IMPACT OF SOME SULPHUR SOURCES ON AMELIORATING SOIL CHARACTERSTICS, WHEAT YIELD AND GRAIN QUALITY UNDER NEWLY RECLAIMED SALINE SOIL CONDITIONS

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ABSTRACT:

A field experiment was carried out on a saline sandy loam soil at Village No. 7, Sahl El-Tina, North Sinai, Egypt during the two successive winter seasons of 2008-2009 and 2009-2010 to study the effective role of different sulphure sources and rates on ameliorating soil characteristics, wheat productivity (*Triticum aestivium* L., Sakha 93 cv.) and grain quality under soil salinity stress. The applied different S-sources and rates were gypsum at the rates of 0, 2, 4 Mg fed^{-1}; elemental sulphur at the rates of 0, 0.2 and 0.4 Mg fed^{-1} and potassium sulphate at the rates of 0, 0.1 and 0.2 Mg fed^{-1}. Gypsum and elemental sulphur were added to the soil at 25 days before wheat grains plantation, and mixed thoroughly in soil surface layer with ploughing, while half dose of potassium sulphate was applied before sowing and other one at 30 days after planting.

The obtained results showed that application of the tested S-sources at the different rates led to significantly increases for plant height, wheat biological yield (straw and grain yields), weight of 1000 grains and grain contents of either some macro- (N, P, K, and S) or micro-nutrients (Fe, Mn and Zn), with a maximized effective role by increasing the applied rates. It is evident from the distribution patterns of nutrients uptake by wheat grains that the effective role of the tested S-sources could be arranged in an ascending order of elemental sulphure ≥ gypsum > potassium sulphate.

As for the influence of the tested different S-sources and rates on some soil properties, the obtained data revealed that there was a clear decline in each of soil ECe and pH value, especially with increasing the applied rates during the two seasons under study. Also, the applied tested different S-sources caused pronounced increases for wheat grain contents of N, P K, S, Fe, Mn and Zn, with a more effective role by increasing the S-source rates. In general, it was could be categorized the applied S-sources according to their beneficial effects on wheat grain contents of nutrients in an ascending order of sulphur ≥ gypsum > potassium sulphate, except of K where K-sulphate surpassed the applied other two S-sources.

Key word: Elemental sulphur, gypsum, potassium sulphate, wheat productivity, nutrients uptake in wheat grains.

INTRODUCTION:

Salt stress has become an ever-increasing threat to food production, irrigation being a major problem of agricultural fields due to gradual salinization. Salt stress has three fold effects, *i.e.*, it reduces water potential, causes ion imbalance or disturbance in ion homeostasis and toxicity. This altered water status leads to initial growth **(Benlloch-González *et al*., 2005)**.

Wheat (*Triticum aestivum* L.) is the most important cereal crop in Egypt where its production increased from 2.08 million ton in 1982/1983 to 6.42 million ton in 2001/2002 season marking, 209% increase (Statistical Data, 2002, ARC, Giza). This increase was achieved by both increasing wheat area from 554,400 to -1,029,000 hectares and continuous rise in grain yield ha^{-1}

from 3.595 to 6.238 ton ha^{-1} as a result of cultivating high yield varieties and improved cultural practices **(Khafaga and Abd-El-Naby, 2007)**.

Sulphur fertilization also improved crop quality by increasing protein content for wheat. Sulphur is one of the major essential plant nutrients, and it contributes to an increase in crop yields by providing direct nutritional value and improving the use efficiency of other essential plant nutrients, particularly nitrogen and phosphorus. As agricultural productivity has increased, the demand for all nutrients has increased. **Marschner (1998)** stated that application of sulphur to the soil has several effects; such as reducing pH, improving soil-water relation and increasing availability of nutrients like P, Fe, Mn and Zn. **Shahsavani, and Gholami (2008)** suggested that the amount of SO_4^{-2}-S immobilized (converted into soil microbial biomass-S or incorporated into soil organic matter) in soil was, as expected, positively correlated with the addition rate. However, the extent to which SO_4^{-2}-S was immobilized, as a percentage of addition, was inversely correlated to the addition rate. **Ahmed (2009)** reported that sulphur fertilization significantly affected plant height and number of green leaves/plant. Also, increasing sulphur levels increased these parameters without significant difference between 50 and 100 kg S/ha in most cases.

