Study of the major elements (Fe, Zn, Cu) in wheat product (Triticum aestivum L) grown in two soils with different gypsum content and treated with phosphorus and magnesium

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Abstract

A field experiment was conducted during the 2023–2024 growing season at the Research Station of the College of Agriculture, Tikrit University, to study the micronutrient status of wheat grown in two soils with different gypsum contents (5% and 15%) and fertilized with different levels of phosphate and magnesium fertilizers, according to a randomized complete block design (RCBD). Magnesium fertilizer (MgSO4.7H2O) was added at three levels (0, 60, and 120 kgMgh^{-1}), and phosphate fertilizer (TSP) was added at four levels (0, 60, 80, and 100 kg P ha^{-1}) in the 5% gypsum soil and (0, 65, 85, and 100 kgph^{-1}) in the 15% gypsum soil**.** The results showed that adding phosphate and magnesium fertilizers led to a significant increase in the dry matter yield of wheat at both locations. The level of (80) kgph^{-1} in 5% soil and (85) kgph^{-1} for phosphorus gave the highest dry matter yield and the highest concentrations of micronutrients (Zn, Cu). At the level of magnesium Mg1 (60 kg Mgh^{-1}) for both soils, iron Fe exceeded the level of (60 and 65) kg p.h^{-1}. As for the interaction, the treatment P1Mg1 (80 kgph^{-1} + 60 kg Mgh^{-1}) in 5% gypsum soil and P_1Mg_1 (85 kgph^{-1} + 60 kgph^{-1}) in 15% gypsum soil were superior in giving the highest dry matter yield and the highest amount of absorbed micronutrients (Zn, Cu) by an amount of 68.75, 12.43 for the two elements respectively in 5% soil and (64.36, 12.24) in 15% soil . As for iron (Fe), the Mg1P2 treatment was superior, yielding (133.71, 109.80) at the 5% and 15% gypsum sites, respectively. The high levels of phosphorus (P_3) and magnesium (2Mg) led to a decrease in the dry matter yield and the amounts of micronutrients (Fe, Zn, Cu) absorbed at both sites.

Keywords: **Micronutrients , gypsum , phosphorus , magnesium , wheat.**

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Introduction

Wheat (Triticum aestivum L.) is one of the most important cereal crops globally, forming a cornerstone of human and animal nutrition. It is considered a crop sensitive to nutrient deficiencies in the soil. Soils in arid and semi-arid regions are characterized by high levels of carbonates and sulfates, along with a high degree of alkalinity and calcium ion saturation. This leads to a deficiency in the availability of most macro- and micronutrients, including iron (Fe), zinc (Zn), and copper (Cu). These elements are essential for plant growth due to their vital role in physiological processes such as enzyme activation, photosynthesis, protein synthesis, and vegetative growth. Consequently, their deficiency in the soil can lead to reduced yields and grain quality[1]. The use of nitrogen, phosphate, and potassium fertilizers to increase cereal crop productivity leads to a continuous depletion of most nutrients, including magnesium and micronutrients, especially in gypsum soils with a low supply capacity for most nutrients. In this regard, [2], in her study of some gypsum soils, indicated that available magnesium decreases with increasing gypsum content. Available magnesium decreased from 18.48 to 7.34 $mgkg^{-1}$ soil when the gypsum content increased from 5% to 25% in the studied soils. Furthermore, adding magnesium to these soils resulted in a significant increase in dry matter yield and the amount of micronutrients absorbed in wheat at all application levels. Proper preparation of the magnesium element for growing plants through the supply capacity of the soil or by adding magnesium fertilizers to the soil will delay the dissolution of chlorophyll in the leaves, or in other words, prolong the period of chlorophyll activity in the leaves, and this will be reflected in the growth and yield of growing plants [3]. In this context, fertilization with phosphorus (P) and magnesium (Mg) directly and indirectly interferes with micronutrient availability. Phosphorus is a key element in plant energy and metabolism, but it can inhibit zinc and iron uptake if present at high levels in the soil due to the formation of non-absorbable complexes or competitive effects between the elements. Magnesium, on the other hand, is essential for chlorophyll synthesis and phosphorus transport within the plant and can affect the balance of other nutrients. These interactions have significant implications for micronutrient uptake and, consequently, for wheat quality and yield [4]. Although there are many studies that have addressed the importance of

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micronutrients (Fe, Zn, Cu) in wheat crop nutrition and their effect on growth and yield, as well as other studies that have discussed the properties of gypsum soils and the effect of gypsum on some chemical and physical properties of the soil, there is a clear lack of studies that integrate these axes within one framework. Therefore, the study aims to study the status of micronutrients in wheat crops growing in two different soils in their gypsum content and treated with phosphorus and magnesium.

