EFFECT OF MAGNESIUM APPLICATION ON PHOSPHORUS USE EFFICIENCY (PUE) OF SOME PHOSPHATE FERTILIZERS AND ON MAGNESIUM AND PHOSPHORUS UPTAKE BY MAIZE (*ZEA MAY* L.)

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ABSTRACT

A field experiment was conducted to evaluate effect of magnesium application on efficiency of some phosphate fertilizers and phosphorus and magnesium uptake of maize. Three types of phosphate fertilizers (Triple super phosphate TSP, Di ammonium phosphate DAP and Urea phosphate UP) and five levels of magnesium (0, 25, 50, 75 and 100 kg Mg ha^{-1}) as $MgSO_4.H_2O$ were used in the study of. Randomized complete block design (RCBD) with three replicates were used. The results showed that the UP fertilizer was the most efficient in increasing P uptake, PUE and obtaining the highest response of maize compared with DAP and TSP. PUE, and they were 75.33, 64.23 and 56.96% for UP, DAP and TSP respectively. The results showed also that all of the plant parameters significantly increased as the level of Mg increased from 0 to 100 kg Mg ha^{-1}. The level of 75 kg Mg ha^{-1} gave the highest values of P uptake in straw part, grains and total uptake and they were 97.87, 43.62 and 140.63 kg ha^{-1}, while the level 100 kg Mg ha^{-1} gave the highest values for Mg uptake which were 71.57, 14.01 and 85.58 kg ha^{-1}respectively. The results showed significant positive correlations of quadratic equation between magnesium level and all of studied parameters.

Key word: DAP , TSP , UP , $MgSO_4$, PUE , maize response
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تأثير اضافة المغنيسيوم في كفاءة استعمال الفسفور في بعض الاسمدة الفوسفاتية وفي امتصاص المغنيسيوم والفسفور في الذرة الصفراء (*Zea mays* L.)

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المستخلص

اجريت تجربة حقلية بهدف معرفة تأثير التسميد بالمغنيسيوم في كفاءة استعمال الفسفور بعض الاسمدة الفوسفاتية وامتصاص الفسفور والمغنيسيوم في الذرة الصفراء. استعملت ثلاثة انواع من الاسمدة الفوسفاتية هي السوبرفوسفات الثلاثي (TSP) وفوسفات الامونيوم الثنائية (DAP) وفوسفات اليوريا (UP) وخمسة مستويات من المغنيسيوم هي 0 و25 و50 و75 و 100 كغم هـ$^{-1}$ اضيفت بصورة كبريتات المغنيسيوم ($MgSO_4.H_2O$). نفذت هذه التجربة العاملية باستعمال تصميم القطاعات العشوائية الكاملة وبثلاث مكررات. اظهرت النتائج تفوق سماد فوسفات اليوريا في تحقيق اعلى زيادة في امتصاص الفسفور والمغنيسيوم في الجزء الخضري الجاف والحبوب والامتصاص الكلي ونسبة الاستجابة في الذرة الصفراء وكفاءة استعمال الفسفور بالسمادين TSPو DAP. وقد بلغت كفاءة استعمال الفسفور 75.33 و 64.23 و 56.96% للاسمدة UP وDAP وTSP على التوالي. اظهرت النتائج ايضا ان زيادة مستوى اضافة المغنيسيوم من من 0 الى 100 كغم هـ$^{-1}$ ادت الى زيادة جميع المؤشرات قيد الدراسة وقد تفوق المستوى 75 كغم Mg هـ$^{-1}$ في تحقيق اعلى امتصاص للفسفور في الجزء الخضري والحبوب والامتصاص الكلي اذ بلغ 97.87 و 43.62 و 140.63 كغم هـ$^{-1}$ بينما تفوق المستوى 100 كغم Mg هـ$^{-1}$ في تحقيق اعلى امتصاص للمغنيسيوم في الجزء الخضري والحبوب والامتصاص الكلي اذ بلغ 71.57 و14.01 و 85.58 كغم هـ$^{-1}$. اظهرت النتائج وجود علاقة ارتباط معنوية بين مستوى اضافة المغنيسيوم مع المؤشرات قيد الدراسة.

