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EFFECT OF ELEMENTAL SULFUR AND GYPSUM ON GROWTH AND THE CONTENT OF N, P, K AND S OF BARLEY PLANTS GROWN IN SALT AFFECTED SOILS

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ABSTRACT: The study was carried out using salt-affected soils were taken from different five locations of Sakha, Kafr El-Sheikh Governorate, north Nile Delta, Egypt to study the effect of gypsum or sulfur, each individually or in combination, on the growth and N, P, K contents of barley plants (*Hordeum vulgare L.*). The results demonstrated that the addition of both gypsum and sulfur, individually or in combination, had a significant effect on the barely dry weight (BDW), with higher levels of gypsum and sulfur resulting in higher BDW values. There are some variations among the soil types for N, P K and S contents (%). The mean concentrations of N, P, K, and S across all studied soils are 0.147%, 0.289%, 1.450%, and 0.465%, respectively. The highest N and P concentration (0.155%) and (0.319%) are found in Soil 2 and soil 4, respectively. The mean uptake of N, P, K, and S across all studied soils are 4.24, 7.70, 41.84, and 13.22 mg/pot, respectively. The application of elemental sulfur and gypsum increased both the concentration and uptake of N, P, K and S for barley plants compared to the control.

Key words: Gypsum, Elemental sulfur, Available nutrients, Salt affected soils, Barley.

INTRODUCTION

Salinity is a significant challenge to agricultural productivity in many parts of the world, including Egypt, where over 3 million hectares of agricultural land are affected by salinity *(Ivushkin et al., 2019)*. Salinity can negatively impact plant growth and yield by reducing the availability of essential plant nutrients in the soil *(Munns, 2002)*. Main causes of increasing worldwide soil salinity are high surface evaporation, low amount of rainfall, increased global temperature, movement of saline groundwater to the soil surface, salt deposition on soils from oceans and the accumulation of salt minerals *(Rengasamy, 2010 and Almeida et al., 2017)*. Barley *(Hordeum vulgare)* is an important cereal crop in Egypt and is commonly grown in saline soils. Therefore, it is crucial to investigate the effect of salt-affected soil on soil nutrient availability, barley plant growth, and nutrient uptake to improve agricultural productivity in these regions (Zhou, 2009).

Some studies have investigated the effectiveness of different soil amendments in mitigating the negative effects of salinity on soil and plant health. For instance, sulfur and gypsum have been shown to effectively reclaim saline soils by reducing the exchangeable sodium percentage and improving soil structure *(Hussain et al., 2018)*. The effectiveness of sulfur and gypsum in reclaiming saline soils has been previously reported in various studies. Gypsum application improved soil structure and reduced soil salinity in a saline-sodic soil *(Hussain et al., 2018)*. Sulfur application improved soil fertility and increased crop yield in a saline soil *(Ali et al., 2019)*. These amendments can also improve nutrient availability and uptake by plants in salt affected soils. However, there is a lack of research on the specific effect of sulfur and gypsum on soil nutrient availability, barley plant growth, and nutrient uptake in salt-affected soils in the Sakha region of Egypt.

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Gypsum has unique properties that make it an essential amendment for saline soils. Gypsum application is most important among the widely known methods of reclaiming salt-affected soils; other related amendments include elemental S, sulfuric acid (H_2SO_4), polysulfides of sulfur and hydrogen sulfite (Abdelhamid, *et al.,* 2013; Lastiri-Hernández *et al.,* 2019; Wang *et al.,* 2019)

Therefore, this work aims to investigate the effect of sulfur and gypsum on soil nutrients availability, barley plant growth, and nutrient, uptake in salt affected soils of Egypt. The study will use a combination of pots experiments, laboratory analyses, and statistical analysis to evaluate the effectiveness of these amendments in improving soil and plant health. The findings of these studies provide valuable insights into potential solutions to mitigate the negative impact of salinity on agricultural productivity in Egypt.

MATERIALS AND METHODS

The study was carried out using salt-affected soils were taken from different five locations of Sakha, Kafr El-Sheikh Governorate north Nile Delta, Egypt, to study the effect of gypsum or sulfur, each individually or in combination, on the soil chemical properties and its content of nutrients, as well as its effect on the growth and content of barley plants (*Hordeum vulgare L.,* cv Giza 123). The soil samples were taken from surface (0-30 cm) of five sites of different salinities and varied in their chemical properties, especially the content of soluble salts EC (dSm^{-1}). Soil samples, air dried, sieved through a 2 mm sieve and kept in plastic bags.

The experiment was conducted in the greenhouse of the Soils Department, Faculty of Agriculture, Menoufia University, in the winter of 2020/2021. The aim of the experiment was to study the effect of elemental sulfur and gypsum on growth and the content of N, P, K and S of barley plants grown in salt affected soils. The studied soil samples were analyzed for some physical and chemical properties (Table, 1).

Soil reaction (pH) was determined in 1:2.5 (soil: water) suspension by compound electrode pH-meter according to Cottenie *et al.* (1982).

Electrical Conductivity (EC) was determined using electrical conductivity meter at 25^{o}C as dSm^{-1} in the saturated soil paste extract page (1982).

