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EVALUATION EFFICIENCY OF MAGNESIUM FERTILIZATION IN CALCAREOUS SOIL TREATED BY SULPHUR

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ABSTRACT: This greenhouse study aimed to evaluate the response of faba bean plant (Ficia Vaba. Giza 716) to magnesium (Mg) fertilization in reaction with sulphur (S) applications, which capitalizes on the uptake and availability of essential nutrients, especially under calcareous soil conditions. The study also looked at how this affected the productivity of faba bean plants.

The data indicate that the application of S and Mg reduced the pH, electrical conductivity (EC), and calcium carbonate ($CaCO_3$) content of calcareous soil, while enhancing organic matter (OM) and the availability of nitrogen (N), phosphorus (P), potassium (K), S, and Mg. The application of sulphur had a more significant impact on the examined variables than the application of magnesium.

An increase in the application rates of both S and Mg resulted in a significant increase in the number of straw and seeds of faba bean plants, where it increased from.3.35 and. 6.13 g/pot in the treatment free from S and Mg to 5.73 and 10.62 g/pot in the plants received 450 and 60 mg/Kg S and Mg, respectively. As well as there were significant increases in straw and seeds uptake (mg /pot) of N, P, K, Mg and S. The uptake of these nutrients escalated from 51.93, 26.23, 38.53, 11.06, and 16.75 to 160.44, 90.53, 117.47, 159.30, and 71.63, and from 128.73, 76.63, 109.11, 31.88, and 49.65 to 390.82, 215.59, 312.23, 159.30, and 172.04 in faba bean straw and seeds, respectively, due to the incremental application of S and Mg, respectively, from 0 to 450 and 60 mg/pot. Therefore, calcareous soil management must include S and Mg applications to improve health and productivity.

Keywords: Calcareous soil, Faba bean, Sulphur and Magnesium fertilization.

INTRODUCTION

Calcareous soils occur naturally in arid and semi-arid regions because of relatively little leaching of soluble salts. More than 30 % of global soils are calcareous (Taalab *et al.,* 2019) and cover more than 500 million hectares of soil globally (Wassif & Wassif, 2021; Pal *et al.,* 2000). More than 15 % $CaCO_3$ is frequently present in calcareous soils, and it can take many different forms, such as crusts, nodules, powder, and concretions (Taalab *et al.,* 2019). High $CaCO_3$ soils are classified as "Calcisols" and are associated with calcic subgroups of other soils. The physical and chemical characteristics of calcareous soils, such as soil crusts and the availability of plant nutrients, may be significantly impacted by the presence of ample levels of $CaCO_3$, which is a characteristic of these soils. Phosphorus (P) and trace elements such as copper (Cu), zinc (Zn), and iron (Fe) are nutrients that plants find difficult to obtain in most calcareous soils (El-Hady & Abo-Sedera, 2006; Bolan *et al.,* 2023). These soils usually have a pH greater than 7, which may rise to more than 8 when they are enriched with free calcium carbonate ($CaCO_3$). In some soils, $CaCO_3$ may exist as a distinct impermeable layer (also known as caliche). With the right management, calcareous soils can yield agricultural products (Wahba *et al.,* 2019). The loss or fixation of specific nutrients and soil nutrient availability is determined by the impact of soil pH on chemical processes (Taalab *et al.,* 2019). Obtaining more fresh irrigation water is often one of the main

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constraints for crop production since calcareous soils are commonly found in semi-arid and dry regions. Another significant issue restricting plant growth in these soils is the limited availability of specific nutrients (Bolan *et al.,* 2023; FAO, 2023). The high $CaCO_3$ content and its effects on decreasing nutrient availability, soil crust formation that affects crop stand and seedling emergence, and the formation of a compacted subsurface pan layer, when combined with a low available moisture range, can inhibit crop production in calcareous soils (Rengasamy *et al.,* 2022).

Applying elemental sulfur (ES), a soil amender, is known to have a long-lasting effect on neutralizing $CaCO_3$ in the soil. This process depends on several soil-related parameters, such as temperature, aeration, texture, and organic matter content (Soaud *et al.*, 2011; Al-Mayahi *et al.*, 2023; and EL-Madah *et al.,* 2024). Additionally, the fresh and dry yields of several crops grown in calcareous soil increased when additional sulfur was combined with compost (Siam *et al.*, 2008; Ramzani *et al.*, 2017; and Nada *et al.*, 2023). According to Awadalla *et al.* (2007), increasing the rate of sulfur in calcareous soil resulted in decreased values of EC, pH, SAR, and ESP. Abou Hussien *et al.* (2020) reported that applying Sulphur compost caused a decrease in calcareous soil pH, EC, and $CaCO_3$ content while increasing soil CEC, OM, and available macro and micronutrients.

Magnesium plays a crucial role in plant defense mechanisms against abiotic stressors and is a necessary ingredient for plant growth. However, 90–98 % of the magnesium in the soil is integrated into the crystal lattice structure of minerals and is therefore not readily absorbed by plants. The primary source of magnesium nutrition for plant growth and development is soil. The amount of magnesium in soil varies greatly, ranging from 0.5 to 5 $g.kg^{-1}$, depending on the parent material's characteristics, the environment, and the degree of weathering (Fei *et al.,* 2023). Generally, less magnesium is released from the soil than is required to maintain optimum crop quality and yield. Plant-available magnesium release from soils is mostly determined by the length and severity of weathering, soil pH, soil moisture, and root-microbial activity (Senbayram *et al.,* 2015).

The distinctive physical and chemical characteristics of calcareous soils make it difficult to maintain soil health and achieve optimal crop productivity. Although various management strategies have been developed, the inherent limitations of these soils continue to pose challenges for sustaining soil fertility and agricultural performance. Consequently, developing sustainable management strategies, such as applying S and Mg, is imperative for mitigating the productivity limitations of calcareous soils and enhancing their fertility and functional capacity.

