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Effects of Increasing Rates of Potassium and Magnesium Fertilizers on the Nutrient Contents of Sunflower Leaf

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ABSRACT

This research was carried out to determine the effects of potassium sulphate (50% K_2O; 0, 4, 8, 12 kg K_2O da^{-1}) and magnesium sulphate (16% MgO; 0, 2, 4, 6 kg MgO da^{-1}) fertilizer applications in a calcareous loamy soil on the contents of macro- (N, P, K, Ca, Mg, S) and micro-nutrients (Fe, Zn, Mn, Cu, B) in sunflower leaves under field conditions in Altınekin District, Konya Province, in 2009 and 2010. A factorial experiment design in randomized blocks with 4 replications of each treatment was used. After conducting soil analysis, a single base application of K and Mg fertilizers were applied during sowing. Applications of K alone in increasing doses increased the some nutrient contents in the leaves, and synergic relationships were determined between K and Fe or Mn. Similarly, applications of Mg alone also increased some nutrient contents in the leaves, and synergic relationships were determined between Mg and Mn or B. Generally, combined applications of K with Mg resulted in maximal nutrient contents in the leaves by reducing the antagonistic effect of Ca, K, and Mg cations in the soil on plant uptake of nutrients.

1. Introduction

Sunflower is one of the most important oil crops in the world, as well as in Turkey; its production is of great importance to Turkey because sunflower is a component of the main crop rotations (especially in the Trakya Region), local consumers usually prefer sunflower oil, it has a wide adaptation capability, and it lends itself to mechanized agricultural practices. In Turkey, 62.5% of sunflower production occurs in the provinces of Tekirdağ, Edirne and Kırklareli. The next highest producing regions are Istanbul, Çanakkale, Balıkesir, Bursa, and Kahramanmaraş, while the Central Anatolia and Black Sea Regions account for 10% of the sunflower acreage in Turkey; cultivation of sunflower appetizers is common in these areas (TUİK 2003).

It is vital to be aware of agricultural practices that can improve seed and oil yields and the overall quality of sunflower plants. One of the more important agricultural management practices is to add organic and/or inorganic nutrients to the soil in sufficient quantities to address deficiencies revealed by soil analysis. These deficiencies can result when essential nutrient contents have been diminished by continuous and intensive management and by plant growth. Moreover, the fertilization of the plants should be applied in an adequate and balanced manner by also considering antagonistic interactions among cations in the soil. However, for many years, only N- and P-fertilizers were commonly used while the consumption of K-fertilizer remained at very low levels since it was thought that the soils contained enough K for plant cultivation. This situation has extremely important impacts on sunflower cultivation, which may remove 38.5 kg ha^{-1} K from the soil during the growing season (Merrien 1992; Çakmak et al. 1996).

Even if K and Mg levels are sufficient in the soil, plant uptake of these elements may be inadequate in calcareous soils because of the antagonistic interaction of these cations with the excessive amounts of exchangeable Ca present (Zengin et al. 2008a, 2008b; Zengin et al. 2009). Similarly, an excessive amount of Ca in soils of the Konya region is a problem that affects sunflower cultivation and the uptake of important elements such as K and Mg by these plants in this type of soil. Therefore, in this study, the most appropriate dose of K and Mg-fertilizer to achieve soil fertility, and the interactions between K and Mg and other macro- and micro-nutrients

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in sunflower leaves, were investigated in cultivated soils of Altınekin District, Konya.

2. Materials and Methods

2.1. Location

Field experiments were conducted at two locations separated by a distance of only 800 m in the fields of local farmers in Mantar Village in Altinekin District, 70 km north of the city centre of Konya during 2009 and 2010 years. The majority of the Konya watershed's soils, including the study site, were Aridisols having high pH, carbonates, low organic matter and moderate textures (Anonymous 1978). The continental climate type is dominant in the area: the long-term means of the annual temperature and the annual total precipitation are 11.1 ºC and 327.1 mm, respectively. During the vegetated periods of the study years, i.e., 2009 and 2010, the mean temperature was 17.2 ºC and 19.9 ºC, respectively, and the total precipitation was 89.0 mm and 75.0 mm (Table 1).