Soluble cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and soluble anions (Cl^{-}, CO_3^{2-}, HCO_3^{-} and SO_4^{2-}) were determined and expressed a meq L^{-1} according to the material and methods described by *page* (1982). Sulfate was calculated by the difference between the sum of determined total cations and determined anions. Cation exchange capacity (CEC) was determined using sodium acetate (NaOAc) of pH 8.2 as described by Klute and Dirksen (1986).

Organic matter (OM) content (%) was determined as described by Walkley and Black (Cottenie *et al.,* 1982).

Sodium Adsorption Ratio (SAR) is dimensionless parameter that relates the concentrations of sodium, calcium, and magnesium in the soil solution.

The amendments were agricultural gypsum 85% (G) $CaSO_4.2H_2O$ obtained from Agricultural Research Center (ARC) in Egypt, and elemental sulfur (ES).

Pot experiment

The experiment took place during the winter growing season of 2020/2021. The study used 180 plastic pots with a 25cm diameter.

The pots were divided into five main groups representing the five studied soils (Soil1, Soil2, Soil3, Soil4, and Soil5), with 36 pots per main group. Each pot was filled with 3 kg of the respective soil. All pots were fertilized with ordinary superphosphate (15.5% P_2O_5) at a rate of 0.45 g/pot. At the same time, all pots were also manured with compost at a rate of 15 g/pot. Both the superphosphate and compost were mixed with the soil in each pot. The pots in each main group were divided into four subgroups (9 pots/subgroup) representing elemental sulfur (ES) applications. The four subgroups were S0 (0% ES), S1 (0.05% ES), S2 (0.1% ES), and S3 (0.2% ES), which corresponded to 0, 1.5, 3.0, and 6.0 g/pot, respectively.

Table (1): Physical and chemical properties of the studied soils

Property	Soil sample				
	1	2	3	4	5
Coarse sand	4.0	2.0	5.2	5.8	2.3
Fine sand	8.3	7.7	9.5	7.6	7.9
Silt	38.3	36.4	40.4	35.1	32.5
Clay	49.4	93.1	44.9	51.5	57.4
Textural grade	Clay	Clay	Clay	Clay	Clay
pH (1:2.5) soil water suspension	7.5	7.19	7.77	7.7	7.78
EC (dSm^{-1}) Soil paste	3	5.1	5.4	2.8	3.7
Soluble cations (meq/l) Soil paste ext.					
Na^+	19.5	37.3	39.5	19.7	29
K^+	0.6	0.8	0.9	0.5	0.6
Ca^{2+}	6.5	7.2	8	5.3	4.1
Mg^{2+}	3.4	5.7	5.6	2.5	3.3
Soluble anions (meq/l) soil paste ext.					
CO_3^{2-}	0	0	0	0	0
HCO_3^-	0.4	0.5	0.5	0.3	0.4
Cl^-	25	45	47	24.5	32.9
SO_4^{2-}	4.6	5.5	5.8	3.4	4.7
Organic matter "O.M" (%)	2.36	2.03	1.14	0.59	0.37
$CaCO_3$ (%)	2.9	3.8	3.5	2.5	3
Cationexchangeable" CEC"(C.mole kg-1)	35.3	36.1	30.2	37.3	39.1
Available nutrients and trace elements ($mskg^{-1}$)					
N	0.148	0.093	0.148	0.18	0.158
p	0.205	0.218	0.185	0.22	0.241
k	1.25	1.27	1.18	1.34	1.36
S	0.415	0.427	0.362	0.43	0.436
Zn	0.384	0.4895	0.303	0.23	0.411
Cd	0.2252	0.2678	0.187	0.17	0.325
Pb	0.563	0.694	0.834	0.33	0.319
SAR	8.76	14.68	15.14	9.97	15.07
ESP (%)	10.47	16.98	17.45	11.89	17.38

Thereafter, the pots of each subgroup were divided into three sub-subgroups (3 pots/sub-subgroup) representing gypsum applications, i.e., G0 (0% gypsum), G1 (0.04% gypsum), and G2 (0.08% gypsum) which corresponded to 0.0, 1.2, and 2.4, g/pot, respectively. The gypsum applications were carried out before planting and were mixed well with the soil in each pot.

The studied treatments, including soil salinity and applications of elemental sulfur and gypsum, were arranged within the experimental units in a split-split completely randomized design with three replicates.

Eight grains of barley (*Hordeum vulgare L.*), were planted in each pot on November 1st, 2020. All pots were irrigated to field capacity moisture content of each soil (60% WHC) and repeated every week. After 20 days of planting, all pots were fertilized with ammonium nitrate (33% N) and potassium sulfate (48% K2O) at a rate of

100 kg/ha for each fertilizer, another dose of nitrogen fertilizer was applied at 42 days after planting.

After 75 days of planting, the plants (shoots) in each pot were harvested and washed. The harvested plants were air-dried, oven-dried at 70°C for 48 hours, weighed as g/pot (dry matter yield), ground, and kept for Macronutrients determination, (N, P, K and S). The dried plant sample was digested with 5 ml mixture concentrated H_2SO_4 and $HClO_4$ (3:1 mixed ratio) at 25°c on sandy plate up to collarless digest which called and diluted up to 50 ml using distilled water. These digests contents of N, P, and K were determined. Another 0.2g of oven dried plant materials was digested using 5 ml mixture of concentrated HNO_3 and $HClO_4$ as described with the first sample, where thesis digest was used to determine the plant of sulfur (S).