الكلمات المفتاحية: فوسفات ثنائي الامونيوم، سوبر فوسفات الكالسيوم الثلاثي ، فوسفات اليوريا ، كبريتات المغنيسيوم ، كفاءة استعمال الفسفور ، نسبة الاستجابة

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INTRODUCTION

Application of phosphate fertilizers to calcareous soils (such Iraqi soils) introduced some problems mainly due to adsorption, precipitation and fixation reactions on, or with clay minerals surfaces, carbonates, organic materials and calcium carbonate surfaces (6). In calcareous soils (higher pH), P fertilizers reacts with Ca and makes P unavailable to plants. Phosphorus availability from inorganic P fertilizer becomes less available with increasing time application. The formation of insoluble compounds due to soil chemical reactions limits the plant available P making phosphate fertilization use efficiency very low by crops (19). Several methods and ways have been used to improve or increase the efficiency of phosphate fertilizers, which have been tested for many types of agricultural soils in their phosphorus availability to ensure the appropriate level of the plant and achieve the highest response in the growth and yield of the plant and these means are: Application P fertilizers in bands, using large practices fertilizers, split application, foliar application, slow-release phosphate fertilizers, phosphate soluble microorganisms, Mycorrhizal fungus, chemical amendments , organic materials, breeding and hybridization methods and genetic engineering techniques (11,36 , 42)

One of the ways that can also improve the efficiency of phosphate fertilizers is the interaction of phosphorus with other nutrients. Many studies indicated that there is an interaction between phosphorus and other nutrients, whether in soil or plant, and may have a negative or positive effect on plant growth. The positive effect of interaction is increase in phosphorus availability or increase the absorption in the plant or in biological and physiological processes. It was found that the interaction of phosphorus with magnesium had a positive effect in the soil and plant. Adding both fertilizers of phosphorus and magnesium together led to more efficient phosphate fertilizer than if the nutrients were added individually (25). In the soil system, magnesium has a role in increasing the availability of phosphorus especially in calcareous soil through the following mechanisms: Magnesium reduces phosphorus deposition and remains more soluble by forming dissolved magnesium phosphate and preventing or reducing the formation of the most stable calcium phosphate precipitates and apatite formation (least solubility) (13 , 29). High concentration of magnesium in soil solution will prevent or reduce the dissolved phosphorus reaction with calcium carbonate, which is high in calcareous soils such as Iraqi soils, through the formation of magnesium carbonate bearing (Mg-bearing calcite) possibly due to the replacement of calcium ions by magnesium ions in the precipitated calcium phosphate (12, 31). The association of magnesium with phosphorus reduces the chances of phosphorus adsorption on the surface of carbonate (24). In the plant system, magnesium plays a role in increasing the uptake of phosphorus in the plant or increasing the efficiency of the phosphate fertilizer. Magnesium acts as a transporter of phosphorus in the plant and activates most of the biological processes that contribute to phosphorus and activates most of the enzymes. Magnesium also plays an important role to convert mineral phosphorus to organic phosphorus within the plant as well as magnesium ions promote the absorption of phosphate ions (20, 32). Phosphorus has a positive effect on magnesium within the plant. Phosphorus contributes to the release of energy for all biological processes, especially in which magnesium contributes to the magnesium pool in the plant through its contribution to the formation and division of cells, to change in root architecture, increase in axial root lengths and root hair density which increased nutrient uptake including magnesium as well as increasing the straw part that requires of magnesium to chlorophyll formation (25). A number of studies have been carried out in which magnesium fertilization was used to increase the phosphorus availability and uptake in the plant and increase the efficiency of phosphate fertilizers, especially in calcareous soils and to obtain a high response to vegetables and cereals crops (10, 21). Mam Rasul et al., (30) found that when using four levels of phosphorus as superphosphate (TSP) 0, 60, 100, 140 kg P ha^{-1} and four levels of magnesium are 0, 40, 80 and 120 kg Mg ha^{-1} as $MgSO_4.7H_2O$ showed that the treatment of interaction of the level of

