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Changes in Nutrient Concentrations of Maize (*Zea mays* var. *intendata*) Leaves under Potassium and Magnesium Applications in Central Anatolia

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ABSTRACT

This research was carried out to determine the effects of potassium (0, 40, 80, 120 kg K_2O ha^{-1}; as potassium sulfate; 50% K_2O) and magnesium (0, 20, 40, 60 kg MgO ha^{-1}; as magnesium sulfate; 16% MgO) applied to the soil, either separately or in various combinations, on some nutrients (N, P, K, Ca, Mg, Fe, Zn) in maize leaves grown under field conditions in semi-arid Central Anatolia in Turkey in 2009 and 2010. The study was designed as a factorial arrangement in randomized block design with four replications. After soil analysis of the study areas, K and Mg-fertilizers were applied at sowing. The results showed that the K applications alone could increase the nutrient concentrations of the leaves, and synergic relations were found between K and P, Fe, or Zn. Synergic relations were also found between Mg and P or Fe. Generally, combined applications of K and Mg resulted in higher nutrient concentrations in the leaves by ameliorating the antagonistic effect of poor soil K-Ca-Mg ionic balances. The leaf nutrient concentrations were generally higher in the first year (2009) than that of the experiment than in the second year (2010).

Keywords: Maize; Leaf; Potassium; Magnesium; Nutrients

İç Anadolu Bölgesi'nde Potasyum ve Magnezyum Uygulanan Mısırın (*Zea mays* var. *intendata*) Yaprak Besin Elementi İçeriklerindeki Değişimler

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ÖZET

Bu araştırma, toprağa ayrı ayrı ve belli kombinasyonlarda uygulanan potasyum (0, 40, 80, 120 kg K_2O ha^{-1}; potasyum sülfat; % 50 K_2O) ve magnezyum (0, 20, 40, 60 kg MgO ha^{-1}; magnezyum sülfat; % 16 MgO)'un İç Anadolu'da yarı kurak iklim koşullarında 2009 ve 2010 yıllarında yetiştirilen mısırın yapraklarındaki bazı besin elementlerine (N, P, K, Ca, Mg, Fe, Zn) etkilerini belirlemek amacıyla yapılmıştır. Denemeler tesadüf bloklarında faktöriyel deneme deseninde dört tekerrürlü olarak planlanmıştır. Toprak analizleri yapılan deneme alanlarına K ve Mg'lu gübreler ekimde tek seferde tabana verilmiştir. Araştırma sonuçlarına göre, tek başına verilen K yaprağın besin elementlerini artırmış, K ile P, Fe ve Zn arasında sinerjik ilişkiler belirlenmiştir. Diğer taraftan, Mg ile P ve Fe arasında sinerjik etkileşimler saptanmıştır. Genellikle K ile Mg'un birlikte uygulanması topraktaki antagonistik ilişkileri azaltarak yaprakta daha yüksek besin elementlerinin bulunmasını sağlamıştır. Denemenin ilk yılında yaprağın besin element içerikleri ikinci yıldakilerden daha yüksek bulunmuştur.

Anahtar Kelimeler**:** Mısır; Yaprak; Potasyum; Magnezyum; Besin elementleri

1. Introduction

Maize, which is the third most important agricultural product after wheat and barley in terms of its production area in Turkey, has a mean yield of about 7,190 kg ha^{-1} and a total yield of 4.25 million tons produced from a cultivated area of 592,000 ha. Maize is also the eighth most important crop after wheat, barley, sugar beet, chickpea, sunflower, rye and beans in the province of Konya, where the mean yield is about 7,930 kg ha^{-1} and the total yield is 104,129 tons produced from an area of 13,138 ha (Anonymous 2009). Generally, while corn has a high yield potential in semi-humid and semi-arid regions, their yields can be relatively low or limited due to inadequate soil and crop macro- and micro-nutrient management practices, climate conditions, and soil properties (Wang et al 2006; Kovačević et al 2008; 2009; Zengin et al 2008; Cela et al 2010; Stingu et al 2011). Since soils in the Konya region are highly calcareous ($CaCO_3$> 15%), the exchangeable and available Ca levels are high, which results in cultivated plants having visible or hidden K and Mg deficiencies even if there are adequate levels of K and Mg in the soils. Consequently, potato and sugar beet plants have exhibited positive responses to additional fertilization with K and Mg that was applied because of previous failures to obtain adequate levels of K and Mg in the plants due to the high levels of Ca in the excessively calcareous soils around Konya and in semi arid Central Anatolia (Zengin et al 2008; 2009). However, neither in the province of Konya nor elsewhere in Turkey, any sufficient number of studies on the effects of K and Mg fertilizers on the levels of maize leaf nutrients has been conducted.

