorghum is a C4 grass adapted to saline and water stress, common in semiarid regions. Therefore, deficit irrigation is an alternative for rural producers, since productivity is not considerably affected. However, the use of brackish water can lead to salinization and/or sodification of the soil. Based on this, the objective was to evaluate the effect of irrigation water salinity and deficient irrigation depth on the soil sodification and salinization process. Two different experiments were carried out, designed in randomized blocks, under four irrigation blades (IB1 = 53%, IB2 = 67%, IB3 = 85% and IB4 = 94% of Culture evapotranspiration (ETc)) and four salinities, expressed in electrical conductivity (ECw) - 1.5; 3.0; 4.5 and 6.0 dS m-1. The variables analyzed were conductivity of the saturation extract (ECse) and the Sodium Adsorption Ratio of the extract (SARse), estimated by soil-water suspension 1:2.5 in layers 0 - 20 and 20 - 40 cm of the soil, considering their average.

Keywords: sodium adsorption ratio, salt stress, water stress, *Sorghum bicolor*.

RESUMO: O sorgo é uma gramínea C4 adaptada aos estresses salino e hídrico, comuns em regiões semiáridas. Portanto, a irrigação deficitária é uma alternativa aos produtores rurais, visto a produtividade não ser consideravelmente afetada. No entanto, a adoção de águas salobras pode acarretar a salinização e/ou sodificação do solo. Com base nisso, objetivou-se avaliar o efeito da salinidade da água de irrigação e da lâmina de irrigação deficitária no processo de sodificação e salinização do solo. Foram realizados dois experimentos distintos, delineados em blocos casualizados, sob quatro lâminas de irrigação (L1 = 53%, L2 = 67%, L3 = 85% e L4 = 94% da Evapotranspiração da cultura (ETc)) e quatro salinidades, expressas em condutividade elétrica (CEa) - 1,5; 3,0; 4,5 e 6,0 dS m-1. As variáveis analisadas foram condutividade do extrato de saturação (CEes) e a Razão de Adsorção de Sódio do extrato (RASes), estimadas por suspensão solo-água 1:2,5 nas camadas 0 – 20 e 20 – 40 cm do solo, considerando-se a média destas. A análise estatística deu-se por análise de variância e regressão. Constatou-se que o solo é mais suscetível a sodificação que a salinização, sendo recomendadas irrigações com CEa ≤ 3,7 dS m-1 e lâmina a 67% da ETc para solo cultivado com BRS Ponta Negra e CEa ≤ 2,5 dS m-1 para o BRS 506, sem interferência da lâmina.

Palavras-chave: razão de adsorção de sódio, estresse salino, estresse hídrico, *Sorghum bicolor*.

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INTRODUCTION

In semiarid regions, problems related to the availability and salinity of irrigation water are recurrent (ROLDÁN-CAÑAS; MORENO-PÉREZ, 2021). In order to develop agricultural production in these areas, research on crops that are tolerant to deficit irrigation has been carried out to make the most of the land given the available resources (CARVALHO et al., 2021; CHENG et al., 2021; SONI et al., 2021). Among these crops, sorghum stands out, a C4 metabolism grass and the fifth most cultivated cereal in the world, with potential for application in forage, in the case of forage, or forage and ethanol, in the case of saccharine (COSTA et al., 2016; MATHUR et al., 2017).

Sorghum tolerance to salinity depends on soil-related factors such as class and texture; to the plant, with reference to the genotype of the cultivar, and to irrigation, considering the depth and salinity adopted, as well as the evapotranspiration of the area. In other studies, Guimarães et al. (2019) found minimal yield losses for grain sorghum varieties 2502-IPA and 1011-IPA under irrigation with water up to 6 dS m-1.

However, brackish water causes accumulation of salts in the soil horizons (ORTIZ; JIN, 2021). This accumulation, mainly in the root zone, induces deleterious effects on plants and long-term salinization and/or sodification of soils. Therefore, deficit irrigation needs to ensure crop development with minimal risk of salinization and/or sodification. In this sense, the objective of this work was to evaluate the effect of irrigation water salinity and deficient irrigation depth on the soil sodification and salinization process.

MATERIAL AND METHODS

The research took place in the field between September and December 2020, at the Cumaru site, located in Upanema - RN, with a BSh climate (ALVARES et al., 2013), that is, arid steppe and hot (BECK et al., 2018).