100 kg P ha^{-1} and the level of 80 kg Mg ha^{-1} gave the highest grain yield to the wheat while at the level of 80 kg P ha^{-1} and 120 kg Mg ha^{-1}, the highest P uptake was 2571.52 kg ha^{-1} and gave the highest P fertilizer use efficiency was 55.24% at the level of 100 kg P ha^{-1}. Al-Duraye (5) used four levels of phosphorus (0, 40, 80 and 160 kg P ha^{-1}) as superphosphate triphosphate (TSP) and four levels of magnesium 0, 30, 60 and 90 kg Mg ha^{-1} as $MgSO_4.7H_2O$ and she found that interaction treatment of the level 60 kg Mg ha^{-1} and 80 kg P ha^{-1} gave the highest p and Mg uptake (124.31 and 140.53 mg pot^{-1}) respectively. A number of studies have confirmed that there was a high response in some cereal crops to application phosphorus and magnesium fertilizers together than adding them separately (2, 7, 26). Studies are limited in this area and have not received much attention in Iraq. This study aimed to evaluate the P use efficiency of some phosphate fertilizers (TSP, DAP and UP) and uptake of P and Mg in maize under magnesium fertilization

MATERIALS AND METHODS

Field experiment was conducted at the Faculty of Agricultural Research Farm in Al-Jadiriya in soil with silty loam soil texture. Before planting soil samples were collected from the surface layer (0 – 30 cm). The samples were air dried, sieved through 2.0 mm sieve. Some of physical and chemical properties were estimated according to Jackson (28) and Page et al., (35) (Table 1). Three types of phosphate fertilizers: Triple super phosphate (TSP), (20% P), Diammonium phosphate (20% P),(18% N) and Urea phosphate (UP) (19% P) and (18% N) were added at a constant level of 80 kg P ha^{-1} and 5 levels of magnesium (0, 25, 50, 75 and 100 kg ha^{-1}) were added as $MgSO_4.7H_2O$ (10% Mg). The field was divided into three blocks, each block includes 15 plots (experimental unit) and the distance between the experiment units was 1 meter while the distance between blocks was 2 meters. Maize variety (Baghdad 3) was planted on 21 July 2018. The nitrogen and potassium fertilizers were applied at the level of 240 kg N ha^{-1} of urea (46% N) and potassium at the rate of 120 kg K ha^{-1} of potassium sulphate (K_2SO_4) (41.5% K) to all treatments. All fertilizers were added in bands and in three doses, first at planting, the second after 30 days of germination and the third after 15 days of the second dose. The crop was harvested at the final maturity stage on 2nd, November 2018. Phosphorus and magnesium concentration were determined in straw and grains according to Jackson (28). Nutrient uptake calculated as follows:

Nutrient uptake = Nutrient concentration (%) X vegetative dry weight

The response percent and P use efficiency were calculated according to Fageria et al., (25) as in the following equation:

$$\text{Response percent (\%)} = \frac{\text{Total yield of fertilized treatment - Yield of control}}{\text{Total yield of fertilized treatment}} \times 100$$

$$\text{P use efficiency (PUE) (\%)} = \frac{\text{P uptake from treatment - P uptake from control}}{\text{Applied P}} \times 100$$

A factorial experiment was carried out according to the design of the complete randomized design (RCBD), which included three types of phosphate fertilizers and 5 levels of magnesium with three replicates. 45 experimental units were used. The least significant difference was used to compare the mean of the treatment at level of 0.05. Nonlinear regression (quadratic equation) was used to describe the relationship between the added magnesium levels and plant parameters (38).