Karaman et al (1999), who investigated the effect of fertilization with K and Mg on maize growth and on K and Mg absorption, stated that K-fertilization should be carried out in proportion to Mg levels, especially in Mg-deficient soils. Spear et al (2003), who studied the effects of growing maize and sunflower under eight different concentrations of K for 27 days, reported that the amount of K in the plant decreased with increasing K concentrations and observed Mg deficiencies. Plant species, soil, climate and growing conditions all affected the K uptake by the plants (Turan & Horuz 2012). Kanyanjua et al (2006) reported that the optimal K dose for maize in Kenya was 30 kg K_2O ha^{-1}. Izsaki (2006) examined the effects of N-P-K fertilization applied in different doses on the levels of nutrient elements in maize leaves in the Szarvas region of Hungary and concluded that the doses of 206 to 232 mg K_2O kg^{-1} increased the levels of other nutrients, except for those of Cu, in maize leaves to a greater extent than higher doses of 321 to 465 mg K_2O kg^{-1}. Tan et al (2007), who investigated the effects of K fertilizers on maize yield in China for 13 years, found that K accumulated at significant levels in the soil with an annual dose of 225 kg K_2O ha^{-1} and proposed that the most appropriate annual dose of K was just 112.5 kg K_2O ha^{-1}. Tomov et al (2008) investigated the effects of a various N-P-K doses and of manure on nutrient uptake and maize yield in the Plovdiv region of Bulgaria. They reported that there was a yield increase of between 35.2% and 21.7% depending on the types and doses of the fertilizer when compared with the control and that 2.0 to 2.7 kg N, 0.6 to 1.2 kg P_2O_5 and 2.0 to 2.9 kg K_2O was required to produce 100 kg of corn.

In this study, the effects of various doses of K and Mg and their interactions on some nutrients concentrations of maize leaves were investigated in Kadınhanı District of Konya Province, semi-arid Central Anatolia.

2. Material and Methods

Field trials by using a hybrid maize cultivar (*Zea mays* var. *indentata*) Pioneer-3394 brand were conducted in the Kadınhanı District of Konya Province in the Central Anatolia Region of Turkey in 2009 and 2010. The experimental area was situated at an altitude of 1100 m above the sea level. Climate in this district is characterized by hot and dry summers and cold and rainy winters with a long-term (1975 to 2010 years) annual mean precipitation of about 327 mm. Total precipitation during the maize growth period in the experimental areas (i.e., between May and October) was 128.8 mm in 2009 and 117.8 mm in 2010 (DMI 2011) (Table 1).

Some physical and chemical properties of the soil samples taken from the experimental areas are given in Table 2. Soils were slightly alkaline, non-saline, low in organic matter, high in lime, and clay loam

Table 1- Some climate parameters of the study years and of a long-time period in Kadınhanı District

Çizelge 1- Çalşmanın yürütüldüğü yıllarda ve uzun yıllar ortalaması olarak Kadınhanı'nın kimi iklim verileri

Climate parameters	*Months*								
	Year	*May*	*June*	*July*	*August*	*September*	*October*	*Mean/ Total*	*Long-term (1975-2010)*
Mean temperature (°C)	2009	12.90	18.25	20.60	19.00	15.32	14.31	16.73	11.10
	2010	14.40	18.22	22.86	24.58	19.29	17.32	19.45	
Total precipitation (mm)	2009	37.4	24.0	8.0	0.2	19.4	21.4	128.8	327.1
	2010	14.6	59.0	0.2	0.8	0.4	26.0	117.8	
Mean air humidity (%)	2009	69	57	55	42	56	59	56.3	61.2

