

Effects of elemental sulfur associated with gypsum on soil salinity attenuation and sweet sorghum growth under saline water irrigation

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Abstract

In the Brazilian semiarid region, one of the great challenges of agriculture is the adoption of cultivation strategies for saline soils utilizing saline waters. This work aims to evaluate the development of sweet sorghum and soil salinity status under increasing doses of elemental sulfur applications associated with gypsum at different irrigation levels. The work was conducted in a Cambisol, in a 4 x 5 factorial scheme, corresponding to 4 levels of elemental sulfur (0, 0.69, 1.39 and 1.99 t ha⁻¹) and 5 saline irrigation levels (6, 12, 18, 24 and 30 mm), equivalent to 20, 40, 60, 80 and 100% of the soil field capacity respectively, with 4 replicates. Gypsum was applied in all treatments in a dose equivalent to 8.49 t ha⁻¹. The effects of these treatments were evaluated by analyzing the chemical properties of the soil and plant growth variables. Increasing elemental sulfur levels promoted reductions in soil pH and electrical conductivity of the saturation extract. Although increasing saline irrigation levels increased soil pH and decreased electrical conductivity of the saturation extract, the highest applied water levels (80 and 100% of the field capacity) negatively affected sorghum growth. Highest levels of elemental sulfur applied (1.39 and 1.99 t ha⁻¹) promoted the best growth of sorghum. The study revealed that the saline irrigation level equivalent to 60% of the field capacity and the sulfur level of 1.39 t ha⁻¹ was sufficient to reduce soil pH and salinity to a level that best promoted sorghum growth.

Keywords: Salt and water stress; semiarid; soil degradation; *Sorghum bicolor* (L) Moench; water quality.

Introduction

The rapid growth of the world's population has led to an increase in food demand. In order to meet the needs of this growing demand, the agriculture sector must find new ways to increase food production. Thus, irrigation has become a very important tool by increasingly the farmable agricultural areas around the world, allowing for agricultural production even in arid and semiarid regions (Medeiros et al., 2010). Due to the scarcity of rainfall in these regions, irrigation practices constitute one important alternative to ensure production in cultivated areas.

Despite its successes, the practice of irrigated agriculture can cause several problems to arise when misused, such as soil salinization. This occurs due to the presence of dissolved salts in the irrigation water that, even at low concentrations, can be absorbed into the soil, making them saline within a few years. The problems associated with excess salts can be intensified depending on the type of soil. However, soil salinization can also be intensified as a function of irrigation water quality, management, groundwater depth, etc., as these factors are related to poor drainage conditions and high rates of evapotranspiration (Ribeiro et al., 2003).

In Northeast Brazil, approximately nine million hectares of soil are affected by the presence of salts (Fageria and Gheyi,

1997). In these areas, which have an extreme water shortage, dams were constructed with vast water storage capacities and irrigated perimeters. However, in most cases, inadequate water use associated with lack of drainage led to an intensified soil salinization problem.

Soil affected by salt has been associated with a negative effect on plant growth due to the presence of high levels of soluble salts, with or without highly exchangeable sodium contents. In addition to the osmotic and toxic effects on plants and the physical effects on the soil, especially in the case that the predominant ion is exchangeable sodium, another major negative effect of soil salinity is the loss of fertility, which leads to losses in both quantity and quality of production, or even total loss of productive capability. Salinity also affects nutrient absorption and availability for plants, which is related to soil element activity in soil solution, element concentration of the solution and soil solution composition (Grattan and Grieve, 1999). For these reasons, cultivation in saline areas is difficult to achieve and has led to challenges for agricultural production in saline soils or under irrigation in saline areas.

The use of crops which are resistant to drought and salinity has become a management alternative adopted in

these regions. In this sense, sweet sorghum is an example of a non-halophytic tolerant plant, which is notable for its tolerance to salt stress and can serve as a resilient option for salinized soil (Almodares and Hadi, 2009). Therefore, studies that seek to reduce the use of salt water in semiarid regions take on extreme importance in reducing soil salinization and the best utilization of limited water resources in the region. As such, it is necessary to study cultures that are best suited and capable of satisfactory production in these adverse conditions.