Ayub (2007) found that gypsum reduced soil pH slowly from (8.5-7.5) in about 20 weeks followed by sulfur (8.5-7.7) and control (8.5-8.2). **Sharma (1986)** studied the effect of gypsum application on soil properties and crop yields of rice and wheat grown in successive periods was extended from one to five years. The results showed that soil pH, electrical conductivity, calcium carbonate and soil dispersion decreased, whereas organic carbon, hydraulic conductivity, water infiltration and storage increased considerably after five years of gypsum application. **Zaman *et al*. (2005)** reported that the excess of released Ca^{2+} ion in the medium of saline soil causes retardation in the growth of shoots, mainly due to Na^+ becomes available, and then the abundance of Ca^{2+} ion is required to check the toxic activities of Na+ ion.

Actually, the accompanied potassium needs of crops had been and are met from native K-sources like weathering of biotite, muscovite and illite, but intensive cropping with high yielding cultivars and high levels of nitrogen and phosphorus fertilizers increased the demand for K due to its slow release from soil that hardly meets crop requirements and as a result K application became necessary **(Ranjha *et al.*, 2001)**. **Catherine (2009)** showed that potassium sulphate is the major potash fertilizer containing S. It is a white material containing 50 to 53 % K_2O and 17 to 18 % S.

Dorudi and Siadat (1999) reported that K significantly increased wheat yield and maximum yield of wheat was obtained from applying 120 kg ha^{-1} SOP in saline soils. **Khadr *et al*. (2002)** reported that increase rate from 24 to 48 kg K_2O/fed enhanced the uptake of K by plants. **Abd El-Kader *et al*. (2007)** pointed out that the increase in total yield caused by K fertilization may be due to the stimulating effect of potassium on photosynthesis, phyloem loading and translocation, as well as synthesis of large molecular weight substances within storage organs, contributing to the rapid bulking of the tubers. **Magda (2007)** found that increase K application rates up to 90 kg /fed significantly increase N, P and K contents and uptake in plants. **Shahzada *et al.* (2007)** indicated that increasing rates of potassium fertilizer increased the number of tillers, plant height (cm), 1000-grain weight, grain and straw yield significantly. Maximum grain yield were found in (90 kg K_2O ha^{-1}). Increasing rates of potassium fertilizer increased concentration of potassium in grain and straw significantly. After harvesting the crop, the extractable potassium contents of soil increased from that of the original soil. **Muhammad *et al.* (2009)** found that foliar application of potassium sulfate significantly improved growth, achene's yield, photosynthetic and transpiration rates, stomata conductance, water use efficiency, leaf and enhanced shoot and leaf K^+ of the salt-stressed sunflower plants. The most effective dose of (K + S) for improving growth and achene's yield was found to be (1.5 % K + 0.62 % S) and (1% K + 0.41% S), respectively. Improvement in growth of sunflower plants due to exogenously applied K_2SO_4 was found to be linked to enhanced photosynthetic capacity, water use efficiency, leaf and relative water content.

This study was carried out at identifying the effective role of some sulphur sources and rates for ameliorating soil characteristics, wheat productivity (*Triticum aestivum* L.) and grain quality under soil salinity stress.

MATERIALS AND METHODS:

To achieve the aforementioned target, the current study was carried out on a saline sandy loam soil at Village No. 7 (private farm at Galbana), Sahl El-Tina, North Sinai, Egypt during the two successive winter seasons of 2008-2009 and 2009-2010. The experiment layout was designed as a completely randomized, with three replicates on a net plot size of 10 x 5 m (50 m^2). Soil samples from 0- 30 cm surface layer were collected to determine the main soil physical and chemical properties as well as available nutrients status, as shown in Table (1).

The applied sulphur sources and rates were elemental sulphur at 0, 0.2 and 0.4 Mg fed^{-1}; gypsum at 0, 2 and 4 Mg fed^{-1} and potassium sulphate at 0, 0.1 and 0.2 Mg fed^{-1}. The applied rates of gypsum and elemental sulphur were added at 25 days before planting wheat grains, and then mixed thoroughly with soil surface layer by using plough. As for potassium sulphate, one half of the applied dose was added before sowing and the other at 30 days after planting. Calcium superphosphate (15.5 P_2O_5 %) was added as a single dose of 30 kg P_2O_5 fed^{-1}, and thoroughly mixed with 0-20 cm soil surface at two weeks before sowing. Urea (46 N %) at a rate of 100 kg N fed^{-1} was added in equal three doses at the periods of 21, 45 and 60 days after wheat planting.

Table 1. Some physical, chemical and fertility characteristics of the studied soil.