Table 1. Chemical and physical properties of soil

Property		Value	Unit
ECe		3.21	dS m^{-1}
pH		7.46	
O.M		11.2	g kg^{-1} soil
Total $CaCO_3$		268.0	g kg^{-1} soil
Gypsum		1.70	g kg^{-1} soil
CEC		20.0	$Cmol_+kg^{-1}$ soil
Soluble ions	Ca^{++}	9.12	mmole L^{-1}
	Mg^{++}	4.71	
	Na^{+}	3.73	
	K^{+}	1.03	
	$CO_3^{=}$	-	
	HCO_3^{-}	2.14	
	$SO_4^{=}$	4.65	
	Cl^{-}	20.11	
	NH_4^{+}	30.70	
	NO_3^{-}	26.30	
Available nutrients	P_{Olsen}	6.30	mg kg^{-1} soil
	K (NH_4OAc)	175.00	
	Mg (NH_4OAc)	81.40	
Particle size analysis			
Clay		121.0	
Silt		523.0	g kg^{-1} soil
Sand		356.0	
Texture		Silty loam	

RESULTS AND DISCUSSION

P uptake in straw, grains and total uptake

The results showed that the highest uptake value of phosphorus was in urea phosphate fertilizer with an average of 77.22, 40.96 and 118.46 kg ha^{-1} for P uptake in the straw part and grains and total uptake respectively (Tables 2).

Table 2. Effect of type of phosphate fertilizer and Mg level on P uptake of straw, grain and total P uptake

Mg Kg ha^{-1}	P uptake in straw (kg ha^{-1})			Mg mean	P uptake in grains (kg ha^{-1})			Mg Mean	Total P uptake (kg ha^{-1})			Mg mean
	TSP	DAP	UP		TSP	DAP	UP		TSP	DAP	UP	
0	23.32	26.91	31.56	27.26	29.27	31.56	32.00	30.94	52.58	58.42	63.56	58.19
25	32.96	53.34	47.67	44.65	32.73	34.15	37.60	34.83	85.72	87.49	85.33	79.51
50	54.42	76.50	92.14	74.35	35.56	38.37	42.43	38.79	89.98	114.87	135.91	113.59
75	79.15	90.07	124.39	97.87	40.60	42.62	47.63	43.62	118.68	133.70	169.51	140.63
100	66.92	76.84	90.36	78.04	39.53	39.21	45.12	41.29	117.44	106.13	137.99	120.52
Fert. Mean	51.35	64.73	77.22		35.54	37.18	40.96		88.88	100.12	118.46	
LSD0.05												
P fertilizer	1.22				0.53				0.92			
Mg	1.57				1.57				1.19			
P X Mg	2.72				2.72				2.07			

Phosphorus uptake in urea phosphate fertilizer increased by 50.38 and 19.30% for the straw part, 15.25 and 10.17% in grains and 33.28% and 18.32% of total P uptake compared to TSP and DAP fertilizers respectively. The superiority of the UP fertilizer on the other two fertilizers may be attributed to its physical properties (high solubility, hydrolysis and rapid spread) and chemical properties such as low pH which is reflected in the reduction of phosphorus reactions such as adsorption and precipitation in calcareous soils, such as Iraqi soil which led to the availability of phosphorus and increase its uptake in the plant as well as increasing the release of phosphorus from soil minerals and increase the availability of some other nutrients, especially micronutrients (Iron, zinc, copper and manganese) (8,23,33,40). The results are consistent with those found by Al-Mussawi (15) and Taaban (39), who indicated superiority of urea phosphate on the rest of phosphate fertilizers which were used in their studies in increasing content and uptake of phosphorus in maize which was also found by Monica (34) in her study on rice plant. The results showed that addition of magnesium significantly affected uptake of P in the straw, grains and total uptake (Table 2). P uptake in straw part increased by 63.79, 172.74, 259.02 and 186.28%, while in grains increased by

