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NOTE

EFFICIENCY OF SULFUR APPLICATION WITH DIFFERENT SIZES AND RATES IN RECLAMATION OF A SALINE-SODIC SOIL IN LABORATORY COLUMNS[1]

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ABSTRACT

A laboratory study was conducted to determine the proper size and application rate of sulfur and its efficiency in reclaiming a clay-silty loam saline-sodic soil (ESP >15, EC >4.0 mmohs cm^{-1} and pH >9.6) in Fars Province of Iran. Furthermore, the efficiency of salt leaching under sulfur applications was investigated. In general, application of 4.0 t ha^{-1} of sulfur granules with smaller than 1 mm in size and application of 0.45 m of water per unit depth of soil improved the saline-sodicity conditions of this soil and decreased the soil pH to 8.3 in the first layer with nearly 10 cm in thickness. However, the granular size of 1-2 mm may have similar effects. The granular size of larger than 2 mm was not as effective as the size of smaller than 2 mm. Application of 4.0 t ha^{-1} of granular size of smaller than 2 mm promoted the efficiency of leaching the salt by water. Furthermore, the granular size of smaller than 2 mm was more efficient in reducing the ESP and resulted in an efficiency of about 44.8%.

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راندمان کاربرد مقادیر مختلف گوگرد در اندازه‌های متفاوت در اصلاح یک خاک شور-قلیا در شرایط آزمایشگاهی.

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خلاصه

این بررسی آزمایشگاهی برای تعیین اندازه ذرات و میزان کاربرد مناسب گوگرد وراندمان آن در اصلاح یک خاک شور-قلیا با بافت لوم سیلتی-رسی (درصد سدیم تبادلی بیش از ۱۵، شوری بیش از ۴ میلی موز بر سانتی متر و پ‌هاش بیش از ۹/۶) در استان فارس - ایران انجام شد. همچنین راندمان آبشویی خاک با کاربرد گوگرد مورد مطالعه قرار گرفت. بطورکلی کاربرد ۴ تن در هکتار گوگرد با ذرات کوچکتر از یک میلیمتر و کاربرد ۰/۴۵ متر آب به ازاء هر یک متر عمق خاک شرایط شور- قلیا بودن این خاک را اصلاح کرده و پ-هاش لایه اول آنرا بضخامت تقریبا ۱۰ سانتی متر به ۸/۳ تقلیل داده است. تاثیر ذرات ۲-۱ میلیمتری ممکن است که با اندازه ذرات کوچکتر از یک میلیمتر باشد ولی ذرات بزرگتر از دو میلیمتر مانند ذرات کوچکتر از ۲ میلیمتر موثر نبود. کاربرد ۴ تن در هکتار

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گوگرد با اندازه کوچکتر از ۲ میلیمتر راندمان آبشویی املاح خاک را افزایش داده است. همچنین ذرات کوچکتر از ۲ میلیمتر در کاهش درصد سدیم تبادلی خاک موثر بوده و دارای راندمان ۴۴/۸ درصد میباشد.

INTRODUCTION

About 25 million na of saline-sodic soils occur in Iran (6). These soils are characterized by high exchangeable sodium, high salt content, varying degree of calcareousness and a pH usually lower than 8.5. However, at least some 2500 ha of such soils exist in the Fars Province of Iran in which the pH is greater than 10 and permeability is very low (2).

Different amendments have been used for reclamation of sodic soils among which gypsum and pyrite were popular in India (10) due to their easy availability, greater efficiency and low cost as compared with other amendments such as sulfur. However, sulfur is plentiful and relatively cheap in Iran (8). The acid produced upon biological oxidation of sulfur, reacts with calcium carbonate of the soil to release calcium for the Na exchange reaction.

Oxidation of sulfur depends upon the particle size because auto-oxidation should be favored by increase in surface area. The optimum range of sulfur size for the least difficulties in use is 1-4 mm (3). Kanwar and Bhumbla (4) observed good yields of rice and barley on sodic soils with 1 t ha^{-1} sulfur application. Kelly (5) reported that the application of 2.5 t ha^{-1} of sulfur along with leaching could reduce the soil pH and ESP effectively with considerable increase in crop yield.

Sulfur application in reclamation of sodic soils and its efficiency might be influenced by the sulfur particle size and rates of application under different soil and leaching conditions. Therefore, this study was conducted to determine the proper size and rate of sulfur application and its efficiency in reclaiming a saline-sodic soil under laboratory conditions in the Fars Province of Iran. Furthermore, the efficiency of salt leaching under sulfur application treatments was investigated.

