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Impact of Magnesium Fertilization on Yield and Nutrients Uptake by Maize Grown on two Different Soils

R. A. El-Dissoky[*], Faten A. Al-Kamar and R. M. Derar
Soils, Water and Environment Res. Inst., Agric. Res. Center, Giza, Egypt

MAGNESIUM deficiency occurs as a result to its low content in soil, competition with other cations especially calcium and potassium and its removal by crops. This study was conducted to investigate the effect of applying magnesium at various rates and methods: as a soil application , *i.e.* 0, 25, 50, 75 and 100 kg magnesium sulphate fed^{-1}, and as foliar spray of 0.25 and 0.5% Mg twice on maize yield components, nutrient status and uptake and the relationships between Mg and both K and Ca for maize grown on two different soils during two summer growing seasons of 2015 and 2016. The first experiment was carried out in clay loam soil at Talkha District, Dakahlia Governorate (31° 16' 72.71" N, 31° 46' 25.80" E), and the second in sandy soil at Ismailia Agricultural Research Station (30.6° 35' 30" N, 32.2° 14' 50" E), Egypt. Results showed that the application of Mg-rates significantly increased grain and stalk yields, 100-grain weight, grain content of oil, protein, P, K, Ca, Mg, Mn and Zn, and the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by stalk yield, with the superiority for Mg-rates 50 Kg fed^{-1} and 0.5% Mg foliar spray in clay loam soil, and for the rate 75 Kg fed^{-1} in sandy soil. Relationships between Mg and K or Ca at ear leaf demonstrated that K:Mg and Ca:Mg ratios increased with the foliar spray of Mg and soil addition of Mg-rates up to 50 kg fed^{-1} in both soils.

Keywords: Magnesium fertilization, Maize yield, Soil texture and Nutrient relationships and Uptake.

Introduction

Maize is one of the most important cereal crops in Egypt that ranks as the third crop after wheat and rice. It is used as a human food and animal feed. It is characterized by a high potential of biomass and grain yield, furthermore it uptakes great amounts of nutritive elements from the soil. The role of magnesium as one of the essential nutrients for plant growth; is being a component of the chlorophyll molecule; it serves as a cofactor in most enzymes that activate phosphorylation processes as a bridge between pyrophosphate structures of ATP or ADP, DNA, RNA and the enzyme molecule; and it is essential for amino acids and fat synthesis (Mengel and Kirkby, 2001). Nevertheless, such element received little attention terms of fertilization. Kacar and Katkat (2007) noticed that chemical fertilizers produced through developing technology do not include Mg, although growing recently developed varieties of plants, having high nutritional elements uptakes besides their ability to remove higher amounts of nutrients from soil.

In principle there are two reasons for Mg deficiency to occur, absolute deficiency and cation competition. Absolute deficiency can be a consequence of (1) low Mg contents in the source rocks, (2) Mg losses from the soil , *e.g.* by mobilization and subsequent leaching and (3) long-term unbalanced crop fertilization practice neglecting Mg depletion of soils through crop Mg removal. Cation competition is a consequence of nutrient imbalances in soils. It is commonly known that the uptake of Mg is strongly influenced by the availability of other cations like NH_4, Ca and K. Nutrient imbalances in the soil could be associated with fertilization practice (Fageria, 2001, Römheld & Kirkby, 2007 and Gransee & Fuhrs, 2013). In this respect, Pathak & Kalra (1971) and Singh & B L Singh (1986) noted that the higher supply of K depressed the Mg uptake. Marschner (1995) in nutrient solution experiments showed that high availability of the cations Ca, K and Mn can lead to strong decreases in Mg uptake.

[*]Corresponding author email: r.eldissoky@yahoo.com
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Symptoms of Mg deficiencies on plants could be related to other nutrient status in soil. Gunes et al. (2002) stated that not only Mg deficiency occurs from lower amount of Mg in soil, but also due to competition with other cations such as H^+, K^+, NH_4^+, Ca^{++} and Mn^{++}. Schulte (2004) demonstrated that deficiency of Mg appears in sandy soils at the application of high rates of K^+ and NH_4^+ fertilizers, since high concentrations of these cations in the soil solution interfere (antagonistic effect) with Mg uptake by plants, and usually does not occur when the soil contains more exchangeable Mg than exchangeable K. He added that the optimum soil test levels for available Mg are 51-250 ppm for sandy soils and of 101-500 ppm for all other soils.

Jacobsen (1993) stated that K:Mg and Ca:Mg ratios are important for balanced Mg nutrition. When the supply of potassium is insufficient, the rate of Mg uptake by plants also decreases, but on the other hand, the too excessive doses of potassium fertilizers negatively influence nutrient balance in the plant. Kovacevic et al. (2004) showed that high correlations were found between ear-leaf Mg (negative correlations) and ear-leaf K as well as ear-leaf Ca (positive correlations). They found that the share of Mg in the sum of K+Ca+Mg among the tested corn hybrids ranged from 9.3 to 21.3%, also K:Mg ratio in the ear leaf ranged from 1.78 to even 6.56, whereas Ca:Mg ratio has less variable property than K:Mg ratio since the values ranged from 1.94 to 3.44. Fertilization programs in Egypt for almost crops neglected application of Mg as a macronutrient. However, many studies showed the importance of magnesium fertilization for increasing crops productivity. Under the Egyptian conditions, Darwish et al. (1997) found that the application of $MgSO_4$ as soil or foliar application resulted in significant increases in 100-seed weight, seed and oil yields of sun flower as well as seed contents of protein and oil. On clayey soil, Ashoub et al. (2003) found that applying magnesium sulphate fertilization of 7.5 or 15 Kg fed^{-1} as soil application, or twice foliar spray applications of 0.5 or 1.0% caused significant increases in the dry matter per plant at the age of 49 days, the head diameter, the weight of 100 seeds, the seed yield per plant, seed, straw and biological yields fed^{-1} with the exception of 7.5 kg fed^{-1}. Badran et al. (2004) studied the growth of wheat grown on calcareous soil, and reported that the highest grain, straw and protein yields, plant height, 1000-grain weight and grain minerals content (N, P, K and Mg) were gained by the application of 75 kg N fed^{-1} under foliar spraying of 400 L fed^{-1} magnesium sulphate 6% solution.