12.57, 25.37, 40.98 and 33.45%, as for total uptake increased by 36.64, 95.21, 141.67 and 107.11% for magnesium levels 25, 50, 75 and 100 kg ha^{-1}, respectively, compared to the control treatment. The increase in magnesium levels from 0 to 100 kg ha^{-1} increased phosphorus uptake in straw, grains and total uptake. The level 75 kg ha^{-1} gave the highest increase value of these parameters. The increase in phosphorus uptake may be attributed to the role of magnesium in reducing the reactions of phosphorus such as adsorption and precipitation in calcareous soils through the formation of the most soluble magnesium phosphate, which contributed to increase availability and absorption of phosphorus in the plant (12, 31). The positively charged magnesium ions promote the absorption of negatively charged phosphate ions (25). The results are consistent with the results of several studies. Al-Jobori (11) found, in his study when adding magnesium at three levels of 0, 40 and 80 kg ha^{-1}, that the level of 80 kg ha^{-1} gave the highest increase of P uptake in the straw part and grains of maize were 86.38 and 35.45% respectively compared with the control. As Al-Duraye (5) indicated in her study of the highest increase of uptake of P in straw and grain and the total uptake of wheat at the level of 60 kg Mg ha^{-1} where the increase were 41.0 , 29.7 and 33.7% compared to the control, in which four levels of magnesium were 0, 30, 60 and 90 kg ha^{-1}. As for the interaction between the type of phosphate fertilizer and the level of magnesium addition, the results showed that the interaction was superior to the addition of the level of 75 kg Mg ha^{-1} with phosphate fertilizers which were 79.15, 90.07 and 124.34 kg ha^{-1} for P uptake in the straw part of TSP, DAP and UP fertilizers respectively, and 40.60, 42.62 and 47.63 kg ha^{-1} in grains and in the total P uptake were 118.68 and 133.70 and 169.51 kg ha^{-1} of these three fertilizers respectively. Increases on uptake of phosphorus in straw, grains and the total P uptakes in maize may be attributed to the positive effect of the interaction between these two nutrients (P and Mg) in the soil and plant systems. Mam- Rasul et al., (30) found an increase in phosphorus uptake in wheat and it was attributed to the interaction effect of adding phosphorus and magnesium together.

Mg uptake in straw, grains and total uptake

The results indicated in (Tables 3) that the magnesium uptakes in the straw were 42.00, 45.66 and 53.90 kg ha^{-1} while the in the grains was 10.98, 11.18 and 12.16 kg ha^{-1} and the total uptake was 52.99, 59.04 and 67.07 kg ha^{-1} for TSP, DAP and UP fertilizers respectively. The results showed that UP fertilizer was superior to other fertilizers. Mg uptake increased in the straw part with UP use by 28.33% and 18.05% and in grains by 10.75% and 8.77% while, the total uptake increased by 26.57 and 13.60% for TSP and DAP respectively. The superiority of urea phosphate fertilizer to other fertilizers may be attributed to the higher uptake of magnesium in the straw, grains and total uptake to its acid reaction (pH = 1.73) as a result of its hydrolysis to urea and phosphoric acid, reducing the soil reaction and dissolving and releasing the mineral magnesium in soil (9,23,33). The results also showed that the magnesium addition at 25, 50, 75 and 100 kg ha^{-1} increased Mg uptake by 19.34, 65.00, 112.23 and 160.63% in straw, 22.56, 41.92, 68.19 and 72.75% in grains and 24.80, 51.35, 114.12 and 140.66% of total uptake respectively as compared with control. The fifth level (100 kg Mg ha^{-1}) was higher than the others levels in achieving the highest uptake of magnesium in maize. The high increase in Mg uptake was at the last level (100 kg Mg ha^{-1}), so as to increase the magnesium availability as a result of fertilization and increase its uptake in the plant. Several studies indicated increase of magnesium uptake in wheat and maize crops as a result of magnesium fertilization (18, 26). The results also agree with Al- Jobori (10) found in his study using three levels of magnesium (0, 40 and 80 kg ha^{-1}) and found that the level of 80 kg Mg ha^{-1} achieved the highest increase in the Mg uptake in the straw and grains of maize by 97.93 and 51.95% compared to the control. Al-Duraye (5) noted that the level of 60 kg Mg ha^{-1} achieved the highest increases in Mg uptake in wheat were 41.0, 29.7 and 33.7% in straw, grains and total respectively compared to the control in which four levels of magnesium (0, 30, 60 and 90