Table 2- Soil analysis results of maize field

Çizelge 2- Mısır tarlası toprak analiz sonuçları

Parameters	*2009*	*2010*	*Method*
pH (1:2.5 s:w)	7.52	7.32	pH meter
EC (1:5 s:w; µS cm^{-1})	141	180	EC meter
Organic matter (%)	1.52	1.93	Walkley-Black
Lime (%)	6.31	16.11	Scheibler calcimeter
Clay (%)	30.4	30.1	Bouyoucos (1951)
Silt (%)	26.0	34.6	Bouyoucos (1951)
Sand (%)	43.6	35.3	Bouyoucos (1951)
Texture	Clay loam	Loam	-
NH_4-N + NO_3-N (mg kg^{-1})	15.3	15.7	Extraction with 2 N KCl
P (mg kg^{-1})	3.76	13.25	Extraction with $NaHCO_3$
K (mg kg^{-1})	603	430	Extraction with NH_4OAc
Ca (mg kg^{-1})	6401	7631	Extraction with NH_4OAc
Mg (mg kg^{-1})	285	316	Extraction with NH_4OAc
K (me 100 g^{-1})	1.54	1.10	Ca:K 20.78 34.68 12 (ideal)
Ca (me 100 g^{-1})	32.00	38.15	Ca:Mg 13.50 14.50 6 (ideal)
Mg (me 100 g^{-1})	2.37	2.63	Mg:K 1.54 2.39 2 (ideal)
Na (mg kg^{-1})	45	143	Flame-photometer
Fe (mg kg^{-1})	1.65	0.16	Soltanpour & Workman (1981)
Zn (mg kg^{-1})	0.55	0.42	Soltanpour & Workman (1981)
Mn (mg kg^{-1})	2.37	2.04	Soltanpour & Workman (1981)
B (mg kg^{-1})	0.90	2.69	Kacar (1994)
Cu (mg kg^{-1})	0.79	1.03	Soltanpour & Workman (1981)

s:w, soil water ratio

and loam in texture. At the two locations, N was low, extractable K and Ca were very high while Mg was sufficient, Fe and Zn were low while Mn, B and Cu were adequate. In addition, while the P level was low in the first area, it was moderate in the second area (Ülgen & Yurtsever 1974; Sillanpaa 1990).

In terms of soil fertility, the most suitable balances between exchangeable Ca, K and Mg are supposed to be Ca:K= 12, Ca:Mg= 6 and Mg:K= 2 (Jokinen 1981); whereas, they were determined to be Ca:K= 20.78, Ca:Mg= 13.50 and Mg:K= 1.54 in the fields for the first year, and Ca:K= 34.68, Ca:Mg= 14.50 and Mg:K= 2.39 in the second year. Therefore, there were imbalances between these cations and Ca was disproportionally high (Table 2). Thus, even if K and Mg were present in the soil in adequate amounts, the plants could not uptake sufficient amounts, and hidden or visible deficiency symptoms could occur.

The basal fertilizers used in the experiments were DAP (18% N, 46% P_2O_5), urea (46% N) and ammonium nitrate (33% N). The fertilizers to be tested using different doses (0, 40, 80, 120 kg K_2O ha^{-1}) were potassium sulfate (50% K_2O, soluble in water) and magnesium sulfate (16% MgO, soluble in water) at the rates of 0, 20, 40, 60 kg MgO ha^{-1}, which were applied during sowing in the both study years.

Based on the results of the soil analysis, K and Mg-fertilizers with the fertilizers to rectify the soil nutrient deficiencies (100 kg P_2O_5 ha^{-1}, 5 kg Fe ha^{-1} and 5 kg Zn ha^{-1}) were applied at the sowing depth to all the plots at once. The 200 kg N ha^{-1} was applied manually to the soil as a top fertilizer, using urea (46% N) during the first hoeing and ammonium nitrate (33% N) during the second hoeing.

Field experiments were conducted according to a completely randomized block design in factorial arrangement. In two years, at each of the locations that were near to each other, 64 plots were established with four replications of each treatment. Plots had dimensions of 4.2 m x 5.0 m (21 m^2). The row intervals were 70 cm at sowing and planting intervals along the rows were set at 22 cm during seed drilling. The separation between the plots was 1 m.

Soil samples were collected from the experiment areas, from the 0 to 30 cm soil layer, before fertilizing and sowing. They were analyzed for; pH in a 1:2.5 soil:water solution ratio with pH-meter; electrical conductivity (EC) in a 1:5 soil:water solution by EC-meter (Jackson 1962); organic matter content using the Smith & Weldon (1941) method; lime content by the Scheibler Calcimeter (Çağlar 1949); texture by Bouyoucos Hydrometer (Bouyoucos 1951); inorganic N (NH_4-N+NO_3-N) in a 2 N KCl extract by Kjeldahl distillation; available P using the Olsen method with a spectrophotometer (Bayraklı 1987); exchangeable cations (K, Ca, Mg and Na) in 1 N NH_4OAc solution (Bayraklı 1987) by the ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectrometer; Varian, Vista Axiel Simultaneous) (Soltanpour & Workman 1981); extractable Fe, Zn, Mn, Cu in the 0.05 M DTPA+0.01 M $CaCl_2$+0.1 M TEA (pH= 7.3) solution (Lindsay & Norvell 1978) using the ICP-AES; and available B in a $CaCl_2$+mannitol solution (Kacar 1972) using the ICP-AES.