Barlog and Frackowiak-Pawlak (2008) found that potassium fertilization increased the average maize grain yield by 2.3%, but the marked grain yield increase was reached owing to the application of both K and Mg at the rates 150 and 16.3 kg ha^{-1}, respectively in the field studies in loamy sand to loamy soils. Szulc (2009) showed that the highest N, K and Mg contents in dry plant matter (37.0, 42.18 and 2.65 g kg^{-1}, respectively) were found by maize fertilized with 15 kg Mg ha^{-1} applied in rows, in comparison with 0 kg and 15 kg Mg ha^{-1} broadcasting. Rasul et al. (2011) found that the application of 80 kg Mg ha^{-1} as $MgSO_4.7H_2O$ and 140 kg P ha^{-1} recorded the highest value of grain yield (5605.2 kg ha^{-1}) of wheat grown in silty clay loam soil. In a field study in clay loam soil under semi-arid condition, Ertiftik and Zengin (2016) stated that synergic relations were found between Mg and P and Fe in maize leaves at the soil applied of Mg (0, 20, 40 and 60 kg MgO ha^{-1} as magnesium sulfate).

This study aims to investigate the response of maize yield grown in two different soil textures (clay loam and sandy soils) under the Egyptian conditions to magnesium fertilization and its effect on nutrients status in plant and grain and also the relationships between Mg and other nutrients.

Materials and Methods

Two field experiments were conducted in two different texture soils to investigate the response of maize to Mg fertilization during the two successful summer growing seasons of 2015 and 2016. The first experiment was performed in clay loam soil at Batra Village, Talkha District, Dakahlia Governorate (Latitude 31° 16' 72.71" N, Longitude 31° 46' 25.80" E), and the second experiment was conducted in sandy soil at Ismailia Agricultural Research Station, Agricultural Research Center (Latitude 30.6° 35' 30" N, Longitude 32.2° 14' 50" E), Ismailia Governorate, Egypt.

Soil samples were taken from the surface layer (0–30 cm) before sowing of each experiment, and then some physical and chemical properties were analyzed according to Jackson (1967) and Hesse (1971) as shown in Table 1.

TABLE 1. Some physical and chemical properties of the study soils

Properties		Site Talkha	Site Ismailia	Properties		Site Talkha	Site Ismailia
Particle size distribution%	Sand	34.45	92.75	**EC (dSm^{-1})		2.04	1.2
	Silt	30.30	0.75	Soluble Cations ($mM\ L^{-1}$)	Ca^{++}	7.0	4.2
	Clay	35.25	6.50		Mg^{++}	5.0	2.5
Texture		Clay loam	Sandy		Na^{+}	7.1	4.95
Saturation percent		65.0	21		K^{+}	0.54	0.35
Organic matter %		0.93	0.31	Soluble anions ($mM\ L^{-1}$)	CO_3^{--}	--	--
$CaCO_3$%		2.40	0.49		HCO_3^{-}	4.0	2.7
*pH		8.16	7.82		Cl^{-}	12.5	6.8
Bulk density ($g\ cm^{-3}$)		1.20	1.71		SO_4^{--}	3.14	2.5
Available nutrients ($mg\ kg^{-1}$)							
N		70	34	Mg		180	70
P		15	11	Fe		3.80	2.40
K		380	139	Mn		2.15	1.22
Ca		1100	300	Zn		0.75	0.30

*pH in soil : water suspension1:2.5, ** EC in soil paste extract.

Experiments design and treatments

The experiments were performed in a Complete Randomized Blocks Design with three replicates. The experimental plot area was 10.5 m^2 (5 lines x 0.60m width x 3.5m length). Each experiment consisted of seven treatments of magnesium sulphate fertilizer (10% Mg) as a soil application and foliar spraying on plants as follows:

- T_1: control (without Mg application).
- T_2: 25 kg $MgSO_4$ fed^{-1} as a soil application.
- T_3: 50 kg $MgSO_4$ fed^{-1} as a soil application.
- T_4: 75 kg $MgSO_4$ fed^{-1} as a soil application.
- T_5: 100 kg $MgSO_4$ fed^{-1} as a soil application.
- T_6: 0.25**%** Mg foliar spraying (twice).
- T_7: 0.5**%** Mg foliar spraying (twice).

Sowing and fertilization

Maize seeds (c.v. single hybrid 30-K-08) were sown at the 1st season on 25th April and 15th May 2015 and harvested on 25th August and 15th September 2015 for Talkha (clay loam soil) and Ismailia (sandy soil) sites, respectively; and were sown at the 2nd season on 27th April and 11th May 2016 and harvested on 28th August and 14th September 2016 in Talkha and Ismailia sites, respectively.