MATERIALS AND METHODS

Soil location and soil sampling

The used calcareous soil (21.9 % $CaCO_3$) in this study was brought from a private farm at WadiEl-Natroun Centre, El Alamein Road, Behaira Governorate, Egypt (30°30'52,80"N, 30° 00' 03,6"E) where five surface soil samples (0-30 cm) were collected from different five sites of the selected area, air-dried, ground, good mixed, sieved through a 2-mm sieve and kept. A sample portion of the fine prepared soil was taken and analysed for its physical and chemical properties and the content of available macro and micronutrients as described by Cottenie *et al.* (1982), Page *et al.* (1982), and Klute (1986). The obtained data are recorded in Table 1.

Table 1: Some physical and chemical properties of the experimental soil.

Particle size distribution (%)				Texture class
Coarse sand	Fine sand	Silt	Clay	
37.1	33.5	19.2	10.2	Sandy loam

Chemical properties				
pH (1:2.5) (Soil: water susp.)	EC $dS.m^{-1}$ (1:5) (Soil: water extract)	OM %	$CaCO_3$ %	CEC $c.mole.kg^{-1}$
8.65	3.52	0.29	21.9	16.4

Available nutrients ($mg.kg^{-1}$)								
N	P	K	S	Mg	Fe	Mn	Zn	Cu
22.5	3.30	170.10	6.15	9.13	3.50	5.22	1.45	0.70

The studied soil amendments

This study used ES and Magnesium acetate as soil amendments. The 99 % pure elemental sulphur (S) used was obtained from El-Help Company, with a pH (1:5 suspension) of 6.42. Mg was used as acetate [Mg $(CH_3COO)_2$ or MgOAC], which contains 16.9 % Mg.

Greenhouse Experiment

A pot experiment was conducted in a greenhouse throughout the winter growing season of 2020/2021. A total of 64 plastic pots with 25 and 30 cm inner diameter and depth were used, respectively. Five kilograms of prepped calcareous soil was manured by compost as an organic fertilizer at a rate of 1% (50 g/ pot) and placed in each pot. The pots were categorized into four main groups, denoted as the leading group (16 pots, main $group^{-1}$), representing S applications (0, 150, 300, and 450 mg/kg). Within each leading group, the pots were further subdivided into three subgroups (4 pots each), representing Mg applications at a rate of 0, 20, 40 and 60 mg/kg (0, 200, 400 and 600 kg/fed) in Mg acetate form (0.00,120.48, 240.96 and 361.44 kg/fed MgOAC). Thus, the experimental treatments were arranged with the experimental units in a completely randomized block design with four replicates.

Before planting, simultaneously, all pots received ordinary superphosphate fertilizer (15.5 % P_2O_5) at the recommended rate (100 $kg.fed^{-1}$ or 5 g/pot), which blended into the soil. The pots were then moistened using tap water to achieve a moisture content equivalent to 60 % of the soil water holding capacity. Each pot was planted with four seeds of faba bean plants (*Vicia Faba* Giza 716) on 15th October 2020. Ten days post-planting, the plants in each pot were thinned to two plants .

At 20 days of plant age, the Mg treatments were carried out with irrigation water. On the same day, all plates were fertilized with ammonium nitrate NH_4NO_3 (33 % N) at a rate of 50 kg/fed (0.25 g/pot) and potassium sulphate K_2SO_4 (48 % K_2O) at a rate of 50 kg/fed (0, 25 g/pot) with irrigation.

At the maturity stage (the first week of April 2021), the plants of each pot were harvested above the soil surface, and the pods of the plants (each plant sample) were separated from the straw. Also, the seeds were separated from the pods and weighed for each plant sample. The straw of each plant sample was weighed and recorded. Both seeds and straw of each plant sample were air dried. The seeds and straw yield were calculated as g/pot (g/two plants). The biological yield was determined by summing each plant sample's seed and straw yields (two plants per pot). The Biological or Harvesting Index (BI) was computed using the following equation: BI = yield of seeds/biological yield. The plant samples (seed and straw) were oven-dried at 70 °C for 24 hours, weighted, ground and kept in clean glasses up to analysed for their content of some essential nutrients (N, P, K, S and Mg) as described by Cottenie *et al.* (1982) and Page *et al.* (1982). After harvesting, the soil of each pot was taken, air dried, ground, and sieved through a 2-mm sieve. A portion of the sieved soil was taken and analysed for some chemical properties and the content of available nutrients, as described before by Cottenie *et al.* (1982) and Page *et al.* (1982).

The obtained results were statistically analyzed using CoStat (CoStat 6.311, Copyright (C) 1998-2005) software according to Snedecor and Cochran (1989).

RESULTS

1. Effect of S and Mg applications on soil chemical properties

a. Soil pH

In general, data in Table 2 show that applications of both S and Mg resulted in a decrease of calcareous soil pH, where the decrease in the pH resulting from S applications was higher than that resulting from Mg applications. Under the studied treatments, the soil pH showed a wide range, where its value ranged between 8.65 in the control treatment (free of S and Mg applications) to 7.85 in the soil treated by 450 and 60 mg/kg S and Mg, respectively. There was a significant decrease in soil pH with an increase rate of added S. For example, with zero Mg applications, soil pH decreased from 8.65 with zero S and Mg applications to 8.55, 8.38 and 8.05 with 150, 300 and 450 $mg.kg^{-1}$ S recorded relative decrease values of -1.16, -3.12 and 6.94 %, respectively.