The use of inputs that alleviate or correct the saline effects on soil and crops has taken on increased importance in plant production in arid and semiarid regions. Gypsum has been commonly used to address sodium soil, mainly due to its low cost (Jalali et al., 2008). However, gypsum use generally requires large applications and its effect on soil pH is insignificant (Stamford et al., 2015). However, sulfur inoculated with *Acidithiobacillus* has been shown to produce sulfuric acid and strongly contributes to the reduction of soil pH and, consequently, leads to an improvement of the physical condition commonly found in sodium soil (Qadir et al., 2008).

In this context, the present study tested the hypothesis that the application of elemental sulfur associated with gypsum could mitigate the effects of soil salinity and irrigation water salinity, leading to improved growth of sweet sorghum. Thus, the objective of this work was to evaluate the status of soil salinity and the development of sweet sorghum under application of increasing doses of elemental sulfur (S^0) associated with gypsum and irrigation at different levels of saline water.

Results and Discussion

Table 3 presents the summary of the variance analysis for the variables studied in the experiment. This table shows that the doses of elemental sulfur (S^0) and the saline irrigation levels in isolation were more strongly with significant variables than the interaction between these factors.

Effects on soil pH and soil salinity

Soil pH was reduced by increasing doses of S^0 (Table 4). We observed that the doses corresponding to 75% and 100% of the gypsum requirement (1.4 and 2.0 t ha⁻¹, respectively) were the most effective in reducing soil pH, which was lowered to a range suitable for sorghum cultivation, which is 5.5 to 8.5 according to Smith and Frederiksen (2000). Despite reductions in soil pH values due to the increase of the applied S^0 doses, we verified that the maximum dose of S^0 applied in the experiment (2.0 t ha⁻¹) reduced the pH value from 8.65 (Table 1) to 8.22 (Table 4), showing a high degree of alkalinity. As such, the data suggests that larger doses should be investigated in order to verify a greater efficiency of S_0 in reducing pH under these conditions. According to Stamford et al., (2015), 45 days after bean cultivation, reductions can be observed in pH values of a Fluvisol from 10.5 to 7.8 at a 1.6 t ha⁻¹ dose of S^0 ; to 7.1 when the S^0 application was 2.4 t ha⁻¹; and to 6.6 at a dose of 3.2 t ha⁻¹. These authors utilized sulfur inoculated with *Acidithiobacillus*, which contributed to an increase of the potential of S^0 to reduce soil pH in comparison to the lower

reduction levels observed in our study, without this inoculation.

The increase in S^0 doses led to a reduction in the electrical conductivity of the soil saturation extract (Table 4). The doses corresponding to 75 and 100% of the gypsum requirement (1.4 t ha⁻¹) were associated with the largest reductions of conductivity. S^0 is considered to be an effective and economically viable soil conditioner for the recovery of saline-sodic and sodic soils (Tarek et al., 2013). Ahmed et al., (2016) found similar results to those observed in our study, in that the doses equivalent to 100% and 125% of the gypsum requirement reduced EC by 54.45% and 55.36% in relation to the initial salinity in a saline-sodic soil containing 25% clay and 30% silt. Kubenkulov et al., (2013) affirm that the association of gypsum and S^0 conditioners has a great effect, regulating both soil pH and total soluble salts in saline-sodic soils. Additionally, these conditioners applied in combination accelerate the leaching of Na⁺ ions from the root zone, which appears to be the main source of pH reductions, electrical conductivity and the sodium absorption ratio to an acceptable level (Abdelhamid et al., 2013).

The soil pH levels and EC corresponding to the saline irrigation levels are shown in Fig 1a and 1b, respectively. A rise in soil pH levels was observed relating to the saline irrigation levels (Fig 1a), which occurred due to high carbonate and bicarbonate content present in the irrigation water (Table 2). This rise in pH values, in addition to affecting salt solubility (Mohd-Aizat et al., 2014), reduces the availability of some nutrients essential to plant development.