Phosphorus fertilizer was added at the rate of 200 Kg fed^{-1} as super phosphate (15% P_2O_5) with soil preparation before sowing for both experiments. Nitrogen fertilizer was added at a rate of 120 kg N fed^{-1} as ammonium nitrate (33.5% N) at two equal doses with the second and third irrigation for maize grown in clay loam soil, as well as it was applied at a rate of 140 Kg N fed^{-1} as ammonium sulphate (20.5% N) at four equal doses, all two week after emergence for maize grown in sandy soil. The potassium fertilizer was applied at a rate of 24 kg K_2O fed^{-1} as potassium sulphate (48% K_2O) with 1st irrigation after sowing for maize grown in clay loam soil, and with sowing in sandy soil. Also, all recommended field practices for maize crop were carried out for the experiments. The field irrigation system was surface irrigated in lines every 15 days in clay loam soil, and it was drip irrigated every two days in sandy soil.

Application of magnesium treatments

Soil applications of Mg treatments (T_2, T_3, T_4 and T_5) were applied as magnesium sulphate (10% Mg) with the second irrigation for experimental at clay loam soil and after sowing by four weeks for experiment in sandy soil. Concerning foliar spraying of Mg treatments (T_6

and T_7), Mg was sprayed at the concentration of 0.25 and 0.5% Mg as magnesium sulphate (10% Mg) twice after 35 and 50 days from sowing (at the rate of 400 L fed^{-1}).

Harvest and chemical analysis

At harvesting stage, plants at each plot were collected and yield parameters were recorded; Plant height (cm), plant dry weight (g), ear length (cm), ear weight (g $plant^{-1}$), 100-grain weight (g), grain weight per ear (g), grain yield (kg fed^{-1}) and stalk yield (kg fed^{-1}). Samples of grain and ear leaf were taken randomly from each plot for chemical analysis to determine nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese and zinc concentrations and uptakes. Nitrogen was determined using Kjeldahl method, phosphorus was determined spectro-photometrically and potassium was determined using flame photometer**.** Calcium, magnesium, iron, zinc and manganese were determined using atomic adsorption plasma - ULTIMA 2-ICP- OES (Inductively Coupled Plasma Optical Emission Spectrometry) at the Unite of Soil and Water Analysis at Soils, Water and Environment Research Institute, ARC, Egypt. The oil content was determined using Soxhlet method according to A.O.A.C. (1990). Protein content was calculated as follows: (protein% = N % in grain × 5.70).

The statistical analysis was done according to Gomez and Gomez (1984) and means of treatments were compared against least significant differences test (LSD) at 5% and Duncan's multiple comparisons Test.

Results and Discussion

Soil characteristics

It is clear from the results in Table 1 that soils at Talkha and Ismailia sites were characterized by a slightly alkaline pH (8.16-7.82) and non saline (2.04- 1.2 dSm^{-1}). Soil of Talkha site (clay loam soil) was moderate in the available P, K and Mg, high in the available N and Ca and low in the available Fe, Mn and Zn; whereas soil in Ismailia site (sandy) was moderate in the available N, P, K and Ca and low in the available Mg, Fe, Mn and Zn. Concerning the relationships between Mg and Ca and K in terms of soil fertility, Jokinen (1981) illustrated that the most suitable balances between exchangeable Ca, K and Mg are supposed to be Ca:K= 12, Ca:Mg= 6 and Mg:K= 2. Whereas, the results of soil analysis before sowing (Table 1) showed that the pervious ratios were; 2.89, 6.11 and 0.47 in Talkha clay loam soil, and 2.16, 4.28 and 0.50 in Ismailia sandy soil, respectively. Therefore, from the previous ratios there were imbalances between these cations in two soils according to Jokinen (1981), whereas Ca was high in clay loam soil. In this respect Ertiftik and Zengin (2016) found that even if Mg was present in the soil in adequate amounts, the plants could not uptake sufficient amounts, and hidden or visible deficiency symptoms could occur.

Maize yield and its components

In Talkha site

Data in Table 2 show that the application of Mg-rates significantly increased grain and stalk yields, plant weight, ear weight $plant^{-1}$ and grain weight ear^{-1}, but had insignificant effect on ear length. The superior in grain yield was recorded with the application of Mg-rate T_7, but without significant differences with yield recorded with Mg-rates; T_3, T_4 and T_6 . Grain yield increased by 8.11, 12.77, 10.44, 9.51, 11.84 and 13.99 % with the application of Mg-rates; T_2, T_3, T_4, T_5 and T_7 as compared with the control (T_1), respectively. Stalk yield significantly increased with Mg-rates application compared with the control (T_1) up to T_3, since the differences among Mg-rates were insignificant. Stalk yield increased by 22.04, 26.33, 23.43, 22.04, 23.65 and 26.18 % with the application of Mg-rates, respectively as compared with the control. As well, the differences among the values recorded with the application of Mg-rates T_2, T_3 and T_7 for plant dry weight, ear weight and grain weight ear^{-1} were insignificant. So, these results demonstrate positive response of maize grown in clay loam soil to Mg fertilization; whereas foliar spray of 0.5 % Mg (T_7) had the superior effect on plant dry weight, ear length, grain weight ear^{-1}, grain and stalk yields.

It is clear from the previous results, the response to application of Mg-rates, which may be attributed to the initial status of soil before sowing (Table 1); whereas soil was moderate in its fertility of Mg and K, and high in available Ca, that may affect the supply of Mg to plant; since there is a competition among Mg, K and Ca. Also, the level of available Mg was insufficient (Fageria 2001, Römheld & Kirkby, 2007 and Gransee & Fuhrs, 2013).

In Ismailia site

Results in Table 2 illustrate that maize grain and stalk yields significantly increased with the application of Mg rates, since these increases were the highest with Mg-rate T_4 (75 Kg $MgSO_4$

fed^{-1}). Grain and stalk yields increased by 11.66 and 11.72 % with the addition of Mg-rate T_4 as compared with the control (T_1); while they increased by 6.04 and 8.14 % with foliar spray of 0.5 % Mg (T_7), respectively. Also, the application of Mg rates had a significant effect on plant weight, ear weight plant^{-1}, ear length and grain weight ear^{-1}. Furthermore, results showed that soil application of Mg-rates was more effective on maize yield and its components as compared with foliar spray of Mg.