In all of the experiments, fully expanded leaves of corncob were sampled at the time of corncob formation and were immediately transported in paper bags inside a cooling bag to laboratory for analysis of the total mineral nutrients. After washing with tap water, they were washed once more with distilled water, then with 0.1 N HCl solution, then further twice with distilled water and once more again with deionized distilled water (Bayraklı 1987). Following drying at 70 ^oC, leaf samples were ground and subjected to digestion by 15 mL HNO_3+5 mL $HClO_4$ using a microwave system (CEM, Mars 5) (Soltanpour & Workman 1981). The amounts of total P, K, Ca, Mg, Fe, and Zn in the extracts were determined by the ICP-AES as described by Soltanpour & Workman (1981). One blank and one certified reference material (1547 Peach Leaves, NIST, National Institute of Standards and Technology, Gaithersburg-USA) were added into the microwave set of 40 cells to confirm the reliability of the leaf analysis (Soltanpour & Workman 1981). Total N concentrations in the leaf samples were determined by micro Kjeldahl method (Bayraklı 1987) after digesting in H_2SO_4+H_2O_2.

Irrigation water was provided on four occasions for a period of eight hours by sprinkler irrigation. The sprinkler irrigation was carried out on the dates specified in Table 3, taking into account the periods when the plants needed water.

Table 3- Time-table for experimental procedure

Çizelge 3- İş-zaman takvimi

Experimental procedure	*2009*	*2010*
Forming of plots and sowing	13.05.2009	10.05.2010
Top fertilizing and 1. hoeing	09.06.2009	17.06.2010
Top fertilizing and 2. hoeing	03.07.2009	13.07.2010
1. Irrigation	11.06.2009	18.06.2010
2. Irrigation	04.07.2009	14.07.2010
3. Irrigation	05.08.2009	12.08.2010
4. Irrigation	01.09.2009	09.09.2010
Leaf sampling	27.07.2009	02.08.2010

The statistical analysis of the data was performed by Minitab for analysis of variance and Mstat for separating the treatments means by LSD and Duncan's Multiple Range Test (Düzgüneş et al 1983).

3. Results and Discussion

3.1. Nitrogen

The KxMg interaction effect was statistically significant (P<0.01) on the total N concentration of the maize leaves for both the first and the second years (Table 4).

In the first year, the total N concentrations in the leaves ranged between 2.28% (K_8Mg_6) and 2.59% (K_4Mg_6), while in the second year they were between 2.27% (K_0Mg_0) and 2.62% ($K_{12}Mg_4$; Table 5). In the first year, the N concentration was increased by 2.0%, compared to the control (N, P), by the K_4Mg_6

Table 4- Analysis of variance results for the effects of K and Mg on some nutrient concentrations of maize leaves in 2009 and 2010

Çizege 4- Mısır yapraklarının bazı besin elementi konsantrasyonlarına K ve Mg'un etkisine ilişkin 2009 ve 2010 yılı varyans analizi sonuçları

		2009				
Source of variation	*Df*	*Mean of squares*				
		N	*P*	*K*	*Ca*	*Mg*
K	3	0.01990	0.00013542	0.037803**	0.0029299*	0.00005556
Mg	3	0.02695	0.00007431	0.045025**	0.0014465	0.00012778
KxMg	9	0.03696**	0.00017801**	0.028153**	0.0009225	0.00015000*
Error	32	0.01221	0.00005625	0.008185	0.0007083	0.00006458
		Fe	*Zn*			
K	3	158.51*	2.086			
Mg	3	106.10	5.194			
KxMg	9	73.35	7.355*			
Error	32	39.37	3.376			
		2010				
Source of variation	*Df*	*Mean of squares*				
		N	*P*	*K*	*Ca*	*Mg*
K	3	0.064208**	0.0005722	0.00894	0.000367	0.0006944
Mg	3	0.059952**	0.0004278	0.03000	0.002789	0.0031722**
KxMg	9	0.038876**	0.0006667**	0.03780*	0.006319	0.0021593**
Error	32	0.009485	0.0002146	0.01521	0.006173	0.0006146
		Fe	*Zn*			
K	3	1495.0**	5.289			
Mg	3	265.4	1.828			
KxMg	9	629.0**	9.430			
Error	32	147.0	7.597			

