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Wheat Productivity and Nutrient Uptake after Inhibitory Soil Salinity Adverse by some Sulphur Sources

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A STUDY was conducted on a village 4, Gilbana town at Sahl El-Tina plain, North Sinai, Egypt during two successive winter seasons of 2011/2012 and 2012/2013, in order to investigate the influence of sulphur from different sources, *i.e.,* gypsum (G) in two rates G1 and G2 , 4 Mega gram (Mg) fed^{-1} and 8 Mg fed^{-1}, respectively as well as elemental sulphur (ES) and sulphuric acid (SA) as soil application on inhibitory the hazardous effects of soil salinity stress on vegetative growth, yield and its quality of new cultivar Masr 2 of wheat (*Triticum aestivum* cv.) grown on a salt affected soil irrigated with low quality water of El-Salam canal as well as some chemical characteristics of the experiment soil after harvest. The obtained results could be summarized as follows:

- The highest values of wheat yield and its attributes as well as grains quality was obtained under the treatment of sulphuric acid. Also, the highest nutrient content and uptake by wheat plants were obtained due to the same treatment.
- The effective of treatments showed a descending increase in the order of, sulphuric acid > elemental sulphur > gypsum, 8.0 Mg fed^{-1} > gypsum 4.0 Mg fed^{-1} > control.
- Proline content gave the highest value (18.4 µmol g^{-1}) under the treatment of gypsum at rate of 4.0 Mg fed^{-1} in a descending order; gypsum, 4.0 Mg fed^{-1} > gypsum, 8.0 Mg fed^{-1} > elemental sulphur > sulphuric acid > control.
- Soil available N, P and K were increased due to application of different treatments over the control. The corresponding highest N and K values were 55.1 and 202 mg kg^{-1} soil, respectively and recorded under application of sulphuric acid while, it was 4.75 mg P kg^{-1} soil due to the treatment of 8 Mg gypsum fed^{-1}. The highest values of Fe, Mn and Zn (2.92, 2.41 and 0.85 mg kg^{-1} soil, respectively) were obtained due to sulphuric acid treatment. Soil pH and soil EC were decreased due to application of the treatments comparing to the control. The lowest soil pH and EC values (7.98 and 7.53 dS m^{-1}, respectively) were obtained under sulphuric acid treatment.

Keywords: Saline soil, Gypsum, Sulphur, Wheat.

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Wheat (*Triticum aestavium* L.) is one of the most important cereal crops in Egypt. Wheat provides 37% of the total calories and 40% of the protein in the Egyptian people diet. Total production of wheat in Egypt reached 8.407 million tons in 2011, produced from an area of 3.058 million feddan (FAO, 2011). Recently, a great attention of several Egyptian investigators has been directed to increase the productivity of wheat to minimize the gap between the production and consumption through increasing land area productivity and increasing cultivated area.

Sahl El-Tina plain is a part of El-Salam Canal surrounding area was a case of saline soil under reclamation. The soil is highly saline in its original state. The agricultural policy was to use the low quality water of El-Salam canal in this region. The promising areas that should be irrigated with El- Salam canal about 620.000 feddan (Ministry of Public Works and Water Resources, 1998). It is worthy to mention that agriculture drainage water is one of the most important non-conventional water resources in Egypt that plays a major role in water plans and policies. Currently, about 5 milliard m^3 of drainage water in the Nile Delta can be reused directly after mixing them with fresh water (El-Refaie and Fahmy, 2005). These waters may contain nutrients and organic materials being fertilizer sources (Mostafa, 2001).

Sulphur is one of the essential nutrients for plant growth and it accumulates 0.2 to 0.5% in plant tissue on dry matter basis. It is required in similar amount as that of phosphorus (De Kok *et al*., 2002 and Ali *et al*., 2008). It is a building block of protein and a key ingredient in the formation of chlorophyll (Duke and Reisenaue, 1986). It is one of major nutrients essential for plant growth, root nodule formation of legumes and plant protection mechanisms (Blake- Kalff *et al.,* 2000).

Sulphuric acid is another amendment that can be applied for reclamation of saline sodic soils. In such soils, sulphuric acid can be used as an ameliorating element which reacts with calcite and provides a soluble source of calcium. Some studies on the amelioration of saline-sodic soils by application of sulphuric acid during crop growth period have pointed out the efficiency of sulphuric acid in soil crusting prevention (Amezketa *et al.,* 2005) and in reclamation of saline-sodic soils (Sadiq *et al.,* 2007).

Gypsum is the most commonly used amendment in Egypt. Gypsum is a moderately soluble source of plants essential nutrients, calcium and sulphur (Dick *et al.,* 2008). It can improve plant growth and improve the physical and chemical properties of soils primarily by maintaining a favorable soil solution electrolyte concentration. The results of studies have revealed that by the application of gypsum to saline-sodic and sodic soils, adsorbed sodium on the soil complex is being replaced by the calcium (Choudhary *et al.*, 2011).

Chemical amendments have long been recognized as ameliorators of sodic soils. Many of these amendments include gypsum, sulphuric acid and sulphur

(Scherer, 2001, Zia *et al*., 2006, Sabir *et al.,* 2007, Mazhar *et al*., 2011 and Bello, 2012), which have been found to be effective in ameliorating sodicity of soil.

The present study was undertaken to evaluate the impact of sulphur from different sources on soil fertility, yield and its components as well as nutrient content of a new wheat cultivar plants grown on a salt affected soil irrigated with El-Salam canal water.