Materials and Methods

Two field experiments were conducted at two different locations with varying gypsum content at the College of Agriculture Research Station, Tikrit University. The first location had soil with a 5% gypsum content, and the second location had soil with a 15% gypsum content, during the 2023-2024 growing season. A soil sample was taken from each location before the experiment to estimate some physical and chemical properties (Table 1). According to the methods described in [5], available phosphorus in the soil was estimated using the [6] method. Available magnesium and potassium were estimated using the [7] method by extraction with ammonium acetate (1N). Gypsum was estimated using the [8] method. The tillage and leveling were carried out using a disc plow. The field was divided into 1.5 m² (1.5 * 1) plots for each soil location, with a spacing of 0.5 m between plots. The experiment was designed for each location according to a randomized complete block design (RCBD) with three magnesium levels and four phosphorus levels, and with three replicates. The number of experimental units per location was 36 (4 × 3 × 3). Magnesium fertilizer was added in a single application at planting in the form of magnesium sulfate ($MgSO_4.7H_2O$) at three levels (0, 60, and 120 $kgMgha^{-1}$). As for the phosphate fertilizer (TSP), it was added in one go at planting at four levels (0, 60, 80, 100 $kgpha^{-1}$) for 5% soil and (0, 65, 85, 100 $kgpha^{-1}$) for 15% soil. The wheat seeds of the Abaa 99 variety were planted on 9/12/2023 and the planting was in rows with a distance between one row and another (15 cm) and at a seeding rate of 132 $kgha^{-1}$. Nitrogen fertilizer was added in the form of urea (46% N) in two applications, the first at planting and the second at the branching stage, at a rate of (200 $kgNha^{-1}$). Potassium

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fertilizer was added at a rate of 160 $kgKha^{-1}$ in the form of potassium sulfate fertilizer (43% K) in two applications, the first at planting and the second at the branching stage, along with the second application of nitrogen fertilizer. Agricultural operations were carried out, including irrigation and pest control, as needed. The experiment was harvested on 15/5/2024, with two average rows from each experimental unit, in order to calculate the dry matter yield and the concentrations and quantities absorbed from the micronutrients (Fe, Zn, Cu). The data were statistically analyzed according to the approved experimental design. Analysis of variance (ANOVA) was performed to determine the significance of the effects of the studied factors and their interactions on the studied traits. When significant differences were found between the treatments, the means were compared using the Least Significant Difference (LSD) test at a probability level of 0.05 to determine the actual differences between the means [9].

Table (1) Some physical and chemical properties of the soil under study

Characteristic	Unit	Soil 1	Soil 2
Sand	$g.kg^{-1}$ soil	730	470
Silt		70	280
Clay		200	250
Soil texture		SCL	L
PH		7.74	7.82
EC	dS/m	2.50	2.30
CEC	$cmol.kg^{-1}$	13.40	12.36
Organic matter	$g.kg^{-1}$ soil	12	10
Gypsum		50	150
CO_3		328	285
$CaCO_3$		105	156
N-available	$ml.kg^{-1}$ soil	23.0	20.2
P- available		6.22	4.22
K- available		118	11.0
Mg- available		19.63	10.78
Dissolved Ions			
Na	$Mmol.L^{-1}$	1.22	1.58
K		0.88	0.86
Ca		7.32	9.75
Mg		5.40	3.42
Cl		2.71	1.96
CO_3		nil	Nil

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HCO_3		1.86	1.98
SO_4		8.95	12.86