In addition, Mg applications significantly decrease the pH of calcareous soil (Table 2). For example, with zero S applications, soil pH decreased from 8.65 with zero Mg application to 8.60, 8.55, and 8.50, with relative decrease values of -0.578, -1.159, and -1.734 % in the soil treated by 20, 40, and 60 $mg.kg^{-1}$ MgOAC, respectively.

Table 2: Effect of S and Mg on soil pH, EC, OM, and calcium carbonate content.

Added S $mg.kg^{-1}$	Added Mg $mg.kg^{-1}$	soil pH	Soil EC $dS.m^{-1}$	OM %	$CaCO_3$ %
0	0	8.65	3.62	0.75	18.33
	20	8.60	3.60	0.79	18.15
	40	8.55	3.50	0.85	17.73
	60	8.50	3.35	0.94	17.25
	Mean	8.58	3.52	0.83	17.87
150	0	8.55	3.60	0.78	18.18
	20	8.53	3.55	0.80	17.93
	40	8.50	3.50	0.85	17.33
	60	8.48	3.39	0.98	16.95
	Mean	8.52	3.51	0.85	17.60
300	0	8.38	3.58	0.82	17.82
	20	8.32	3.52	0.85	17.40
	40	8.25	3.42	0.93	16.90
	60	8.11	3.35	1.10	16.42
	Mean	8.27	3.47	0.93	17.14
450	0	8.05	3.55	0.82	17.50
	20	8.01	3.50	0.42	16.95
	40	7.93	3.36	1.02	16.32
	60	7.85	3.28	1.18	13.80
	Mean	7.96	3.42	0.86	16.14
LSD	A	0.043	0.044	0.008	0.083
	B	0.060	0.026	0.007	0.054
	A*B	0.120	0.053	0.015	0.107

b. Soil EC ($dS.m^{-1}$)

Data in Table 2 shows a significant decrease in calcareous soil EC affected by the tested application rates of both S and Mg individually and together. Its value ranged between 3.62 $dS.m^{-1}$ in the control treatment and 3.28 $dS.m^{-1}$, with a recorded relative decrease of -9.392 % in the soil treated by 450 and 60 $mg.kg^{-1}$ S and Mg, respectively.

At the same rate of added MgOAC, an increasing rate of added S was associated with a significant decrease in soil EC (Table 2). For example, at zero Mg application, soil EC decreased from 3.62 $dS.m^{-1}$ with zero S application to 3.60, 3.58, and 3.55 $dS.m^{-1}$, with a relative decrease of -0.552, -1.105, and -1.934 % in the soil treated by 150, 300, and 450 $mg.kg^{-1}$ S, respectively.

At the same application rate as S, increasing the rate of added Mg resulted in a slight decrease in soil EC (Table 2). For example, with zero S applications, soil EC decreased from 3.62 $dS.m^{-1}$ with zero Mg application to 3.60, 3.56, and 3.35 $dS.m^{-1}$, with a recorded relative decrease of -0.552, -3.315, and -7.460 % in the soil treated by 20, 40, and 60 $mg.kg^{-1}$ MgOAC, respectively.

c. OM content

The calcareous soil content of OM is low, where it was lower than 1.20 % under the experimental treatments (Table 2). Under experimental conditions, the soil content of OM ranged between 0.75 % without applications of S and Mg (control treatment) and 1.18 % in the soil receiving 450 and 60 $mg.kg^{-1}$ S and Mg, respectively. This variation was significant. Also, this variation revealed a significant effect of combined S and Mg applications on the soil content of OM.

Data on S applications on the soil content of OM, as shown in Table 2, clearly showed that S applications resulted in a significant increase in the soil content of OM. For example, at zero Mg applications, the content of OM increased from 0.75 % without S and MgOAC applications to 0.78, 0.82, and 0.82 % with a recorded relative increase of 4.00, 9.33, and 9.33 % with S application individually at rates of 150, 300, and 450 $mg.kg^{-1}$, respectively.

Regarding the effect of added Mg on the soil content of OM, the data in Table 2 show that increasing the rate of added Mg resulted in a clear increase in the soil content of OM. For example, with zero S applications, the content of soil OM was increased from 0.75 % without any applications of S and Mg to 0.79, 0.85, and 0.94 % with Mg application at rates of 20, 40, and 60 $mg.kg^{-1}$, increasing by 5.33 %, 13.33 %, and 25.33 %, respectively. This means that individual S resulted in a greater increase in OM's soil content than that resulting from individual Mg applications.

d. $CaCO_3$ content

Data in Table 2 showed a wide range in the soil content of $CaCO_3$ according to the studied treatments of both S and Mg and their application rates. This content ranged from 18.33 % in the soil receiving no S and Mg to 13.80 % in the soil fertilized by 450 and 60 $mg.kg^{-1}$ S and Mg. This means that S and Mg applications significantly decreased in the soil content of $CaCO_3$.

The application of Individual S led to a notable reduction in the soil concentration of $CaCO_3$ (Table 2). For example, in the soil received 0 $mg.kg^{-1}$ S and Mg, the soil content of $CaCO_3$ decreased from 18.33 % to 18.18, 17.82, and 17.5 %, with a recorded relative decrease of -0.818, 2.782, and -4.825 % with the increase rate of added S individually to 150, 300, and 450 $mg.kg^{-1}$, respectively.

2. The effect of S and Mg applications on the calcareous soil content of available N, P, K, and S.

The data in Table 3 showed the calcareous soil content ($mg.kg^{-1}$) of available N, P, K, and S affected by individual and combined applications of S and Mg.

The contents of these nutrients appeared wide response to both S and Mg applications, where these contents increased from 23.30, 3.33, 170.70 and 6.11 mg.kg^{-1} in the soil without applications (control) to 26.25, 4.73, 231.30 and 81.13 mg.kg^{-1} recorded relative increase of 12.67, 42.04, 35.50 and 1227.8 % for available N, P, K and S to the soil fertilized by 450 and 60 mg.kg^{-1} S and Mg, respectively. The rate increases of these nutrient contents were significant.