Material and Methods

The study was conducted on a saline soil located in village No. 4 at Sahl El-Tina plain in the east of Suez Canal, North Sinai Governorate for two successive winter seasons 2011/2012 & 2012/2013, cultivated with new wheat cultivar (*Triticium aestivum* cv. Misr 2). The area is one of the new reclaimed soils and irrigated with El-Salam canal 1:1 mixture of agriculture drainage water and fresh water (Nile water). A representative soil sample (0 – 30 cm) was taken before planting to determine some physical, chemical and nutritional properties (Table 1**)**. Irrigation water parameters during the two successive seasons of the experiment are recorded in Table 2. A complete randomized block design with three replicates, having a plot area 12 X 13 m, was used. Each plot was sown with grains of new wheat cultivar (*Triticum aestivum* cv. Misr 2) on the 2nd and 5th of November, 2011 and 2012 and harvested on the 21th and 25th of April, 2012 and 2013, respectively.

TABLE 1. Some physical and chemical properties of the soil used in the current study.

Properties		Values	Properties		Values
Particle size distribution (%)			Available nutrients (mg kg^{-1})		
- Clay		15.6	Macro	- N	49.0
- Silt		5.30		- P	4.12
- Sand		79.1		- K	199
Texture class		Sandy loam	Micro	- Fe	2.96
Organic matter (g kg^{-1})		6.71		- Mn	2.35
$CaCO_3$ (g kg^{-1})		78.3		- Zn	0.89
pH (Soil suspension 1:2.5)		8.35	- SAR		22.8
EC (dSm^{-1}) at soil paste extract		16.7	- ESP		24.5
			- CEC ($cmol_c$ kg^{-1})		19.8
¶Soluble ions ($mmol_c$ L^{-1})					
Cations	- Na^+	94.1	Anions	- Cl^-	89.1
	- K^+	8.30		- HCO_3^-	19.7
	- Ca^{2+}	28.2		- $SO_4^=$	58.3
	- Mg^{2+}	36.4			

¶ in soil paste .

Urea (46 % N) was applied as soil application at a rate of 100 kg N fed^{-1} in two equal splits, before the 1^{st} and the 2^{nd} irrigations. Phosphorus fertilizer was added to all plots before sowing at a rate of 15 kg P fed^{-1} as superphosphate (6.8 % P). Potassium sulphate (40 % K) was applied as soil application at a rate of 40 kg K fed^{-1} in two equal splits, 30 and 45 days after sowing. The used treatments in this study were 1) control; 2) gypsum at rate of 4 Mega gram (Mg) fed^{-1}, (G1); 3) gypsum at rate of 8 Mg fed^{-1}, (G2); 4) elemental sulphur at rate of 2 Mg fed^{-1} (ES) and 5) sulphuric acid, (SA) at a rate of 500 L sulfuric acid (36%) in 1000 L water per fed. Gypsum requirements (GR) were calculated to reduce the initial ESP from 24.5 to 10% for 30-cm soil matrix according to USDA (1954).

TABLE 2. Some chemical properties of the used irrigation water during wheat plant.

Properties	**2012**	**2013**	**Properties**	**2012**	**2013**
pH	7.93	7.89	**Micronutrients (mg L^{-1})**		
EC (dSm^{-1})	1.30	1.26	Fe	0.95	0.88
Macronutrients (mg L^{-1})			Mn	1.34	1.39
$N - NH_4^+$	6.98	6.71	Zn	0.75	0.78
$N - NO_3^-$	17.8	18.8			
P	1.97	2.06			
K	9.03	9.06			

ES and SA were added in two equal splits, 60 and 30 days before planting and interrupted by leaching process and then followed by flipping and deep plowing of the sub-soil.

Plant samples were taken at 30, 45,70 and 140 days after sowing (DAS) corresponding to vegetative, tillering, booting and maturity stages, respectively. Total content of N, P and K as well as Fe, Mn and Zn in plant samples were measured.

At maturity, 2 m^2 of each plot were harvested, plants were air dried and yields were recorded. In addition, representative ten plants were taken randomly from each plot and recorded the following characters: plant height (cm), number of spikes $plant^{-1}$, 1000-grains weight (g), grains yield (Mg fed^{-1}) and straw yield (Mg fed^{-1}) were recorded. Grain protein content was obtained by multiplying grain N concentration by 6.25. Protein yield (kg fed^{-1}) = protein percentage x grain yield.

Soil sampling

After crop harvesting, three soil layer samples corresponding depths of 0 –20, 20 – 40 and 40 – 60 cm from each treatment were collected separately. The samples were dried, ground to pass through 2 mm sieve, labeled and stored for analyses for some soil characteristics, *i.e.*, pH, EC, available N, P, K, Fe, Mn and Zn.

Methods of analysis

The plant materials were oven dried at 70^{o}C ground and kept for chemical analysis. 0.4 g was wet-digested using mixture of concentrated sulphuric and perchloric acids and different analysis were done according to Ryan *et al.* (1996). The analysis of soil and water were made using the methods described by Klute (1986) and Page (1982). Available and total phosphorus as well as Fe, Mn, and Zn were determined using Inductively Coupled Plasma (ICP) and spectrometry model 400 after Soltanpour (1985). Ammonium and nitrate of irrigation water were determined according to the method described by Markus *et al.* (1982).

Chlorophyll a and b were determined in fresh weight of leaf according to Saric *et al.* (1967). Total proline content was determined as by Bates *et al.* (1973).

Statistical analysis

Statistical analysis was assigned using MSTAT-C developed by Russel (1994).