kg ha $^{-1}$) were used. The results showed that the difference between the type of phosphate fertilizer and the level of the added magnesium was significant in Mg uptake in the straw, grains and total. Mg uptake in the three phosphate fertilizers increased with increase levels of the added magnesium from 0 to 100 kg ha^{-1} (Table 3). The highest increase was at 100 kg ha^{-1} and Mg uptakes in the straw were 63.21, 69.03 and 82.43 kg ha^{-1} and in of straw, grain and total Mg uptake grains were 13.37, 13.70 and 14.95 kg ha^{-1} and in the total uptake were 76.58, 82.73 and 97.43 kg ha^{-1} for TSP, DAP and UP respectively. The increase in Mg uptake in the fifth level of magnesium (100 kg ha^{-1}) with phosphate fertilizers was attributed to the positive effect between phosphorus and magnesium. Phosphorus contributes to cells formation and division and increases efficiency of the root mass by increasing growth and branching of roots and increasing number and the density of root hairs leading to increased absorption of nutrients, including magnesium (25). A number of studies indicated a positive effect of the interaction between phosphorus and magnesium in increasing magnesium uptake in wheat and maize (7, 17, 30).

Table 3. Effect of type of phosphate fertilizer and Mg level on Mg uptake

Mg kg ha^{-1}	Mg uptake in straw (kg ha^{-1})			Mg mean	Mg uptake in grains (kg ha^{-1})			Mg mean	Total Mg uptake (kg ha^{-1})			Mg mean
	TSP	DAP	UP		TSP	DAP	UP		TSP	DAP	UP	
0	23.73	27.09	31.55	27.46	8.17	8.06	8.09	8.11	31.90	35.15	39.64	35.56
25	27.63	33.18	37.50	32.77	9.36	9.86	10.60	9.94	36.99	43.04	53.10	44.38
50	39.67	46.80	49.47	45.31	10.66	11.14	12.73	11.51	50.33	57.94	62.20	53.82
75	55.78	52.20	68.52	58.80	13.35	13.12	14.45	13.64	69.13	76.33	82.97	76.14
100	63.21	69.03	82.48	71.57	13.37	13.70	14.95	14.01	76.58	82.73	97.43	85.58
Fert. Mean	42.00	45.66	53.90		10.98	11.18	12.16		52.99	59.04	67.07	
						LSD0.05						
P fertilizer		1.06				0.23				0.81		
Mg		1.36				0.30				1.04		
P X Mg		2.37				0.52				1.81		

Response percent

The results in (Table 4) showed that the response rate in total yield of maize plant was significantly affected by the type of phosphate fertilizer and the level of magnesium addition and overlap. The results showed a difference in the overall response rate with the type of phosphate fertilizer. It reached an average of 20.32, 23.56 and 30.87% for TSP, DAP and UP respectively. The UP fertilizer was superior and showed the highest response rate in total maize production compared to other fertilizers. The increase was 51.92% and 31.03% in the UP fertilizer compared to TSP and DAP respectively. Urea phosphate increased the response rate in the total yield of the maize plant compared to other fertilizers. This is due to the fact that the UP fertilizer increased phosphorus availability, whether it is added or already present in the soil. This may be due to its physical, chemical properties and method of its production (rapid hydrolysis to phosphoric acid and urea) which was reflected in increased phosphorus uptake of maize and increased activity in major biological processes (3,8,40). The results are consistent with the results of several studies, Al- Jiboori (9), Al-Salmani and Al- Mussawi (16) and Taaban (39), that indicated the superiority of urea phosphate fertilizer to the rest of the phosphate fertilizers used in their study. The results also showed increase level of magnesium application to led to increase response percentages which were 18.26, 28.91, 35.16 and 17.36% for levels 25, 50, 75 and 100 kg Mg ha^{-1} and the level 75 kg ha^{-1} gave the highest response percent which an increase of 92.55 and 21.62% compared to 25 and 50 kg Mg ha^{-1} levels respectively. The increase in the response percent in maize due to increase level of magnesium application is due to of magnesium fertilization increased P availability and increased its uptake and led to increase activity of enzymes which play an important role in photophosphorylation as well as its entry into the formation of chlorophyll molecule, which was reflected in increase of biological processes within the plant such as photosynthesis and respiration which increases plant parameters and high response for plant (25). The results are consistent with the findings of a number of researchers (1, 10, 14, 27) who found a high response in maize due to magnesium fertilization.

Table 4. Effect of type of phosphate fertilizer and Mg level on response percent and P use efficiency.