Soil characteristics	Value	Soil characteristics.	Value
Particle size distribution %:		*Analytical analysis of soil paste extract:*	
Sand	79.47	EC (dS/m)	10.34
Silt	8.38	*Soluble ions (m molc L^{-1}):*	
Clay	12.15	Ca^{++}	11.41
Textural class	SL*	Mg^{++}	14.23
Some soil physio-chemical properties:		Na^{+}	78.00
$CaCO_3$ %	10.91	K^{+}	0.86
Organic matter %	0.70	CO_3^{--}	0.00
pH (1:2.5 soil water suspension)	8.30	HCO_3^{-}	3.38
CEC (c molc kg^{-1} soil)	11.75	Cl^{-}	73.00
ESP	9.64	SO_4^{--}	28.02

Available contents of some macro and micronutrients (mg kg^{-1} soil)						
N	P	K	S	Fe	Mn	Zn
40.50	3.85	197	4.12	3.69	1.21	0.65

*SL = Sandy loam

Wheat grains (*Triticum aestivum* L., cultivar Sakha 93) were sown using drill hand machine on 22nd and 25th November as well as harvesting was carried out on 2nd and 4th May in the first and second seasons, respectively. At harvest, the plants were air-dried and separated into grain and straw to determine the biological yield of wheat. At the same times, soil samples were collected from the surface layer (0–30 cm depth), and then air-dried, ground, passed through 2 mm sieve and mixed thoroughly to determine particle size distribution **(Piper, 1950)**, $CaCO_3$ content % using a Calcimeter and organic matter content % **(Jackson, 1973)**. Total soluble salts (ECe) and soluble ions were determined in the soil paste **(Jackson, 1973).** Soil pH was measured in 1:2.5 soil water suspensions using a pH-meter (**Richards, 1954)**. Available nitrogen was determined according to the modified Kjeldahal method by **Black *et al.* (19652).** Phosphorous was extracted by 0.5 N sodium bicarbonate and determined calorimetrically using Olsen's method (**Jackson, 1973).** Available K was extracted (**Soltanpour and Schwab, 1977) and** measured using the Flame Photometer**.** Sulphur contents in both soil and plant were determined by using a standard turbidity method **(Issam and Sayegh, 2007)**. Available micronutrients were extracted using DTPA-ammonium bicarbonate **(Soltanpour and Schwab, 1977)** and measured using Inductively Coupled Plasma Spectrometry model 400.

A sample of ten plants were collected from each plot one day before harvesting, divided into grains and straw, oven-dried at 70 C^{o} , weighted to obtain their dry matter per plant. The selected samples of plant parts were ground, and then 0.5 g of each sample was digested using the methods described by **Parakinson and Allen (1975)**. Wheat grain contents of N, P, K, S, Fe, Mn, and Zn were determined in plant digested solutions using methods described by **Jackson (1973), Cottenie *et al.* (1982) and Page *et al.* (1982)**. Micronutrients of Fe, Mn and Zn were measured using Atomic Absorption Spectrometer (model GBC-932 plus) from the filtrate obtained after dry ash **(Chapman and Pratt, 1961)**.

The least significant difference test (LSD) at p = 0.05 level was used to verify the differences between treatments as mentioned by **Snedecor and Cochran (1980).**

RESULTS AND DISCUSSION:

I. Plant parameters of wheat as affected by the applied treatments:

It is evident from data presented in Table (1) that the experimental soil is suffering from some problems, particularly soil salinity and fertility status, which negatively reflected on grown plants growth, and in turn their yields of wheat straw and grains. Undoubtedly, directly effect of the applied different sulphur sources should be supported wheat growth and its biological yield, as expected from the presented data in Table (2).

Table (2): Some wheat parameters as affected by the applied S-sources and rates under soil salinity stress.