Results and Discussion

Soil properties after harvest

Soil pH and EC (dS m^{-1})

The data representing effect of sulphur sources on soil EC and pH are presented in Table 3. Values in combined data of the two studied seasons show that, soil pH was slightly decreased and ranged between 8.35 – 7.92 for control and SA treatments, respectively in 0 – 20 cm layer; 8.30 – 7.95 for the same treatments but at 20-40 cm depth layer and 8.24 – 8.01 at 40 – 60 cm layer. The range between the two treatments narrowed by depth. Application of gypsum at the rate of 4 Mg fed^{-1} and 8 Mg fed^{-1} slightly decreased soil pH as compared to that in the control plot. This trend was true for all soil layers (0 - 20 cm), (20-40 cm) and (40-60 cm). However, the decrease in soil pH in these layers could be discussed as follows: calcium ions react with bicarbonate to precipitate calcite ($CaCO_3$) and release protons (H^+) in soil solution which neutralize the hydroxide ions (OH^-) and decrease the soil pH (Rasouli *et al.*, 2013). Also, the decrease in soil pH due to gypsum application was probably due to combination of more than one factor, mainly the replacement of sodium by calcium and the formation of neutral salts with $SO4^=$ and a decrease in sodium concentration as a fraction of the cations. Moreover, gypsum solubility is also enhanced as a result of increased ionic strength of solution and the formation of the sodium sulfate ion pair. Besides, large quantities of CO_2 have been evolved during leaching process, some of which would become soluble in soil solution giving carbonic acids (Abdel-Fattah, 2012). These results are in a harmony with those obtained with Ahmed *et al.* (2006) and Sabir *et al*. (2007).

With respect to ES and SA, the pH values were found to have decreased by 0.28 and 0.32 pH units, respectively and SA treatment gave the lowest value

(7.92) at 0 – 20 cm layer compared with the control. Poraas *et al.* (2009) indicated that the use of the acidic sulphur materials such as mineral sulphur had very negligible influence on reduce the pH. Farook and Khan (2010) stated that, the use of sulfidic materials decreased soil pH by 0.1 to 0.2 pH units compared with the initial soils.

TABLE 3. Soil pH, EC, available macro and micronutrients content in soil after harvest at different depth layers (0 – 60 cm).

Measurements		Seasons	Control			G1			G2			ES			SA		
			Depth layers (cm)			Depth layers (cm)			Depth layers (cm)			Depth layers (cm)			Depth layers (cm)		
			0-20	**- 40**	**-60**	**0- 20**	**- 40**	**-60**	**0- 20**	**- 40**	**-60**	**0-20**	**- 40**	**-60**	**0- 20**	**- 40**	**-60**
pH (1:2.5)		1st	8.31	8.34	8.19	8.05	8.06	8.04	8.15	8.13	8.09	8.01	8.02	8.03	7.95	8.00	8.02
		2nd	8.39	8.26	8.29	8.02	8.03	8.01	7.89	7.95	8.01	7.98	7.99	8.02	7.88	7.90	8.00
		combined	**8.35**	**8.30**	**8.24**	**8.04**	**8.05**	**8.03**	**8.02**	**8.04**	**8.05**	**8.00**	**8.01**	**8.03**	**7.92**	**7.95**	**8.01**
EC (dSm^{-1})		1st	13.4	12.7	13.9	8.63	8.97	9.14	7.86	7.96	7.68	7.56	7.63	8.47	7.26	7.34	8.33
		2nd	12.4	13.6	12.9	7.15	8.20	8.94	7.60	7.68	8.08	7.33	7.86	8.28	6.82	6.88	7.12
		combined	**12.9**	**13.1**	**13.4**	**7.89**	**8.59**	**9.04**	**7.73**	**7.82**	**7.88**	**7.45**	**7.75**	**8.38**	**7.04**	**7.11**	**7.73**
Available macro and micronutrients ($mg\ kg^{-1}$)	N	1st	43.8	42.1	41.7	48.6	48.6	46.9	55.6	58.6	43.6	52.1	49.6	48.7	58.2	56.9	51.3
		2nd	41.4	42.7	42.3	55.2	52.5	48.4	51.6	46.2	57.6	56.1	54.4	50.8	61.3	58.8	53.5
		combined	**42.6**	**42.4**	**42.0**	**51.9**	**50.6**	**47.7**	**53.6**	**52.4**	**50.6**	**54.1**	**52.0**	**49.8**	**59.8**	**57.9**	**52.4**
	P	1st	3.72	3.89	3.79	4.92	4.88	3.55	5.76	4.99	4.56	4.98	4.96	3.73	5.04	5.01	3.89
		2nd	3.92	3.61	3.43	4.96	4.92	3.72	4.16	4.63	4.70	5.02	4.99	4.02	5.09	5.05	3.91
		combined	**3.82**	**3.75**	**3.61**	**4.94**	**4.90**	**3.64**	**4.96**	**4.81**	**4.63**	**5.00**	**4.98**	**3.88**	**5.07**	**5.03**	**3.91**
	K	1st	206	181	189	198	195	185	214	199	198	203	198	194	207	203	197
		2nd	192	193	173	203	201	188	192	193	186	209	206	197	213	208	201
		combined	**199**	**187**	**181**	**201**	**198**	**187**	**203**	**196**	**192**	**206**	**202**	**196**	**210**	**206**	**199**
	Fe	1st	2.81	1.96	1.63	2.79	2.83	2.72	2.76	2.89	2.64	2.88	2.84	2.77	2.98	2.94	2.88
		2nd	3.11	1.70	1.99	2.82	2.86	2.74	2.96	2.77	2.78	2.93	2.94	2.85	3.04	3.00	2.90
		combined	**2.96**	**1.83**	**1.81**	**2.81**	**2.85**	**2.73**	**2.86**	**2.83**	**2.71**	**2.91**	**2.89**	**2.81**	**3.01**	**2.97**	**2.89**
	Mn	1st	1.95	1.99	1.86	2.11	1.86	1.97	2.01	2.05	1.98	2.12	2.07	2.00	2.31	2.46	2.29
		2nd	1.98	2.03	1.91	1.93	2.00	1.73	2.07	2.05	2.01	2.15	2.10	2.04	2.39	2.12	2.13
		combined	**1.97**	**2.01**	**1.89**	**2.02**	**1.93**	**1.85**	**2.04**	**2.05**	**2.00**	**2.14**	**2.09**	**2.02**	**2.35**	**2.29**	**2.21**
	Zn	1st	0.78	0.79	0.71	0.93	0.81	0.73	0.89	0.82	0.76	0.93	0.81	0.73	0.88	0.84	0.79
		2nd	0.81	0.83	0.74	0.85	0.83	0.79	0.92	0.84	0.80	0.85	0.91	0.89	0.97	0.90	0.88
		combined	**0.80**	**0.81**	**0.73**	**0.89**	**0.82**	**0.76**	**0.91**	**0.83**	**0.78**	**0.89**	**0.86**	**0.81**	**0.93**	**0.87**	**0.84**