Mg Kg ha^{-1}	Response percent (%)			Mg Mean	P use efficiency (%)			Mg Mean
	TSP	DAP	UP		TSP	DAP	UP	
25	12.62	14.50	27.66	18.26	16.42	36.33	26.22	26.33
50	24.71	29.68	32.33	28.91	46.74	70.86	89.44	69.01
75	32.43	36.21	36.84	35.16	83.62	90.09	94.56	89.42
100	11.51	13.86	26.63	17.36	81.07	59.63	91.11	78.12
Fert. Mean	20.32	23.56	30.87		56.96	64.23	75.33	
LSD0.05								
P fertilizer	1.13				0.92			
Mg	1.31				1.06			
F X Mg	2.27				1.84			

The results also showed a significant effect of the interaction between type of phosphate fertilizer and magnesium application in the response percent in the total yield of maize (Table 3). The results showed an increase in the level of 75 kg Mg ha^{-1} with phosphate fertilizers. The response percent were 32.43, 36.21 and 36.48%. The response percent in UP fertilizer was higher than the TSP fertilizer by 12.95% while the increase was not significant with DAP fertilizer. The results show that the level of 75 kg Mg ha^{-1}, which achieved the highest response rate in maize plant by interfering with the three phosphate fertilizers, indicating that this optimum level of magnesium, which can be added with phosphate fertilizers to obtain the highest response to the plant under study conditions.

Phosphorus use efficiency (PUE)

The results shown in (Table 3) indicated effect of phosphate fertilizer and magnesium level and their interaction on PUE. The results showed that PUE values 56.96, 64.23, and 75.33% for TSP, DAP and UP respectively. The highest efficiency was obtained for UP which increased by 32.25 and 17.28% compared with TSP and DAP respectively, while efficiency of P use in the study increased as follows: UP > DAP > TSP. The results showed that the type of phosphate fertilizer had a significant effect on the PUE. The superiority of urea phosphate fertilizer over other fertilizers may be attributed to its high water solubility and movement within the plant roots as well as to the rapid hydrolysis to phosphoric acid and urea which reduced soil pH and phosphorus reactions (adsorption and precipitation) especially in calcareous soils as well as the releasing phosphorus in soil minerals, which contributed to the increased its availability and uptake in the plant compared to other fertilizers (3, 23,33). These results are consistent with many researchers finding. Al- Jiboori (9) used three phosphate fertilizers (TSP, DAP and UP) to the maize, and he found that UP followed by DAP and TSP and that the highest P efficiency use values were 11.07, 10.12 and 7.58% for UP, DAP and TSP, respectively. As Al-Salmani and Al- Mussawi (16) explained when using phosphate fertilizers in the growth and yield of maize, PUE arrangement was as follows: UP > DAP > MAP > TSP. The results are also consistent with those found in Taaban (39) in where UP fertilizer is superior to the other used fertilizers in his study. PUE were 4.6, 9.6 and 11.6% for TSP, DAP and UP respectively for maize. This is confirmed by Monica (34) and Rusek et al., (37). As for the magnesium application, the results showed a significant effect in PUE (Table 3). The increase in the magnesium level increased PUE by 26.33, 69.03, 88.57 and 78.12% in 50, 75 and 100 kg Mg ha^{-1} levels respectively. The highest efficiency was achieved at the level of 75 kg Mg ha^{-1} may be due to the role of magnesium in increasing phosphorus availability by reducing the phosphorus reactions with calcium and in calcareous soils and the formation of the most soluble magnesium phosphate (12 , 13). The results are consistent with the results of a number of researchers who found that PUE increased due to add phosphorus and magnesium fertilization together (2, 4, 30). The results also showed a significant interaction effect between type of phosphate fertilizer and level of magnesium application in PUE. The results showed an increase in PUE values to 83.62, 90.09 and 94.56% for TSP, DAP and UP respectively,

The high P use efficiency of phosphate fertilizers when they were mixed with magnesium fertilization was due to the positive effect of the interaction between phosphorus and magnesium in the soil and plant systems in phosphorus uptake, PUE and plant parameters. The results obtained are consistent with the results of several studies (4, 5, 7). The addition of magnesium fertilizer with phosphate fertilizers has increased the PUE in maize. This confirms that the addition of magnesium has increased the uptake of phosphorus and obtained a high response in the plant. The addition of Mg and P together was more beneficial to the plant than if they were added separately. This interaction of the addition of nutrients (phosphorus and magnesium) together is more importance by improving PUE to ensure optimal production as well as the economic importance of fertilizer use.