Treatment	Rate (Mg/fed)	Plant height (cm)		No. of grain/spike		1000 grains weight (g)		Grain yield (kg fed^{-1})		Straw yield (kg fed^{-1})	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Gypsum	0.0	70	72	41	43	35	38	1055	1085	2187	2153
	2.0	76	77	46	47	39	42	2102	2122	3249	3255
	4.0	79	81	49	55	45	49	2139	2145	3275	3281
Elemental sulphur	0.0	69	72	40	42	36	37	1049	1098	2184	2215
	0.2	74	76	48	53	42	45	2122	2135	3260	3269
	0.4	80	82	51	58	48	50	2144	2156	3288	3292
K-sulphate	0.0	71	72	41	43	35	38	1053	1082	2183	2210
	0.1	75	77	45	49	41	46	2098	2125	3175	3189
	0.2	78	81	48	53	44	49	2127	2148	3216	3258
Statistical analysis											
Source, S		*		ns		*		***		**	
Rate, R		ns		ns		**		***		**	
Season, Y		ns		ns		ns		ns		ns	
S x R		ns		ns		ns		*		**	
S x Y		ns		ns		ns		ns		ns	
R x S		ns		ns		ns		ns		ns	
S x R x Y		ns		ns		ns		*		**	

The obtained data showed that the studied wheat plant parameters, *i.e.*, plant height, No. of grains $spike^{-1}$, 1000 grain weight, grain and straw yields were significantly increased as a result of applied the different sulphur sources and rates. Also, the increments of these plant parameters were maximized with increasing the applied rates for all tested S-sources, however, the greatest values were recorded at the solely treatment of 0.4 Mg elemental sulphur fed^{-1}. This may be due to a more reduction in each of soil salinity and sodicity was expected and associated with the applied S-sources, gypsum, elemental sulphur and potassium sulphate. These results suggested the effective role of the tested S-sources on ameliorating the injurious effect of salts in the experimental soil, which positively reflected on the wheat plant growth and biological yield.

The benefits of different sulphur sources on the studied wheat parameters, Table (2), could be categorized in an ascending order of elemental sulphure ≥ gypsum > potassium sulphate. These results are in agreement with those reported by **Singh (1990)** who conducted experiments on rice and wheat and found significantly increases in their yield at all levels of gypsum applied. On the other hand, potassium sulphate have an effective role on physiological conditions of plants such as keeping cell turgid under salt stress, enzymatic activity and reducing Na^+ uptake contributed to considerable wheat growth under such conditions of soil salinity. In addition, the role of accompanied K in potassium sulphate was achieved through relieving the ions imbalance that might be enable wheat plants to withstand the salt stress. Thus, the role of potassium sulphate in promoting assimilates translocation from leaf to storage organs enhanced photosynthesis and produce more dry matter as well as enlarged the leaf area index to the optimum limit. These obtained results are in agreement with those reported by **Azyed *et al.* (2007)**.

II. Wheat grain contents of nutrients as affected by the applied treatments:
a. Macronutrients and protein content:

Data in Tables (3 and 4) revealed that application of different sulphur sources and rates were significantly increased wheat grain contents and uptake of N, P, K and S uptake as well as protein content.

Table (3): Wheat grain contents of some macronutrients and protein % as affected by the applied S-sources and rates under soil salinity stress.

Treatment	Rate (Mg/fed)	N %		P %		K %		S %		Protein %	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Gypsum	0.0	2.59	2.64	0.25	0.28	0.40	0.44	0.129	0.135	14.76	15.05
	2.0	2.67	2.75	0.31	0.38	0.47	0.59	0.137	0.143	15.22	15.67
	4.0	2.72	2.78	0.34	0.40	0.52	0.62	0.139	0.148	15.50	15.85
Elemental sulphur	0.0	2.60	2.65	0.26	0.27	0.40	0.44	0.128	0.134	14.82	15.11
	0.2	2.75	2.84	0.34	0.39	0.55	0.61	0.146	0.158	15.67	16.19
	0.4	2.80	2.87	0.38	0.42	0.60	0.64	0.155	0.163	15.96	16.36
K-sulphate	0.0	2.61	2.64	0.26	0.27	0.41	0.45	0.129	0.132	14.87	15.04
	0.1	2.66	2.69	0.32	0.35	0.54	0.55	0.143	0.147	15.16	15.33
	0.2	2.69	2.74	0.34	0.38	0.56	0.57	0.145	0.151	15.33	15.62
Statistical analysis											
Source, S		*		***		***		***		*	
Rate, R		ns		***		***		***		ns	
Season, Y		ns		***		***		***		ns	
S x R		ns		***		***		***		ns	
S x Y		ns		***		***		ns		ns	
R x S		ns		***		***		Ns		ns	
S x R x Y		ns		ns		**		Ns		ns	

Table (4): Uptake of some macronutrients by wheat grains as affected by the applied S-sources and rates under soil salinity stress.