**, P<0.01; *, P<0.05; Df, degrees of freedom treatment, while in the second year it did so by 15.4% in the case of $K_{12}Mg_4$. The measured total N values were considered to be slightly deficient according to the reported optimal range of total N values (2.7% to 4.0%) for maize leaves (Jones et al 1991). Under the current conditions, the amount of N applied (200 kg N ha^{-1}) was probably too low for growing maize. In the first year of the experiments, the measured total N concentration of the leaves was less than the one in the second year (Table 5). The reason for this could be differences in the weather conditions (Table 1), studied soils (Table 2), and the timing of the leaf sampling (Table 3). In both years, the N concentrations of the leaves were slightly higher with the KxMg applications than with applications of either K or Mg alone. This observation may result from the better plant growth in terms of better utilizing the N as a result of the improvement of the initially poor K-Ca-Mg balance in the experimental soils by the combination of KxMg fertilizers. Samui et al (1987), Izsaki (2006) and Szulc (2010) reported similar results.

3.2. Phosphorus

The KxMg interaction had a statistically significant ($P<0.01$) effect on the total P in maize leaves in both years (Table 4). In the first year, the total values of P ranged between 0.110% (K_8Mg_2) and 0.137% ($K_{12}Mg_4$), while in the second year they were between 0.070% (K_0Mg_0) and 0.117% (K_8Mg_6) (Table 5). In the first year, the P concentration of the leaf was increased as high as 14.2% comparing to the control

Table 5- Effects of K and Mg on total N, P and K concentrations of maize leaves

Çizelge 5- Mısır yapraklarının toplam N, P ve K konsantrasyonlarına K ve Mg'un etkisi

Fertilizer	*Doses (kg K_2O-MgO ha^{-1})*	*N (%)*		*P (%)*		*K (%)*	
		1. Year	*2. Year*	*1. Year*	*2. Year*	*1. Year*	*2. Year*
K	0	2.54	2.27	0.120	0.070	1.33	1.12
	K_4	2.52	2.52	0.133	0.093	1.41	1.05
	K_8	2.35	2.57	0.127	0.083	1.34	1.24
	K_{12}	2.39	2.29	0.133	0.117	1.21	1.33
	LSD (P<0.05)	-	-	-	-	-	-
Mg	0	2.54	2.27	0.120	0.070	1.33	1.12
	Mg_2	2.38	2.57	0.127	0.097	1.46	1.18
	Mg_4	2.48	2.57	0.130	0.083	1.51	1.30
	Mg_6	2.45	2.38	0.130	0.103	1.23	1.30
	LSD (P<0.05)	-	-	-	-	-	-
KxMg	K_0Mg_0	2.54 a*	2.27 d	0.120 ab	0.070 c	1.33 bc	1.12 cd
	K_4Mg_2	2.52 a	2.27 d	0.133 a	0.083 bc	1.44 ab	1.14 bcd
	K_4Mg_4	2.54 a	2.30 cd	0.123 ab	0.113 a	1.33 bc	1.37 a
	K_4Mg_6	2.59 a	2.45 bc	0.130 a	0.110 ab	1.32 bc	1.34 ab
	K_8Mg_2	2.32 b	2.46 abc	0.110 c	0.107 ab	1.24 c	1.16 bcd
	K_8Mg_4	2.57 a	2.42 bcd	0.133 a	0.087 bc	1.31 bc	1.16 bcd
	K_8Mg_6	2.28 b	2.44 bc	0.120 bc	0.117 a	1.54 a	1.25 abcd
	$K_{12}Mg_2$	2.31 b	2.52 ab	0.120 bc	0.103 ab	1.33 bc	1.27 abc
	$K_{12}Mg_4$	2.53 a	2.62 a	0.137 a	0.103 ab	1.31 bc	1.27 abc
	$K_{12}Mg_6$	2.52 a	2.40 bcd	0.123 ab	0.080 c	1.35 bc	1.05 d
	Lowest	2.28	2.27	0.110	0.070	1.21	1.05
	Highest	2.59	2.62	0.137	0.117	1.54	1.37
	LSD (P<0.05)	0.183	0.162	0.012	0.024	0.150	0.205