MATERIALS AND METHODS

The saline-sodic soil samples were obtained from Elyas-Abad

(Marvdasnt) located 75 km north-east of Shiraz (Fars Province) at 0-30 and 30-60 cm deptns (Typic Salorthids clay and silty loam, respectively). Some physico-chemical properties of the soil are shown in Table 1. The soil was air-dried, passed through a 2-mm sieve and then placed in 19 4 mm I.D. P.V.C. tubes with 75 cm length. The bottom of the tubes was closed by plastic screen and Whatman paper No. 42. The length of soil column was, on the average, 53 cm in which the lower half was filled with soil of 30-60 cm depth and the upper half was filled with soil of 0-30 cm depth. The soil in column was compacted to a bulk density of 1.38 ± 0.05 g cm^{-3}. In preparing the soil columns, the top 10 cm of soil was mixed with a sufficient amount of granular sulfur (a by-product of Isfahan Oil Refinery), of size smaller than 1 mm, 1-2 mm or larger than 2 mm to represent application rates of 0, 2, 4 and 6 t ha^{-1} The experimental design was a 3x4 factorial with three replicates.

The soil columns were placed over an iron stool with funnel and leachate collector bottles underneath. Enough tap water was added to each column to raise the soil water to the field capacity. Then columns were covered with plastic sheets to prevent surface evaporation. A few holes were made in the plastic sheets for gaseous exchange.

The soil columns were kept in greenhouse conditions for 154 days. The average daily maximum and minimum air temperature and the average daily maximum and minimum relative humidity were 26.4 and 9.8°C (with average value of 18.1°C) and 55.6 and 26.0% (with average value of 40.8%), respectively.

After the incubation period, leaching of the soil columns with tap water was commenced. The columns were continuously ponded with 5-8 cm tap water. The chemical analysis of the tap water is given in Table 1. The first 50 cm^3 of the leachate from the bottom of the soil columns were collected as the first leachate sample. Thereafter, 50 cm^3 aliquots were sampled after every 1000 cm^3 of leachate had been

Table 1. Some physico-chemical properties of soil and chemical analysis of tap water used for leaching.

Properties	0-30 cm depth	30-60 cm depth	Leaching water
Sand (%)	14.3	19.4	-
Silt (%)	33.3	42.1	-
Clay (%)	52.4	38.5	-
Saturation percentage	54.3	45.5	-
Soil water content at $-\frac{1}{3}$ bar, (% dry wt. basis)	26.0	25.0	-
Soil water content at -15 bars (% dry wt. basis)	17.1	10.8	-
Saturated paste and leaching water pH	10.0	9.65	7.5
Electerical conductivity of saturation extract and leaching water (mmhos cm^{-1})	56.5	6.75	0.53
Exchangeable sodium percentage	86.1	47.8	-
Cation exchange capacity (meq 100^{-1}g)	16.7	10.9	-
Calcium carbonate (%)	31.1	39.0	-
Gypsum (%)	0.017	0.009	-
Chemical analysis of saturation extract and leaching water (meq lit^{-1})			
Na	591.3	63.0	0.33
K	0.6	0.08	-
Ca+Mg	4.0	2.0	6.20
CO_3	76.0	-	-
HCO_3	79.0	19.0	5.60
Cl	357.5	30.0	0.35
SO_4	75.0	13.0	0.45

collected at the bottom of the columns. After passing approximately 1.3 ± 0.3 pore volume of leachate from the columns of different treatments, the leaching process was terminated. Then, the soil columns were sectioned into four layers with average thicknesses of 9.1 cm (first layer), 13.65 cm (second layer), 13.5 cm (third layer) and 18.35 cm (fourth layer).

The soil samples of each layer were air-dried and their saturation extract were prepared according to procedure described by U.S. Salinity Laboratory (11). The pH of soil paste, the electrical conductivity, Na^{+}, $Ca^{++} + Mg^{++}$ and $SO_4^{=}$ of the saturation extracts and the soil ESP were determined according to the procedure described by U.S. Salinity Laboratory (11).