Two drip-irrigated Cambisol areas were studied, one cultivated with BRS Ponta Negra sorghum (C1) and the other with BRS 506 sorghum (C2). The average values of temperature and relative humidity are shown in Table 1.

Table 1. Mean temperature and relative humidity in the studied months and water depths adopted for irrigation of the cultivars, in mm.

Temperature	Relative humidity		Irrigation blade	
			Ponta Negra	506
ºC	%	% ETc	mm	mm
		100	546,3	537,2
		53	289,5	284,7
28,5	56,3	67	366,0	359,9
		85	464,3	456,6
		94	513,5	505,0

ETc – Crop evapotranspiration (%).

The experiment was designed in randomized blocks in a 4 x 4 double factorial scheme, evaluating the influence of four concentrations of salts in the irrigation water, expressed in electrical conductivity (ECw) - 1.5, 3.0, 4.5 and 6.0 dS m-1 and 4 slides (IB1 = 53, IB2 = 67, IB3 = 85 and IB4 = 94% of Crop evapotranspiration) (Table 1) on soil salinity and sodicity.

The salinity was obtained by mixing CaCl.2H2O, MgSO4.7H2O and NaCl, simulating the 7:2:1 molar ratio of the most common cation charges found in Brazilian semiarid waters (MEDEIROS, 1992), while the irrigation varied according to crop evapotranspiration (ETc). Table 2 presents the final composition of the water used, the sodium adsorption ratio (SAR) and the corrected sodium adsorption ratio (SARc), which considers the bicarbonate ions, coming from the supply water, coming from the Jandaíra limestone, rich in CaCO3. The samples were collected in layers 0 - 20 and 20 - 40 cm, from where they were taken to the laboratory to be air-dried, crushed and sieved in a 2.0 mm mesh, in order to obtain air-dried fine earth.

Table 2. Chemical composition of waters used for irrigation in the experiment.

Water	EC	Na	Ca	Mg	K	Cl	SO_4	HCO_3	SAR	SARc
	$dS\ m^{-1}$	---------------------------			$mmol_c\ L^{-1}$		---------------------------------		$(mmol\ L^{-1})^{0,5}$	
S1	1,50	5,0	8,0	2,0	0,12	8,1	0,3	7,0	2,2	3,4
S2	3,00	19,0	8,0	3,0	0,12	22,1	1,3	6,9	8,1	11,4
S3	4,50	28,5	12,0	4,5	0,12	35,6	2,8	6,9	9,9	14,2
S4	6,00	38,0	16,0	6,0	0,12	49,1	4,3	6,8	11,5	16,5

S1 = Salinity 1; S2 = Salinity 2; S3 = Salinity 3; S4 = Salinity 4; EC = Electrical conductivity; SAR = Sodium adsorption ratio; SARc = Sodium adsorption ratio corrected

Two blocks were studied, each one consisting of 16 samples (four salinities and four slides), totaling 32 samples. In the laboratory, the salinity of 15 of these, randomly chosen, was determined via soil-water suspension 1:2.5 and saturation extract (TEIXEIRA et al., 2017), and the relationship found between the EC's allowed the conversion of the other EC 1:2.5 in EC of the saturation extract, using the equation $ECse = 4.13EC1{:}2.5 - 0.24$ ($R^2 = 0.987$). Although the most suitable method to express soil conductivity is the saturation paste, the soil-water suspension is less laborious and faster, requiring only correction factors due to the effect of dilution, irrigation method and soil texture (GHARAIBEH; ALBALASMEH; HANANDEH, 2021). Sodicity was expressed by the sodium adsorption ratio of the saturation extract (SARse) and also estimated by the SAR measured in the supernatant of the soil-water suspension of the 15 samples, where $SARse = 2.19SAR1{:}2.5 + 4.47$ ($R^2 = 0.889$).

Statistical analysis was performed using Microsoft Excel software, considering the average of the values obtained in the two layers of each plot. Data were submitted to statistical significance of the F test and regression, unfolding the interaction when significant at 5%.