Data on calcareous soil content of available N affected by S applications individually in Table 3 showed a significant increase in this content. For example, the content of available N was increased from 23.30 mg.kg^{-1} with zero S and Mg application to 23.45, 23.70, and 24.15 mg.kg^{-1}, recording an increase of 0.64, 1.72, and 3.65 % with application of 150, 300, and 450 mg.kg^{-1} of S alone, respectively.

Similar increases in the soil content of available N were observed with Mg applications (Table 3). For example, with zero S and Mg application, the content of available N was 23.30 mg kg^{-1}, which increased to 23.50, 23.82, and 24.25 mg.kg^{-1} with increases of 0.86, 2.23, and 4.20 % in the soil fertilized by Mg individually at rates of 20, 40, and 60 mg.kg^{-1}, respectively.

Individual S applications under calcareous soil conditions were associated with a significant increase in the soil content of available P (Table 3). For example, the soil content of available P was increased from 3.33 mg.kg^{-1} with zero S and Mg applications to 3.37, 3.44, and 3.55 mg.kg^{-1}, recording an increase of 1.20, 3.30, and 6.61 % in the soil receiving 150, 300, and 450 mg.kg^{-1} S alone. A similar increase in the soil content of available P was observed with Mg applications (Table 3). For example, the Calcareous soil content of available P was increased from 3.33 mg.kg^{-1} in the unfertilized soil with either S or Mg to 3.40, 3.60, and 3.92 mg.kg^{-1} with relative increases of 2.10, 8.10, and 17.72 % in the soil treated by Mg at 20, 40, and 60 mg.kg^{-1}, respectively.

Data in Table 3 shows a slight increase in the calcareous soil content of available K. For example, the soil content of available K was increased from 170.70 mg.kg^{-1} in the soil without applications of S and Mg to 172.50, 173.50 and 175.10 mg.kg^{-1} recorded increase percent of 1.05, 1.64 and 2.58 % in the soil fertilized by S alone at rates of 150, 300 and 450 mg.kg^{-1}, respectively. A similar slight increase in the calcareous soil content was observed in Table 3. For example, under experimental conditions, the soil content of available Mg was increased from 170.70 mg.kg^{-1} with zero S and Mg applications to 171.50, 178.30 and 190.50 mg.kg^{-1} with percent increases of 0.47, 4.45 and 11.56 % in the soil fertilized by 20, 40 and 60 mg.kg^{-1} of Mg individually, respectively.

In general, individual S applications to calcareous soils resulted in their content of available S (Table 3). For example, the soil content of available S was increased from 6.11mg kg^{-1} with zero S and Mg applications to 25.46, 50.50, and 72.70 mg.kg^{-1} in the soil received 150, 300, and 450 mg.kg^{-1} S with zero Mg application, resulting in an increase of 316.70, 726.51, and 1089.85 %. Individual applications of Mg significantly affected the soil content of available S, especially at high application rates, as shown in Table 3. For example, this content was increased from 6.11 mg.kg^{-1} without S and Mg applications to 6.33, 6.37, and 6.50 mg.kg^{-1} with an increase of 3.60, 4.26, and 6.38 % in the soil fertilized by 20, 40, and 60 mg.kg^{-1} Mg alone, respectively.

3- Magnesium forms in the calcareous soil affected by S and Mg applications

Data on both soluble and available content of Mg in the calcareous soil showed a clear response to both individuals. They combined S and Mg applications, where these applications resulted in a significant increase in the soil content of both soluble and available Mg. The contents of soluble and available Mg increased from 2.33 and 9.11 mg.kg^{-1} without S and Mg applications to 24.50 and 70.78 mg.kg^{-1} with recorded increase percentage of 952.50 and 676.87 % in the soils receiving 450 and 60 mg.kg^{-1} S and Mg, respectively.

Data in Table 3 showed a significant increase in the soluble and available Mg content in the calcareous soil as added S increased from 0 to 450 mg.kg^{-1}. For example, the contents of soluble and available Mg were increased from 2.33 and 9.11 mg.kg^{-1} in the soil untreated by either S or Mg to 2.40, 2.50 and 2.65 mg.kg^{-1} recording increase percents of 3.00, 7.30 and 13.73 % for soluble Mg and to 9.65, 10.22 and 10.93 mg.kg^{-1} with increase percents of 5.93, 12.18 and 19.98 % for available Mg in the soil fertilized by 150, 300 and 450 mg.kg^{-1} S without Mg applications, respectively.

Similar increases in the calcareous soil contents of both soluble and available Mg resulted from Mg applications alone (Table 3). For example, with zero S and Mg applications, the soil content of soluble and available Mg were 2.33 and 9.11 mg.kg^{-1} which increased to 5.95, 9.13 and 16.22 mg.kg^{-1} recording increase percent of 155.54, 291.85 and 596.14 % for the content of soluble Mg and to 16.16, 30.30 and 50.15 mg.kg^{-1} with increase percent of 77.39, 232.60 and 450.99 % for the content of available Mg with Mg applications at rates of 20, 40 and 60 mg.kg^{-1}, respectively.

Table (3): Effect of adding S and Mg on the content (mg.kg^{-1}) of some available soil nutrients.