RESULTS AND DISCUSSION

Electrical Conductivity of Saturation Extract, ECe

The ECe in different layers of the soil columns at the termination of leaching are shown in Table 2. Application of sulfur with granular sizes of smaller than 2 mm significantly decreased the ECe of the first layer. The application rate of 2 t ha^{-1} with granular size of smaller than 2 mm resulted in the lowest ECe in these layers. Application of sulfur did not decrease the ECe of the second layer significantly, in comparison to control.

In the third layer, the applications of 4 and 6 t ha^{-1} of granular size of 1-2 mm significantly decreased the ECe to lower than 4 mmhos cm^{-1} compared with the control (Table 2). These application rates resulted in 51.4 and 43.3% reduction in ECe compared with the control. The ECe values in the third layer were reduced to 25.9% and 21.0-14.7% of its initial value for the control and the treated columns, respectively.

Although the sulfur application (2-6 t ha^{-1}) of granular

Table 2. Electrical conductivity of the saturation extract (mmhos cm^{-1} at 25° C) in different layers of soil and at different sizes and application rates of sulfur.

Sulfur application rates (tons ha^{-1})	Granular size (mm) <1	1 - 2	>2	mean
		First layer		
0	2.15a*	2.03a	2.37a	2.18a
2	2.68ab	3.10b	3.22a	3.00b
4	3.45bc	3.47bc	3.28a	3.40bc
6	4.27c	4.03c	3.22a	3.84c
Mean	3.15A	3.16A	3.02A	
		Second layer		
0	3.50ab	4.00a	3.48a	3.66a
2	3.00a	3.58a	3.47a	3.35a
4	3.92ab	3.45a	3.67a	3.68a
6	4.22b	4.03a	3.80a	4.02a
Mean	3.66A	3.76A	3.60A	
		Third layer		
0	3.98a	6.03c	4.48a	4.83a
2	3.60a	4.90bc	4.85a	4.45a
4	3.48a	2.93a	3.88a	3.43a
6	3.75a	3.42ab	4.58a	3.92a
Mean	3.70A	4.32A	4.45A	
		Fourth layer		
0	7.63a	11.13c	8.27a	9.01b
2	6.25a	5.72ab	11.13a	7.70ab
4	4.08a	4.83a	7.08a	5.33a
6	4.78a	5.82b	6.85a	5.82a
Mean	5.68A	6.87A	8.33A	

* Means within each layer in each column followed by the same letter are not significantly different at P=0.05. Capital letters are used for the horizontal main effects.

size of 1-2 mm reduced the ECe in the fourth layer significantly in comparison to 0 t ha^{-1} (on the average 51.0% of control), there was no significant difference among the ECe in treated columns of 2-6 t ha^{-1} (Table 2). In general, the ECe in the fourth layer was not reduced to 4.0 mmhos cm^{-1}, but only 4.0 t ha^{-1} of granular size of smaller than 1 mm barely reduced the ECe to this value.

The results in Table 2 indicated that if reduction in the soil ESP is not the main goal, there should be no need to apply sulfur for reducing the ECe in the first to third layers and leaching alone could be sufficient. Of course, in this case, a large amount of leaching water should be applied. This point will be discussed later.

Soil pH

The pH of soil paste in different layers are shown in Table 3. The sulfur application of granular size of larger than 2 mm did not influence the soil pH in the second to fourth layers significantly. However, the pH of first layer was significantly reduced under this treatment. On the other hand, the sulfur application of granular size of smaller than 2 mm significantly reduced the soil pH in the all soil layers. The acceptable values of soil pH (smaller than 8.6) were obtained in the first layer with sulfur application of 4 t ha^{-1} of granular size of smaller than 1 mm, and 6 t ha^{-1} with 1-2 mm size.

Exchangeable Sodium Percentage, ESP

The ESP in different soil layers are shown in Table 4. The 6.0 and 4.0 t ha^{-1} sulfur application of granular size of smaller than 1 mm decreased the ESP in the first layer to the lowest value (8.6) and to the marginal value (15), respectively. The interaction between application rates and granular sizes was significant at $P = 0.05$, at the first layer. Therefore, the mean values of ESP were not given in Table 4. Smaller size and higher application rate of sulfur

Table 3. pH of soil saturated paste in different layers and at different sizes and application rates of sulfur.