G1: gypsum rate 4 Mg fed^{-1}; G2: gypsum rate 8 Mg fed^{-1}; ES: elemental sulphur ; SA: sulphuric acid.

As for soil salinity, data in Table 3 declare a noticeable decrease in soil salinity as a result of treating soil with different treatments for all soil layers 0-20 cm, 20-40 cm and 40-60 cm in compare with the control. The effect is more pronounced due to the sulphuric acid treatment and the EC value 7.53 dS m^{-1} was recorded compared with

EC value of control (13.2 dS m^{-1}) and gave 43% rate of depression than the control.

Regarding the effect of the treatments it's followed the order; SA > ES > G2 > G1 > Control for both pH and EC. In addition, sulphuric acid was capable to mobilize base cations from the soil. The H^+ ion in the acidic water displaces the cations from the exchange sites, reduces the exchangeable cations and increases the concentrations of these cations in the soil solution. Similar results were obtained by Mahmood *et al.* (2013).

Residual available N, P and K macronutrients

Table 3 reveals that the application of different sulphur sources increased the concentration of available nitrogen, phosphorus and potassium in the soil compared with the control for all soil layers under study. In this regard, El-Kouny (2009) pointed out that application of elemental sulphur increased total N and availability of P and K in soil sample as compared with the control. The plots under sulphuric acid treatment showed the maximum accumulation of available N, P and K. Highest soil available N and K contents for combined data (55.1 and 202 mg kg^{-1}), respectively were obtained due to sulphuric acid treatment while, it was 4.75 mg kg^{-1} for available P due to G2 treatment.

Residual available Fe, Mn and Zn micronutrients

The concentration of available Fe, Mn and Zn followed the same trend of that observed for macronutrients hence, application of SA, ES, G1 and G2 treatments were increased the concentration of available Fe, Mn and Zn in the soil compared with the control. In this regard, Khan *et al.* (2007) reported that application of sulfidic materials was effective in enhancing the release of essential plant nutrients into the growing media, which are very essential for crop production in poor soils. The highest soil available Fe, Mn and Zn contents for combined data (2.92, 2.41 and 0.85 mg kg^{-1}), respectively were obtained due to sulphuric acid treatment.

Regarding to soil profile depths, the differences among those depths were slightly. They were in gradual decreases in their content by depth. That observation could be attributed to sulphur in different sources added to plough layer moved slowly downward depth in addition to plant consumption where no pronounced quantities of these nutrients were in excess to flow down profile depth.

Yield and its attributes

Growth characters

Some growth characters of wheat plants are shown in Table 4. Gypsum, elemental sulphur and sulphuric acid treatments significantly increased 1000-grains weight, plant height and number of spikes $plant^{-1}$ as compared to the control treatments. These increases may be due to calcium, while it is an essential for plant cell wall structure, provides normal transport and retention of other elements as well as strength in the plant. Among the treatments, SA was found to be the best source of

S followed by ES, G2 and then G1 because of its high concentrations its influence on reducing soil pH, improving soil structure and increasing the availability of certain plant nutrients. Data also indicated that application of sulphuric acid gave the highest values and increased the plant height, number of spikes plant^{-1} and 1000-grains weight by about (36.8, 78.9 and 82.6%) compared with untreated plants. Ali *et al.* (2012) reported that S application significantly enhanced wheat growth and yield. Tillering, plant height, spike length, number of grain spike-1, 1000-grain weight, straw and grain were statistically significant. This was the most probably due to increased Ca and K and decreased Na contents resulting in healthy environment for plant growth. These results are in harmony with those obtained by Ali *et al.* (2008) and Mazhar *et al.* (2011).

TABLE 4. Yield and yield attributes of wheat as affected by sulphur applications.

