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Evaluations of Bentonite Plated Sulfur Application on Fe and Zn Bioavailability of Saline and Sodic Soil

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

In saline and sodic soils, high pH strongly have affected on soil micronutrient availability. The study was conducted to evaluate using soil amendments (sulfur and manure) on some soil characteristics, iron and zinc concentrations of saline and sodic soil. A factorial randomized complete blocks design was considered with three replications. The main factor included organic matter (manure) as two levels (M0 = without manure and M1 = 40 tons manure/ha) and subfactors were bentonite plated sulfur and *Thiobacillus thiooxidans* (five treatments) includes S0 = control without S, S_1 = sulfur applying as soil gypsum requirement (1620 kg/ha), S_2 = sulfur applying as double soil gypsum requirement (3240 kg/ha), $S_1T = S_1+$ *Thiobacillus thiooxidans* treatment, $S_2T = S_2+$ *Thiobacillus thiooxidans*. The irrigation treatments were performed based on soil moisture monitoring plots. Also, the soil samples were taken in depth 0-30 cm and analyzed for determing soil pH, electrical conductivity (EC), sodium adsorption ratio (SAR), soil Fe and Zn DTPA (diethylene triamine pentaacetic acid) -extractable concentrations. The results showed that the manure and sulfur treatments were significant difference on soil EC, SAR and Zn DTPA-extractable. Also, the compare mean Duncan's treatments revealed that Zn DTPA-extractable concentrations was increased from 1.7 (M_0S_0) to 4.1 (M_1S_2) mg/kg ($p<0.05$). Fe DTPA-extractable

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concentrations had increasing trend from 5.3 (M_0S_0) to 8.2 (M_0S_1T) mg/kg but the differences had not significant statistics (p<0.05). The interactive effects of sulfur and organic matter application reduced soil SAR from 15.5 in the M_0S_0) treatment to 9.9 in the M_0S_2T treatment (in which sulfur was used together with *Thiobacillus thiooxidans*. Finally, organic manure and sulfur were recommended for increasing efficiency saline and sodic soils.

Keywords: Soil amendments; Fe; Zn; soil characteristics.

1. INTRODUCTION

The soil salinity and drought are the most common environmental stress around the world including Iran [1]. The parts of natural and agricultural ecosystems are influenced under salt stress [2] and the soils were extended with difference's characteristics on the world [3]. Tóth et al. [4] reported that the area of salt affected soils is estimated at about one billion hectares. Sulfur application is amended for soil reclamation. The results explain the effect of the oxidizing bacteria, especially *Thiobacillus thiooxidans* [5].

Pot studies conducted in recent years at the Soil and Water Research Institute of Iran, suggest sulfur (if used together with *Thiobacillus thiooxidans*) has positive effects on soil physical, chemical, and biological properties [6].

Sardinha et al. [7] mentioned that organic and inorganic amendments consumption on saline soisl can modify the effects of salinity on microbial activity and biochemical properties of soils. Nowadays, the large number of organic amendments such as mulch, manure and compost are used to improve saline and saline–sodic soils [8]. Increased organic matter content can be a suitable method for solubilization of calcium carbonate and other minerals naturally occurring in soils [9,10]. In saline or sodic soils, application of organic matter may increase leaching of sodium, reduce soil salinity, and increase soil water holding capacity and aggregate stability [11]. Moreover, Jalali and Ranjbar [12] showed using organic amendments increased cation exchange capacity, saturated calcium (Ca), magnesium (Mg), and potassium (K) exchange sites, and prevented sodium from entering the exchange phase. When organic amendments are added to saline-sodic soils, more sodium is leached from soils, and soil properties such as infiltrability, water holding capacity, and aggregate stability are increased, while salinity and exchangeable sodium percentage declined [11]. Moreover, application of organic amendments reduces exchangeable sodium percentage [11,13]. The researches have shown that the using of gypsum, compost and organic matter in saline soils increase leaching of sodium, soil permeability and are decreased soil exchangeable sodium and electrical conductivity [13].