Sulfur application rates (tons ha^{-1})	Granular size (mm) <1	1-2	>2	mean
		First layer		
0	9.93c*	9.37b	9.33c	9.34c
2	8.82b	8.85a	9.02bc	8.90b
4	8.32a	8.92a	8.78ab	8.67b
6	8.03a	8.58a	8.58a	8.40a
Mean	8.62A	8.93B	8.93B	
		Second layer		
0	9.83c	9.87c	9.57a	9.76c
2	9.53bc	9.57bc	9.57a	9.56b
4	9.28ab	9.38ab	9.53a	9.40ab
6	9.10a	9.12a	9.47a	9.23a
Mean	9.43A	9.48A	9.53A	
		Third layer		
0	9.85b	9.83b	9.80a	9.83c
2	9.70a	9.83b	9.82a	9.78bc
4	9.60a	9.68a	9.77a	9.68a
6	9.62a	9.68a	9.70a	9.67a
Mean	9.69A	9.75AB	9.77B	
		Fourth layer		
0	10.03b	10.02b	9.98a	10.01b
2	9.90ab	9.87ab	10.02a	9.93a
4	9.80a	9.82a	9.87a	9.83a
6	9.73a	9.85a	9.88a	9.82a
Mean	9.86A	9.89A	9.94A	

* Means within each layer in each column followed by the same letter are not significantly different at P=0.05. Capital letters are used for the horizontal main effects.

Table 4. Exchangeable sodium percentage in different layers of soil at different sizes and application rates of sulfur.

Sulfur application rates (tons ha^{-1})	Granular size (mm) < 1	1-2	> 2	Mean
		First layer		
0	24.1c*	20.4a	14.2a	-
2	19.6bc	21.3a	16.5a	-
4	16.0b	21.9a	18.2a	-
6	8.6a	22.7a	15.4a	-
Mean	-	-	-	
		Second layer		
0	31.5b	30.0a	32.7b	31.4b
2	20.3a	27.9a	31.8b	26.6ab
4	20.0a	30.6a	24.9ab	25.2a
6	18.2a	27.2a	21.0a	22.2a
Mean	22.5A	28.9B	27.6B	
		Third layer		
0	29.4a	37.2b	42.7a	36.4b
2	28.3a	39.6b	41.6a	36.5b
4	18.8a	19.3a	29.9a	22.7a
6	20.8a	21.0a	34.5a	25.4a
Mean	24.3A	29.3A	37.2B	
		Fourth layer		
0	57.1a	59.8a	55.1a	57.3b
2	47.8a	42.5a	52.8a	47.7ab
4	40.6a	35.3a	50.6a	42.2a
6	36.5a	41.8a	46.9a	41.7a
Mean	45.5A	44.9A	51.4A	

* Means within each layer in each column followed by the same letter are not significantly different at P=0.05. Capital letters are used for the horizontal main effects.

enhance its oxidation in soil (3, 4), which result in more improvement in soil sodicity. Therefore, the great difference between ESP values of 6 and 4 t ha^{-1} of sulfur with size of smaller than 1 mm could be a result of positive interaction between fine sulfur particle and higher rate of application. The ESP in the first layer was reduced to 28.0, 22.7, 18.5 and 10.0% of its initial value for 0, 2, 4, and 6 t ha^{-1} sulfur application of granular size of smaller than 1 mm, respectively. Furthermore, the application of 4 and 6 t ha^{-1} of granular size of smaller than 1 mm and larger than 2 mm decreased the ESP values in the second and third layers to about 18-25 which is tolerable to many Na semi-tolerant and Na tolerant species (9). In the fourth layer, the sulfur application did not reduce the ESP significantly.

The initial ESP of the fourth layer was 47.8 (Table 1). Comparison between this value and those for fourth layer (Table 4) shows that no considerable changes might have occurred due to sulfur application. Increase in ESP values in the fourth layer in comparison to the other layers might be due to the Na movement from upper layers to the lower ones. Furthermore, the application rates might have not been adequate to result in any significant improvement in ESP in the fourth layer.

Soil Sulfate

The sulfate concentration in the soil saturation extract in the different layers are shown in Table 5. The application of sulfur of different grain sizes significantly increased the sulfate content in the first and second layers. However, the sulfur application of granular size of smaller than 1 mm increased the soil sulfate in the third layer. The application of 4, 6 and 2 t ha^{-1} with granular sizes of smaller than 1 mm, 1-2 mm and larger than 2 mm, respectively, was more effective in increasing sulfate content in the

Table 5. Sulfate concentration of the saturation extract (meq lit^{-1}) in different layers of soil at different sizes and application rates of sulfur.