RESULTS AND DISCUSSION

Salinity and salinity-blade interaction interfered in all ECse and SARse studied, except for the salinity-blade interaction in ECse of sorghum BRS 506 (Table 3). The isolated blade does not interfere with the results, as it is the ions of the salts that make up the water that salinize/sodify the soil, not the volume of water itself. However, the greater volume of water reduces the osmotic potential of the soil solution and increases the availability of water for plants (CALONE et al., 2020). In addition, semiarid regions have high evaporation rates, due to high temperatures and spatio-temporal irregularity of rainfall, helping to accumulate salts in the soil. Thus, the smaller the amount of water applied, the faster the salts accumulate, which justifies the effect of the interaction between salinity and irrigation blade.

Table 3. Statistical significance of F test for ECse and SARse in the soil cultivated with the sorghum cultivars studied.

SV	DF	BRS Ponta Negra		BRS 506	
		ECse	SARse	ECse	SARse
Block	1	-	-	-	-
S	3	<0,00001	<0,00001	<0,00001	<0,00001
IB	3	0,94651	0,55364	0,97194	0,10828
S x IB	9	0,02745	<0,00001	0,11767	<0,00001
Error	15	-	-	-	-
Mean	-	2,87	13,66	3,04	17,08
CV (%)	-	39,4	25,1	28,3	23,9

Note: S – Salinity; IB – Irrigation blade; S x IB – Interaction between salinity and irrigation blade; CV – Coefficient of variation.

Soils with a pH lower than 8.5 are considered saline when ECse ≥ 4.0 dS m-1 and sodium when the SARse exceeds 15 (mmol L-1)0.5 or the exchangeable sodium percentage (ESP) is greater than 15% (RICHARDS, 1954). However, the diagnosis of salinity/sodicity is not decisive in the development of cultures, which is more linked to their sensitivity to salinity, especially to Na+ toxicity. In the case of sorghum, it is a semi-tolerant crop, with no productivity losses when the irrigation water conductivity is 4.5 dS m-1 (AYERS; WESTCOT, 1985). In the BRS Ponta Negra cultivar, ECse exceeds 4.0 dS m-1 when the EC of irrigation water is 4.30, 7.18, 6.00 and 6.71 dS m-1 for IB1, IB2, IB3 and IB4, respectively. The lower EC of salinity water to reach the soil salinity at 53% of the culture evapotranspiration depth can be explained by the volume being insufficient to leach the salts. Mathematically, the angular coefficient of the electrical conductivity equation of the extract in IB1 was approximately double that for the other slides (Figure 1).

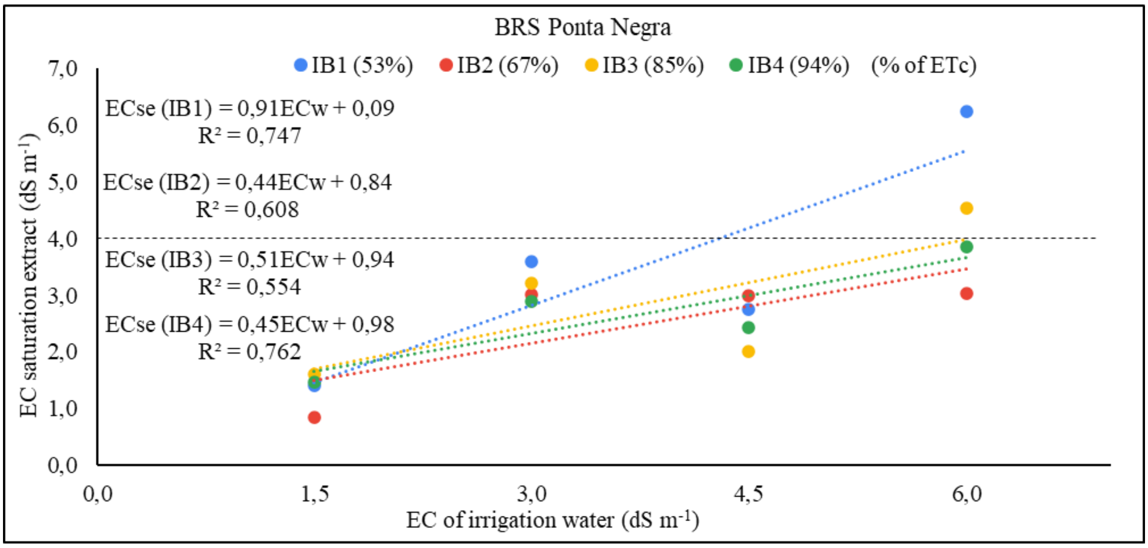

Figure 1. Electrical conductivity of soil saturation extract according to irrigation water salinity for each irrigation blade applied in the BRS Ponta Negra sorghum area.