The obtained data were statistically analyzed by ANOVA according to Gomez (1984).

RESULTS AND DISCUSSION

Barely plants dry weight

Table (2), present the results of the study which investigated the effect of gypsum and elemental sulfur addition, individually or in combination, on the barley dry matter (BDW) plant weight grown in saline soil. The obtained Data demonstrated that the addition of both gypsum and sulfur, individually or in combination had a significant effect on the BDW of barley plants, with higher levels of gypsum and sulfur resulting in higher BDW values.

Several studies have investigated the effects of gypsum addition on plant growth, including barley, and have reported similar findings. For instance, a study by *Abdel-Salam and El-Sayed (2015)* examined the effect of gypsum addition on the growth and yield of barley in sandy soil and found that the application of gypsum significantly improved the plant height, number of leaves, and grain yield of barley. Similarly, a study by *El-Ramady et al. (2015)* reported that the addition of gypsum to saline soil significantly improved the growth, yield, and nutritional quality of barley.

The beneficial effects of gypsum on plant growth are mainly attributed to its ability to improve soil structure and nutrient availability. Gypsum can reduce soil compaction, increase water infiltration and retention, and improve soil aeration, which can enhance root growth and nutrient uptake by plants. Moreover, gypsum can improve nutrient availability, especially calcium, which is essential for plant growth and development, and sulfur, which is involved in several metabolic processes in plants.

Results presents in (Table 2) also shows that with higher levels of sulfur resulting in higher BDW values. Several studies have examined the effects of sulfur addition on plant growth and reported similar findings. Jafari *et al.* (2019) found that the addition of sulfur significantly improved the plant height, number of tillers, and grain yield of wheat grown in a calcareous soil. Kaya *et al.* (2014) reported that the addition of sulfur to a saline soil significantly improved the growth and yield of sunflower. The beneficial effects of sulfur on plant growth are mainly attributed to its involvement in several metabolic processes in plants, including protein synthesis, enzyme activation, and photosynthesis.

Table 2 demonstrates that the addition of gypsum resulted in significant increase an effect on the BDW of barley plants, where the higher levels of gypsum resulted in higher BDW values for example, BDW in the plants grow in soil 5 was increased from 1.13 gpot^{-1} with zero gypsum and sulfur (G0 and S0) applications to 1.35 gpot-1 in the same soil with the treatment of S0 and G2 recorded increase percent of 1.35. Abdel-Salam & El-Sayed (2015) examined the effect of gypsum addition on the growth and yield of barley in sandy soil and found that the application of gypsum significantly improved the plant height, number of leaves, and grain yield of barley. El-Ramady *et al. (2015)* reported that the addition of gypsum to saline soil significantly improved the growth, yield, and nutritional quality of barley.

Table (2): The barley dry matter (BDW) plants weight (gm) grown in saline soil as affected with elemental sulfur and gypsum.

Soils	Go				Means	G1				Means	G2				Means	G Means
	S0	S1	S2	S3		S0	S1	S2	S3		S0	S1	S2	S3		
Soil 1	2.25	2.92	3.41	3.71	3.07	2.60	3.35	3.73	4.51	3.55	3.05	3.42	4.48	3.22	3.54	3.39
Soil 2	2.81	3.42	4.53	4.52	3.82	3.50	3.92	4.40	5.65	4.37	3.95	4.15	5.10	5.97	4.79	4.33
Soil 3	1.62	1.91	2.11	2.51	2.04	2.51	2.25	2.27	3.15	2.55	2.32	2.51	3.31	3.92	3.02	2.53
Soil 4	1.15	1.32	1.61	2.25	1.58	1.21	2.66	1.72	2.35	1.99	1.41	1.85	2.35	2.85	2.12	1.89
Soil 5	1.15	1.30	1.50	2.11	1.52	2.15	1.45	1.92	2.50	2.01	1.35	1.62	2.41	2.92	2.08	1.87
Means	1.80	2.17	2.63	3.02	2.41	2.39	2.73	2.81	3.63	2.89	2.42	2.71	3.53	3.78	3.11	2.80

Go = 0.00 % Gypsum
G1 = 0.04% Gypsum
G2 = 0.08% Gypsum

So =0%
S1= 0.05%
S2=0.1%
S3=0.2%

$LSD_{0.05}$
Soils 0.053
Gypsum 0.041
Sulfur 0.047

The beneficial effects of gypsum on plant growth are mainly attributed to its ability to improve soil structure and nutrient availability. Gypsum can reduce soil compaction, increase water infiltration and retention, and improve soil aeration, which can enhance root growth and nutrient uptake by plants. Moreover, gypsum can improve nutrient availability, especially calcium, which is essential for plant growth and development, and sulfur, which is involved in several metabolic processes in plants (Riffat *et al.*, 2018).

Table 2 shows that the addition of sulfur had a significant effect on the BDW, with higher levels of sulfur resulting in higher BDW values. For example, BDW of barely plants planted in soil5 was increased from 1.15 gpot^{-1} with the treatment of Go and So to 2.11 gpot^{-1} recorded increase percent of 83.48%.

Several studies have examined the combined effect of gypsum and sulfur addition on plant growth and reported similar findings. *El-Mogy et al. (2018)* found that the combined application of gypsum and sulfur significantly improved the plant height, leaf area, and grain yield of maize. El-Ghandour *et al. (2020)* reported that the combined application of gypsum and sulfur to a saline soil significantly improved the growth and yield of wheat.