Added S mg.kg^{-1}	Added Mg mg.kg^{-1}	N	P	K	S	Mg	
						Soluble	Available
0	0	23.30	3.33	170.70	6.11	2.33	9.11
	20	23.50	3.40	171.50	6.23	5.95	16.16
	40	23.82	3.60	178.30	6.32	9.13	30.30
	60	24.25	3.92	190.50	6.50	16.22	50.15
	Mean	23.72	3.56	177.75	6.29	8.41	26.43
150	0	23.45	3.37	172.50	25.46	2.40	9.65
	20	23.75	3.47	173.40	26.50	6.05	17.85
	40	23.98	3.72	182.90	28.10	11.55	33.50
	60	24.82	4.15	204.40	30.30	17.80	54.45
	Mean	24.00	3.68	183.30	27.59	9.45	28.86
300	0	23.70	3.44	173.50	50.50	2.50	10.22
	20	24.15	3.55	177.70	52.15	6.82	19.93
	40	24.87	3.95	190.80	53.75	12.73	31.65
	60	25.92	4.50	211.56	56.17	20.20	60.75
	Mean	24.66	3.86	188.39	53.14	10.56	30.64
450	0	24.15	3.55	175.10	72.70	2.65	10.93
	20	24.63	3.65	179.20	74.85	8.05	24.50
	40	25.10	4.05	198.10	77.77	13.64	40.65
	60	26.25	4.73	231.30	81.13	24.50	70.78
	Mean	25.03	4.00	195.93	76.61	12.21	36.72
LSD	A	0.080	0.007	0.094	0.065	0.044	0.044
	B	0.043	0.012	0.098	0.035	0.037	0.037
	A*B	0.086	0.024	0.196	0.071	0.074	0.073

4- Effect of S and Mg applications on faba bean yield

Straw, seeds, and biological yields of faba bean plants were significantly affected by both individual and combined applications of S and Mg under calcareous soil conditions (Table 4). These yields appeared to vary widely depending on the experimental treatments, ranging between 3.35, 6.13, and 9.48 $g.pot^{-1}$ in the soil without S and Mg applications and 5.73, 10.62, and 16.35 $g.pot^{-1}$, recording an increase of 71.04, 73.25, and 72.45 % in the soil treated by combined application of 450 and 60 $mg.kg^{-1}$, respectively.

Individual S applications at different rates were associated with a significant increase in straw, seeds, and biological yields of faba bean plants grown on the calcareous soil, as shown in Table 4. For example, straw, seeds, and biological yields increased from 3.35, 6.13, and 9.48 $g.pot^{-1}$ in the soil receiving 0 S and Mg applications to 3.70, 4.13, and 4.62 $g.pot^{-1}$, with an increase of 9.46, 23.28, and 37.91 % for straw yield, 7.25, 7.85, and 8.57$g.pot^{-1}$ recorded an increase of 18.27, 28.06, and 39.80 % for seed yield and 10.93, 11.98, and 13.19 $g.pot^{-1}$, with an increase of 15.30, 25.37, and 39.14 % for biological yield in the plants fertilized by 150, 300, and 450 $g.kg^{-1}$ S alone, respectively.

As well as straw, seeds, and biological yields of faba bean were increased significantly, followed by single applications of Mg (Table 4). For example, these yields were increased from 3.35, 6.13 and 9.48 $g.pot^{-1}$ to 3.60, 3.93 and 4.30 $g.pot^{-1}$ recording increase percent of 7.46, 17.31 and 28.35% for straw yield, 6.60, 7.48 and 8.62 $g.pot^{-1}$ with increase percent of 7.67, 22.02 and 40.62% for seeds yield and 10.20, 11.41 and 12.92g pot^{-1} with increase percent of 7.59, 20.36 and 39.29 % for biological yield in the soil treated by 20, 40 and 60 $mg.kg^{-1}$ Mg alone, respectively.

5- Effects of S and Mg applications on nutrient uptake by faba bean plants

As shown in Table 5, increasing rates of S and Mg addition alone and in combination significantly increased the uptake of N, P, K, S, and Mg by the bean plant (seed and straw), with these contents appearing in a wide range, for the seeds the uptake of N, P, K, Mg ranged between 128.73, 76.63, 109.11, 31.88 and 49.65 $mg.pot^{-1}$ with zero application S and Mg applications and 390.82, 215.59, 312.23, 159.30 and 172.04 $mg.pot^{-1}$ for the plants grown on the soil fertilized by 450 and 60 mg S kg^{-1}, respectively. The ranges in the straw were 51.93, 26.13, 38.53, 11.06, and 16.75 $mg.pot^{-1}$ without S and Mg applications and 160.44, 90.53, 117.47, 46.99, and 71.63 $mg.pot^{-1}$ with 450 and 60 mg S and Mg application rates, respectively. This means that, with the same S and Mg treatment, nutrient uptake by seeds of faba bean plants was higher than that found in the straw.

Data of N uptake by both seeds and straw of faba bean plants as shown in Table (5) show a significant increase in this uptake followed by individual applications of S. For example, seeds and straw uptake of N was increased from 128.73 and 51.93 mg pot^{-1} without S and Mg applications to 160.95, 188.40 and 229.68 mg pot^{-1} recording increase percent of 25.02, 46.35 and78.42 % for seeds and up to 59.20, 80.48 and 85.47 $mg.pot^{-1}$ with increase percent of 13.20, 54.98 and 58.81% for straw in the plants fertilized by 150, 300 and 450 $mg.kg^{-1}$ S alone, respectively. In addition, similar increases in N uptake by both seeds and straw of faba bean plants grown on calcareous soil were found due to Mg application alone, especially at its high application rate (Table 5). For example, in the soil unfertilized by S, N uptake by seeds and straw were increased from128.73 and 51.93 mg pot^{-1} to 150.48, 198.22 and 271.53 $mg.pot^{-1}$ with increase percent of 16.90, 53.98 and 110.93 % for the seeds and to 58.68, 70.74 and 88.15 $mg.pot^{-1}$ with increase percent of 12.99, 36.22 and 69.74 % for the straw of faba bean plants fertilized by 20, 40 and 60 $mg.kg^{-1}$ Mg alone, respectively.