Considering sodic soils in Iran often contain calcium in the form of calcium carbonate, it is possible to use sulfur for amending these soils. The purpose of the study was to determine effective sulfur on soil micronutrients concentrations (Iron (Fe), Zinc (Zn)) and influenced soil pH and salinity in saline.

2. MATERIALS AND METHODS

A factorial (manner) experiment using the randomized complete blocks design with three replications was conducted in saline-alkali soils 45 km on Ahvaz regions of South west Iran. There were 10 treatments. The each plots area was 4 × 2.5 (10 m^2). Manure levels (cow manure), 0 (M_0) and 40 t/ha (M_1), were applied to the main factors. Sulfur in the form of pelletized sulfur-bentonite mixture (made by Iran petrochemical national company) and *Thiobacillus. thiooxidans* (5 treatments), including S0 (the control with no sulfur), S_1 (sulfur as the gypsum requirement: 1620 kg/ha), S_2 (sulfur twice as much as the gypsum requirement: 3240 kg/ha), S_1T (S_1+ *Thiobacillus. thiooxidans*), and S_2T (S_2+ *Thiobacillus. thiooxidans*) were in the sub factors.

Gypsum requirement (GR) was calculated as fallowed equation 1:

$$GR=\frac{(ESPi-ESPf)\times CEC\times BD\times D\times 8.61}{100f} \quad (1)$$

ESPi: Initial ESP; ESPf: Final ESP; CEC: Cation Exchange Capacity (me.100 /grsoil); BD: Bulk density (gr/cm^3); D: Soil depth (cm) and f: Gypsum convert coefficient to sulfur (0.57).

The soil samples were taken in depths of 0-30 to determine initial soil properties, and water samples were taken to evaluate irrigation water quality in the region. After applying the treatments, the plots were irrigated. Irrigation interval during the experiment was determined by monitoring soil moisture. At the end of the experiment, soil samples were taken from depths of 0-30 cm in each treatment, and pH, soil salinity, sodium adsorption ratio (SAR), and available iron (Fe) and Zn (Zinc) were measured. Available Zn and Fe concentration were extracted by 0.05 M diethylene triamine pentaacetic acid (DTPA) [14] and measured by furnace atomic absorption spectrometry (Perkin Elmer model 3100). Soil pH was measured in saturated paste using a pH-meter (Model Metrohm 644), electrical conductivity (EC) in saturated paste extract by EC-meter (Model Metrohm 691). The SAR was calculated using equation follow as:

$$SAR=\frac{Na^{+}}{\sqrt[2]{Ca^{2+}+Mg^{2+}/2}}$$

Where Na (sodium), Ca (calcium) and Mg (magnesium) are the concentrations are concentrations (in meq/l) of sodium, calcium, and magnesium ions in the soil solution. Concentrations of sodium, calcium, and magnesium are determined by first extracting the ions from the soil into solution. The MSTAT-C software (a software can analyze statistical designs) was applied for statistical analysis of the data and for the preparation of the variance analysis, and Duncan's multiple range test was employed for comparison of the means.

3. RESULTS AND DISCUSSION

Table 1, shows results obtained from analysis of soil samples taken in the region.

Soil salinity (EC>4) and sodium absorption ratio (SAR>13) exceeded the standard limits [15] and, hence, the soil was saline-sodic. Moreover, the soil was classified as calcareous, and it had a medium texture.

Table 2, shows results observed in the analysis of water samples taken in the region.

Irrigation water salinity was in class C_3S_1 (salinity: 0.0750-2.250 dS/m and SAR<10) of Wilcox water quality table. Therefore, the water in the region was classified as very saline and of low sodium concentration.

3.1 Effects of Treatments on Soil Properties

Results of ANOVA related to the applied treatments are presented in Table 3.

The individual effects of organic matter on salinity, SAR, and Zn showed statistically significant differences (p<0.05). However, the individual effects of sulfur on none of the studied properties were significantly different (p<0.05). Moreover, the interactive effects of organic matter and sulfur on the studied properties did not show statistically significant differences (p<0.05). Comparison of the means showed the individual effects of organic matter application on all of the studied properties (except Fe) were significant (p<0.05) (Table 4).