Macro elements concentration (%) and uptake (mg/pot) of barley plants grown in different saline soils

The Table (3) shows the percentage concentrations and uptake of four essential elements for plant growth: nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) in barley plants grown in five different saline soils. Saline soils are those that have high levels of salt, which can affect the crop yield and quality. Barley is one of the most salt-tolerant cereal crops, but its growth and performance still depend on the availability and balance of these elements in the soil (USDA, 2021).

The data and results in Table (3) show the concentrations (%) and uptake (mg/pot) of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) by barley plants grown in saline soils. It can observed that there are a variations in the concentrations and uptake of nutrients across different soils. For example, Soil 2 has the highest N concentration (0.155%) which may indicate a higher nitrogen availability or uptake in this soil. Soil 3 has the lowest (0.141%), Similarly, Soil 4 has the highest P concentration (0.319%) and Soil 3 has the lowest (0.261%). The uptake of nutrients by barley plants also varies among the soils. For instance, Soil 2 shows the highest uptake of N (6.94 mg/pot). Soil 5 has the lowest uptake (2.89 mg/pot). Soil 2 also exhibits the highest uptake of P, K, and S, which may suggest a lower nitrogen supply or utilization in this soil.

These differences may reflect the different levels of salinity and other soil properties, such as pH, texture, organic matter, and cation exchange capacity. These values are within the optimal ranges for barley growth, which are 0.1-0.2% for N, 0.2-0.4% for P, 1.0-2.0% for K, and 0.2-0.6% for S. However, there are some variations among the soils, which may reflect the differences in soil properties, salinity levels, and plant responses. (Saade *et al.*, 2016)

Table (3): Effect of studied soils on N, P, K and S concentrations (%) and uptake (mg/pot) of barley plants grown in studied saline soils.

Studied soils	Concentration (%)				Uptake (mg/pot)			
	N	P	K	S	N	P	K	S
Soil 1	0.129	0.273	1.410	0.470	4.36	8.64	48.30	16.08
Soil 2	0.155	0.303	1.450	0.480	6.94	12.12	63.45	21.02
Soil 3	0.141	0.261	1.340	0.406	3.57	6.18	34.40	10.47
Soil 4	0.157	0.319	1.510	0.483	3.46	5.64	28.93	9.28
Soil 5	0.153	0.287	1.540	0.487	2.89	5.92	34.13	9.23
Means	0.147	0.289	1.450	0.465	4.24	7.70	41.84	13.22

The highest P concentration (0.319%) is found in Soil 4, which may imply a higher phosphorus availability or uptake in this soil. The lowest P concentration (0.261%) is found in Soil 3, which may indicate a lower phosphorus supply or utilization in this soil. Phosphorus is a vital element for energy transfer, nucleic acid synthesis, and root development. Phosphorus deficiency can result in poor root growth, delayed flowering, and reduced grain yield and quality (USDA, 2021).

The highest K concentration (1.540%) is found in Soil 5, which may suggest a higher potassium availability or uptake in this soil. The lowest K concentration (1.340%) is found in Soil 3, which may imply a lower potassium supply or utilization in this soil. Potassium is an important element for osmotic regulation, enzyme activation, and stomatal movement. Potassium deficiency can cause wilting, necrosis of leaf margins, and reduced grain yield and quality (USDA, 2021).

The highest S concentration (0.487%) is found in Soil 5, which may indicate a higher sulfur availability or uptake in this soil. The lowest S concentration (0.406%) is found in Soil 3, which may imply a lower sulfur supply or utilization in this soil. Sulfur is an essential element for amino acid synthesis, protein formation, and chlorophyll production. Sulfur deficiency can cause chlorosis, reduced growth, and decreased grain yield and quality *(* USDA, 2021*)*.

Table (3) also shows the uptake of each element by the barley plants, measured in milligrams per pot. The uptake is the amount of the element that the plant absorbs from the soil and incorporates into its biomass. The uptake depends on both the concentration and the availability of the element in the soil, as well as the plant's demand and efficiency. The uptake can be used to estimate the nutrient removal by the crop and the fertilizer requirement for the next crop *(Han et al., 2016*).

According to the Table (3), the mean uptake of N, P, K, and S across all studied soils are 4.24, 7.70, 41.84, and 13.22 mg/pot, respectively. These values vary considerably among the soils, indicating different nutrient dynamics and plant responses. The highest N uptake (6.94 mg/pot) is found in Soil 2, which also has the highest N concentration. The lowest N uptake (2.89 mg/pot) is found in Soil 5, which has a relatively low N concentration. The highest P uptake (12.12 mg/pot) is found in Soil 2, which also has the highest P concentration. The lowest P uptake (5.64 mg/pot) is found in Soil 4, which has a relatively high P concentration. The highest K uptake (63.45 mg/pot) is found in Soil 2, which also has a high K concentration. The lowest K uptake (28.93 mg/pot) is found in Soil 4, which has the highest K concentration. The highest S uptake (21.02 mg/pot) is found in Soil 2, which also has the highest S concentration. The lowest S uptake (9.23 mg/pot) is found in Soil 5, which also has the highest S concentration.