Table (4): Straw, seeds, and biological yield (g/ pot) and biological index of faba bean plants affected by S and Mg application in calcareous soil

Added S $mg.kg^{-1}$	Added Mg $mg.kg^{-1}$	Straw yield	Seeds yield	Biological yield	Biological index
0	0	3.35	6.13	9.48	0.647
	20	3.6	6.6	10.20	0.647
	40	3.93	7.48	11.41	0.656
	60	4.3	8.62	12.92	0.667
	Mean	3.795	7.208	11.00	0.654
150	0	3.70	7.25	10.95	0.662
	20	3.82	7.87	11.69	0.673
	40	4.10	7.98	12.08	0.661
	60	4.85	9.40	14.25	0.660
	Mean	4.12	8.13	12.24	0.664
300	0	4.13	7.85	11.98	0.655
	20	4.35	8.12	12.47	0.651
	40	4.77	9.20	13.97	0.659
	60	5.25	10.48	15.73	0.666
	Mean	4.63	8.91	13.54	0.658
450	0	4.62	8.57	13.19	0.650
	20	4.93	9.22	14.15	0.652
	40	5.15	9.93	15.08	0.658
	60	5.73	10.62	16.35	0.650
	Mean	5.11	9.59	14.69	0.652
LSD	**A**	0.024	0.033	0.124	
	B	0.013	0.029	0.061	
	A*B	0.027	0.058	0.121	

Data in Table 5 shows a significant increase in P uptake by both seeds and straw of faba bean plants grown on calcareous soil due to individual and combined applications of S and Mg. For example, seeds and straw uptake of P was increased from 76.63 and26.13 $mg.pot^{-1}$ with S and Mg applications to 94.25, 107.55 and 126.84 mg pot^{-1} with increase percent of 22.99, 40.35 and 65.22 % in the seeds and reached to 29.60, 34.28 and 39.27 mg pot^{-1} with increase percents of 13.28, 31.19 and 50.29 % in the straw of faba bean plants fertilized by 150, 300 and 450 $mg.kg^{-1}$ S, respectively. On the other hand, with zero S and Mg applications, P uptake by seeds and straw of faba bean plants were increased from 76.63 and 26.13 $mg.pot^{-1}$ to 85.14, 97.24 and 148.26 $mg.pot^{-1}$ with increase percent of 11.11, 26.90 and 93.48 % in the seeds and to 29.52, 37.34 and 51.60 $mg.kg^{-1}$ with increase percents of 12.97, 42.90 and 97.47 % in the straw of faba bean plants fertilized by 20, 40 and 60 $mg.kg^{-1}$ Mg alone, respectively.

K uptake ($mg.pot^{-1}$) by both seeds and straw of faba bean plants planted on calcareous soil increased significantly as a result of S and Mg applications in single and combined applications (Table, 5), where K uptake increased from 109.11 and 38.53 $mg.pot^{-1}$ in the seeds and straw of faba bean planted on the soil without any applications of S and Mg to 131.95, 153.08 and 167.12 $mg.pot^{-1}$ with increase percents of 20.93, 40.96 and 53.17 % with the seeds and to 43.66, 51.63 and 62.37 $mg.pot^{-1}$ with percent increases of 13.31, 45.92 and 61.87 % with the straw of faba bean plants fertilized by 150, 300 and 450 $mg.kg^{-1}$ S individually, respectively. Also these contents reached to121.44, 146.61 and 187.92 mg.pot^{-1} in the seeds with increase percents of 11.30, 34.37 and 72.23 % in the seeds and to 43.20, 51.09 and 63.64 mg kg^{-1} recorded increase percents of 12.12, 32.60 and 65.17 % in the straw in soils fertilized by 20, 40 and 60 mg.kg^{-1} Mg, alone, respectively.

Similar significant increases of Mg uptake by seeds and straw of faba bean plants were achieved due to S and Mg application individually and in combination (Table 5). Individual S applications increased Mg uptake by seeds and straw from 31.88 and 11.06 mg.pot^{-1} with zero S application to39.15, 45.53 and 53.13 mg.pot^{-1} with increase percents of 22.80, 42.82 and 66.66 % and to 12.21, 15.69 and 19.40 mg.pot^{-1} with recorded increase percents of 10.40, 41.86 and 75.41 % in the straw of faba bean plants planted on the soil treated by single applications of S at rates of 150, 300 and 450 mg.kg^{-1}, respectively. As well as, similar increases of Mg uptake by seeds and straw were resulted from single Mg applications, where its values reached to39.60, 54.60 and 77.58 mg.pot^{-1} recorded increase percents of 24.22, 71.27 and 143.35 % in the seeds and 12.60, 15.72 and 15.48 mg.pot^{-1} with increase percents of 13.92, 42.13 and 39.96 % in the straw of the plants fertilized by 20, 40 and 60 mg.kg^{-1} Mg, respectively.

Table (5): Seeds and straw of faba bean plants uptake (mg/pot) of N, P, K, Mg, and S affected by S and Mg applications in calcareous soil.