From the previous results, it is clear that there were positive response from maize yield grown on clay loam and sandy soils to the application of Mg-rates; which were the highest with Mg-rate T_7 for maize grown on clay loam soil, and with T_4 for maize grown on sandy soil. These responses may be attributed to the initial level of available Mg in soil before sowing as shown in Table 1 that was moderate in clay loam soil and low in sandy soil, as well as, to imbalances between Mg and Ca and K as shown in soil characteristics which reflects on the soil supply ability of Mg and consequently on maize yield (Römheld & Kirkby, 2007, Gransee & Fuhrs, 2013 and Ertiftik & Zengin, 2016).

Grain quality and its contents

In Talkha site

Data in Table 3 illustrate that 100-grain weight, oil and protein% (as grain quality) significantly increased with the application of Mg-rates. The highest value of 100-grain weight and oil% was recorded with the application of Mg-rate T_7. However, the differences among the obtained results of 100-grain weight recorded with other Mg-rates were insignificant. Concerning grain content of P, K, Ca, Mg, Fe, Mn and Zn, it is clear from the results that grin content of P, K, Ca, Mg, Mn and Zn significantly increased with the application of Mg-rates up to T_3 (50 kg $MgSO_4$), but had insignificant effect on Fe content. These increases in grain content of protein, oil, P, K, Ca, Mg, Fe, Mn and Zn mean increase the quality and the nutritional value of grain. Singh & Singh (1986), Rasul et al. (2011) and Ertiftik & Zengin (2016) reported similar results.

In Ismailia site

Application of Mg-rates as soil or foliar spraying had significant effect on 100-grain weight, protein% and oil % in maize grain. The values of 100-grain weight and protein content significantly increased up to T_3. Also, the application of Mg-rates significantly increased grain content of P, K, Ca, Mn and Zn, but had insignificant effect on grain content of Mg and Fe. The highest grain content of Ca, Mg, Fe, Mn and Zn were recorded with the application of Mg-rate T_5 (100 kg $MgSO_4$ fed^{-1}), but this content was insignificant with that recorded with Mg-rate T_4 (75 kg $MgSO_4$ fed^{-1}).

It is obvious from the mentioned results for grain content of maize grown in clay loam and sandy soils, that the application of Mg-rates had a positive effect on 100-grain weight, oil and protein percentages and its content of phosphorus, calcium, iron and zinc; and these results are in accordance with that obtained by Ertiftik and Zengin (2016). In this respect, Mengel & Kirkby (2001), Grzebisz (2004) and Barlog & Frackowiak-Pawlak (2008) stated that K and Mg exerted a positive influence on the weight of 1000 kernels, since both elements participate in the transport of carbohydrates to the sink organs. As well, these results are correlated with the importance of Mg for the plant; it serves as a cofactor in most enzymes that activate phosphorylation processes as a bridge between pyrophosphate structures of ATP or ADP, DNA, RNA and the enzyme molecule, it is essential for amino acids and fat synthesis (Mengel and Kirkby, 2001). As well, maize is considered as an exhaustive crop, and Mg both had been found to enhance the carbohydrate content like K.

Ear leaf content of nutrient

In Talkha site

The chemical analysis of ear leaf as shown in Table 4 demonstrate that its content of N, P, K, Ca, Mg, Fe, Mn and Zn concentrations significantly increased with the application of Mg-rates. Nitrogen, K, Ca and Zn concentrations in ear leaf significantly increased with the application of Mg-rates up to T_3 , however leaf content of Mg, Fe and Mn increased up to T_4 , since P content increased with Mg-rates application up to T_5 , Moreover, foliar spraying of 0.5% Mg (T_7) increased ear leaf content of K, Ca, Mn and Zn without significant differences with those recorded with Mg-rates T_3 and T_4. Increasing the Mg rate of application up to T_3 had a positive effect on the ear leaf content of K and Ca, but its concentrations decreased with the application of Mg-rates; T_4, T_5 and T_6; and this may be returned to the competition among Mg, K and Ca for plant uptake, since

TABLE 2. Effect of magnesium application rates and methods on maize yield and its components grown in clayey loam and sandy soils

Treatments / Parameters	Plant height (cm)	Plant weight (g)	Ear length (cm)	Ear weight (g)	Grain weight ear^{-1}	Grain yield ($kg\ fed^{-1}$)	Stalk yield ($kg\ fed^{-1}$)
Talkha experiment (clay loam soil)							
T_1: Control	310c	251b	19.5a	241c	214d	3429d	4519b
T_2: 25 kg $MgSO_4$ fed^{-1}	333a	303a	19.7a	252bc	232c	3707c	5515a
T_3: 50 kg $MgSO_4$ fed^{-1}	327ab	314a	20.3a	274a	242ab	3867ab	5709a
T_4: 75 kg $MgSO_4$ fed^{-1}	315bc	307a	19.8a	262ab	237abc	3787abc	5578a
T_5: 100 kg $MgSO_4$ fed^{-1}	325ab	303a	20.5a	260ab	235bc	3755bc	5515a
T_6: 0.25% Mg foliar	315bc	307a	20.8a	270a	240abc	3835abc	5588a
T_7: 0.5% Mg foliar	317bc	314a	21.0a	274a	244a	3909a	5702a
L.S.D. at 5%	13.4	17.1	NS	16.1	7.8	124.3	421.7
Ismailia experiment (sandy soil)							
T_1: Control	217a	189b	17.5c	182d	155	2615e	4250g
T_2: 25 kg $MgSO_4$ fed^{-1}	217a	201a	18.9b	192c	162	2697d	4530d
T_3: 50 kg $MgSO_4$ fed^{-1}	218a	209a	20.7a	196abc	169	2876ab	4695b
T_4: 75 kg $MgSO_4$ fed^{-1}	218a	211a	20.8a	199ab	169	2920a	4748a
T_5: 100 kg $MgSO_4$ fed^{-1}	218a	208a	20.1a	202a	167	2845b	4465e
T_6: 0.25% Mg foliar	216a	201a	19.8ab	194bc	165	2673d	4405f
T_7: 0.5% Mg foliar	218a	204a	19.9ab	196abc	167	2773c	4596c
L.S.D. at 5%	Ns	12.2	1.2	5.8	3.9	46.1	36.0