When the rate of organic matter application was raised to 40 t/ha, salinity levels increased. This shows the organic matter used in the experiment was not of good quality. Application of various rates of sulfur together with *Thiobacillus thiooxidans* bacteria did not have significant effects on the studied properties (p<0.05), but applying sulfur (individually or together with *Thiobacillus thiooxidans*) had positive effects on improving the studied properties (although these improvements did not cause statistically significant differences p<0.05).

3.2 Interactive Effects of Treatments on Soil Properties

Table 4 revealed that the interactive effects of the applied treatments on the measured

Table 1. Soil chemical properties analysis

Depth (cm)	EC* (dS/m)	pH	OC (%)	SAR	P (mg/kg)	K (mg/kg)	TNV (%)	Sand (%)	Silt (%)	Clay (%)
0-30	33.6	8	0.23	27.7	2.2	253	50	44	36	20

**: EC: Electrical conductivity; pH: Soil acidity; OC: Organic carbone; SAR: Sodium absorption ratio; P: Phosphorous; K; Potassium; TNV: Total neutralization value*

Table 2. Water chemical properties analysis

EC (dS/m)	pH -	HCO_3^- me/l	Cl^-	So_4^{-2}	T.A*	Ca^{+2}	Mg^{+2}	Na^+	T.C
1.99	7.9	4	11	5.4	20.4	6	4	10.4	20.4

-T.A: Total Anions, T.C: Total Cations

Table 3. Analysis of soil properties variance

S.O.V	d.f	Salinity	pH	SAR	Fe	Zn
Replication	2	448.3	0.001	46.6	1.16	1.4
OM	1	2239.4*	0.3	77.1*	0.38	6.8*
Sulfur (S)	4	302.3	0.023	38.1	1.11	1.4
OM× S	4	285.3	0.034	8.5	3.8	0.73
Error	18	247.7	0.022	20.6	2.47	1.3

**- There is a significant difference between treatments at 0.05 levels (p<0.05)*

Table 4. Comparison of the means soil properties of the study interactions between sulfur and organic matter (0-30 cm)

Treatment		EC (dS/m)	pH	SAR	Zn (mg/kg)	Fe (mg/kg)
M_0	S0	21.6 b*	7.6 a	15.5 ab	1.7 b	5.3 a
	S1	24.5 b	7.53 abc	15 abc	1.93 ab	6.3 a
	S_2	24.6 b	7.53 abc	11.6 ab	2.82 ab	7.1 a
	S_1T	16.7 b	7.57 ab	10.6 ab	2.00 ab	8.2 a
	S_2T	20.7 b	7.54 abc	9.9 b	2.7 ab	6.3 a
M_1	S_0	54.4 a	7.27 cd	19.4 a	3.7ab	6.1 a
	S_1	46.3 ab	7.23 d	18.2 ab	2.87 ab	7.5 a
	S_2	21.5 b	7.57 ab	11.9 ab	4.1 a	7.4 a
	S_1T	41.9 ab	7.3 bcd	13.1 ab	2.3 ab	6.4 a
	S_2T	39.4 ab	7.4 a-d	13 ab	3.1 ab	7.6 a

**: The similar letters has not significant differences at p<0.05, M_0: Without organic matter M_1: Using 40 (tons/ha); S_0: Without sulfur, S_1: Using sulfur as gypsum requirement, S_2: Using Sulfur as 2-fold gypsum requirement; T: Using + Thiobacillus. thiooxidans*

properties. The means of the interactive effects on salinity levels were different in the treatment, where organic matter was not applied as compared to treatments with various rates of sulfur application. All organic matter treatments had significantly increased on the mean salinity levels, this is due to organic matter used in the experiment was of high salt-containing and caused these changes in the soil. Furthermore, the trend of changes in salinity at both rates of organic matter application showed that the various sulfur application treatments caused reducing soil salinity. In treatments, where the organic matter (high-salt containing) was applied, these changes were more pronounced and salinity declined from 54.4 dS/m in the M_1S_0 to 21.5 dS/m in the M_1S_2 (Table 4).