Treatment		Season	Plant height (cm)	No. spike plant^{-1}	1000 grains weight (g)	Yield (Mg fed^{-1})			Crop index (CI)	Yield efficiency (%)
						Biological	Grains	Straw		
Control		2012	69.9	5.46	31.5	2.15	0.93	1.22	0.76	43.3
		2013	71.3	4.69	30.2	2.66	0.87	1.79	0.49	32.7
		Combined	**70.6 e**	**5.08 b**	**30.89 d**	**2.41 b**	**0.90 b**	**1.51 c**	**0.62**	**38.0**
Sulphur sources	G1	2012	84.6	7.69	45.7	3.14	1.29	1.85	0.70	41.1
		2013	86.0	8.14	48.3	3.31	1.35	1.96	0.69	40.8
		Combined	**85.3 d**	**7.92 a**	**47.0 c**	**3.23 a**	**1.32 a**	**1.91 b**	**0.69**	**40.9**
	G2	2012	88.7	8.88	51.6	3.42	1.39	2.05	0.68	40.6
		2013	87.0	9.05	53.1	3.52	1.37	2.15	0.64	40.9
		Combined	**87.8 c**	**8.97 a**	**52.4 b**	**3.47 a**	**1.38 a**	**2.10 ab**	**0.66**	**40.8**
	ES	2012	89.0	8.87	52.1	3.50	1.36	2.14	0.64	38.9
		2013	93.5	9.14	54.5	3.60	1.42	2.18	0.65	39.4
		Combined	**91.2 b**	**9.06 a**	**53.3 b**	**3.55 a**	**1.39 a**	**2.16 ab**	**0.64**	**39.2**
	SA	2012	95.8	8.95	55.1	3.61	1.37	2.24	0.61	38.0
		2013	97.3	9.23	57.7	3.75	1.47	2.28	0.65	39.2
		Combined	**96.5 a**	**9.09 a**	**56.4 a**	**3.68 a**	**1.42 a**	**2.26 a**	**0.63**	**38.6**
LSD at 0.05 (Combined)			**1.29**	**2.01**	**1.18**	**0.58**	**0.30**	**0.35**	**ns**	**ns**

G1: gypsum rate 4 Mg fed^{-1}. G2: gypsum rate 8 Mg fed^{-1}. ES: elemental Sulphur. SA: sulphuric acid.
The values followed by a different letters are significantly different at $p \leq 0.05$. Ns: not significant.
Crop index (CI): (seed/straw) ratio; Yield efficiency (YE): yield of grains / (yield of straw + grains) x 100,

Straw and grain yields

Data presented in Table 4 show that grains and straw yield were significantly increased due to the addition of gypsum, elemental sulphur and sulphuric acid compared to the control treatment. These increases might be attributed to the role of calcium, which is essential for plant as previously mentioned. Also, calcium is essential for many plant functions, some of them are proper cell division and elongation, enzyme activity and metabolism. These results are well supported by the findings of Sabir *et al.* (2007) and Farook & Khan (2010).

The maximum straw and grain yields (2.26 and 1.42 Mg fed^{-1}, respectively) were produced by the treatment of sulphuric acid. It was followed by elemental sulphur, G2 and then G1 treatments. The increase percentage over the control for SA, ES, G2 and G1 treatments were 57.8, 54.4, 53.3 and 46.7 % for grains as well as 49.7, 43.0, 39.0 and 26.5 % for straw, respectively. The data presents the following descending order; SA > ES > G2 > G1> control. These results are similar to that obtained by Ghaudhry (2001), who concluded that gypsum application to rice and wheat crops at 75% G.R. enhanced the paddy and grain yield by 18 and 17%, respectively. In this regard, Farook and Khan (2010) pointed out that the application of sulphidic material increased the grain yield of rice plant by 108% over the control for Sirajgonj soil and 135% for Gazipur soil irrespective of application rates. In case of gypsum, these increments were 35% and 58% for Sirajgonj soil and Gazipur soil, respectively. Tan *et al.* (2000) found that all sulphur sources (ammonium sulphate, elemental sulphur and gypsum) had a positive effect on rice yield from 9 to 10 percent higher than plots receiving no S showing that application of sulphuric acid resulted in higher yield and promoted rapid amelioration of saline-sodic soils. These results are in agreement with Sadiq *et al*. (2007) and Jena & Kabi (2012).

Yield efficiency (%) and Crop index (CI)

From data in Table 4, it can be observed that application of gypsum and sulphur treatments insignificantly increased **y**ield efficiency and crop index of wheat plants. The values were 7.76%, 7.31 %, 3.05% and 1.58 % for the yield efficiency and 11.1%, 5.45 %, 3.21% and 0.80 % for crop index due to the treatments, respectively in the following descending order: G1 > G2 > ES > SA of the control. Similarly, harvest index showed the same trend of yield efficiency. Farook and Khan (2010) pointed out that the application of sulphidic material exerted significant effects in increasing the harvest index of rice, but the application of gypsum was not always significant. In addition, Haq *et al.* (2007) indicated that gypsum at full rate of 100 % gypsum requirements significantly increased harvest index of wheat as compared to control.

Macro and micronutrients content at different growth stages

Data presented in Fig.1 illustrated that the application of gypsum and sulphur as elemental sulphur or sulphuric acid increased the concentrations of N, P, K, Fe, Mn and Zn in wheat plants compared to the control. This was true at all growth stages. Mazhar *et al.* (2011) stated that sulphur improves the use efficiency of the essential plant nutrients; particularly nitrogen and phosphorus. Also, application of gypsum showed more pronounced effects on the nutrients percentage in all plant organs than sulphur treatments. This effect seemed to be dependent on soil properties that limit the buffering capacity and native nutrient content.