TABLE 3. Effect of magnesium application rates and methods on grain contents of maize grown in clayey loam and sandy soils

Treatments / Parameters	100-grain weight (g)	(%)						($mg\ kg^{-1}$)		
		Oil	Protein	P	K	Ca	Mg	Fe	Mn	Zn
Talkha experiment (clay loam soil)										
T_1	29.49b	9.97d	5.65d	0.258de	0.25c	0.057b	0.075b	547b	7.2c	137b
T_2	31.11a	10.19c	6.75a	0.271d	0.28bc	0.058b	0.078b	592ab	9.2b	142b
T_3	31.27a	10.20c	6.84ab	0.303c	0.36a	0.069ab	0.085a	641a	9.7ab	166a
T_4	31.28a	10.39b	7.13a	0.352a	0.30b	0.078a	0.082ab	616ab	10.5ab	143b
T_5	31.29a	9.57e	6.56b	0.249de	0.20d	0.059b	0.078b	630ab	11.3a	145b
T_6	31.28a	10.14c	6.16c	0.329b	0.27bc	0.062b	0.080ab	553b	8.8bc	153ab
T_7	31.77a	10.52a	6.75b	0.242e	0.29bc	0.064b	0.085a	606ab	9.7ab	168a
L.S.D. at 5%	0.75	0.087	0.29	0.022	0.04	0.012	0.006	NS	1.78	15.5
Ismailia experiment (sandy soil)										
T_1	30.50c	9.16c	5.44d	0.380c	0.403c	0.080b	0.095a	486b	9.3c	184d
T_2	32.30c	9.21c	6.37b	0.410ab	0.433ab	0.120a	0.099a	549ab	9.7c	188cd
T_3	37.20a	9.25bc	6.75a	0.360d	0.440a	0.088b	0.108a	586a	11.7bc	208bc
T_4	36.50ab	9.38b	6.82a	0.343e	0.417abc	0.073b	0.115a	566a	14.2ab	215ab
T_5	35.90ab	9.61a	5.80c	0.340e	0.410bc	0.123a	0.120a	594a	16.0a	232a
T_6	35.10b	9.20c	5.57cd	0.420a	0.430ab	0.073b	0.096a	530ab	10.3c	190cd
T_7	36.20ab	9.30bc	6.27b	0.400b	0.423abc	0.093b	0.104a	537ab	13.3ab	220ab
L.S.D. at 5%	2.10	0.15	0.29	0.012	0.022	0.022	Ns	Ns	2.59	19.9

TABLE 4. Effect of magnesium application rates and methods on ear leaf contents of maize grown in clayey loam and sandy soils

Parameters / Treatments	(%)					(mg kg^{-1})		
	N	P	K	Ca	Mg	Fe	Mn	Zn
Talkha experiment (clay loam soil)								
T_1	1.20d	0.219f	1.17de	0.88c	0.350d	640e	27d	112d
T_2	1.25bcd	0.232e	1.21cde	0.97ab	0.366c	686cd	38b	130bc
T_3	1.33ab	0.248d	1.27ab	1.03a	0.379b	700bc	40b	143ab
T_4	1.40a	0.323b	1.25abc	0.93bc	0.391ab	747a	46a	148a
T_5	1.30bc	0.374a	1.15e	0.87c	0.403a	758a	47a	133abc
T_6	1.24cd	0.232e	1.22bcd	0.90c	0.362cd	668d	34c	120cd
T_7	1.31bc	0.261c	1.30a	1.00a	0.380b	712b	46a	133abc
L.S.D. at 5%	0.08	0.004	0.05	0.06	0.012	20.2	4.1	16.3
Ismailia experiment (sandy soil)								
T_1	0.92c	0.150	0.86e	0.75c	0.277d	720d	41d	52d
T_2	1.07b	0.160	1.03abc	0.86b	0.333cd	807b	61a	70bc
T_3	1.17a	0.163	1.09a	0.88b	0.347bc	860a	55b	72ab
T_4	1.23a	0.170	1.05ab	0.97a	0.400ab	870a	47c	71bc
T_5	1.00b	0.174a	0.97bcd	0.90b	0.407a	892a	62a	77a
T_6	1.02b	0.155	0.92de	0.79c	0.290cd	763c	46cd	65c
T_7	1.08b	0.162	0.95cde	0.86b	0.300cd	786bc	60a	75ab
L.S.D. at 5%	0.08	Ns	0.082	0.054	0.056	38.2	4.5	5.4

there were imbalances between these nutrient in soil before sowing (as shown in Table 1). These results are consistent with Römheld & Kirkby (2007) and Gransee & Fuhrs (2013).