*, means shown with the same letters in the same column are not significant

for $K_{12}Mg_4$ treatment, while in the second year it showed tremendous increase by 67.1% in the K_8Mg_6 case. The measured values of P were well below the optimal P range (0.25% to 0.50%) for maize leaves (Jones et al 1991). The phosphorous fertilization (100 kg P_2O_5 ha^{-1}) in the current study was probably too low to meet the P requirement of maize. In the first year of the experiment, the P concentrations of the leaves were found to be greater than they were in the second year, as was the case for K and Zn (Table 5). The reason for this observation may be due to the differences in the weather conditions (Table 1), properties of the soils (Table 2) and the timing of leaf sampling (Table 3) in the two successive growing seasons. This occurred despite of smaller amounts of available P and higher alkaline pH value in the soil in the first year. In the second year, K and Mg applications resulted in decreases in the P concentration of the leaves. This could result from a relatively lower absorption of P in the plants that were growing better due to the improved Mg balance. In addition, P might not be taken up in adequate amounts by the plant due to the high pH and Ca concentration of the soil. Blasko (2006) and Izsaki (2006) reported similar results. Leaf P increased with the increases in Mg doses. Aktaş & Ateş (1998) also reported a synergic relation between Mg and P, while Szulc (2009) reported that P increased in corn leaves following an application of Mg.

3.3. Potassium

The KxMg interaction more significantly affected the total K concentration of the leaves ($P<0.01$) in the first year than in the second year ($P<0.05$) (Table 4). In the first year, the K values ranged between 1.21% (K_{12}) and 1.54% (K_8Mg_6), while in the second year they were between 1.05% (K_4) and 1.37% (K_4Mg_4; Table 5). The K concentration of the leaf was increased by 15.8 and 22.3% comparing to control in the first and second years, respectively. Results showed that the levels of both of the elements, K and Mg, need to be addressed in order to improve the K-Ca-Mg balance, which was initially poor due to the high Ca in the region's soils. Despite observation of no visual deficiency symptoms, the K concentrations were just below the deficiency threshold (1.7% to 3.0%) for maize leaves (Jones et al 1991). This situation can be affected by the maize variety, and differences in soil and climate factors. Comparatively higher K concentrations were observed in the first year. This could be attributed to lower exchangeable Ca was lower and higher exchangeable K resulting in a Ca:K ratio closer (20.78 and 34.68 in the first and second year respectively) to the ideal one (12) in the first years experimental field (Jokinen 1981). However, Zengin et al (2008; 2009) demonstrated that K and Mg fertilization was necessary for sugar beet under similar growth conditions in order to establish appropriate Ca-K and Ca-Mg balances in soils with excessive exchangeable Ca. Zengin et al (2008) reported similar results for potato cultivation in the region. Excessive Ca in the soil results in an antagonistic interaction among the three elements that hinders the plant uptake of K (Aktaş & Ateş 1998). The K and Mg treatments resulted in either increase or decrease in the leaf K concentration in the first growing season whereas there was a treatment induced increase in K concentration in the second year. In accordance with our results, Karaman et al (1999) emphasized that importance of proportional K and Mg treatments for a balanced Ca, Mg and K nutrition. Hermans et al (2004), Zengin et al (2008; 2009) and Szulc (2009) have noted the different responses of plants to K applications.

3.4. Calcium

The effect of only adding K on Ca concentration of the leaf was statistically significant ($P<0.05$) in the first year; however, none of the applications had a significant effect in the second year (Table 4). In the first year, the Ca values ranged between 0.283% (K_8Mg_6) and 0.360% (K_{12}), while they were between 0.460% (K_4) and 0.613% (Mg_4) in the second year (Table 6). The measured Ca concentrations were well in the optimal Ca range (0.21% to 1.00%) for maize leaves (Jones et al 1991). In both years, treatment induced-changes in the Ca concentrations of the leaves were related to the balance of K-Ca-Mg in the soil. According to Doll & Lucas (1973) the base saturation of a soil should be in the range of 3-5%

for K, 65-85% for Ca, and 6-12% for Mg in order to maintain ideal Ca, Mg and K nutrition of the plants. Similarly, the respective saturation rates were reported as 5%, 60% and about 10% for K, Ca, and Mg, respectively. The ideal ratios of the exchangeable cations should be Ca:K= 12, Ca:Mg= 6, and Mg:K= 2 to ensure adequate uptake of K, Ca and Mg from the soil (Jokinen 1981). However, in this study, the balances between these elements in either of the two experimental fields were not suitable for optimal K, Mg and Ca nutrition of plants.