Irrigation under 67% of ETc (IB2) did not provide soil salinization for the ECw studied, probably because of salt accumulation in sorghum cultivars is higher in soils with mild to moderate salinity (KAUSAR; GULL, 2019), so that possibly, part of the salts was absorbed by the plant. The fact that drip irrigation was adopted corroborates this idea, since the salts are concentrated in the root zone (ZHANG et al., 2021), facilitating the absorption of salts by the roots (Figure 1).

As for sodicity, the SARse exceeds 15 (mmol L-1)0.5 under irrigation with waters of 3.67, 4.84, 4.39 and 4.65 dS m-1 for IB1, IB2, IB3 and IB4 (Figure 2). It is worth mentioning that for the water EC and studied slides, there was less variability between the SARse's (CV = 25.1%) than between the ECse's (CV = 39.4%). Probably because the conductivity of the extract considers all salts dissolved in the soil solution, whereas the SAR is measured only on the basis of Na+, Ca2+ and Mg2+ ions. Dilution in the soil-water suspension promotes this variability through the difference in the solubility of salts and precipitation of possible calcium carbonates or sulfates formed, if the water is rich in carbonates and sulfates of sodium and magnesium, which can also increase the proportion of exchangeable Ca2+ (MONTELEONE et al., 2016).

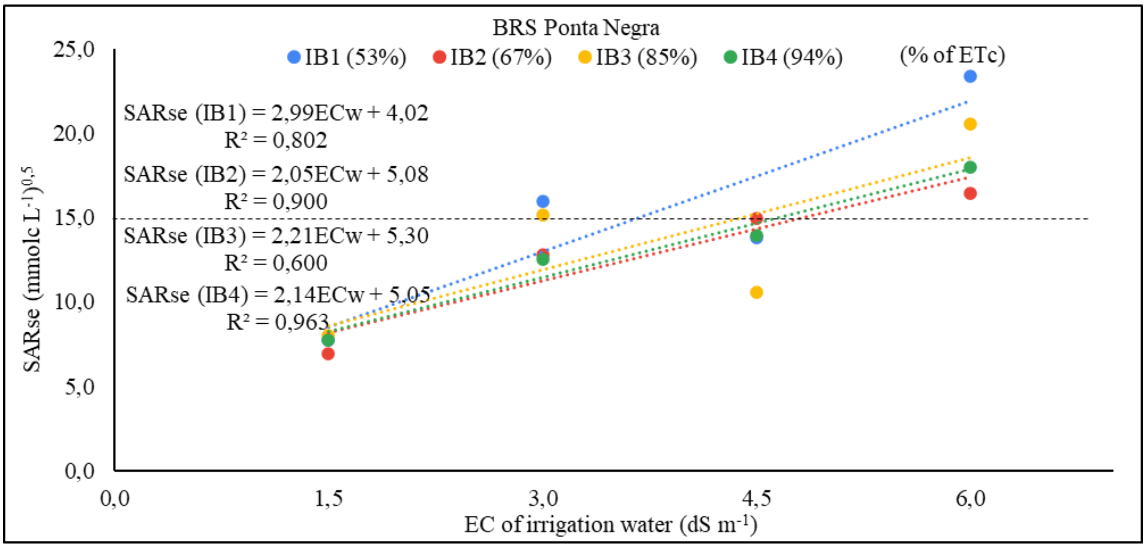

Figure 2. Sodium adsorption ratio in the saturation extract according to irrigation water salinity for each irrigation depth applied in the BRS Ponta Negra sorghum area.

Among the treatments studied, the culture evaporation depth of 67% was the one with the lowest potential for soil salinization (ECw = 4.84 dS m-1), which was already expected, considering the values found in ECse. Likewise, IB1 (53% of ETc) resulted in a higher propensity to sodicity (ECw = 3.67 dS m-1), while the slides at 85% (IB3) and 94% (IB4) of culture evapotranspiration were intermediate.

Therefore, the application of water slides at 67% or more of the ETc of the BRS Ponta Negra cultivar and below 3.7 dS m-1 is the most recommended to avoid problems related to salinity and sodicity of the soils.