In Ismailia site

Results in Table 4 show that the application of Mg-rates had a significant effect on ear leaf content of N, K, Ca, Mg, Fe, Mn and Zn, but had an insignificant effect on ear leaf content of P. Ear leaf content of N, K, Fe and Zn significantly increased with application of Mg-rates up to T_3, and up to T_4 for ear leaf content of Ca and Mg. It is obvious from the mentioned results that the application of Mg-rates had a positive effect on maize grown in sandy soil, related with results of analysis of soil before sowing (Table 1), that was low in available Mg. These results are consistent with that obtained by Kovacevic et al. (2004), Szulc (2009) and Ertiftik & Zengin (2016). In this respect, Izsaki (2006) and Szulc (2009) reported that P in corn leaves increased with the increases in Mg doses.

Relationships among ear leaf content of Mg, K and Ca

The results in Table 5 show the relationships between ear leaf content of Mg, K and Ca as for K:Mg and Ca:Mg ratios and the percentage of Mg for sum K+Ca+Mg concentrations.

In Talkha site

It is clear from the results that the value of K:Mg ratio was not changed with application of Mg-rates T_2 and T_3, then it decreased with increasing the rate of soil application of Mg up to T_5 (100 kg $MgSO_4$). However, the ratio of K:Mg was increased with foliar spraying of Mg (as T_6 and T_7). The ratio of K:Mg arranged from 2.85 (the lowest ratio that recoded at T_5) to 3.41 (the highest ratio that recoded at T_7). The increases in K:Mg ratio related with increases that recorded in ear leaf content of K and Mg (Table 4). Concerning Ca: Mg ratio, it is obvious that their values were increased with application of Mg-rates T_2, T_3 and T_7, but it decreased with

Mg-rates; T_4 and T_5 and T_6 compared with control (T_1). However, the differences among T_2, T_3 and T_7 for Ca:Mg ratio were insignificant, which correlated with its concentrations in ear leaf. Regarding % of Mg for sum (K+Ca+Mg), it is obvious that percentage was significantly increased with application of Mg-rates up to T_5 (100 kg $MgSO_4$ fed^{-1}), since the highest percent was 16.62 % that recorded with addition of Mg-rate T_5. It is clear from previous results that application of Mg-rates; T_2, T_3 and T_7 (25 and 50 kg $MgSO_4$ fed^{-1} and foliar spray of 0.5% Mg) were sufficient to maintain the balance between Mg, K and Ca, as well as these results agree with that obtained by Kovacevic et al. (2004).

In Ismailia site

The results in Table 5 show that K:Mg ratio was affected with the application of Mg-rates; whereas it increased with the rate of T_3 and foliar spray of Mg at 0.25 and 0.5% Mg. K:Mg ratio ranged from 2.39 (the lowest ratio that recoded at T_5) to 3 .22 (the highest ratio that recoded at T_7). Also the ratio of Ca:Mg increased with foliar spray of Mg at 0.25 and 0.5% Mg (T_6 and T_7), but it decreased with soil application of Mg-rates; T_2, T_3, T_4 and T_5 as compared with control (T_1). This ratio correlated negatively with the increases in ear leaf content of Mg. Concerning percentage of Mg for sum (K+Ca+Mg), it is obvious that increased with application of Mg-rates up to T_5, which recorded the highest percentage (17.94 %).

Kovacevic et al. (2004) demonstrated that the share of Mg in the sum K+Ca+Mg for corn hybrids ranged from 9.3 to 21.3%; K:Mg ratio ranged from 1.78 to even 6.56, whereas Ca:Mg ratio ranged from 1.94 to 3.44. Hence, the obtained results (a shown in Table 5) are in agreement with that result. So it is clear from mentioned results that foliar spray of 0.5% Mg was sufficient to maize growing in clay loam soil; as well as soil application of 75 kg magnesium sulfate per fed-1 was sufficient to maize growing in sandy soil; which maintain on the balance between K, Mg and Ca in ear leaf.

The uptake of nutrient by grain yield

In Talkha site

The data in Table 6 show that the application of Mg-rates significantly increased the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by grain. The uptake of N, P and Ca by grain yield significantly increased up to T4 and then decreased. As well, the uptake of K by grain significantly increased up to Mg-rate T_3 then decreased. However the differences among the uptakes of N, Ca, Mg, Fe, and Zn by grain that recorded under Mg-rates T3 and T7 were insignificant. So these results illustrate the importance of Mg supply at the rate of T_3 (50 kg $MgSO_4$) as soil application or at the rate of T_7 (0.5 % Mg) as a foliar spray on maize grown in clay loam soil.

In Ismailia site

The application of Mg-rates as magnesium sulphate had a significant effect on the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by grain, since the uptake of N, K, Mg, and Fe significantly increased with soil application of Mg-rates up to the rate of 50 kg $MgSO_4$ (T_3). Generally, it is clear from mentioned results that application o Mg-rates improved the uptakes of mostly nutrients by grain, and this demonstrates the importance of Mg supply for maize crop grown in sandy soil, and this accordance with results that obtained by Izsaki (2006), Szulc (2009) and Ertiftik & Zengin (2016).

The uptake of nutrient by stalk yield

The data shown in Table 7 illustrate the effect of the application Mg-rates on the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by stalk yield of maize grown in clay loam and sandy soils.

In Talkha site

The results demonstrated that the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by maize stalk yield significantly increased with the application of Mg-rates, with superiority for Mg-rates; T_3 and T_7 in the mostly for nutrient uptake without significance differences among them. The highest uptake by stalk yield of N and Zn (78.0 Kg fed^{-1} and 827 g fed^{-1}, respectively) were recorded with soil application of 75 kg $MgSO_4$ fed^{-1} (T_4), moreover the highest uptake of P, Mg, Fe and Mn were recorded with soil application of 100 kg $MgSO_4$ fed^{-1} (T_5). So these results illustrate that there were synergic relationship among Mg and these pervious elements, and this accordance with results that obtained by Ertiftik and Zengin (2016). On contrast, the uptake of K and Ca were decreased with increasing the rate of soil application of Mg, and this may be attributed to competition among these elements in high rates of Mg supply (Fageria 2001, Guneş et al., 2002, Römheld & Kirkby 2007 and Gransee & Fuhrs, 2013).