EC values showed an inverse relation to the pH of the soil, being reduced by the rising saline irrigation levels (Fig 1b). This was attributed to the greater leaching of salts with the increased levels. Geerts et al., (2008) argue that one consequence of reduced irrigation water use is a greater risk of increasing soil salinity due to reduced leaching. Furthermore, as pH affects salt solubility, the higher saline irrigation levels lead to greater soil alkalinity and less solubilized salts (Mohd-Aizat et al., 2014). This indicates the difficulty of sufficient irrigation with waters that have high levels of salinity and alkalinity, because while an increase in irrigation water level promotes greater leaching of the salts, this leads to increasing pH values, making the soils more alkaline.

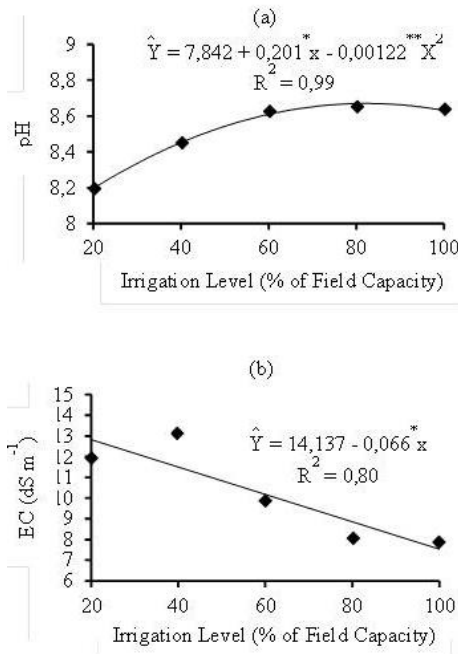
Effects of elemental sulfur doses and saline irrigation level on sorghum growth

Although increased saline irrigation levels reduced soil salinity, we observed that the larger levels (80 and 100% of field capacity) negatively affected sorghum development under our experimental conditions and caused a reduction in all examined variables (Table 5). The saline irrigation level corresponding to 100% of the field capacity caused the death of the plants at this saline irrigation level. The results observed in this study indicate that the saline irrigation level corresponding to 60% of field capacity promoted the best plant growth, although this saline irrigation level was not the most effective at reducing soil salinity (Fig 1b). The sweet sorghum is a C₄ plant, characterized by a high biomass yield and high photosynthetic efficiency (Bryan, 1990; Billa et al., 1997), and highly efficient water usage (Mastrorilli et al.,

Table 1. Chemical and physical characterization of the Cambisol used in the experiment.

Attribute	Attribute	Attribute	Attribute
pH	8.65	Fine sand (g kg ⁻¹)	252.20
EC (dS m ⁻¹)	27.70	Coarse sand (g kg ⁻¹)	65.20
Ca ²⁺ (cmol _c kg ⁻¹)	17.80	Silt (g kg ⁻¹)	428.20
Mg ²⁺ (cmol _c kg ⁻¹)	2.97	Clay (g kg ⁻¹)	254.40
Na ⁺ (cmol _c kg ⁻¹)	3.92	WDC (g kg ⁻¹)	216.40
K ⁺ (cmol _c kg ⁻¹)	1.16	BD (d cm ⁻³)	1.56
ESP (%)	25.85	PD (d cm ⁻³)	2.44
SAR (mmol _c L ⁻¹) ^{0.5}	37.07	P (%)	36.07
P (mg kg ⁻¹)	65.70		
OC (dag kg ⁻¹)	0.97		

*EC: Electrical Conductivity; ESP: Exchangeable Sodium Percentage; SAR: Sodium Adsorption Ratio; OC: Organic Carbon; WDC: Water-Dispersible Clay; BD: Bulk Density; PD: Particle Density; P: Total Porosity.

**Fig 1.** Soil pH (a) and Electrical Conductivity (EC) as a function of the irrigation water level.**Table 2.** Chemical characterization of saline water used in the experiment.

pH	EC (dS m ⁻¹)	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Cl ⁻	SO ₄ ²⁻	CO ₃ ²⁻	HCO ₃ ⁻	SAR (mmol _c L ⁻¹) ^{0.5}
		mmol _c L ⁻¹								
8.59	2.70	0.68	0.83	1.87	25.89	20.50	1.88	2.80	20.40	29.80

*EC: Electrical Conductivity; SAR: Sodium Adsorption Ratio.