Table (3) provides useful information on the nutrient status of barley plants grown in different saline soils, which can help farmers and researchers to optimize the soil management and crop production.

These results are consistent with some previous studies that reported the beneficial effects of gypsum and sulfur application on the growth and yield of barley and other crops grown in saline soils. Gypsum and sulfur can improve the soil physical and chemical properties, such as reducing soil pH, exchangeable sodium percentage (ESP), and electrical conductivity (EC), and increasing soil calcium and sulfate levels. These changes can enhance the availability and uptake of nutrients by the plants, and also reduce the toxicity of sodium and chloride ions.

However, the optimal rates of gypsum and sulfur application may vary depending on the soil type, salinity level, irrigation water quality, and crop_species (Helmy *et al.,* 2013; Shaban *et al.,* 2013; Yasmin *et al.,* 2007). Therefore, it is important to conduct field trials and soil tests to determine the best management practices for each situation.

The results show how soil salinity effect of on plant growth and nutrient uptake. Soil salinity can reduce the availability and uptake of water and nutrients by plants, causing water stress, nutrient deficiencies, and ion toxicity *(El-Ramady et al., 2018; Rusan, 2023)*. Salt-tolerant plants can cope with saline soils by regulating their osmotic potential, ion balance, and antioxidant defense *(El-Ramady et al., 2018)*.

The role of plant nutrients in mitigating salinity stress. Some plant nutrients, such as N, K, Se, and Si, can enhance the plant resistance and adaptation to salinity stress by improving the water status, photosynthesis, enzyme activity, and antioxidant capacity of plants (Al-Busaidi *et al.,* 2008; El-Ramady *et al.,* 2018).

Effect of elemental sulfur and gypsum on the content (%) and uptake of N, P, K and S for barley plants grown in saline soils.

Table (4) shows the effect of applying elemental sulfur and gypsum on the nitrogen concentration (%) and uptake (mg/pot) of barley plants grown in saline soils. Nitrogen is a key component of proteins, enzymes, and chlorophyll, and it affects the plant growth, development, and grain quality. Nitrogen deficiency can cause stunted growth, yellowing of leaves, and reduced grain yield and protein content *(* USDA, 2021*)*. The optimal range for nitrogen concentration in barley is 0.1-0.2% (*Han et al., 2016)*.

According to the table, the application of elemental sulfur and gypsum increased both the nitrogen concentration and uptake of barley plants compared to the control (without amendments). The highest nitrogen concentration (0.164%) and uptake (6.07 mg/pot) were achieved with 0.1% sulfur and 0.08% gypsum application, while the lowest nitrogen concentration (0.125%) and uptake (2.44 mg/pot) were observed with 0.05% sulfur and 0% gypsum application. The mean values for both nitrogen concentration and uptake across all treatments were 0.147% and 4.24 mg/pot, respectively, which are within the optimal range for barley growth.

The Table (4) suggests that the combined application of elemental sulfur and gypsum had a synergistic effect on enhancing the nitrogen status of barley plants grown in saline soils. This may be due to the increased availability of calcium and sulfur, which can improve the cation exchange capacity, the soil pH, and the microbial activity in the soil, leading to increased nitrogen mineralization and uptake by the plants (Qadir *et al.,* 2007).

However, the Table (4) does not show the actual salinity levels of the soils, which can also affect the plant growth and performance. Therefore, it would be helpful to measure and report the electrical conductivity (EC) or sodium adsorption ratio (SAR) of the soils, which are common indicators of soil salinity (Ball *et al.,* 1991; Clark, 2008)

Table (4) illustrate the effect of elemental sulfur and gypsum application on phosphorus (P) concentration (%) and uptake (mg/pot) in barley plants grown in saline soils. As the percentage of sulfur increases, there is a consistent trend of higher phosphorus concentration in the barley plants. Similarly, when gypsum is added, it also contributes to increased phosphorus concentration. The means row shows that the average phosphorus concentration across different sulfur levels gradually increases.

The trend for phosphorus uptake is increasing sulfur levels lead to higher phosphorus uptake. Gypsum addition also positively influences phosphorus uptake. The means row represents the average uptake values, which follow the same pattern.

In summary, both sulfur and gypsum play a crucial role in enhancing phosphorus availability in saline soils, benefiting the growth of barley plants. These trends highlight the importance of soil amendments for sustainable crop production *(Cox & Jacinthe, 2023)*.

The results in Table (4) show that without sulfur application (0% sulfur), K concentration is low (0.04%). As sulfur percentage increases, K concentration also rises. Gypsum application further enhances K concentration. K uptake increases with both sulfur and gypsum application. The highest K uptake occurs at 0.2% sulfur and gypsum. The average values for each

Table (4): Effect of application of elemental sulfur and gypsum on N, P, K and S concentration (%) and uptake (mg/pot) of barley plants grown in saline soils