TABLE 5. Effect of magnesium application rates and methods on the ratios of investigated cations in ear leaf for maize grown in two different soils.

Parameters / Treatments	Ratios		% Mg in (K+Ca+Mg)
	K:Mg	Ca:Mg	
Talkha experiment (clay loam soil)			
T_1: control	3.36ab	2.50ab	14.58bc
T_2: 25 kg $MgSO_4$ fed^{-1}	3.31ab	2.66a	14.36c
T_3: 50 kg $MgSO_4$ fed^{-1}	3.36ab	2.72a	14.14c
T_4: 75 kg $MgSO_4$ fed^{-1}	3.20b	2.37bc	15.22b
T_5: 100 kg $MgSO_4$ fed^{-1}	2.85c	2.17c	16.62a
T_6: 0.25 % Mg foliar	3.38ab	2.49ab	14.55bc
T_7: 0.5 % Mg foliar	3.41a	2.64a	14.20c
L.S.D. at 5%	0.18	0.21	0.68
Ismailia experiment (sandy soil)			
T_1: control	3.12	2.72	14.67
T_2: 25 kg $MgSO_4$ fed^{-1}	3.10	2.59	14.98
T_3: 50 kg $MgSO_4$ fed^{-1}	3.16	2.54	14.94
T_4: 75 kg $MgSO_4$ fed^{-1}	2.65	2.46	16.52
T_5: 100 kg $MgSO_4$ fed^{-1}	2.39	2.22	17.94
T_6: 0.25% Mg foliar	3.19	2.74	14.45
T_7: 0.5% Mg foliar	3.22	2.91	14.20
L.S.D. at 5%	Ns	Ns	Ns

TABLE 6. Effect of magnesium application rates and methods on the uptake of some macro- and micronutrients by grain of maize grown in two different soils.

Parameters / Treatments	N	P	K	Ca	Mg	Fe	Mn	Zn
	($Kg\ fed^{-1}$)					($g\ fed^{-1}$)		
Talkha experiment (clay loam soil)								
T_1	34.00d	8.84d	8.57c	1.96c	2.58c	1875c	25c	468d
T_2	43.85b	10.04c	10.49b	2.13bc	2.89b	2191ab	34ab	525cd
T_3	46.38a	11.71b	14.06a	2.66ab	3.29a	2478a	37ab	641ab
T_4	47.33a	13.31a	11.52b	2.97a	3.09ab	2333ab	40ab	539c
T_5	43.18b	9.36cd	7.69c	2.23bc	2.91b	2365ab	43a	545c
T_6	41.40c	12.61a	10.46b	2.39bc	3.07ab	2119bc	34ab	588bc
T_7	46.26a	9.47cd	11.37b	2.50abc	3.33a	2368ab	38ab	655a
L.S.D. at 5%	2.04	0.84	1.57	0.51	0.28	293.8	7.9	59.4
Ismailia experiment (sandy soil)								
T_1	24.97d	9.94c	10.55c	2.09b	2.49c	1271b	24e	481c
T_2	30.12bc	11.06a	11.69b	3.24a	2.66bc	1482ab	26e	507c
T_3	34.03a	10.35b	12.65a	2.53b	3.11abc	1685a	34cd	598b
T_4	34.95a	10.03bc	12.17ab	2.14b	3.36ab	1653a	42ab	629ab
T_5	28.92c	9.67c	11.67b	3.51a	3.41a	1691a	46a	659a
T_6	26.11d	11.23a	11.49b	1.96b	2.57c	1417b	27de	509c
T_7	30.50b	11.09a	11.74b	2.59b	2.89abc	1490ab	37bc	610ab
L.S.D. at 5%	1.33	0.38	0.65	0.62	0.66	205.6	6.7	54.6

TABLE 7. Effect of magnesium application rates and methods on the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by stalk of maize grown in two different soils.

Parameters / Treatments	(Kg fed^{-1})					(g fed^{-1})		
	N	P	K	Ca	Mg	Fe	Mn	Zn
Talkha experiment (clay loam soil)								
T_1	54.20d	9.92f	53.06e	39.59e	15.80c	2889c	120d	503d
T_2	68.90c	12.79e	66.62bcd	53.60bc	20.15b	3782b	211bc	718a
T_3	76.09ab	14.16cd	72.71ab	58.71a	21.65ab	3996abc	227ab	818bc
T_4	78.00a	17.96b	69.76abc	51.74cd	21.80ab	4165a	259a	827a
T_5	71.71bc	20.64a	63.25d	48.10d	22.21a	4181a	261a	737abc
T_6	69.47c	12.97de	68.37bcd	50.37cd	20.22b	3730b	189c	671c
T_7	74.68abc	14.90c	73.95a	57.17ab	21.69ab	4057ab	260a	755abc
L.S.D. at 5%	5.36	1.25	4.98	5.74	1.60	306.5	33.0	98.9
Ismailia experiment (sandy soil)								
T_1	38.96e	6.38d	36.70e	31.88d	11.76d	3060d	176d	221d
T_2	48.32cd	7.25bc	46.67bc	39.11b	15.10bc	3655b	276a	317b
T_3	54.77b	7.67ab	51.33a	41.31b	16.27ab	4037a	257a	336ab
T_4	58.56a	8.07a	49.69ab	46.21a	18.99a	4131a	225b	335ab
T_5	44.65d	7.77ab	43.16	40.04b	18.16a	3983a	275a	345a
T_6	44.79d	6.83cd	40.69d	34.96c	12.78cd	3362c	203c	286c
T_7	49.79c	7.43abc	43.51cd	39.53b	13.79bcd	3612b	274a	346a
L.S.D. at 5%	3.74	0.68	3.84	2.52	2.63	176.7	21.2	23.7