Table 3. Summary of variance analysis of plant height (PH), stem diameter (SD), number of leaves (NL), fresh matter (FM) and dry matter (DM) of sorghum plants, pH and electrical conductivity (EC), submitted to the different treatments.

Source of variation	Mean square						
	PH	SD	NL	FM	DM	pH	EC
Doses of S ⁰ (S ⁰)	256.2**	04.6**	3.1**	072.6*	08.3*	74.5****	40.4****
Levels of Irrigation (LI)	293.3**	12.5**	4.3**	288.2**	20.4**	61.1****	86.6****
S ⁰ x LI	058.6 ^{ns}	05.1 ^{ns}	0.4 ^{ns}	110.4 ^{ns}	14.3**	6.2**	6.4 ^{ns}
Residue	42.1	02.4**	0.6**	040.9**	04.2**	1.7	5.2
CV (%)	74.9	3.6	0.9	71.5	7.4	10.8	85.1

CV = coefficient of variation; * and ** = significant to 5 and 1% respectively; and ^{ns} = non-significant.

Table 4. Mean values of soil pH and Electrical Conductivity (EC) as a function of the applied elemental sulfur doses (S^0).

Doses of S^0 (t ha ⁻¹)	pH	EC
0.0	8.57 a	12.0 a
0.7	8.60 a	10.45 ab
1.4	8.46 a	8.65 b
2.0	8.22 b	9.60 b

Averages followed by the same letter in the column do not differ significantly from one another by the Tukey test in a 5% probability.

Table 5. Mean values of plant height (PH), stem diameter (SD), number of leaves (NL), fresh matter (FM) and dry matter (DM) of sorghum plants as a function of irrigation water levels and applied sulfur doses.

Source of variation	PH (cm)	SD (mm)	NL	FM — (g) —	DM
Irrigation water level (% of field capacity)					
20%	52.61 b	08.87 b	3.67 b	15.16 cb	4.53 bb
40%	53.12 b	10.48 b	4.33 ab	19.56 bc	5.84 ab
60%	63.33 a	11.33 a	5.00 a	26.86 aa	7.70 aa
80%	55.98 b	10.28 ab	4.83 a	22.26 ab	5.77 ab
Doses of S^0 (t ha ⁻¹)					
0.0	50.42 b	9.65 b	3.75 b	18.19 b	4.97 b
0.69	55.12 ab	10.64 ab	4.42 ab	20.28 ab	5.89 ab
1.39	61.21 a	10.89 a	4.83 a	24.11 a	7.01 a
1.99	58.29 ab	9.79 ab	4.63 a	21.28 ab	5.99 ab

*Averages followed by the same letter in the column do not differ significantly from one another by the Tukey test in a 5% probability.

1999) being highly resistant to drought and salt (Almodares et al., 2011). As such, sweet sorghum is an important potential crop for cultivation in saline soils, especially in regions where high quality irrigation water is unavailable. Bonfim-Silva et al., (2011) also verified that the irrigation water level equivalent to 60% of field capacity of an Oxisol best promoted sorghum growth, presenting greater plant height, dry shoot mass and number of leaves per pot, corroborating the results obtained in our study.

The tested sulfur doses (S^0) significantly influenced sorghum development, and the highest doses (1.39 and 1.99 t ha⁻¹) best promoted sorghum development, presenting higher values of examined variables (Table 5). This can be attributed to the fact that these doses were the most efficient in reducing soil salinity (Table 4). Furthermore, S is considered the fourth most essential mineral nutrient after nitrogen (N), phosphorus (P) and potassium (K), having an important role not only in plant growth and development, but also in the plants tolerance for stress (Marshner, 1995). Additionally, adequate S nutrition improves photosynthesis and plant growth, in turn stimulating an interaction that regulates assimilation with N (Scherer, 2008).