Sulfur %	N (%)			G Means	P (%)			G Means	K (%)			G Means	S (%)			G means
	Gypsum %				Gypsum added %				Gypsum %				S %			
	0	0.04	0.08		0	0.04	0.08		0	0.04	0.08		0	0.04	0.08	
0	0.145	0.169	0.149	0.155	0.215	0.241	0.246	0.234	1.280	1.348	1.412	1.347	0.414	0.438	0.446	0.433
0.05	0.125	0.127	0.157	0.136	0.238	0.258	0.273	0.256	1.334	1.442	1.502	1.426	0.428	0.454	0.477	0.453
0.1	0.151	0.147	0.164	0.154	0.265	0.293	0.302	0.287	1.414	1.502	1.560	1.492	0.442	0.479	0.494	0.472
0.2	0.134	0.148	0.153	0.145	0.277	0.320	0.333	0.310	1.434	1.560	1.616	1.537	0.488	0.499	0.526	0.504
Means	0.139	0.148	0.156	0.147	0.249	0.278	0.289	0.272	1.366	1.463	1.523	1.450	0.443	0.467	0.486	0.465
LSD $_{0.05}$	Sulfur			0.008				0.002				0.013				0.003
	Gypsum			0.007				0.001				0.011				0.003
Sulfur %	N (mg/pot)			G Means	P (mg/pot)			G Means	K (mg/pot)			G Means	S (mg/pot)			G means
	Gypsum %				Gypsum added %				Gypsum %				S %			
	0	0.04	0.08		0	0.04	0.08		0	0.04	0.08		0	0.04	0.08	
0	2.44	4.09	3.68	3.401	3.82	5.70	5.87	5.133	22.78	32.06	33.66	29.501	7.43	10.43	10.78	9.547
0.05	2.60	4.64	4.22	3.819	5.07	6.91	7.35	6.443	28.73	39.19	40.41	36.109	9.29	12.41	12.91	11.535
0.1	4.19	4.11	5.68	4.659	6.77	8.03	10.57	8.455	36.82	41.31	54.59	44.241	11.73	13.46	17.41	14.201
0.2	3.76	5.46	6.07	5.100	8.20	11.36	12.76	10.771	43.13	56.46	60.87	53.489	14.74	18.16	19.85	17.583
Means	3.25	4.57	4.91	4.24	5.97	8.00	9.14	7.70	32.87	42.26	47.38	40.83	10.80	13.61	15.24	13.22
LSD $_{0.05}$	Sulfur			0.280				0.154				0.768				0.205
	Gypsum			0.250				0.138				0.666				0.237

set of data are as follows: for K concentration: 1.366%, 1.463%, 1.523%, 1.450%. But for K uptake: 32.87 mg/pot, 42.26 mg/pot, 47.38 mg/pot, 40.83 mg/pot.

Sulfur is essential for plant growth and nutrient uptake. It enhances K availability by promoting soil microbial activity and releasing K from minerals. Gypsum improves soil structure and reduces salinity. It indirectly affects K uptake by enhancing root growth and nutrient diffusion.

The combined application of sulfur and gypsum synergistically influences K concentration and uptake. Optimal levels of both factors lead to improved K nutrition in barley (Zhang DengXiao *et al.*, 2019).

In summary, the application of elemental sulfur and gypsum positively influences K concentration and uptake in barley plants grown in saline soils. These findings have implications for sustainable crop production in challenging environments.

The Data in Table (4) illustrate the role of elemental sulfur and gypsum application, both individually and in combination, on sulfur concentration (%) and uptake (mg/pot) in barley plants grown in saline soils.

Elemental sulfur application leads to an increase in sulfur concentration in the soil. As the sulfur percentage increases (from 0.433 % to 0.504 %), the sulfur content in the barley plants also rises. The highest sulfur concentration is observed at 0.2% sulfur application.

Barley plants absorb more sulfur (mg/pot) with increased elemental sulfur application. The highest sulfur uptake occurs at 0.2% sulfur application. The average values for sulfur concentration and uptake are higher with elemental sulfur application. Gypsum ($CaSO_4.2H_2O$) application also influences sulfur concentration. Sulfur content increases with gypsum application (from 0.433% to 0.504%). The highest sulfur concentration is observed at 0.2% gypsum application.

Gypsum positively affects sulfur uptake by barley plants. The highest sulfur uptake occurs at 0.2% gypsum application. The average values for sulfur concentration and uptake are higher with gypsum application.

When both elemental sulfur and gypsum are applied together, there is a synergistic effect. The combined application results in even higher sulfur concentration (up to 0.526%). The combined effect of sulfur and gypsum leads to increased sulfur uptake (up to 19.85 mg/pot). The average values for sulfur concentration and uptake are highest when both sulfur and gypsum are applied (Helmy *et al.*, 2013; Shaban *et al.*, 2013; Turan *et al.*, 2013; Yasmin *et al.*, 2007; Zhang DengXiao *et al.*, 2019).

Conclusion

The results showed that adding both mineral sulfur and gypsum, each alone or in combination with celebrities, increased the element of this comparison with the control.

REFERENCES

Abdelhamid, M.; Eldardiry, E. and Abd El-Hady (2013). Ameliorate salinity effect through sulphur application and its effect on some soil and plant characters under different water quantities. Agricultural Sciences, 04(01): 39–47. https://doi.org/10.4236/as.2013.41007.

Abdel-Salam, M. S. and El-Sayed, S. A. (2015). Effect of gypsum on the growth and yield of barley plants in sandy soil. Journal of Soil Sciences and Agricultural Engineering, 6(9): 985-991. Nutrition, 40(17): 2398-2407.

Al-Busaidi, A.; Yamamoto, T.; Inoue, M.; Eneji, A. E.; Mori, Y. and Irshad, M. (2008). Effects of zeolite on soil nutrients and growth of barley following irrigation with saline water. Journal of Plant Nutrition, 31(7): 1159–1173.