In Ismailia site

The results showed that the application of Mg-rates from (T_2 to T_7) significantly increased the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by stalk yield of maize grown in sandy soil compared with control (T_1). The highest stalk yield uptake of N, P, Ca, Mg and Fe (58.56, 8.07, 46.21, 18.99 and 4.131 kg fed^{-1}, respectively) were recorded with the application of Mg-rate T_4 (75 kg $MgSO_4$ fed^{-1}). As well as the highest stalk yield uptake of K (51.33 kg fed^{-1}) was recorded with the application of Mg-rate T_3 (50 kg $MgSO_4$ fed^{-1}) then its uptake decreased. So, these results demonstrate the importance of soil supply by Mg as magnesium sulfate for increasing growth, yield and nutrient uptakes of maize grown in sandy soil and keep balance between nutrient, whereas soil was low in its fertility especially available Mg (Table 1). In this respect, Szulc (2009) showed that the highest N, K and Mg contents in dry plant matter (37.0, 42.18 and 2.65 g kg^{-1} DM, respectively) were found by maize fertilized with 15 kg Mg ha^{-1} (nearly 62.5 kg $MgSO_4$ fed^{-1}). As well, Ertiftik and Zengin (2016) illustrated that the application of Mg enhanced the nutritional status of maize through synergic relations between Mg and P, S, Fe and Zn.

Finally, it can be concluded from the previous results that the response of maize crop grown on clay loam and sandy soils to magnesium fertilization was significant, since the responses were the best in clay loam soil at soil application of 50 kg magnesium sulfate fed^{-1} and also at the foliar spray of 0.5% Mg twice, and they were the highest in sandy soil with the soil application of 75 kg magnesium sulfate fed^{-1}.

Conclusion

Under conditions of Dakahlia Governorate (clay loam soils) and Ismalia Governorate (sandy soils), supplying maize with magnesium sulfate as foliar spraying with 0.5 % Mg twice after 35 and 50 days from sowing for the clayey loam soil and the treatment of 75 Kg magnesium sulfate fed^{-1} as soil application for the sandy soil can be recommended to get the highest yields and the best quality traits with the addition the recommended doses of other nutrients.

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تأثير التسميد بالماغنسيوم على المحصول وامتصاص العناصر الغذائية للذرة الشامية المنزرعه في تربتين مختلفتين

رمضان عوض الدسوقي ، فاتن عبد العزيز الكمار و رشاد عبد المنعم درار
معهد بحوث الأراضي والمياه والبيئة - مركز البحوث الزراعية – الجيزة – مصر

الماغنسيوم أحد العناصر الغذائية الضرورية لنمو النبات والتي تظهر أعراض نقصه نتيجة لانخفاض محتوي التربة من الميسر منه وفى حالة التنافس مع الكاتيونات الأخرى وخاصة الكالسيوم والبوتاسيوم نظرا لعدم التوازن بينها وكذلك مع استنزاف المحاصيل له؛ لذا أجريت هذه الدراسة لتقييم تأثير إضافة الماغنسيوم بمستويات وطرق مختلفة: أرضياً "بمعدلات صفر، 25، 50، 75 و 100 كجم كبريتات الماغنسيوم للفدان" ورشاً على النباتات "بتركزي 0,25 و 0,50 % ماغنسيوم في صورة كبريتات الماغنسيوم" علي محصول الذرة الشامية ومكوناته وتركيز العناصر الغذائية والممتص منها والعلاقة بين الماغنسيوم والعناصر الغذائية الأخرى وخاصة البوتاسيوم والكالسيوم للذرة المزروعة بتربتين مختلفتين فى القوام خلال موسمي الزراعة الصيفيين لعامي 2015 و 2016؛ أجريت التجربة الأولى بأرض طينية طمية بمركز طلخا-محافظة الدقهلية (31° 16' 72.71" N, 31° 46' 25.80" E) والثانية بأرض رملية بمحطة البحوث الزراعية بالإسماعيلية (30° 35' 30.6" N, 32.2° 14' 50" E) - مصر.

وأوضحت النتائج زيادة محصولي حبوب وحطب الذرة، وزن المائة حبه، محتوي الحبوب من الزيت، البروتين، الفوسفور، البوتاسيوم، الكالسيوم، الماغنسيوم، المنجنيز والزنك والممتص من النتروجين، الفوسفور، البوتاسيوم، الكالسيوم، الماغنسيوم، الحديد، المنجنيز والزنك بواسطة محصول الحطب معنويا مع إضافة معدلات الماغنسيوم؛ وذلك مع تفوق معدل الإضافة الأرضية 50 كجم كبريتات ماغنسيوم للفدان وكذلك الرش الورقي بتركيز 0,5% ماغنسيوم للذرة المزروعة بالأرض الطينية الطميية ومع تفوق المعدل 75 كجم كبريتات ماغنسيوم للفدان للذرة المزروعة بالأرض الرملية؛ بالإضافة لذلك أوضحت العلاقات بين الماغنسيوم والبوتاسيوم والكالسيوم بورقة العلم (الكوز) زيادة نسب كل من البوتاسيوم للماغنسيوم و الكالسيوم للماغنسيوم مع الرش الورقي للماغنسيوم والإضافة الأرضية لكبريتات الماغنسيوم حتي معدل 50 كجم للفدان فى كلا التربتين.