Plant requirements of sulphur are equal to or exceed those for phosphorus. It is one of major nutrients essential for plant growth and plant protection mechanisms. Sulphur application enhanced the uptake of N, P, K and Zn by the plant. Due to its synergistic effect, the efficiency of these elements is enhanced which results in increased crop productivity. Application of S is useful not only for increasing crop production and quality of the produce but also improves soil conditions for healthy crop (Zhao, 1999). These results are in agreement with those obtained by Badr *et al.* (2002) and Farook & Khan (2010).

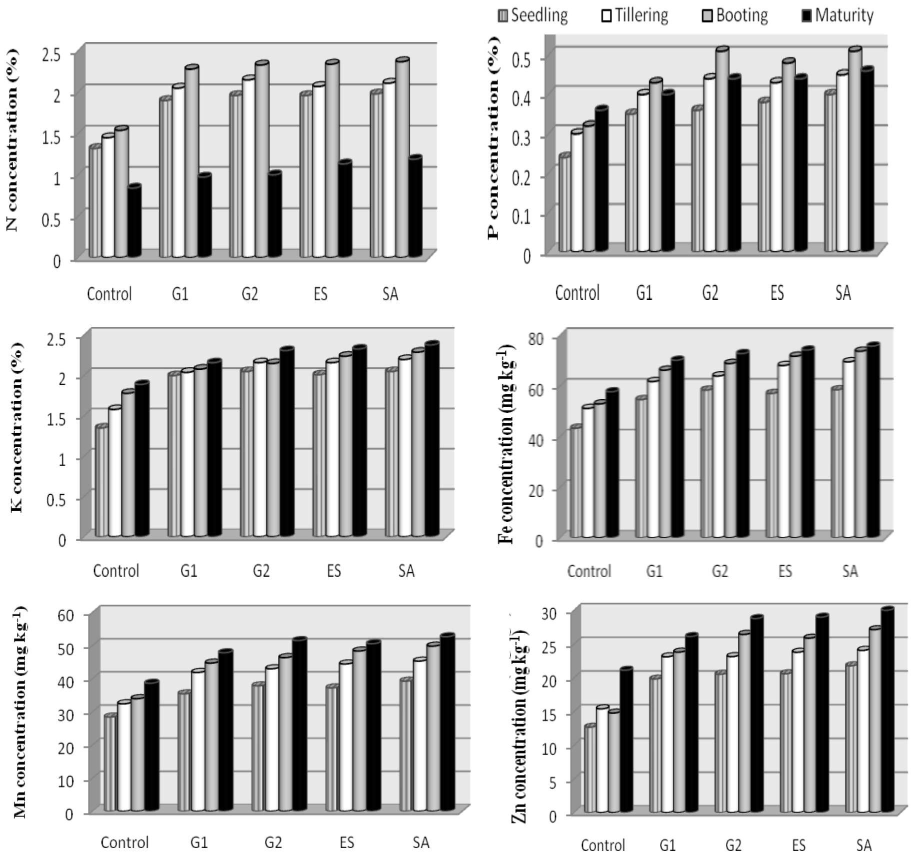

Fig. 1. N, P and K content (%) as well as Fe, Mn and Zn content (mg kg^{-1}) of wheat during different growth stages (seedling, booting, tillering and straw at maturity) as affected by different sulphur sources.
G1: gypsum rate, 4 Mg fed^{-1}; G2: gypsum rate, 8 Mg fed^{-1}; ES: elemental sulphur; SA: sulphuric acid.

Macronutrients content

Data in Table 5 show that N, P and K uptake were increased significantly due to addition of all treatments. Sulphuric acid treatment was superior for increasing the uptake of N, P and K as compared to the other treatments. This promoting effect could be related to the supplementary effect of gypsum and sulphur on reducing soil pH, improving soil structure and increasing the availability of nutrients in soil and also, improves the use efficiency of other essential plant nutrients, particularly nitrogen and phosphorus (Mazhar *et al.*, 2011). These results are in a harmony with those obtained by Ali *et al.* (2008) and Haq *et al.* (2007).

Statistical analysis shows that sulphuric acid treatment was superior for increasing the uptake of N, P and K to the other treatments. The positive effect was in the ascending order of SA > ES > G2 > G1 > control for all nutrients under study either for straw or grains. The applications showed insignificant differences among them for N and P uptake while, SA was significant than gypsum for K uptake.

Highest N, P and k-uptake of straw 26.9, 10.3 and 54.4 kg fed^{-1}, respectively as well as 33.1, 8.95 and 23.8 kg fed^{-1}, respectively for grains were obtained due to the sulphuric acid treatment.

TABLE 5. Macronutrients uptake (kg fed^{-1}) in wheat plants as affected by sulphur applications.

Treatment		Season	Macronutrients (kg fed^{-1})					
			Straw			Grains		
			N	P	K	N	P	K
Control		2012	10.7	4.76	24.8	12.9	3.35	9.86
		2013	14.7	5.65	33.0	12.6	3.65	10.4
		Combined	**12.7 b**	**5.21 b**	**28.9 c**	**12.8 b**	**3.50 b**	**10.1 b**
Sulphur sources	G1	2012	17.9	7.92	39.9	27.6	6.58	19.1
		2013	19.3	7.22	43.3	29.3	7.16	20.9
		Combined	**18.6 a**	**7.57 ab**	**41.6 b**	**28.5 a**	**6.87 ab**	**20.0 a**
	G2	2012	20.3	10.1	48.1	30.6	8.20	22.0
		2013	21.7	9.50	51.9	30.8	7.12	22.7
		Combined	**21.0 a**	**9.79 a**	**50.0 ab**	**30.7 a**	**7.66 a**	**22.4 a**
	ES	2012	24.0	10.0	50.2	30.3	7.75	22.2
		2013	24.9	8.93	52.4	32.1	8.24	23.7
		Combined	**24.5 a**	**9.46 a**	**51.3 ab**	**31.2 a**	**7.99 a**	**23.0 a**
	SA	2012	26.4	10.7	54.4	31.6	8.49	22.7
		2013	27.4	9.98	54.5	34.5	9.41	24.8
		Combined	**26.9 a**	**10.3 a**	**54.4 a**	**33.1 a**	**8.95 a**	**23.8 a**
LSD at 0.05 (Combined)			**7.42**	**3.12**	**12.0**	**8.15**	**3.52**	**6.89**

See footnotes of Table 4.