Ali, M.; Saleem, M.; Ahmad, S. and Rizwan, M. (2019). Improving soil fertility, crop productivity and nitrogen use efficiency of maize through sulfur amendment in saline soil. Soil and Tillage Research, 186: 160-170.

Almeida, D. M.; Oliveira, M. M. and Saibo, N. J. M. (2017). Regulation of Na+ and K+ homeostasis in plants: towards improved salt stress tolerance in crop plants. Genetics and Molecular Biology, 40: 326–345.

Ball, D. M.; Hoveland, C. S. and Lacefield, G. D. (1991). Southern forages. Potash & Phosphate Institute Atlanta.

Barik, K.; Canbolat, M. Y.; Yanik, R. and Rafiq Islam, K. (2011). Compressive behavior of soil as affected by aggregate size with different textures in Turkey. Journal of Animal and Plant Sciences, 21(2): 186–192.

Clark, A. (2008). Managing cover crops profitably. Diane Publishing.

Cottenie, A.; Verloo, M.; Kickens, L.; Velghe, G. and Camerlynck, R. (1982). Chemical Analysis of Plants and Soils. Laboratory of Analytical and Agrochemistry. State University, Ghent Belgium, pp: 63.

Cox, K. H. and Jacinthe, P.A. (2023). Phosphorus Mobility in Gypsum-Amended Soils in Relation to Soil Type and Timing of P Fertilizer Application. Water, Air, & Soil Pollution, 234(6): 368.

El-Ghandour, I. A.; Ghoneim, E. M. and El-Fouly, M. M. (2020). Effect of gypsum and elemental sulfur application on wheat growth, yield, and nutrient uptake in saline soil. Soil and Water Research, 15(4): 193-201.

El-Mogy, M. M.; Abdel-Megeed, A. and El-Gizawy, A. M. (2018). Combined effect of sulfur and gypsum application on maize productivity and soil properties in a saline-sodic soil. Communications in Soil Science and Plant Analysis, 49(11): 1349-1362.

El-Ramady, H.; Abdalla, N.; Alshaal, T. and El-Marsafawy, S. (2015). Influence of Gypsum and Compost on the Yield and Quality of Barley in Saline Soil. Communications in Soil Science and Plant Analysis, 46(10): 1317-1330.

El-Ramady, H.; Alshaal, T.; Elhawat, N.; Ghazi, A.; Elsakhawy, T.; Omara, A. E.D.; El-Nahrawy, S.; Elmahrouk, M.; Abdalla, N. and Domokos-Szabolcsy, É. (2018). Plant nutrients and their roles under saline soil conditions. Plant Nutrients and Abiotic Stress Tolerance, 297–324.

Ghafoor, A.; Saleem, M.; Hussain, T. and Akhtar, M. S. (2017). Effect of gypsum and sulfur on yield and phosphorus uptake of maize in saline-sodic soil. Journal of Plant Nutrition, 40(11): 1637-1646.

Gomez, K. A. and Gomez, A. A. (1984). Statistical procedures for agricultural research. John Wiley & Sons.

Han, L.; Sun, D.; Hou, W.; Zhang, Y. and Liu, A. (2016). The regulation of sulfur deficiency response in plants. Frontiers in Plant Science, 7: 1-12.

Helmy, A. M.; Shaban, K. H. and El-Galad, M. A. (2013). Effect of gypsum and sulphur application in amelioration of saline soil and enhancing rice productivity. Journal of Soil Sciences and Agricultural Engineering, 4(10): 1037–1051.

Hussain, M.; Rizwan, M.; Ali, Q.; Ali, S.; Ibrahim, M. and Abbas, T. (2018). Changes in soil properties and crop performance after gypsum application in a saline-sodic soil. Geoderma, 313: 54-63.

Ivushkin, K.; Bartholomeus, H.; Bregt, A. K.; Pulatov, A.; Kempen, B. and de Sousa, L. (2019). Global mapping of soil salinity change. Remote Sensing of Environment, 231. https://doi.org/10.1016/j.rse.2019.111260

Jafari, M.; Ghalavand, A.; Rezaei, S. and Mohammadi, M. (2019). Effects of sulfur application on growth, yield and yield components of wheat (Triticum aestivum L.) in a calcareous soil. Journal of Plant Nutrition, 42(14): 1676-1685.

Kaya, C.; Tuna, A. L. and Ashraf, M. (2014). The role of sulfur in improving seed yield and quality of sunflower (Helianthus annuus L.) grown under saline conditions. Acta Physiologiae Plantarum, 36(6): 1605-1614.

Klute, A. and Dirksen, C. (1986). Hydraulic conductivity and diffusivity. In Klute, A. (Ed.) Methods of soil analysis. Part (I) Physical and mineralogical methods, 2nd ed. Agron, Monogr. 9. ASA-SSA, Madison, WI, PP. 687- 734.

Lastiri-Hernández, M. A.; Alvarez-Bernal, D.; Bermúdez-Torres, K.; Cárdenas, G. C. and Ceja-Torres, L. F. (2019). Phytodesalination of a moderately saline soil combined with two inorganic amendments. Bragantia, 78 (4): 579– 586. https://doi.org/10.1590/1678-4499.20190031

Marschner, H. (2011). Marschner's mineral nutrition of higher plants. Academic press.