Sulfur application rates (tons ha^{-1})	Granular size (mm) < 1	1-2	> 2	Mean
		First layer		
0	3.0c*	2.8c	1.8b	2.6d
2	18.5b	24.3b	23.2a	22.0c
4	30.2a	26.3b	24.7a	24.1b
6	36.0a	35.2a	27.3a	32.8a
Mean	21.9A	22.2A	19.3A	
		Second layer		
0	1.0b	5.7c	3.0c	-
2	4.0b	19.3a	15.8b	-
4	21.0a	11.3bc	21.2ab	-
6	20.8a	15.8ab	23.8a	-
Mean	-	-	-	
		Third layer		
0	6.7b	11.7a	7.2a	8.5b
2	15.0ab	14.0a	7.7a	12.2ab
4	22.8a	11.2a	13.2a	15.7a
6	20.2a	13.5a	15.3a	16.3a
Mean	16.2A	12.6A	10.8A	
		Fourth layer		
0	7.0a	13.0a	11.0a	10.3a
2	11.0a	5.7a	20.0a	12.2a
4	6.2a	4.7a	7.0a	6.0a
6	3.8a	8.8a	13.5a	8.7a
Mean	7.0A	8.0A	12.9A	

* Means within each layer in each column followed by the same letter are not significantly different at P=0.05. Capital letters are used for the horizontal main effects.

first layer. The application of 4, 2 and 6 t ha^{-1} with granular sizes of smaller than 1 mm, 1-2 mm and larger than 2 mm sizes, respectively, was more effective in sulfate increase in the second layer. In the third layer, application of 4 t ha^{-1} of granular size of smaller than 1 mm significantly increased the sulfate content. The application of sulfur had statistically no effect on the sulfate content in the fourth layer. The fourth layer collects the soluble salts from the above layers in the forms of Na_2SO_4 and $CaSO_4$ for sulfate. Although gypsum was not measured in the soil layers at the end of the experiment, but it is speculated that gypsum might have not been moved from the top layer to the fourth layer under the conditions of the present study.

EC of Leachate

The EC of leachates from the bottom of the soil columns at the 0.5 pore volume and at the termination of experiment are shown in Table 6. Application of sulfur significantly reduced the EC of leachate at the 0.5 pore volume. Application of 2 t ha^{-1} of granular size of smaller than 2 mm were sufficient for reduction in EC of leachate at 0.5 pore volume. On the other hand, at least 4 t ha^{-1} of granular size larger than 2 mm was required for a significant reduction in EC of leachate at 0.5 pore volume, while 6 t ha^{-1} further reduced the EC of leachate.

At the termination of the experiment, application of 6 t ha^{-1} of granular sizes of smaller than 1 mm, 1-2 mm, and larger than 2 mm resulted in 55, 75 and 48% reduction in the EC of leachate, respectively.

Comparing the ECe for the fourth layer (Table 2) and the EC of the leachate at the end of the experiment (Table 6) shows a great difference in their values. This might be attributed to the fact that distilled water dilutes the soil salt in the process of saturation extract preparation.

Table 6. EC of leachate for 0.5 pore volume and at the termination of experiment (mmhos cm^{-1} at 25°C) as influenced by the different sizes and rates of application of sulfur.

Sulfur application rates (tons ha^{-1})	Granular size (mm) < 1	1-2	> 2	Mean
		0.5 pore volume		
0	48.8c*	43.7b	54.0c	
2	36.2a	30.0a	53.3c	
4	40.2b	31.5a	45.0b	
6	37.2ab	33.0a	27.0a	
Mean				
		End		
0	22.6a	35.0b	23.9a	27.2c
2	19.6a	18.8a	18.9a	19.1b
4	15.2a	18.8a	20.5a	18.2b
6	10.2a	8.8a	12.5a	10.5a
Mean	16.9A	20.4A	18.9A	

* Mean within each part in each column followed by the same letter are not significantly different at P=0.05. Capital letter are used for the horizontal main effects.

Salt Leaching Efficiency

The amount of water per unit depth of soil required to decrease the ECe of soil to 4.0 mmhos cm^{-1} and the amount of saving in leaching water in percent at different sulfur sizes and application rates are shown in Table 7. The application rate of greater than 4 t ha^{-1} of granular size of smaller than 2 mm resulted in more than 60% saving in the required leaching water. The amount of saving in leaching water was smaller than 30% for application of coarse granules (larger than 2 mm) or at low application rates (2 t ha^{-1}).