Correlation relationships

The results of the regression analysis showed that the relationship between the level of addition of magnesium and the plant parameters of phosphate fertilizers were described quadratic (Tables 5,6 and7). These relationships or response curves can predict the response of maize to the added phosphorus as well as determine the optimal level to achieve the highest response and maximum P and Mg uptake ad PUE. Many researchers found positive correlations of quadratic equation between added magnesium and plant parameters of some crops (wheat, barley and maize) (18, 27, 41).

Table 5.The relationship between plant parameters and Mg level of TSP fertilizer according to the quadratic equation.

Property	Equation	Correlation coefficient (R)*
P uptake in straw	$Y = 18.895 + 0.996X – 0.005X^2$	0.939
P uptake in grains	$Y = 28.881 + 0.192X – 0.001X^2$	0.973
Total P uptake	$Y = 54.013 + 1.157X – 0.005X^2$	0.972
Mg uptake in straw	$Y = 22.671 + 0.215X + 0.003X^2$	0.996
Mg uptake in grains	$Y = 7.968 + 0.680X + 0.001X^2$	0.973
Total Mg uptake	$Y = 30.639 + 0.283X + 0.002X^2$	0.995
Response percent	$Y = -11.325 + 1.362X – 0.011X^2$	0.930
P use efficiency	$Y = -18.605 + 1.817X – 0.008X^2$	0.985

*** Table R value at 0.05: 0.878**

Table 6.The relationship between plant parameters and Mg level of DAP fertilizer according to the quadratic equation.

Property	Equation	Correlation coefficient (R)*
P uptake in straw	$Y = 24.713 + 1.562X – 0.010X^2$	0.988
P uptake in grains	$Y = 30.718 + 0.232X – 0.001X^2$	0.938
Total P uptake	$Y = 54.392 + 1.959X – 0.014X^2$	0.967
Mg uptake in straw	$Y = 26.475 + 0.347X + 0.001X^2$	0.992
Mg uptake in grains	$Y = 8.019 + 0.078X – 0.001X^2$	0.995
Total Mg uptake	$Y = 33.901 + 0.425X + 0.001X^2$	0.995
Response percent	$Y = -12.541 + 1.556X – 0.013X^2$	0.957
P use efficiency	$Y = -15.566 + 2.936X – 0.022X^2$	0.967

***Table R value at 0.05: 0.878**

Table 7.The relationship between plant parameters and Mg level of UP fertilizer according to the quadratic equation.\

Property	Equation	Correlation coefficient (R)*
P uptake in straw	$Y = 22.344 + 2.057X – 0.013X^2$	0.917
P uptake in grains	$Y = 31.438 + 0.326X – 0.002X^2$	0.980
Total P uptake	$Y = 54.195 + 2.345X – 0.14X^2$	0.938
Mg uptake in straw	$Y = 30.628 + 0.268X + 0.003X^2$	0.996
Mg uptake in grains	$Y = 8.017 + 0.121X – 0.001X^2$	0.999
Total Mg uptake	$Y = 39.931 + 0.426X + 0.002X^2$	0.996
Response percent	$Y = 16.823 + 0.608X – 0.005X^2$	0.891
P use efficiency	$Y = -31.977 + 3.430X – 0.022X^2$	0.989

***Table R value at 0.05: 0.878**

UP was the most efficient in increasing the phosphorus availability and increasing all the plant parameters compared with others phosphate fertilizers (DAP and TSP). Magnesium application increased all plant parameters and the 75 kg Mg ha^{-1} level gave the highest value for those parameters. Positive interaction between Mg and phosphate fertilizers gave the highest response in maize.

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