Micronutrients content

As shown in Table 6, Fe, Mn and Zn uptake followed the same trend of that for N, P and K uptake. Hence, the addition of all treatment significantly increased

Fe, Mn and Zn uptake compared to the control. Sulphuric acid treatment was most effective for increasing the uptake of Fe, Mn and Zn as compared to the other treatments. The responses percentage to Fe, Mn and Zn uptake by wheat straw over control was 102, 106 and 112 %, and for grains 108, 147 and 254 %, respectively. Jena and Kabi (2012) stated that sulphur application increased Fe, Mn , Zn and Cu uptake by rice plants. Also, significant improvement is usually expected in the use of gypsum on saline soils as sources of Ca and S. Bello (2012) found that the improvement in yield and nutrient content is due to the displacement of sodium by calcium and increase in nutrient use efficiency of rice crop. Sulphur fertilization enhanced the uptake of N, P, K and Zn in the plant. Due to its synergistic effect, the efficiency of these elements is enhanced which results in increased crop productivity. Application of S fertilizer is useful not only for increasing crop production and quality of the produce but also improves soil conditions for healthy crop. These results are in a harmony with those obtained by Badr *et al.* (2002).

TABLE 6. Micronutrients uptake (kg fed^{-1}) in wheat plants as affected by sulphur applications during the two growing seasons of 2011/2012 & 2012/2013 and their combined analysis .

Treatment		Season	Micronutrients (g fed.$^{-1}$)					
			Straw			Grains		
			Fe	Mn	Zn	Fe	Mn	Zn
Control		**2012**	103	48.3	24.2	54.4	30.8	10.9
		2013	158	67.4	40.0	49.6	30.7	15.2
		Combined	**131 c**	**57.8 c**	**32.1 c**	**52.0 b**	**30.8 b**	**13.1 d**
Sulphur sources	G1	**2012**	179	87.2	48.7	92.2	48.4	33.5
		2013	206	95.1	50.7	92.9	53.2	29.7
		Combined	**193 b**	**91.1 b**	**49.7 b**	**92.6 a**	**50.8 a**	**31.6 c**
	G2	**2012**	219	107	61.2	103	59.2	36.4
		2013	220	108	59.5	98.1	60.7	37.8
		Combined	**220 ab**	**108ab**	**60.4 a**	**100 a**	**60.0 a**	**37.1 bc**
	ES	**2012**	242	106	61.9	102	63.5	38.8
		2013	238	112	63.2	104	71.1	43.9
		Combined	**240 ab**	**109 ab**	**62.6 a**	**103 a**	**67.3 a**	**41.3 ab**
	SA	**2012**	258	119	66.0	102	70.7	44.4
		2013	269	120	69.7	113	81.3	48.4
		Combined	**264 a**	**119 a**	**67.9 a**	**108 a**	**76.0 a**	**46.4 a**
LSD at 0.05 (Combined)			**38.8**	**19.8**	**10.8**	**33.1**	**11.7**	**9.09**

See footnotes of Table 4.

Total chlorophyll and proline content

It is clear from Table 7 that the content of chlorophyll (a+b) was significantly increased by the addition of treatments SA, ES, G2 and G1 compared to the control while, the differences among the applications were insignificant. The highest chlorophyll content 2.66 mg g^{-1} fresh weight of leaves was obtained due to the application of sulphuric acid representing an increase of 49.4 % over the control.

As for proline content in fresh weight of leaves, obtained data revealed that there were significant differences between gypsum rates compared to control and the other sulphur sources, without significant differences among them. Mazhar *et al.* (2011) pointed out that proline content decreased by using gypsum or sulphur in the leaves, stem and roots of (*Schefflera arboricola*). Also, there is evidence that proline accumulation is a sign of injury rather that of resistance. Pratiksha *et al.* (2010) reported that proline content increased as the external supply of calcium to saline soil increased. According to Table 7 the increases followed the order: G1 > G2 > ES > control > SA.

TABLE 7. Protein content (%) and protein yield (kg fed^{-1}) of wheat grains as well as chlorophyll a+b (mg g^{-1} fresh weight of leaves) and proline content (μmolg^{-1} fresh weight of leaves) as affected by sulphur applications.

	Treatment	Season	Protein (%)	Protein yield (kg fed^{-1})	Chlorophyll (a+b) (mg g^{-1})	Proline (μmol g^{-1})
	Control	2012	8.69	80.8	1.67	13.6
		2013	9.06	78.8	1.89	12.1
		Combined	**8.88 c**	**79.8 b**	**1.78 b**	**12.9 c**
Sulphur sources	G1	2012	13.4	172.9	2.55	19.0
		2013	13.6	183.6	2.58	17.7
		Combined	**13.5 b**	**178.3 a**	**2.57 a**	**18.4 a**
	G2	2012	13.8	191.8	2.63	16.2
		2013	14.1	193.2	2.53	14.6
		Combined	**13.9 ab**	**191.8 a**	**2.58 a**	**15.4 b**
	ES	2012	13.9	189.0	2.63	14.5
		2013	14.1	200.2	2.59	12.0
		Combined	**14.1 ab**	**196.0 a**	**2.61 a**	**13.3 c**
	SA	2012	14.4	197.3	2.67	10.7
		2013	14.7	216.1	2.64	12.9
		Combined	**14.6 a**	**207.3 a**	**2.66 a**	**11.8 c**
LSD at 0.05 (Combined)			**0.903**	**51.8**	**0.51**	**1.63**

See footnote of Table 4.