Management of salinity and sodicity become more complicated when both occur in the same soil together. In research conducted in Iran, the positive effects of sulfur in reducing soil pH, salinity, and sodic, were greatest in Golestan province followed by Orumiyeh Province in the second place. However, sulfur application did not have these effects (or only had slight effects) in other provinces [5]. A saline-sodic soil normally does not exhibit strong sodicity symptoms. The Ca can be replaced with sodium due to it has more valiant and ionic strength. Soil amendments are materials, such as gypsum, that directly supply soluble calcium for the replacement of exchangeable sodium, or other substances, such as or sulfur acid and or sulfur, that indirectly through chemical or biological action, make the relatively insoluble calcium carbonate commonly found in sodic soils, available for replacement of sodium.

The interactive effects of sulfur and organic matter application reduced soil SAR from 15.5 in the M_0S_0 treatment to 9.9 in the M_0S_2T treatment (in which sulfur was used together with *Thiobacillus thiooxidans*) (Table 4). Moreover, application of organic matter significantly increased SAR (as compared to treatments in which organic matter was not applied) because the organic matter was of the high salt-containing. Even under these conditions, the trend of changes in the studied properties was a descending, and sulfur application improved the sodic condition of the soil.

Application of sulfur and organic matter also caused changes in the chemical properties of the soil (such as its sodium and chlorine contents), and these changes were similar to those observed in salinity levels and in SAR. Applying organic matter and sulfur caused relative improvement in soil chemical properties and improved saline and sodic conditions of the soil (Table 4). The interactive effects of organic matter and sulfur on the levels of Fe and Zn availability are shown in Table 4 shows changes in the concentrations of Zn and Fe. Sulfur application significantly increased availability of nutrients so that Zn concentration increased from 1.7 in the control to 4.1 mg/kg in the M_1S_2 treatment.

Furthermore, changes in concentrations of nutrients were greater in treatments of organic matter application compared to treatments in which organic matter was not applied. Results shown in Table 4 indicate Fe concentrations followed a similar trend and increased from 5.3 in the M_0S_0 treatment to 8.2 mg/kg in the M_0S_1T treatment (but this increase was not statistically significant $p<0.05$).

SAR followed a descending trend when higher rates of sulfur were applied without *Thiobacillus thiooxidans* and declined from 15.5 in the M_0S_0 treatment to 9.9 in the M_0S_2T treatment, which was a significant reduction (Table 4). With the decrease in SAR, concentrations of Zn and Fe followed an ascending trend. In other words, with soil sodic improved, soil fertility also followed an ascending trend of improvement. As shown in Table 4, SAR substantially increased with increased rates of organic matter application, and this increase in SAR can have adverse effects on concentrations of nutrients. However, increasing both the application rates of sulfur *and Thiobacillus thiooxidans*, will increase Zn and Fe availability, which modifies soil salinity and sodicity. This positive effect results from converting S to SO_4^{-2} by *Thiobacillus thiooxidans*, which increases the acidity of soil solution and hence increasing Fe and Zn solubility in soil.

4. CONCLUSION

Saline and sodic soils are main challenge for agricultural plan on Khuzestan province, Iran. In saline and sodic soils, high pH strongly have affected on soil micronutrient availability. The results showed that the manure and sulfur with *Thiobacillus thiooxidans* treatments were significant difference on soil EC, SAR and Zn DTPA-extractable. So, this is very effective to reduce micronutrient deficiencies (iron, zinc) in the production of healthy agricultural crop and food in saline and sodic soils.

The comparison between means of different treatments revealed significant differences in DTPA-extractable Zn concentrations among treatments.

In summary application of a combination of manure and sulfur is recommended for reclaiming soil salinity and sodicity. In addition as pervious researches showed, the application of these amendments increases micronutrients uptake (e.g. Fe and Zn) by crops.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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