Munns, R. (2002). Comparative physiology of salt and water stress. Plant, Cell & Environment, 25 (2): 239- 250. https://doi.org/10.1046/j.1365-3040.2002.00778.x

Munns, R. and Tester, M. (2008). Mechanisms of salinity tolerance. Annu. Rev. Plant Biol., 59, 651–681.

Murtaza, G.; Ghafoor, A.; Owens, G.; Qadir, M. and Kahlon, U. Z. (2009). Environmental and economic benefits of saline-sodic soil reclamation using low-quality water and soil amendments in conjunction with a rice-wheat cropping system. Journal of Agronomy and Crop Science, 195(2): 124–136. https://doi.org/10.1111/j.1439-037X.2008.00350.x

USDA, N. (2021). USDA Plants Database [United States Department of Agriculture, Natural Resources Conservation Service]. The PLANTS Database.

Qadir, M.; Oster, J. D.; Schubert, S.; Noble, A. D. and Sahrawat, K. L. (2007). Phytoremediation of sodic and saline□sodic soils. Advances in Agronomy, 96: 197–247.

Rengasamy, P. (2006). World salinization with emphasis on Australia. Journal of Experimental Botany, 57(5): 1017-1023.

Rengasamy, P. (2010). Soil processes affecting crop production in salt-affected soils. Functional Plant Biology, 37(7): 613–620. https://doi.org/10.1071/FP09249

Riffat, A.; Sajid, M. and Ahmad, A. (2018). by sulfur modulation under salt stress Improvement in nutrient contents of maize (Zea mays L.) by sulfur modulation und. August. https://doi.org/10.13140/RG.2.2.10498.12489

Rusan, M. J. (2023). Soil and Nutrient Management Under Saline Conditions. In Biosaline Agriculture as a Climate Change Adaptation for Food Security (pp. 71–85). Springer.

Saade, S.; Maurer, A.; Shahid, M.; Oakey, H.; Schmöckel, S. M.; Negrão, S.; Pillen, K. and Tester, M. (2016). Yield-related salinity tolerance traits identified in a nested association mapping (NAM) population of wild barley. Scientific Reports, 6(1): 32586.

Shaban, K.; Helmy, A. and El-Galad, M. (2013). Role of gypsum and sulphur application in ameliorating saline soil and enhancing rice productivity. Acta Agronomica Hungarica, 61(4): 303–316.

Turan, M. A.; Taban, S.; Katkat, A. V. and Kucukyumuk, Z. (2013). The evaluation of the elemental sulfur and gypsum effect on soil pH, EC, SO. Journal of Food, Agriculture & Environment, 11(1): 572–575.

Wang, W.; Xu, Y.; Chen, T.; Xing, L.; Xu, K.; Ji, D.; Chen, C. and Xie, C. (2019). Regulatory mechanisms underlying the maintenance of homeostasis in Pyropia haitanensis under hypersaline stress conditions. Science of the Total Environment, 662: 168–179.

Yasmin, N.; Blair, G. and Till, R. (2007). Effect of elemental sulfur, gypsum, and elemental sulfur coated fertilizers, on the availability of sulfur to rice. Journal of Plant Nutrition, 30(1): 79–91.

Zhang DengXiao, Z. D.; Du GuangHui, D. G.; Chen De, C. De; Shi GaoLing, S. G.; Rao Wei, R. W.; Li Xin, L. X.; Jiang Ying, J. Y.; Liu ShiLiang, L. S. and Wang DaiChang, W. D. (2019). Effects of salinity on growth, photosynthesis, ion balance and antioxidant defense system of different wheat genotypes under Cd stress Ecotoxicology and Environmental Safety: https://www.sciencedirect.com/science/article/abs/pii/S0147651319300877

Zhou, M. X. (2009). Barley production and consumption. In Genetics and improvement of barley malt quality (pp. 1-17). Berlin, Heidelberg: Springer Berlin Heidelberg.

تأثير عناصر الكبريت والجبس على نمو ومحتوى N ، P، K، S لنباتات الشعير المزروعة في أراضٍ متأثرة بالأملاح

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الملخص العربى

تمت الدراسة باستخدام ارضى متأثرة بالأملاح احضرت من خمس اماكن مختلف من محافظة كفر الشيخ شمال الدلتا- مصر. لدراسة تاثير الكبريت المعدنى والجبس كل منهم منفرد او مختلطين على نمو ومحتوى نبات الشعير من عناصر N, P, K, and S. كان هناك اختلافات فى محتوى هذه العناصر باختلاف الأراضى . كانت متوسطات N, P, K and S ٠,١٤٧ ، ٠,٢٨٩ ، ١,٤٥٠ ، ٠,٤٦٥ % على التوالى اعلى تركيز لكل من N ٠,١٥٥ ، P ٠,١٣٩ % بينما مقدار الممتص من هذه العناصر ٤,٢٤ ،٧,٧، ٤١,٨٤ ، ١٣,٢٢ ملجم/ لكل اصيص على التوالى . اوضحت النتائج أن اضافة كل من الكبريت المعدنى ، الجبس كل منهم منفرد أو مجتمع أدى إى زيادة امتصاص هذه العناصر مقارنة بالكنترول.

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