Results and Discussion

Dry Matter Yield

Table (2) shows the results of the wheat dry matter yield significantly affected by the addition of phosphate and magnesium fertilizers at both locations. The addition of phosphate fertilizer resulted in a significant increase in dry matter yield. The percentage increase compared to the no-fertilization treatment (P0) was 87.45%, 93.33%, and 72.16% at the first location (5% gypsum), while at the second location (15% gypsum) it was 100.83%, 97.08%, and 65.83% at levels P1, P2, and P3, respectively. This indicates a high response to phosphate fertilization under these gypsum soil conditions, as the available phosphorus at both locations was below the critical limit for available phosphorus. The results also show that the percentage increase in yield compared to the P0 treatment (no addition) was highest at the second site (15% gypsum). This is related to phosphorus adsorption at exchange sites in the soil, which is consistent with the findings of Al-[4]. Their results indicated that increasing the amount of gypsum led to a decrease in phosphorus adsorption values, and that most of the adsorbed phosphorus was at the Xm3 and Xm2 surfaces with a low binding energy. This allowed the phosphorus to be easily released, thus increasing the phosphorus concentration in the soil solution. This was reflected in the dry matter yield and the amounts of nutrients absorbed. Therefore, the effect on dry matter yield was evident at the second site (15% gypsum) compared to the first site (5% gypsum). The results indicate that level P1 (as an average) was optimal, yielding the highest dry matter yield and not significantly different from level P2. Thus, the phosphorus levels of 80 and 85 kg P ha^{-1} for the two sites, respectively, are the required levels to achieve the highest grain yield at both sites under the conditions of this experiment. It was also observed that dry matter yield decreased at high levels of added phosphorus (P3). These results are consistent with the findings of [10] and [11] who indicated that high phosphorus levels reduced the dry matter yield of wheat grown under gypsum soil conditions. The addition of magnesium fertilizer significantly increased dry matter yield at both sites. The increase compared to the control treatment (Mg0) was 25.28% and 21.67% at the first site (5% gypsum), while at the second site

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(15% gypsum), the increase was 21.11% and 11.11% at the Mg1 and Mg2 levels, respectively. The results show that the highest dry matter yield was achieved at the Mg1 level. Increasing the Mg2 level resulted in a decrease in grain yield of 2.88% and 8.25% at the two experimental sites, respectively. This shows that the Mg1 level was sufficient to give the highest grain yield under the conditions of this gypsum soil, and that the high levels of magnesium led to the creation of a positive imbalance between the nutrients in the soil, and this was reflected in the dry matter yield of the wheat crop. These results are consistent with what [12] found, that adding different levels of magnesium fertilizer to gypsum soil led to a significant increase in the dry matter yield of the wheat crop at all levels of magnesium addition. [13], indicated that the use of high levels of magnesium in the soil led to a decrease in plant growth (biomass and yield) by affecting physiological processes and interfering with the absorption of other elements such as calcium and potassium. As for the effect of the interaction between phosphorus levels at the suggested concentrations and magnesium levels, the results in Table (2) show that the highest dry matter yield from the interaction between phosphorus and Mg0 was 4.40 g plant^{-1} at the first site (5% gypsum) and at the P1Mg1 treatment, which is not significantly different from the P2Mg1 treatment, which gave 5.35 and 5.44 g plant^{-1} for the two sites, respectively. This shows that the treatment of 60 kg P.ha^{-1} + 60 kg Mg.ha^{-1} at the 5% gypsum site and 65 kg P.ha^{-1} + 60 kg Mg.ha^{-1} at the 15% site, compared to the no-add P0Mg0 treatment, which gave the lowest dry matter yield of 2.10 and 2.22 g plant^{-1} for the two soils, respectively.

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Table (2) Effect of phosphorus and magnesium fertilization and their interaction on dry matter yield (g. $plant^{-1}$) for the two study soils (5 and 15%) gypsum

Phosphorus levels	Mg P	Soil of 5% gypsum			Mean	Phosphorus levels	Mg P	Soil of 15% gypsum			Mean
		Mg_0	Mg_{30}	Mg_{60}				Mg_0	Mg_{30}	Mg_{60}	
0	P_0	2.10	2.84	2.70	2.55	0	P_0	2.22	2.74	2.26	2.40
60	P_1	3.68	5.35	5.30	4.78	65	P_1	3.85	5.44	5.18	4.82
80	P_2	4.40	5.26	5.13	4.93	85	P_2	4.55	5.15	4.48	4.73
100	P_3	4.20	4.58	4.40	4.39	100	P_3	3.77	4.10	4.08	3.98
Mean		3.60	4.51	4.38				3.60	4.36	4.00	
L.S.D	P=0.1680 Mg=0.1589 P*Mg=0.2894						P=0.1606 Mg=0.1391 P*Mg=0.2761				