Grains protein content

As shown in Table 7, data presented that the protein content percentage of wheat grains was significantly increased as affected by the treatments of sulphuric acid, elemental sulphur and gypsum compared to the control while, there was no significant difference between SA, ES, G1 and G2 treatments. This relative effect could be clarified the effect of sulphuric acid on enhancing the growth of wheat and improving the fertility of the studied soil compared with the low rate of gypsum (G1). The highest value of protein due to the treatment of sulphuric acid corresponded 64.4 % increase over control. These results are in agreement with those obtained by Khan *et al*. (2007).

Respecting protein yield, it can be seen from results that there were no significant differences between the applications. Highest value (207 kg fed^{-1}) of protein yield was obtained due to addition of sulphuric acid which gave the highest nitrogen content and grain yield. Regarding the effect of the treatments it is can be arranged as follows: SA > ES > G2 > G1 > control.

Conclusion

From the above mentioned results, it can be concluded that gypsum, sulphuric acid or elemental sulphur applications had decreased the hazard effect of salinity, in addition to favorable effect on growth and availability of chemical composition to wheat plants grown on saline soils. Sulphuric acid treatment was superior for enhancing the productivity and wheat quality than the other amendments used in the current study. This effect seemed to be dependent on soil properties that improving the buffering capacity and native nutrient content. Also, the favorable effect of soil amendments were referred to their influence on reducing soil pH, improving soil structure and increasing the availability of the studied nutrients in soil. Therefore, it is recommended that farmers can apply the studied sulphur materials for increasing the productivity of wheat crop with good seed quality under saline soil conditions.

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إنتاجية القمح وإمتصاص العناصر الغذائية بعد تثبيط الإجهاد الناتج عن ملوحة التربة بواسطة بعض مصادر الكبريت

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إقيمت تجربتان حقليتان خلال موسمي شتاء 2012/2011 و 2013/2012 م لدراسة الدور الفعال لإضافة مصادر مختلفة من الكبريت وهي الكبريت المعدني (كب) وحامض الكبريتيك (يد$_2$كب أ$_4$) وكذلك الجبس الزراعي جـ1 ، جـ2 بمعدلات 4 ، 8 ميجاجرام فدان$^{-1}$ علي التوالي علي تثبيط التأثير الضار للملوحة ورفع كفاءة وجودة أنتاجية صنف جديد من القمح (*Triticum aestivum* cv.) ومصر2 وكذلك امتصاص بعض العناصر الغذائية الكبرى الصغري وتأثير ذلك علي خصوبة التربة من خلال تحليل التربة بعد الحصاد لتقدير بعض الخواص الكيميائية وبعض العناصر الميسرة الكبري و الصغري بالتربة والتي اقيمت بقرية جلبانة رقم "4" بمنطقة سهل الطينة بمحافظة شمال سيناء، ويمكن تلخيص أهم النتائج المتحصل عليها كما يلي:

- كانت أعلي القيم المتحصل عليها لمحصول القمح ومساهماتة وكذلك لجودة الحبوب ومحتوي وإمتصاص العناصر الكبري و الصغري بواسطة القش والحبوب كنتيجة للمعاملة المستخدم بها حامض الكبريتيك.
- كان تسلسل الزيادة للمعاملات كالتالي: يد$_2$كب أ$_4$ > كب> جـ2, 8 ميجاجرام فدان$^{-1}$ > جـ 1, 4 ميجاجرام فدان$^{-1}$ > المقارنة.
- إزداد محتوي البرولين نتيجة لإضافة المعاملات المختلفة بينما إنخفض نتيجة معاملة حامض الكبريتيك و كان تسلسل الزيادة بالنسبة للمعاملات: جـ4,1 ميجاجرام للفدان > جـ2 ,8 ميجاجرام للفدان > كب > يد$_2$كب أ$_4$ > المقارنة.
- إزدادت العناصر الميسرة الكبري و الصغري بالتربة نتيجة لإضافة المعاملات المختلفة تحت الدراسة.
- إنخفضت قيم حموضة التربة و التوصيل الكهربي نتيجة لإضافة المعاملات تحت الدراسة مقارنة بالمقارنة وكانت أقل القيم قد تم التحصل عليها نتيجة المعاملة بحامض الكبريتيك.
- كانت المعاملة بحامض الكبريتيك هي الأحسن علي الإطلاق مقارنة بباقى المعاملات المستخدمة وذلك لمعظم القياسات تحت الدراسة.
- يمكن من النتائج السابقة التوصية (بمعاملة التربة الملحية بحامض الكبريتيك المركز قبل الزراعة علي أكثر من دفعة ثم الغسيل والحرث بعد إضافة الإحتياجات الجبسية اللازمة لخفض نسبة الصوديوم المتبادل إلي 10% مما يساعد علي التغلب علي التأثير المثبط للملوحة ورفع إنتاجية وجودة القمح الناتج وزيادة العناصر الغذائية الميسرة في تلك النوعية من الأراضى.