Treatment	Rate (Mg/fed)	N (kg/fed)		P (kg/fed)		K (kg/fed)		S (kg/fed)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Gypsum	0.0	27.27	28.56	2.63	3.03	4.21	4.76	1.36	1.46
	2.0	56.01	58.44	6.50	8.07	9.86	12.54	2.87	3.08
	4.0	57.85	59.71	7.23	8.59	11.06	13.31	2.95	3.18
Elemental sulphur	0.0	27.27	29.10	2.72	2.96	4.19	4.83	1.34	1.47
	0.2	57.80	60.63	7.15	8.33	11.56	13.02	3.07	3.37
	0.4	60.00	61.87	8.14	9.05	12.86	13.80	3.32	3.51
K-sulphate	0.0	27.53	28.64	2.74	2.92	4.32	4.88	1.36	1.43
	0.1	56.18	57.10	6.76	7.43	11.40	11.67	3.02	3.12
	0.2	57.54	58.77	7.27	8.15	11.97	12.22	3.10	3.24
Statistical analysis									
Source, S		**		***		**		**	
Rate, R		**		**		**		**	
Season, Y		ns		**		ns		ns	
S x R		ns		ns		**		ns	
S x Y		ns		ns		ns		ns	
R x S		ns		ns		ns		ns	
S x R x Y		ns		ns		ns		ns	

Increasing of sulphur rate also led to a gradual increase in each of N, P, K and S contents and uptake as well as protein content in grains. That was true for protein content, since protein content % was calculated by multiplying N % by a constant factor **(Deyoe and Shellenberger, 1965)**. These results are in agreement with the findings outlined by **Sharma and Ramma (1993)** and **Abid *et al.* (2007)** who indicated that application of K-released enhances the bio-fixed NH_4^+ ion from soil and helps the crop better uptake of nitrogen. In contrast, there was a significant increase in S-uptake by above ground biomass of wheat crop due to application of both gypsum and elemental sulphure. The uptake of both P and K were remained at almost similar contents when different potassium sulphate rates were applied. These results reemphasized the utility of gypsum, elemental sulphure and potassium sulphate for improving plant growth due to accelerated soil amelioration.

Also, influence of gypsum application at the rates of 2 and 4 Mg fed^{-1} causes a reduction in the ratio of Na^+/Ca^{+2}, and then it increases K-absorption and accumulation in grain as well as increases protein content. Meanwhile, using of potassium sulphate at the rates of 0.1 and 0.2 Mg fed^{-1} causes an increase in macronutrient contents in wheat grains. Thus, there was an enhance effect of the applied potassium sulphate rates on increasing N, P and S in wheat grains. This was quit expected, where increasing K^+ content in the growth media increased its uptake by the plant as well as the reduction in Na^+ content could be attributed to the antagonism between K^+ and Na^+, these results are in agreement with those reported by **Khadr *et al.* (2002)**.

b. Micronutrients:

The availability of most micronutrients in the soil depends on soil pH as well as the nature of binding sites on organic and inorganic particle surfaces. In saline and sodic soil, the availability of micronutrients (*i.e.*, Fe, Mn and Zn) is particularly low and plants grown in these soil often experience deficiencies in these nutrients **(Page *et al*., 1990)**. **Hu and Schmidhalter (2001)** reported that the micronutrients of Mn, Zn and Fe in growing and mature leaves of wheat were largely unaffected by soil salinity.

Effects of applied S-sources at the different rates on the contents and uptake of some micronutrients (Fe, Mn and Zn) in wheat grains are presented in Table (5). The data obtained showed markedly increases in the contents and uptake of Fe Mn and Zn in wheat grains, with a more pronounced increase with increasing the applied S-source rates. Uptake of these micronutrients was adversely increased with increased soil pH, and was proportionally affected by relatively high available phosphorus content. Meanwhile, uptake of zinc was adversely affected by high levels of available phosphorus, due to the antagonism phenomenon between b^{ot}h micr^{o}- and macro-nutrients.

Table (5): Contents and uptake of some micronutrients by wheat grains as affected by the applied S-sources and rates under soil salinity stress.