Table 1
Some meteorological data for the study years and long-term mean values of Altınekin District.

Climate parameters	Years	Months						Long-term mean 1975-2010
		May	June	July	August	Sept	Mean	
Mean temp. (ºC)	2009	12.9	18.2	20.6	19.0	15.3	17.2	11.1
	2010	14.4	18.2	22.9	24.6	19.3	19.9	
Precipitation (mm)	2009	37.4	24.0	8.0	0.2	19.4	89.0	327.1
	2010	14.6	59.0	0.2	0.8	0.4	75.0	
Mean air humidity (%)	2009	69	57	55	42	56	55.8	61.2
	2010	61	66	52	38	47	52.8	

2.2. Soil and plant analysis

Disturbed soil samples were collected for analysis from the upper cultivated layer (0-30 cm) in three different places within the study areas before establishing the plots or applying fertilizers. Soil texture was determined using the Bouyoucos Hydrometer method (Bouyoucos 1962). Soil pH was measured with a pH-meter in a 1:2.5 soil:distilled water solution and EC by an EC-meter in a 1:5 soil:distilled water solution (Richard 1954). Organic matter content was determined by oxidation with sulphuric acid using the modified Walkley-Black method (Bayraklı 1987). Lime was measured with a Scheibler calcimeter (Çağlar 1949). Inorganic N (NH_4-N + NO_3-N) was determined with a Kjeldahl distillation device using 2 N KCl for extraction (Bayraklı 1987). Available P was determined by the method of Olsen et al. (1954) using 0.5 M $NaHCO_3$ (pH 8.5) for extraction. An Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES) was used to measure: available K, Ca and Mg in 1 N NH_4OAc (pH 7) extracts (Bayraklı 1987; Soltanpour and Workman 1981); trace elements (Fe, Zn, Mn, Cu) in 0.05 M DTPA extracts (Lindsay and Norwell 1972); and soluble B in a mannitol-calcium chloride extract (Kacar 1994; Soltanpour and Workman 1981).

Sunflower plant leaves were sampled at the middle of the growing season. The plant samples were first washed with tap water, then 0.1 N HCl, and finally with distilled water twice and then wiped with tissue paper before drying at 70 ºC in an oven for a two-day period (Kacar 1972). The dried leaf samples were ground using a mortar and pestle. Subsamples of the ground material were digested with a solution of 15 ml HNO_3 - 5 ml $HClO_4$ in a microwave system (CEM-Mars-5 model), and total P, K, Ca, Mg, S, Fe, Zn, Mn, Cu and B amounts were then determined by the ICP-AES (Soltanpour and Workman 1981). Other subsamples were digested by a solution of H_2SO_4 + H_2O_2 and total N was then measured using the micro-Kjeldahl method (Bayraklı 1987).

3.3. Soil characteristics

The soils at the study site were characterized by a slightly alkaline pH (7.59-7.50), low level of salinity (178 to 203 µs cm^{-1}), medium levels of lime (9.07%-5.70%), low to medium-levels of organic matter (1.78%-2.21%), and moderate textures (clay-loamy, loamy). Inorganic N and P levels were low and K, Ca, Zn and B levels were high, while those of Mg, Fe and Mn were considered to be sufficient for sunflower cultivation (Table 2). At the beginning of the growing season, the K, Mg and Ca contents of the soils in 2009 and 2010 years were 729 mg kg^{-1} and 631 mg kg^{-1}, 301 mg kg^{-1} and 217 mg kg^{-1}, and 5206 mg kg^{-1} and 3692 mg kg^{-1}, respectively. In terms of soil fertility, it is supposed that the most appropriate balances among exchangeable K, Ca and Mg should be Ca/K=12, Ca/Mg=6, and Mg/K=2 (Jokinen 1981). However, in the study site soils (in both 2009 and 2010) these were determined to be Ca/K=13.92 and 11.39, Ca/Mg = 10.37 and 10.20, and Mg/K = 1.34 and 1.12. Therefore, at the study site there was a poor or inappropriate balance among these three cations in the soil when considering plant cultivation.