Materials and methods

Description of the experimental area

The research was carried out in a greenhouse on the campus of the Rural Federal University of Pernambuco - Serra Talhada Campus- UFRPE / UAST, in the city of Serra Talhada - Pernambuco. The experimental area is located in the Pajeú watershed, at the geographical coordinates 7° 59' 7" South latitude and 38° 17' 34" West longitude, with a mean altitude of 443 m. The dominant climate of the region is classified as hot and dry, with extremely infrequent rainy seasons. The average temperature of the region ranges from

23° to 27° C with an annual mean rainfall of less than 800 mm, relative humidity of around 50% and evaporation of 2,000 mm year⁻¹ (Moura et al., 2007).

Experimental design and description of treatments

This experiment utilized a Cambisol collected from the superficial soil layer (0-20 cm) within the irrigated perimeter of the National Department of Works Against Drought (Departamento Nacional de Obras Contra a Seca – DNOCS) in the city of Serra Talhada. After collection, the collected soil was air-dried, stripped and sieved through a 2 mm mesh for both chemical (Richards, 1954) and physical (Embrapa, 1997) characterization (Table 1); and additionally in a 4 mm mesh in order to carry out the experiment.

In order to prepare the experiment, the sieved soil was homogenized and conditioned in 7 kg soil pots, where chemical conditioners were applied: gypsum – 8.49 t ha⁻¹, corresponding to 100% of the gypsum requirement for this soil, and elemental sulfur (S^0), at doses of 0; 0.69; 1.39; and 1.99 t ha⁻¹, equivalent to 0%, 35%, 75% and 100% of the applied gypsum dose. Soil irrigation was achieved utilizing high salinity and alkalinity water on alternating days, totaling a 48 hour irrigation schedule, applying saline irrigation levels corresponding to 20, 40, 60, 80 and 100% of field capacity, corresponding to 6, 12, 18, 24 and 30 mm respectively. Thus, the experiment consisted of a 4 x 5 factorial arrangement - four doses of S^0 and five saline irrigation levels, in four replications, totaling 80 experimental units. The experimental design adopted a completely randomized spatial distribution. The saline water used in the experiment was collected at the Pernambuco Agronomy Institute (Instituto Agronômico de Pernambuco – IPA) and had a chemical characterization established as C4S4, with a high risk of salinization and sodification (Table 2), following the classification described by Richards (1954).

In addition, the water also showed high levels of carbonates and bicarbonates, which tend to raise soil pH. Thus, the motivation of applying sulfur to the soil was to address this elevated pH, since gypsum itself has no effect on pH levels. Sweet sorghum seeds (*Sorghum bicolor* (L) Moench), cultivar IPA 4674-2, were used for the sowing phase of the experiment. The seeds were sown in polyethylene trays filled with sterilized soil. The seedlings were transplanted to the experimental pots.

Plant and soil measurements

Biometric variables (number of leaves, plant height, stem diameter, fresh and dry shoot mass) of the sorghum were recorded after 90 days. After collecting the plants, the entire soil mass was removed from the pots for final chemical analysis. The chemical attributes examined at this phase of the experiment consisted of soil pH levels and the electrical conductivity of the saturation extract (EC), according to Richards (1954).

Statistical analysis

The soil and plant data were submitted to variance analysis, regression analysis and Tukey's test, at a 5% probability level for comparison of means to the evaluated treatments ($p \leq 0.05$).

Conclusion

Increasing elemental sulfur levels promoted reductions in soil pH and electrical conductivity of the saturation extract, however, increasing saline irrigation levels increased soil pH and decreased electrical conductivity of the saturation extract. Thus, the study revealed that the saline irrigation level equivalent to 60% of the field capacity and the sulfur level of 1.39 t ha^{-1} was sufficient to reduce soil pH and salinity to a level that best promoted sorghum growth.

Acknowledgements

This research was supported by a grant from the Institutional Scholarship Program for Scientific and Technological Initiation (PIBIC) of the Rural Federal University of Pernambuco (UFRPE) - Serra Talhada Campus (UAST).

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