Treatment	Rate (Mg/fed)	Micronutrient contents (mg kg^{-1})						Micronutrient uptake (kg fed^{-1})					
		Fe		Mn		Zn		Fe		Mn		Zn	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Gypsum	0.0	65	68	49	52	18	20	0.684	0.736	0.516	0.562	0.190	0.216
	2.0	78	82	56	59	24	27	1.636	1.743	1.175	1.254	0.504	0.574
	4.0	82	86	59	63	28	30	1.744	1.847	1.255	1.352	0.596	0.644
Elemental sulphur	0.0	66	68	51	53	19	21	0.692	0.747	0.535	0.820	0.199	0.231
	0.2	81	85	59	62	27	30	1.703	1.815	1.240	1.324	0.568	0.641
	0.4	85	89	62	65	32	34	1.822	1.919	1.330	1.401	0.686	0.733
K-sulphate	0.0	67	70	51	54	20	22	0.707	0.759	0.538	0.586	0.211	0.239
	0.1	79	83	55	59	25	29	1.670	1.761	1.162	1.252	0.528	0.615
	0.2	83	86	60	64	29	32	1.775	1.884	1.283	1.373	0.620	0.686

It is evident from the distribution patterns of Fe, Mn and Zn uptake, that the applied S-sources could be arranged as their beneficial effects on micronutrients contents and uptake by wheat grains in an ascending order of elemental sulphure ≥ Gypsum > potassium sulphate. It is noteworthy to mention that nutrient contents and uptake in wheat grains, generally, are more attributed to their available contents in the soil as well as the pronounced reduction in the values of soil ECe and pH under different sulphur resources and rates used. These results are in harmony with those obtained by **Marschner (1998)**.

III. Soil properties as affected by the applied treatments:

a. Soil salinity (ECe):

Soil salinity package of the chosen experimental pilot units, under different sulphur sources, is given in Table (6). The obtained data showed that the studied experimental soil plots are, generally, characterized from the salinity point of view by the land characters found in the arid and semi-arid regions.

The previous characteristics are adversely found in all the studied soils regardless the sulphur-sources used, particularly at the applied highest rates. It is evident that the ECe values tended to decrease, where a pronounced amount of salts leached out from the treated soils, and in turn such favourable condition should be positively reflected on the associated soil properties during the tested two seasons. In contrast, a clear decline was observed for the ECe value as a result of applied S-sources, especially at the highest rate. The decline distribution patterns in ECe values could be arranged according to the effective role of tested S-sources for salts leached out from the soil in an ascending order of elemental sulphur > gypsm > potassium sulphate. However, the corresponding ECe values were decreased from 9.05, 9.18 and 9.22 dS m^{-1} at the control treatments to 5.42, 5.65 and 5.85 dS m^{-1} (as an average for the tested two seasons) at the applied highest rates, with relative decrease percentages of 40.11, 38.45 and 36.55 %, respectively.

That was true, since elemental sulphur could be transformed to H_2SO_4 throughout the bio-oxidation reaction that consequently reacts with the native $CaCO_3$ in the soil, which causing Ca^{2+} ion released. The later plays an important role in soil aggregation and creating the conductive pores which accelerating the soluble salts leached out from the soil. The soil treated with gypsum was almost followed a similar trend, but with slowly reaction because gypsum ($CaSO_4.2H_2O$) is classified as a slowly soluble salt. These results are in agreement with those reported by **Koriem (1994)** who found that elemental sulphur application improves soil aggregation, structure, permeability, infiltration rate, ECe and SAR values. Also, **Abdurrahman *et al.* (2004)** reported that the application of gypsum alone to a saline-alkaline soil has successfully reduced its ECe and ESP values, where the ECe decreased from 12.35 to 1.98 dS m^{-1} and ESP from 14.75 to 6.69 %.

Table (6): Soil pH, EC, available macro and micronutrient contents as affected by the applied S-sources and rates under soil salinity stress.