3.4. Experimental design and timetable

The research was carried out using a factorial experiment design in randomized blocks with 4 replications. Therefore, in each year, 64 plots were used: 4 K doses x 4 Mg doses x 4 replications. Despite the experimental design consisting of 4 replications in each of the study years, the assessments made in the statistical analyses of the outcomes were based on 3 replications following the removal of the most deviant replicate from the dataset. Analysis of variance was carried out using the Minitab Package Program to evaluate the findings and Duncan's multiple comparison tests were carried out to differentiate among treatments that were significant (Düzgüneş et al. 1983).

Table 2
Some physical and chemical properties of the study soils.

Parameters	2009	2010	Interpretations 2009/2010
pH (1:2.5 soil:water)	7.59	7.51	Slightly alkaline
EC (1:5 s:w; µS cm^{-1})	178	203	Not salty
Organic matter (%)	1.78	2.21	Moderate
Lime ($CaCO_3$; %)	9.07	5.70	Moderate
Textural class	Clay Loam	Loam	Normal
NH_4-N+NO_3-N (mg kg^{-1})	21.2	29.5	Low
P (mg kg^{-1})	5.9	6.7	Low
K (mg kg^{-1})	729	631	High
Ca (mg kg^{-1})	5206	3692	High
Mg (mg kg^{-1})	301	217	Sufficient
K (me 100 g^{-1})	1.87	1.62	-
Ca (me 100 g^{-1})	26.03	18.46	-
Mg (me 100 g^{-1})	2.51	1.81	-
Ca/K (should be 12)	13.92	11.39	K is deficient/K is high
Ca/Mg (should be 6)	10.37	10.20	Mg is deficient
Mg/K (should be 2)	1.34	1.12	Mg is deficient
Fe (mg kg^{-1})	5.06	7.83	Sufficient
Zn (mg kg^{-1})	2.98	2.60	High
Mn (mg kg^{-1})	5.16	5.41	Sufficient
Cu (mg kg^{-1})	1.03	3.70	Sufficient
B (mg kg^{-1})	3.11	4.05	High

Table 3
Study schedule for 2009 and 2010

Experiment operations	2009	2010
Sowing	14.05	07.05
Sprouting irrigation	16.05	10.05
Beginning of sprouting	21.05	14.05
First top fertilization	09.06	17.06
First irrigation	11.06	17.06
Hoeing	09.06	16.06
Second top fertilization	29.06	03.07
Second irrigation	30.06	04.07
Leaf sampling for analysis	29.07	15.07
Third irrigation	28.07	02.08
Fourth irrigation	17.08	20.08
Harvest	15.09	14.09
Threshing and weighing	28.09	01.10

Hybrid sunflower seeds (for sunflower oil production), which have been widely planted in the region of Konya in recent years, were used in this study; 'C 70165' and Alhaja were used in the first (2009) and second (2010) years, respectively. These two varieties both have certain distinctive features. For instance, early maturation, drought-resistance, medium-plant height, solid-body, and large-heads downwards sufficiently to prevent damage due to sunburn or birds. In the experiments, potassium sulphate (50% K_2O) and magnesium sulphate (16% MgO) were the investigated fertilizers while all plots received some base fertilizers such as DAP (18% N, 46% P_2O_5), urea (46% N), and ammonium nitrate (33% N). The potassium sulphate and magnesium sulphate fertilizers were tested in combinations of doses of 0, 4, 8 and 12 kg of K_2O da^{-1} and 0, 2, 4 and 6 kg of MgO da^{-1}. Along with the K- and Mg-fertilizers, nutrients that were determined by the soil analysis to be deficient were also applied as a base fertilizer to the plots during sowing. Fertilization with 6 kg P_2O_5 da^{-1} in the form of DAP was also applied in all plots during sowing; further nitrogen applications were made, half as 5 kg N da^{-1} of urea (46% N) applied manually during the first hoeing and the remaining half as 5 kg N da^{-1} of ammonium nitrate (33% N) during the second hoeing (Table 3).

Seeds were sown by a pneumatic seed drill in rows with a spacing of 70 cm and the rows were separated by 25 cm. Plots were all 6 m long and 4 rows wide and were separated by 1 m wide strips. In the middle of the growing season during the formation of the heads, young matured leaves, which had recently completed their development, were sampled from the middle of the plant and were analyzed in the laboratory. The plants were irrigated four times by sprinklers for a period of 6 hours (total 500 mm water per year) each in both years. The growing season was 108 days in the first study year, and 130 days in the second year.