Added S mg.kg^{-1}	Added Mg mg.kg^{-1}	N		P		K		Mg		S	
		Seeds	Straw	Seeds	Straw	Seeds	Straw	Seeds	Straw	Seeds	Straw
0	0	128.73	76.63	109.11	26.13	38.53	51.93	31.88	11.06	49.65	16.75
	20	150.48	85.14	121.44	29.52	43.20	58.68	39.60	12.60	55.44	18.72
	40	198.22	97.24	146.61	37.34	51.09	70.74	54.60	15.72	71.06	23.58
	60	271.53	148.26	187.92	51.60	63.64	88.15	77.58	15.48	82.75	32.25
	Mean	187.24	101.82	135.33	36.15	49.11	67.37	50.92	13.71	64.73	22.83
150	0	160.95	94.25	131.95	29.60	43.66	59.20	39.15	12.21	63.80	19.61
	20	188.88	107.82	153.47	33.23	48.13	64.94	47.22	16.04	74.77	22.92
	40	237.01	128.48	167.58	45.10	56.58	79.95	59.05	18.86	87.78	29.93
	60	314.90	167.32	218.08	65.96	77.60	113.98	103.40	26.68	124.08	42.68
	Mean	225.43	124.47	167.77	43.47	56.49	79.52	62.21	18.45	87.61	28.79
300	0	188.40	107.55	153.08	34.28	51.63	70.62	45.53	15.69	76.93	28.08
	20	215.18	117.74	164.84	40.46	56.99	80.48	55.22	21.75	87.70	34.80
	40	299.00	163.76	202.40	58.19	71.55	103.99	78.20	27.67	115.92	44.36
	60	368.90	195.98	259.90	75.60	93.45	131.25	131.00	36.75	155.10	58.80
	Mean	267.87	146.26	195.05	52.13	68.40	91.02	77.49	25.47	108.91	41.51
450	0	229.68	126.84	167.12	39.27	62.37	85.47	53.13	19.40	98.56	36.96
	20	274.76	146.60	201.00	48.31	70.50	97.12	70.07	28.59	113.41	45.36
	40	337.62	183.71	258.18	66.95	93.73	120.00	95.33	33.48	139.02	56.14
	60	390.82	215.59	312.23	90.53	117.47	160.44	159.30	46.99	172.04	71.63
	Mean	308.22	168.18	234.63	61.27	86.02	115.76	94.46	32.11	130.76	52.52
LSD	**A**	0.078	0.052	0.028	0.051	0.057	0.019	0.041	0.024	0.021	0.033
	B	0.046	0.049	0.031	0.037	0.040	0.016	0.023	0.028	0.024	0.027
	A*B	0.091	0.097	0.063	0.074	0.080	0.033	0.047	0.056	0.048	0.053

Data in Table 5 shows a significant increase in S uptake by both seeds and straw of faba bean plants grown on calcareous soil due to individual and combined applications of S and Mg. For example, an increasing added rate of Mg from 0 to 60 $mg.kg^{-1}$ resulted in an increase of S uptake from 49.65 and 16.75 to 82.75 and 32.25, with a corresponding increase of 66.67 and 92.53 % in faba bean seeds and straw, respectively. Similar increases in faba bean seeds and straw uptake of S resulted from individual S application. However, higher increments of S uptake were noticed in combined applications of S and Mg. For example, with higher application rates of Mg and S applications (20 and 450 $mg.kg^{-1}$), S uptake by seeds and straw of faba bean plants was 172.04 and 71.63 $mg.pot^{-1}$, with an increase of 246.50 and 327.64 %, respectively.

DISCUSSION

1- Effect S and Mg application on chemical properties of calcareous soil

a- Soil pH

Calcareous soil pH appeared to be highly affected by S applications compared to that of Mg application. Such slight decreases may be attributed to some acidic organic compounds produced from plant roots and soil microorganisms. Similar decrease in soil pH due to Mg application was pointed out before that in calcareous soils fertilized by different sources of Mg fertilizers (Hamad et al., 2015). They added that, following Mg application as fertilizer, a portion of $CaCO_3$ may be transferred to $MgCO_3$, which is characterized by a lower pH than that of $CaCO_3$.

These decreases mainly resulted from S oxidation chemically and biologically, which produced H_2S and H_2SO_4 (El Gamal, 2015). In this respect as well as under calcareous soil conditions, Nada et al. (2023) found a significant decrease in soil pH treated by different forms of S. As well as Aiad (2024) pointed that compost application in Sulphur compost form resulted in a more decrease in soil pH compared that resulted from un-Sulphur compost applications. These results are similar to those obtained before by Elgezery (2016) and Abou Hussien *et al.* (2017). Recently, Radwan *et al.* (2024) showed a superior decrease effect of ES on soil pH compared with that resulting from gypsum applications.

With the S application, $CaCO_3$ is transferred to $CaSO_4$, which is characterized by low pH, especially under calcareous soil conditions (El Gamal, 2015; Nada *et al.,* 2023). Combined applications of both S and Mg to calcareous soil led to greater decreases in the soil pH compared with their individual applications.

b- Soil EC

This study's data also showed a decrease in EC values of calcareous soil as a result of individual and combined applications of S and Mg, where these additions enhanced plant growth and its uptake of different elements. Moreover, S and Mg applications may react with some soil compounds, producing insoluble and precipitated compounds that decrease soil EC (Tantawy *et al.*, 2012; El Gamal, 2015; Hamad *et al.*, 2015).

c. Soil OM and $CaCO_3$

The slight increase in the soil content of OM as a result of S and Mg applications individually and in combination may be explained by the effect of these applications on the increase in plant growth and residues reaching the soil. As well as these applications increased the biomass of soil microorganisms and plant roots exudates (Hamad *et al.*, 2015, and El Melegi, 2023). On the other hand, S and Mg applications decreased the soil content of $CaCO_3$, where S transferred $CaCO_3$ to $CaSO_4$, while Mg applications transferred calcium in carbonate to $MgCO_3$. $CaSO_4$ and $MgCO_3$ were less stable and more soluble than $CaCO_3$. Also, H_2SO_4 produced in the soil as a product of S oxidation reacted with $CaCO_3$, producing Ca $(HCO_3)_2$, which is characterized by high solubilization (El Gamal, 2015; Abd ElHafez, 2023; Nada *et al.,* 2023, and Aiad, 2024)

2- Effect of S and Mg applications on available N, P, K, S, and Mg soil content

In general, calcareous soils, especially those characterized by coarse texture, have a low content of available macro and micronutrients. This low content is attributed mainly to high pH and the content of $CaCO_3$, where these properties resulted in a loss of N in volatilization as NH_3, and most of these nutrients reacted with $CaCO_3$ and transferred to unavailable forms. The main reaction is the precipitation of P in calcium phosphate form, while CO_3^{-2} ions transfer most micronutrients in carbonate form (Basak, 2006; Marschner, 2012). Therefore, these soils must be treated with soil amendments such as ES, and fertilization must be carried out in a suitable form.