Table (3) shows the amount of iron, zinc, and copper absorbed by wheat crops grown in two soils: 5% and 15% gypsum. The results indicate that the amount of absorbed elements was affected by both the level of phosphate fertilizer and the level of added magnesium. Increasing phosphorus from P0 to P3 led to a significant increase in the amount of iron, zinc, and copper absorbed. The percentage increase for iron in the 5% gypsum soil was 130.89%, 220.19%, and 132.78%, while the percentage increase for zinc was 151.11%, 157.88%, and 98.61%. As for copper, the percentage increase was 421.01%, 438.86%, and 225.91% at phosphorus levels P1, P2, and P3, respectively, compared to the unfertilized P0 treatment. The results show that the amount of iron, zinc and copper absorbed decreased at the high level of phosphorus P3 and that the highest amount absorbed was at the P2 level of the added phosphate fertilizer. For the 15% gypsum soil, raising the phosphorus level from P0 to P3 significantly increased the uptake of iron, zinc, and copper. The increase for iron was 184.96%, 210.08%, and 127.23%, while for zinc it was 190.11%, 185.15%, and 119.59%. For copper, the increase was 758.55%, 691.89%, and 410.81% at levels P1, P2, and P3, respectively, compared to the unfertilized P0 treatment. These results indicate that the uptake of iron, zinc, and copper decreased at the high phosphorus level (P3), similar to the 5% gypsum soil. It is noted from the results in Table 3 that the highest amount of iron, zinc, and copper absorbed by the wheat crop was in the 15% soil. This is due to the difference in the nature of this soil (5% and 15%) and its response to the levels of added phosphorus. The highest percentage increase in the amount absorbed was for copper, then zinc, and finally iron. It has been indicated that

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adding phosphate fertilizer to the soil in the presence of water leads to the reaction of the fertilizer with the soil and the formation of phosphoric acid around the fertilizer particle, which leads to the formation of a solution with a pH of 1.5. This acidic solution leads to the dissolution of soil particles near the fertilizer, and this leads to the release of iron, zinc, potassium, copper, and calcium, which contributes to increasing the absorption of these elements by the growing crop [1]. This is especially true when phosphate fertilizer is applied in a band, as was the case with wheat crops grown in both soils. Regarding the effect of adding different levels of magnesium, the results show that the uptake of iron, zinc, and copper (3) was affected by the magnesium levels in both soils. Increasing the magnesium level from Mg0 to Mg2 led to a significant increase in the uptake of iron, zinc, and copper. The percentage increase in soil uptake was 5% for iron (34.73%, 23.21%, and 69.29% for zinc, and 56.47% for copper) at Mg1 and Mg2 levels, respectively, compared to the unfertilized Mg0 treatment. This is attributed to the fact that changes in magnesium levels can lead to changes in the uptake of micronutrients such as iron, zinc, and copper within the plant, through magnesium's interaction with the transport and absorption processes in the roots and its effect on ion balance in plant tissues [14]. The table shows that the uptake of iron, zinc, and copper decreased at the high magnesium level (Mg2), while the highest uptake of these elements was at the Mg1 level. This is because excessive magnesium concentration in the soil solution can lead to competition for absorption sites in root membranes, reducing the availability and uptake of some micronutrients, especially iron and zinc. Recent studies have shown that high magnesium concentration can cause nutrient imbalances and affect the dynamics of micronutrient translocation within the plant, thus impacting its biological efficiency [15].