In soil cultivated with BRS 506 sorghum, the ECse varied only according to the salinity of the irrigation water, so the graphic representation of the salinity x irrigation blade interaction is not necessary. The equation that defines ECse was ECse = 0.655ECw + 0.583 (R^2 = 0.944), that is, the soil salinizes when the irrigation water conductivity exceeds 5.22 dS m-1.

Compared to C1, the soil cultivated with sorghum BRS 506 was more susceptible to salinity, given that the water EC required for ECse to be 4.0 dS m-1 is considerably lower than that observed in IB2, IB3 and IB4 of C1. As for sodicity, the SARse reaches 15 (mmol L-1)0.5 for water with EC of 3.08, 3.97, 2.54 and 2.85 dS m-1 in IB1, IB2, IB3 and IB4, which shows a greater risk to sodification than to salinization, since it is possible to have an

ECw of 2.5 dS m-1. Except for ECw of 1.5 dS m-1, IB1 at ECw = 3.0 dS m-1 and IB2 at ECw= 4.5 dS m-1, all slides represented potential for sodification (Figure 3).

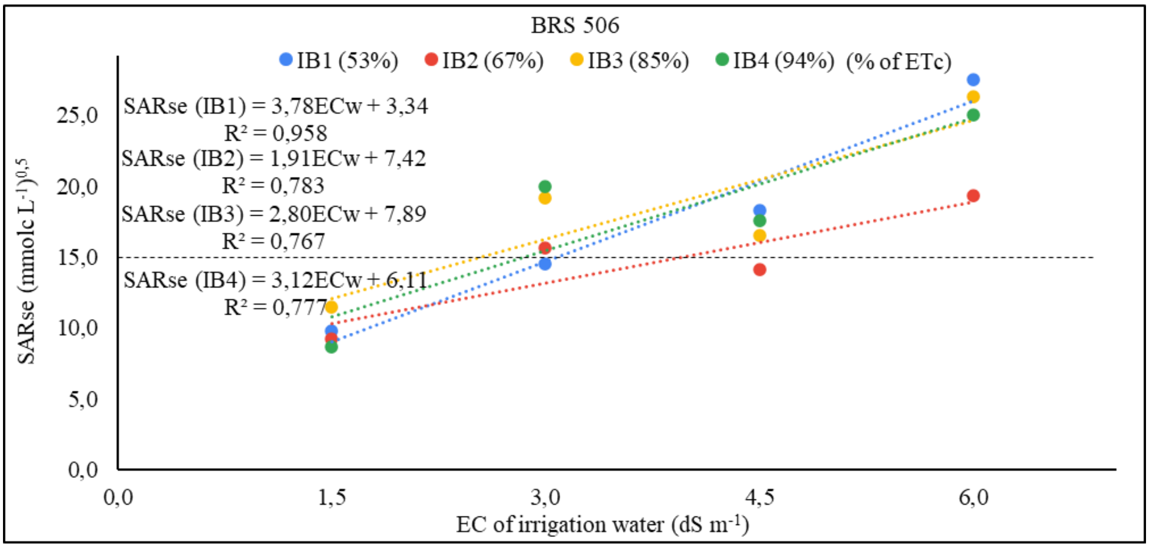

Figure 3. Sodium adsorption ratio in the saturation extract according to the salinity of the irrigation water for the different irrigation depths applied in the BRS 506 sorghum area.

This fact is linked to the groundwater of the Jandaíra Limestone, rich in calcium bicarbonate (FOSTER; GARDUÑO, 2005), whose use in irrigation causes calcium to precipitate and sodium to dissolve in the soil solution. Meanwhile, magnesium migrates to the shoot of sorghum under salt stress (KAUSAR; GULL, 2019). Therefore, the concentration of Na^+ increases in relation to Ca^{2+} and Mg^{2+}, raising the SAR and ESP of the soil.

CONCLUSIONS

The studied soil is more susceptible to sodification than to salinization**.**

For soil cultivated with BRS Ponta Negra sorghum, the application of laminating at 67% of ETc and EC below 3.7 dS m^{-1} prevents salinization and sodification processes.

In soil cultivated with BRS 506, there is no minimum/maximum water depth that interferes with the electrical conductivity of the extract, provided that the salinity of the irrigation water is less than 2.5 dS m^{-1}.

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