3.5. Magnesium

The effects of the KxMg interaction on the total Mg concentration of the leaves were statistically significant in both growing seasons (Table 4). In the first year Mg concentrations range was 0.100% (K_4) and 0.117% (K_4Mg_2, K_8Mg_2, $K_{12}Mg_6$), while in the second year it was 0.143% (K_0Mg_0) and 0.230% (K_8Mg_4; Table 6). Leaf Mg concentrations were proportional to Mg treatments in both years whereas K treatments resulted in a decrease in the first year and an increase in the second year. Treatment induced increases in Mg concentrations were detrimental in the second growing season with as high as 60.8% in the K_8Mg_4 case. The leaf Mg concentrations were just about the deficiency threshold (0.2%) for maize leaves (Jones et al 1991). However, no Mg deficiency symptoms were evident in the plants.

Table 6- Effects of K and Mg on total Ca, Mg and Fe concentrations of maize leaves

Çizelge 6- Mısır yapraklarının toplam Ca, Mg ve Fe konsantrasyonlarına K ve Mg'un etkisi

Fertilizer	*Doses*	*Ca (%)*		*Mg (%)*		*Fe* (mg kg^{-1})	
	(kg K_2O-MgO da^{-1})	*1. Year*	*2. Year*	*1. Year*	*2. Year*	*1. Year*	*2. Year*
K	0	0.353 a*	0.486	0.113	0.143	73.19 b	111.90
	K_4	0.310 b	0.460	0.100	0.173	83.64 a	118.86
	K_8	0.320 ab	0.580	0.116	0.183	75.86 ab	102.73
	K_{12}	0.360 a	0.517	0.116	0.203	70.99 b	116.68
	LSD (P<0.05)	0.044	-	-	-	10.44	-
Mg	0	0.353	0.486	0.113	0.143	73.19	111.90
	Mg_2	0.357	0.493	0.114	0.203	81.63	115.16
	Mg_4	0.330	0.613	0.116	0.217	81.46	124.59
	Mg_6	0.350	0.517	0.115	0.213	84.94	129.73
	LSD (P<0.05)	-	-	-	-	-	-
KxMg	K_0Mg_0	0.353	0.486	0.113 a	0.143 d	73.19	111.90 bc
	K_4Mg_2	0.353	0.500	0.117 a	0.147 d	76.62	73.06 d
	K_4Mg_4	0.326	0.550	0.113 a	0.167 cd	75.84	112.12 bc
	K_4Mg_6	0.303	0.543	0.103 ab	0.173 cd	87.22	139.91 a
	K_8Mg_2	0.337	0.503	0.117 a	0.193 bc	79.58	137.87 a
	K_8Mg_4	0.333	0.493	0.107 ab	0.230 a	89.87	127.57 ab
	K_8Mg_6	0.283	0.553	0.103 ab	0.197 bc	69.81	107.09 c
	$K_{12}Mg_2$	0.310	0.500	0.100 b	0.150 d	74.81	115.49 bc
	$K_{12}Mg_4$	0.333	0.523	0.113 a	0.200 bc	77.14	110.83 bc
	$K_{12}Mg_6$	0.317	0.513	0.117 a	0.207 bc	78.18	122.31 abc
	Lowest	0.283	0.460	0.100	0.143	69.81	73.06
	Highest	0.360	0.613	0.117	0.230	89.87	139.91
	LSD (P<0.05)	-	-	0.013	0.041	-	20.16

*, means shown with the same letters in the same column are not significant

In the second year, the balances between exchangeable K-Ca-Mg in the study soils were worse than in the first year, which resulted in higher Mg contents in the leaves in the second year. Because Mg use improved bad ratio of Ca:Mg and Mg:K in the second year. Combinations of K and Mg were given in different doses that raised the Mg concentration of the leaves to higher levels than those in the control by reducing the antagonistic interaction. The concentrations of Mg in the leaves were increased as the doses of K increased. This situation is interested in Mg:K ratio in the soil. This ratio is high than normal value, so K applying was supported good plant growth and Mg absorption. However Aktaş & Ateş (1998), Sepehr et al (2002), Zengin et al (2008) and Szulc (2009) have all mentioned that increasing the doses of K applications reduced the Mg concentration of the leaves due to the antagonistic effect.