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Table (3) Amounts absorbed of micronutrients in the dry matter of 5% soil

Phosphorus levels	Mg P	Fe				Zn				Cu			
		Mg_0	Mg_{30}	Mg_{60}	Mean	Mg_0	Mg_{30}	Mg_{60}	Mean	Mg_0	Mg_{30}	Mg_{60}	Mean
0	P_0	29.59	41.39	40.31	**37.10**	13.91	26.82	23.94	**21.56**	1.54	2.21	2.05	**1.93**
60	P_1	63.48	102.56	90.93	**85.66**	30.73	68.75	62.93	**54.14**	6.11	12.43	11.63	**10.06**
80	P_2	99.55	133.71	123.12	**118.79**	42.17	64.33	60.30	**55.60**	8.33	11.81	11.07	**10.40**
100	P_3	82.20	92.61	84.28	**86.36**	35.89	47.79	44.79	**42.82**	4.98	7.13	6.76	**6.29**
Mean		**68.71**	**92.57**	**84.66**		**30.67**	**51.92**	**47.99**	**21.56**	**5.24**	**8.39**	**7.88**	
L.S.D	**P=4.011 Mg=3.474 P*Mg=6.948**					**P=2.459 Mg=2.130 P*Mg=4.259**				**P=0.433 Mg=0375 P*Mg=0.751**			

As for the 15% gypsum soil, raising the level of magnesium addition from Mg0 to Mg2 led to a significant increase in the amount absorbed by iron, zinc and copper. The percentage increase for iron was 35.27%, 17.17%, while for zinc it was 65.32%, 42.66%, and for copper it was 70.75%, 56.24% at the levels of Mg1, Mg2 respectively, compared to the non-fertilized treatment Mg0. The table shows that the highest absorption of the above elements occurred at the Mg1 level and decreased at the Mg2 level. This indicates that high magnesium levels negatively impacted the absorption of these elements. The absorption results for iron, zinc, and copper in both soils suggest that the addition of phosphorus, in the presence of added magnesium, led to increased wheat growth, which positively affected the absorption and concentration of these elements by the wheat crop. The presence of magnesium in the soil encourages or stimulates the absorption of phosphorus and vice versa. This is known as the stimulatory effect between the two elements, which positively impacts plant growth through its effect on root development. Consequently, it increases the uptake of nutrients, including iron, zinc, and copper, in wheat crops [1]. The results show that the effect of both phosphorus and magnesium on the uptake of zinc and copper was greater than their effect on the uptake of iron in wheat crops in both soil types. It should be noted that the uptake of these elements is a function of their

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concentration in the plant and the degree of growth achieved. [16] indicated that the ionic radius of zinc is similar to or close to that of iron and magnesium ions, allowing these ions to replace zinc (isotropic substitution) in mineral structures. Therefore, adding magnesium to wheat crops in both soils increased the availability of zinc and iron, which positively impacted the uptake of these elements and their concentrations in the wheat plant.

Table (4) Amount of micronutrients absorbed in the dry matter of 15% soil

Phosphorus levels	Mg P	Fe				Zn				Cu			
		Mg_0	Mg_{30}	Mg_{60}	Mean	Mg_0	Mg_{30}	Mg_{60}	Mean	Mg_0	Mg_{30}	Mg_{60}	Mean
0	P_0	28.57	35.58	28.40	**30.85**	12.90	19.91	17.88	**16.90**	0.91	1.36	1.06	**1.11**
60	P_1	59.84	107.89	96.01	**87.91**	26.75	64.36	55.98	**49.03**	5.00	12.24	11.35	**9.53**
80	P_2	86.88	109.80	90.30	**95.66**	40.82	57.91	45.85	**48.19**	7.13	10.40	8.83	**8.79**
100	P_3	67.43	75.04	69.67	**70.10**	30.72	41.66	38.96	**37.11**	4.60	6.10	6.32	**5.67**
Mean		**60.68**	**82.08**	**71.10**		**27.80**	**45.96**	**39.66**	**16.90**	**4.41**	**7.53**	**6.89**	
L.S.D	**P=3.433 Mg=2.973 P*Mg=5.947**					**P=2.238 Mg=1.938 P*Mg=3.877**				**P=0.289 Mg=0.250 P*Mg=0.500**			