So, in this study, S and Mg were added; these additions improve the chemical properties of these soils, especially the decrease in both soil pH and the content of $CaCO_3$, plus their positive effect on the soil content of OM. These changes significantly increased nutrient availability (El Gamal,2015; Hamad *et al.,* 2015). Before that, Hamad *et al.* (2015), Elgezery (2016), and Abou Hussien *et al.* (2017) found a significant increase in the calcareous soil content of available nutrients as a result of S and Mg applications. Recently, Nada *et al.* (2023) obtained similar results under calcareous soil conditions, following S applications in different forms.

3- Effect of S and Mg applications on the yield of faba bean (seeds and straw) plant and its uptake of nutrients

Plant growth is greatly affected by soil chemical properties and the content of available plant nutrients. Therefore, they were associated with improving and enhancing plant growth and its uptake of essential nutrients. This enhancement of plant growth resulted from improvements in the growing media, such as a decrease in soil pH and EC and an increase in the content of OM and available nutrients. This means that S and Mg applications reduced the harmful effects of $CaCO_3$ on plant growth and their uptake of nutrients. Before that, Tantawy and Hamad (2012) and Hamad *et al.* (2015) found a significant increase in plant growth under calcareous soil conditions due to Mg applications in different forms. Before that, Elgezery (2016) and Abou Hussien *et al*. (2017) found a significant increase in barley plant growth and its uptake of macro and micronutrients in the calcareous soil treated with ES and S compost forms. Abd ElHafez (2023) and El Melegi (2024) found a similar increase in the effect of S application in different forms (elemental, gypsum, and S compost) on plant growth and its nutrient uptake under salt-affected soil conditions, where these additions reduced soil pH and EC and increased the soil content of available nutrients. Aiad (2024) recently found a high growth rate and nutrient uptake by tomato plants planted on saline soil by adding S compost in the nano size fraction.

CONCLUSIONS

The obtained data of this study concluded that Effective management of calcareous soils is essential for achieving sustainable agricultural production, given the challenges posed by their unique chemical and physical characteristics. Among the various management strategies, S application is recognized as a key amendment for improving calcareous soils. It plays a significant role in enhancing soil chemical properties and increasing nutrient availability. Furthermore, the application of sulfur has been shown to improve the efficiency of Mg fertilizers. Notably, the combined and individual applications of S and Mg have led to significant improvements in both the yield and quality of faba bean (Vicia faba L.) grown in calcareous soils.

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تقييم كفاءة التسميد بالمغنيسيوم في الأراضى الجيرية المعاملة بالكبريت

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الملخص

تم إجراء تجربة لتقيم استجابة نبات الفول البلدي (جيزة ٧١٦) للتسميد بالمغنسيوم وتفاعله مع اضافات الكبريت التى تعظم من امتصاص العناصر الغذائية المتوفرة فى التربة الجيرية وتشير الدراسة إلى كيفية تأثير ذلك على إنتاجية نبات الفول البلدي وتشير النتائج التى تم الحصول عليها أن الرقم الهيدروجينى للتربة والتوصيل الكهربى ومحتواها من كربونات الكالسيوم قد انخفض نتيجة اضافات الكبريت، والمغنيسيوم. فى حين أدت هذه الاضافات إلى زيادة محتوى التربة من المادة العضوية والعناصر الغذائية النيتروجين والفوسفور والبوتاسيوم والكبريت وكذلك المغنيسيوم وكانت إضافات الكبريت أعلى مقارنة بتلك الناتجة من المغنيسيوم أدى استخدام الكبريت، والمغنسيوم إلى زيادة معدلات القش وبذور نبات الفول البلدي من ٣,٣٥ الى٦,١٣ جم/أصيص. وعند المعاملات الخالية من الكبريت، والمغنيسيوم إلى زيادة من ٥,٧٣الى١٠,٦٢ والنباتات التى تلقت من ٤٥٠,٦٠ كبريت ومغنسيوم /كجم. بالإضافة إلى هناك زيادة معنوية فى امتصاص القش والبذور (ملجم/اصيص) نيتروجين وفوسفور، بوتاسيوم، مغنسيوم. زاد معدل امتصاص العناصر من ٥١,٩٣، ٢٦,٢٣، ٣٨,٥٣، ١١,٠٦ و١٦,٧٥ إلى ١٦٠,٤٤، ٩٠,٥٣، ١١٧,٤٧، ١٥٩,٣٠ و٧١,٦٣، ومن ١٢٨,٧٣، ٧٦,٦٣، ١٠٩,١١، ٣١,٨٨ و٤٩,٦٥ إلى ٣٩٠,٨٢، ٢١٥,٥٩، ٣١٢,٢٣، ١٥٩,٣٠ و ١٧٢,٠٤ فى قش وبذور نبات الفول البلدي بالترتيب مع نتائج زيادة إضافة الكبريت والمغنيسيوم من صفر الى ٤٥٠,٦٠ملجم/أصيص. لذا فإن إدارة الأراضي الجيرية يجب تتضمن اضافات الكبريت والمغنيسيوم لتحسين جودة الأرض الجيرية وانتاجيتها.

الكلمات المفتاحية: التربة الجيرية، الفول البلدي، التسميد بالكبريت والمغنيسيوم.