Treatment	Rate (Mg/fed)	Season	pH (1:2.5)	EC (dS/m)	Macronutrients (mg kg^{-1} soil)				Micronutrients (mg kg^{-1} soil)		
					N	P	K	S	Mn	Zn	Fe
Gypsum	0	2009	8.25	9.72	59	4.37	210	4.25	1.54	0.79	3.88
		2010	8.21	8.63	62	4.42	215	4.33	1.62	0.82	3.93
	2	2009	8.04	7.83	67	5.37	218	5.98	2.03	1.03	4.19
		2010	8.02	6.24	73	5.59	223	6.04	2.06	1.06	4.24
	4	2009	7.70	6.00	77	5.67	219	6.12	2.12	1.13	4.72
		2010	7.64	5.29	83	5.73	225	6.30	2.14	1.15	4.84
Sulphur	0	2009	8.15	9.65	60	4.38	211	4.32	1.57	0.80	3.92
		2010	8.12	8.45	64	4.47	220	4.46	1.64	0.83	3.95
	0.2	2009	7.85	7.35	77	5.62	223	6.59	2.22	1.13	4.62
		2010	7.82	6.02	86	5.79	228	6.67	2.25	1.16	4.67
	0.4	2009	7.62	5.73	84	5.71	225	6.85	2.39	1.19	4.85
		2010	7.58	5.10	87	5.83	230	6.93	2.42	1.23	4.92
Potassium sulphate	0	2009	8.20	9.75	60	4.35	212	4.26	1.39	0.72	3.84
		2010	8.18	8.68	63	4.39	214	5.31	1.49	0.75	3.89
	0.1	2009	8.10	7.97	75	5.34	227	5.87	1.86	0.92	3.95
		2010	8.07	6.48	79	5.55	232	5.93	1.89	0.95	3.99
	0.2	2009	8.00	6.12	80	5.62	234	6.02	1.92	0.99	4.18
		2010	8.01	5.58	83	5.70	238	6.06	1.96	1.01	4.26
Statistical analysis											
Sulphur sources			--	**	**	ns	ns	ns	ns	ns	ns
Rates			--	*	**	ns	ns	ns	ns	ns	ns
Seasons			--	**	*	ns	ns	ns	ns	ns	ns

b. Soil pH:

It is well known that the applied sulphur sources, *i.e.*, gypsum, elemental sulphur and potassium sulphate are used for the reclamation of alkali soils. In view of the fact that many studies on the effect of such soil amendments as related to ameliorate the different soil properties, especially chemical one, are scant. Therefore, it was found of interest to investigate the effective role of these S-sources and different rates on the improvement of soil pH value during the tested two seasons. Results of soil analysis in Table (6) showed that soil pH was reduced due to the addition of gypsum, elemental sulphur and potassium sulphate, with a reduction pronounced case at the highest rates.

The corresponding relative decreases in soil pH were from 8.23 to 7.67, from 8.14 to 7.60 and from 8.19 to 8.05 (as an average for the tested two seasons) from the control treatments to the applied highest rates of gypsum, elemental sulphur and potassium sulphate, respectively. That means elemental sulphur surpassed the other tested S-sources, followed by gypsum and potassium sulphate. These results are in agreement with those found by **Ayub *et al*. (2007)** who reported that the application of gypsum and elemental sulphur was more effective for reducing soil pH.

c. Available macronutrient contents:

The obtained data in Table (6) indicated also that application of different sulphur sources and rates caused an appreciated increase in the availability of N, P, K, s, Fe, Mn and Zn in the soil as well as their contents were maximized with increasing the applied rates. However, the greatest values of available N, P and S, *i*.e., 87.00, 5.83 and 6.93 mg kg^{-1} soil were recorded at the highest rate of elemental sulphur (0.4 Mg fed^{-1}) in the second season. Meanwhile, the greatest value of available K (238 mg kg^{-}1 soil) was recorded at the highest rate of potassium sulphate (0.2 Mg fed^{-1}) in the second season.

The corresponding relative increase percentages at the highest rates of gypsum, elemental sulphur and potassium sulphate (as an average for the tested two seasons) were 32.23, 37.90 and 32.52 % for N; 29.69, 30.40 and 29.52 % for P; 4.47, 5.57 and 10.80 % for K and 44.75, 56.95 and 40.96 % for S as compared the control treatments, respectively. That means elemental sulphur surpassed the other two applied S-sources of gypsum and potassium sulphate for increasing the available contents of N, P and S, while the greatest values of K were more attributed as expected with potassium sulphate.

In general, the positive effects of the used different sulphur sources and rates on available N, P, K and S in the studied soil could be arranged in an ascending order of elemental sulphur > gypsum ≥ potassium sulphate for N, P and S as well as potassium sulphate > elemental sulphur ≥ gypsum for K.
These results obtained are in agreement with those outlined by **Modaihsh *et al.* (1989)** who found that sulphur application generally increased P availability in the soil. Moreover, **Amar and Meena (2004)** found that the application of 20, 40 and 60 kg S/ha was affected the improvement of residual available S in the soil, which was obviously due to poor recovery with increasing S level. Also, available N status of soil was improved due to applied S over the control, where the effect of added S resulted in N-significantly increased with increasing the applied S rates to the soil. Also, these results are in accordance with those obtained by **Ahmed (2007)**.

d. Available micronutrient contents:

The application of gypsum, elemental sulphur and potassium sulphate was positively affected the available contents of Fe, Mn, and Zn in the treated soil under growing wheat plants in both two tested seasons, as shown in Table (6). The obtained data also showed that the available Fe, Mn and Zn contents in the soil increased as the applied rates of the different s-sources increased, with a superiority for elemental sulphur , followed by gypsum and potassium sulphate. The corresponding relative increase percentages (as an average of the two seasons) were 22.41, 23.98 and 9.18 % for Fe; 34.81, 38.63 and 34.72 % for Mn and 41.61, 48.47 and 36.05 % for Zn as compared with the control treatments, respectively. From the aforementioned results, it could be concluded that the more pronounce increases in the available Fe, Mn and Zn contents in the studied soil with increasing the applied rates of different sulphur sources, particularly in case of elemental sulphur, are more attributed to improve soil pH. These results are in agreement with those reported by **Marschner (1998)**. It is noteworthy to mention that the contents of all the studied available micronutrients in the treated soils at the highest rates of S-sources, in general, lay within the sufficient limits of Fe, Mn, and Zn in the critical limits identical division for the others **(FAO, 1992)**.

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تأثير بعض مصادر الكبريت على تحسين خواص التربة ومحصول القمح وجودة الحبوب تحت ظروف تربة ملحية حديثة الإستصلاح

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أجريت تجربة حقلية على تربة طميية رملية ملحية بالقرية رقم ٧، منطقة سهل الطينة، شمال سيناء، مصر خلال الموسمين الشتويين المتتاليين لأعوام ٢٠٠٨-٢٠٠٩، ٢٠٠٩- ٢٠١٠ م لدراسة الدور الفعال لمصادر ومعدلات مختلفة من الكبريت على تحسين خواص التربة، إنتاجية القمح صنف سخا ٩٣ (*Triticum aestivium* L., Sakha 93 cv.)، وجودة الحبوب تحت ظروف شدة الملوحة فى التربة. وكانت مصادر ومعدلات الكبريت المختلفة هي الجبس (بمعدلات ٠، ٢، ٤ ميجا جرام/فدان)، الكبريت المعدنى (بمعدلات ٠، ٠.٢، ٠.٤ ميجا جرام/فدان)، كبريتات البوتاسيوم (بمعدلات ٠، ٠.١، ٠.٢ ميجا جرام/فدان)، حيث تم إضافة الجبس والكبريت المعدنى أثناء عمليات الخدمة وقبل الزراعة بـ٢٥ يوم، وقد تم خلطهما جيدا بالطبقة السطحية للتربة عن طريق الحرث، بينما أضيف نصف المعدل المقرر من كبريتات البوتاسيوم قبل الزراعة والنصف الآخر بعد ٣٠ يوم من الزراعة.

وتوضح النتائج المتحصل عليها أن إضافة مصادر الكبريت المختبرة عند المعدلات المختلفة قد أدت إلى زيادة معنوية فى طول النبات، المحصول البيولوجى (محصولى الحبوب والقش)، وزن الـ١٠٠٠ حبة، محتوى الحبوب من كلا المغذيات الكبرى (النتروجين، الفوسفور، البوتاسيوم، الكبريت) أو الصغرى (الحديد، المنجنيز، الزنك)، بتعاظم الدور الفعال بزيادة المعدلات المضافة. وقد إتضح من نمط توزيع المغذيات الممتصة بواسطة حبوب القمح أن الدور الفعال لمصادر الكبريت قد أمكن ترتيبها تنازليا فى الرتبة Elemental sulphure ≥ gypsum > potassium sulphate.

وبالنسبة لتأثير مصادر ومعدلات الكبريت المختلفة على بعض خواص التربة، فان النتائج المتحصل عليها قد أشارت إلى حدوث إنخفاض واضح فى قيم كل من Soil ECe and pH value، خاصة بزيادة معدل الإضافة خلال الموسميين تحت الدراسة. وأيضا تسببت إضافة مصادر الكبريت المختلفة فى زيادات ملحوظة فى محتوى حبوب القمح من مغذيات N, P K, S, Fe, Mn and Zn، بدور فعال لمعدل الإضافة من مصادر الكبريت. وبصفة عامة، فقد أمكن حصر مصادر الكبريت المضافة تبعا لتأثيراتها المفيدة على محتوى حبوب القمح من المغذيات فى الترتيب التنازلى التالى:

Sulphur ≥ gypsum > potassium sulphate

فيما عدا البوتاسيوم، حيث تسود كبريتات البوتاسيوم كلا المصدرين الآخرين من مصادر الكبريت المضافة.

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