The results of Tables (5, 6) indicate the concentrations of iron, zinc and copper in the wheat crop for both soils. It was found that the concentrations of these elements were low, and were even lower in the soil containing 15% gypsum. This was related to the low availability of these elements in the two soils, as shown in Table (1), as they were less than the critical limit for these elements It has been suggested that the available amount of nutrients is sufficient for plant growth if iron concentrations are greater than 4.5 ppm, zinc greater than 1 ppm, and copper greater than 0.5 ppm [16]. This was clearly reflected in the iron, zinc, and copper concentrations in growing wheat plants, which were associated with gypsum soil conditions and the absence of micronutrient fertilizers, resulting in sub-critical concentrations of these elements. Recent studies have shown that iron and zinc content in wheat plants is often below

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the critical limits required for optimal growth and yield, even in areas where no obvious deficiency symptoms are present—a condition known as hidden hunger. For example, a large analysis indicates that zinc and iron in wheat grains often fall below the target levels required for human health, despite good yields [17]. A general bibliographic analysis also showed that zinc deficiency in calcareous/ gypsiferous soils is a common problem affecting the availability of this element in plants [18]. Other studies indicate that a significant proportion of wheat soils exhibit iron and zinc deficiencies, particularly in soils with high pH, which impairs the uptake of these elements within the plant [19]

Table (5) Concentration of micronutrients in the dry matter of 5% soil

Phosphorus levels	Mg P	Fe				Zn				Cu			
		Mg_0	Mg_{30}	Mg_{60}	Mean	Mg_0	Mg_{30}	Mg_{60}	Mean	Mg_0	Mg_{30}	Mg_{60}	Mean
0	P_0	14.05	14.59	14.93	**14.52**	6.65	9.46	8.87	**8.33**	0.73	0.78	0.76	**0.76**
60	P_1	17.25	19.17	17.44	**17.95**	8.35	12.85	12.05	**11.08**	1.66	2.33	2.23	**2.07**
80	P_2	22.40	25.15	23.68	**23.74**	9.47	12.10	11.60	**11.06**	1.87	2.22	2.13	**2.07**
100	P_3	19.19	20.20	19.13	**19.51**	7.78	10.42	10.17	**9.46**	1.19	1.55	1.54	**1.43**
Mean		**18.22**	**19.78**	**18.80**		**8.06**	**11.21**	**10.67**	**8.33**	**1.36**	**1.72**	**1.67**	
L.S.D	**P=2.016 Mg=1.746 P*Mg=3.49**					**P=0.369 Mg=0.320 P*Mg=0.640**				**P=0.059 Mg=0.045 P*Mg=0.091**			

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Table (6) Nutrient concentration in 15% dry matter soil

Phosphorus levels	Mg P	Fe				Zn				Cu			
		Mg_{0}	Mg_{30}	Mg_{60}	Mean	Mg_{0}	Mg_{30}	Mg_{60}	Mean	Mg_{0}	Mg_{30}	Mg_{60}	Mean
0	P_0	12.89	13.05	12.55	**12.83**	5.82	7.30	7.90	**7.01**	0.41	0.48	0.47	**0.45**
60	P_1	15.80	19.83	18.55	**18.06**	7.06	11.83	10.81	**9.90**	1.32	2.25	2.19	**1.92**
80	P_2	19.94	21.30	20.46	**20.46**	8.98	11.23	10.23	**9.29**	1.57	2.02	1.97	**1.85**
100	P_3	17.89	18.32	16.88	**17.77**	8.15	10.17	9.56	**9.29**	1.22	1.49	1.55	**1.42**
Mean		12.89	**18.13**	**17.08**		**7.50**	**10.13**	**9.63**	**7.01**	**1.13**	**1.56**	**1.55**	
L.S.D	**P=1.906 Mg=1.594 P*Mg=3.170**					**P=0.324 Mg=0.281 P*Mg=0.561**				**P=0.053 Mg=0.045 P*Mg=0.089**			

Conclusions and Recommendations:

We conclude from this study that the concentrations of the micronutrients iron, zinc and copper are below the required levels for wheat crops growing in gypsum soils. This is reflected in the grain yield and requires a review of fertilization programs and the inclusion of micronutrient addition within the fertilization program for grain crops growing in gypsum soils.

References:

[1]Al-Muaini, A. T. (2024). Soil fertility and fertilization under arid and semi-arid conditions. Nirkal Press.