The results in Table 7 indicate that sulfur application improved the efficiency of leaching the salt. Similar results have been reported by Alperovitch and Shainberg (1). They stated that by application of $CaCl_2$ solutions as leaching solutions with concentrations of 6.8 to 0.34 N the salt leaching requirements were lowered to 54 to 13%, respectively.

Sulfur Application Efficiency

The differences between the reduction in ESP (i.e. ΔESP) of control and different treatments were determined and were assumed to be the amount of ΔESP due to the sulfur application (ΔESP*). Then, the following equation was used to calculate gypsum requirements for ΔESP* as meq 100^{-1}g of soil:

$$\text{Gypsum requirements} = \frac{\Delta ESP^*}{100} (CEC)$$

In which, CEC is the cation exchange capacity in meq 100^{-1}g of soil obtained from Table 1. The sulfur requirement is calculated by the following (7) equation:

$$\text{Sulfur requirement} = \text{Gypsum requirement as meq } 100^{-1}\text{g soil} \times 0.186$$

The ratio of calculated sulfur requirement to the applied sulfur could be considered as sulfur application efficiency

Table 7. The amounts of leaching water to bring EC_e to 4 mmhos cm^{-1} per unit depth of soil (d/D) and leaching water savings (%) as influenced by the different granular sizes and application rates of sulfur.

Sulfur application rates (tons ha^{-1})	Granular size (mm) <1 d/D	<1 Saving	1-2 d/D	1-2 saving	>2 d/D	>2 saving
0	1.25	0	1.25	0	1.25	0
2	1.00	20	1.00	20	0.90	30
4	0.45	64	0.50	60	1.00	20
6	0.33	74	0.33	74	1.25	0

Table 8. Sulfur application efficiency(%) as influenced by the different sizes and application rates of sulfur.

Sulfur application rates (tons ha^{-1})	Granular size (mm) <1	1-2	>2	Mean
2	53.4a*	45.1a	7.6a	35.4a
4	46.9a	50.7a	23.8a	40.5a
6	40.5a	32.4a	20.0a	31.0a
Mean	46.9B	42.7B	17.1A	

* Means within each column followed by the same letter are not significantly different at P=0.05. Capital letters are used for the horizontal main effects.

assuming that the calculated gypsum requirements were supplied solely by the added sulfur.

The results of estimated sulfur application efficiency (%) are shown in Table 8. There was no significant difference in the sulfur application efficiency among the different application rates. However, the sulfur application efficiency was significantly lower for granular size of larger than 2 mm. The sulfur application efficiencies were 17.1% for larger than 2 mm size and 44.8% for smaller than 2 mm size.

Because of the possible presence of some free soda and bicarbonate in the soil (Table 1), the efficiency of sulfur in Na replacement was lower than 100%. Kovda (6) reported that the amount of decrease in the sulfur application efficiency is proportional to the amount of free soda and bicarbonate in soil. However, the efficiency of the sulfur application was different with different sizes of the sulfur granules (Table 8). The lower efficiency of the larger granules (> 2 mm) might be due to the slower kinetics of the oxidation of sulfur of the larger size in the soil.

The application rates of sulfur did not influenced the efficiency of ESP reduction significantly (Table 8). However, this might not be the case with other chemical amendments. Alperovitch and Shainberg (1) showed that the efficiency of replacing Na by application of $CaCl_2$ solutions was the highest (63%) in the most concentrated treatment (6.8 N $CaCl_2$) and decreased with decrease in concentration of $CaCl_2$ solution.

CONCLUSION

The results of this laboratory experiment indicate that, in general, application of 4 t ha^{-1} of sulfur granular size of smaller than 1 mm improved the sodicity conditions of this soil and lowered its pH from 10 the 8.3 in the first layer of soil. However, the granular size of 1-2 mm may have similar effect, but the granular size of larger than 2 mm was not as effective as the size smaller than 2 mm.

Application of 4 t ha^{-1} of granular size of smaller than 2 mm promoted the efficiency of salt leaching by water. Furthermore, the granular size of smaller than 2 mm was more efficient in reducting ESP and an efficiency of about 44.8% has been resulted. Although some limitations might be claimed in extending these results to the field conditions, however, these findings might help to estimate the sulfur requirements for reclamation of such saline-sodic soils.

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