3.6. Iron

Both K and KxMg interaction had significant effects on Fe concentration of the maize leaves (Table 4). The Fe concentration ranges were 69.81 (K_8Mg_6), 89.87 mg kg^{-1} (K_8Mg_4) and 73.06 (K_4Mg_2), 139.91 mg kg^{-1} (K_4Mg_6) (Table 6) in first and second years, respectively. There was 22.8 (K_8Mg_4) and 25% (K_4Mg_6) treatment induced increase in Fe concentration in first and second years. The Fe concentrations were in the optimal range (21 to 250 mg kg^{-1}) for maize leaves (Jones et al 1991).

As the individual effects of K or Mg fertilizers considered, the total Fe concentration of the leaves was first increased and then decreased upon K fertilization, but it was proportionally increased due to Mg fertilization. This may be attributed to the synergistic relation of both K and Mg with Fe (Aktaş & Ateş 1998). In addition, the Fe concentrations were considerably lower in the first year. These changes in Fe concentrations can be related to differences in soil characteristics such as pH and organic matter (Table 2) and climate conditions (Table 1). As the pH value increased the available Fe concentration would be reduced (Aktaş 1991; Eyüpoğlu et al 1998). Izsaki (2006) reported that the Fe concentration of the leaves was increased by K fertilization to maize.

3.7. Zinc

The effect of the KxMg interaction on Zn concentration of the leaves was only statistically significant (P< of 0.05) in the first year (Table 4). The Zn concentration range were 15.44 (K_8Mg_6)-19.91 mg kg^{-1} (K_4) and 12.79 ($K_{12}Mg_4$)-18.44 mg kg^{-1} (K_8Mg_2) in the first and second years, respectively (Table 7). There was a general increase in Zn concentrations of the leaves depending on K and Mg treatments. However, the observed

Table 7- Effects of K and Mg on total Zn concentration of maize leaves

Çizelge 7- Mısır yapraklarının toplam Zn konsantrasyonuna K ve Mg'un etkisi

Fertilizer	*Doses (kg K_2O-MgO da^{-1})*	*Zn (mg kg^{-1})*	
		1. Year	*2. Year*
K	0	16.68	13.31
	K_4	19.91	13.55
	K_8	15.59	14.06
	K_{12}	18.82	16.74
	LSD (P<0.05)	-	-
Mg	0	16.68	13.31
	Mg_2	17.03	15.33
	Mg_4	16.37	12.88
	Mg_6	19.52	15.40
	LSD (P<0.05)	-	-
KxMg	K_0Mg_0	16.68 ab*	13.31
	K_4Mg_2	19.00 a	13.18
	K_4Mg_4	18.56 a	15.16
	K_4Mg_6	17.62 ab	14.39
	K_8Mg_2	18.10 ab	18.44
	K_8Mg_4	16.36 ab	14.68
	K_8Mg_6	15.44 b	16.24
	$K_{12}Mg_2$	17.56 ab	14.91
	$K_{12}Mg_4$	17.72 ab	12.79
	$K_{12}Mg_6$	19.33 a	13.86
	Lowest	15.44	12.79
	Highest	19.91	18.44
	LSD (P<0.05)	3.056	-

*, means shown with the same letters in the same column are not significant

Zn concentrations were below the optimal Zn concentration range (25 to 100 mg kg^{-1}) for maize leaves (Jones et al 1991). This could be attributed to insufficient basal Zn fertilization (5 kg ha^{-1}) and very high Zn adsorption capacity of calcareous soils. On the other hand, Aktaş & Ateş (1998) have reported that high lime contents and high pH hinder Zn uptake of plants.

Sepehr et al (2002) and Izsaki (2006) also reported that K increased the Zn concentration of the leaves, as in this study. This situation can be related to the increased plant growth induced Zn uptake from the soil.

As a conclusion; even if K and Mg concentrations were adequate in the experimental soils, the maize plants could not uptake sufficient amounts of K and Mg elements because of the excessive Ca saturation induced nutritional imbalances. Manipulations of the balances among Ca, Mg, and K resulted in enhancement in the nutritional status of maize through synergic relations between K or Mg and P, S, Fe, and Zn. In general, when the K and Mg were applied together to optimize the Ca:K, Ca:Mg and K:Mg ratios, the excessive Ca saturation related nutritional disorders in maize can be corrected to some extent in calcareous soils.

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