[2] Khudair, G. S. M. (2014). Magnesium status in soils with different gypsum content and the response of wheat crop (Triticum aestivum L.) to magnesium fertilization (Master's thesis, Tikrit University, College of Agriculture).

[3] Cakmak, I., & Kirkby, E. A. (2008). Role of magnesium in carbon partitioning and alleviating photo-oxidative damage. Physiologia Plantarum, 133(4), 692–704.

[4]Al-Hamdani, H. M., & Al-Muaini, A. M. T. (2020). The effect of magnesium addition on determining phosphate fertilizer requirements from the adsorption curves of wheat yield

ISSN 2072-3857

(Triticum aestivum L.) in soils with different gypsum content. Kirkuk Journal of Agricultural Sciences.

[5]Page, A. L., Miller, R. H., & Keeney, D. R. (Eds.). (1982). Methods of soil analysis. Part 2: Chemical and microbiological properties (2nd ed.). American Society of Agronomy.

[6]Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (USDA Circular No. 939). United States Department of Agriculture.

[7]Pratt, P. F. (1965). Potassium. In C. A. Black (Ed.), Methods of soil analysis (Agronomy Monograph No. 9, pp. 1022–1030). American Society of Agronomy.

[8] Artieda, O., Herrero, J., & Drohan, P. J. (2006). Refinement of the differential water loss method for gypsum determination in soil. Soil Science Society of America Journal, 70, 1932–1935.

[9]Al-Zubaidi, K. M. D., & Al-Jubouri, K. K. A. (2016). Design and analysis of genetic experiments. Dar Al-Waddah Publishing & Dijla Library for Printing and Publishing.

[10]Al-Majma'i, K. H. H. (2013). The effect of phosphate fertilizer on phosphorus availability, growth, and yield in wheat plants (Master's thesis, Tikrit University, College of Agriculture).

[11]Malhotra, H., Pandey, R., & Sharma, S. (2018). Phosphorus nutrition: Plant growth in response to deficiency and excess. In M. Hasanuzzaman, M. Fujita, H. Oku, & K. Nahar (Eds.), Plant nutrients and abiotic stress tolerance (pp. 171–190). Springer Nature Singapore.

[12] Khudair, G. S.M (2019). The effect of soil gypsum and organic matter content on the movement of potassium, magnesium, phosphorus, and nitrogen, and on the growth and yield of bread wheat (Triticum aestivum L.) (Doctoral dissertation, Tikrit University, College of Agriculture).

[13] Lamichhane, S., Tarpley, L.,&Dou, F. (2023). Impact of excess magnesium salt supply on rice yield, physiological response, and grain mineral content. Sustainability, 15(22), Article 15741

[14]El-Dissoky, R. A., Al-Kamar, F. A., & Derar, R. M. (2017). Impact of magnesium fertilization on yield and nutrients uptake by maize grown on

ISSN 2072-3857

two different soils. Egyptian Journal of Soil Science, 57(4), 455–466.

[15]Perelman, A. (2026). Interactions between plant nutrients: A deep understanding. ICL Growing Solutions.

[16] Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2016). Soil fertility and fertilizers: An introduction to nutrient management (8th ed.).

[17] Devkota, M. K., Sileshi, G. W., Senthilkumar, K., Broadley, M. R., Mutambu, D., Sila, A., ... & Kihara, J. M. (2026). Grain zinc, iron and protein concentrations of contemporary wheat cultivars fall short of targets for human health. *Nature Food, 7*, 283–295.

[18] Martínez-Ríos, O., Bravo-Vinaja, Á., San-Martín-Hernández, C., Hidalgo-Moreno, C. I., Sánchez-de-Jesús, M. A., Llampallas-Díaz, J. D., Santillan-Balderas, D. R., & García-Preciado, J. C. (2024). Zinc deficiency in calcareous soils: A bibliometric analysis from 1989 to 2024. Agriculture, 14(12).

[19] Hafeez, B., Khan, A. A., Ullah, A., Khan, H. Z., Munsif, F., & Irshad, M. (2021). Application of zinc and iron-based fertilizers improves micronutrient status and grain quality of wheat. *Frontiers in Nutrition, 8*, 779595.

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