3. Results and Discussion

The effect of the K and Mg fertilizers and their interactions on the total nitrogen contents of the leaves was statistically insignificant in the first year while, in the second year, the effect of Mg and of the KxMg interaction was statistically significant ($P < 0.01$) (Table 4).

Table 4

Analysis of variance significance results for the effects of potassium and magnesium on the macro- and micro-nutrient contents of sunflower leaves.

Nutrients	Variance source					
	2009			2010		
	K	Mg	K x Mg	K	Mg	K x Mg
N	ns	ns	ns	ns	**	**
P	ns	ns	ns	*	**	ns
K	*	*	**	ns	ns	**
Ca	ns	*	ns	ns	**	**
Mg	ns	ns	ns	ns	**	**
S	ns	ns	ns	ns	ns	**
Fe	ns	*	**	**	ns	**
Zn	ns	**	ns	**	ns	ns
Mn	*	ns	ns	ns	ns	**
Cu	**	**	**	**	ns	*
B	ns	ns	*	**	**	*

* $P < 0.05$; ** $P < 0.01$; ns: non significant

In the first year (2009), the range of total N values measured in the leaves was between 3.97% (Mg_6) and 4.55% ($K_{12}Mg_4$) and, in the second year (2010), between 2.55% (K_4Mg_6) and 3.50% (K_4) (Table 5). In the first and second years, in comparison with the control (K_0Mg_0), the N contents were increased by 6.8% and 17% by applications of $K_{12}Mg_4$ and K_4, respectively. The measured N contents were slightly deficient or sufficient according to the normal total N limit values (2.5-4.5%) for sunflower leaves (Jones et al. 1991).

The total N contents of the leaves were higher in the first than in the second year; the N contents of the leaves were greater for the KxMg applications than those for K or Mg alone. These findings could be related to the differences in soil properties, sunflower type (‘C 70165’ and Alhaja), and/or meteorological conditions (air temperature was 17.2 ºC mm in the first year and 19.9 ºC in the second year, in addition precipitation was 89.0 mm in the first year and 75.0 mm in the second year) which was possibly better achieved in the first year (Tables 1 and 2). This situation may also result from the plants developing better at the near optimal rates of N by the correction of the poor K-Ca-Mg balance in the soils at the study site by the use of combinations of K x Mg fertilizers. Mg was more sufficient in the experiment soil in the first year. Samui et al. (1987), Izsaki (2006) and Szulc (2010) reported similar results.

The effect of fertilizers on the total P contents of the leaves was insignificant in the first year, which was similar to the case of N; however, in the second year the effect of K and Mg fertilizers was significant (Table 4). In the first year, measured total values of P ranged between 0.19% (K_4Mg_6) and 0.26% (K_4Mg_4) but, in the second year, the values were higher and ranged between 0.31% (K_8Mg_6) and 0.49% ($K_{12}Mg_4$). In the first year, in comparison with the control, the P content in the leaves increased by 11.7% for the K_4Mg_4 treatments whereas, in the second year, the increase was by 27.1% for the $K_{12}Mg_4$ application. Based on the reported normal total P limits (0.25-0.50%) for sunflower leaves (Jones et al. 1991), the measured P contents of the leaves were considered as either slightly deficient or sufficient. The P contents, as well as the contents of K, Ca, Mg, S, Fe, Zn, Mn, Cu and B of the leaves in the first year were lower than those in the second year. In the second year, K and Mg fertilizer applications had a smaller effect on the P content of the leaves, due to the lack of P in the well-developed plants even after restoring the poor K-Ca-Mg balance. Similar results were reported by others including Draycott and Allison (1998), Blasko (2006) and Izsaki (2006). However, Szulc (2009) reported that P in the leaves was increased by a dose of Mg fertilizer. These findings can be related to the plant species, soil and meteorological conditions, and differences in the type and amount of fertilizer that was applied (Tables 1 and 2). Notably, there was less P and more lime in the soil at the location of the first year's field experiment.

The interaction effect of KxMg on the total K content of the leaves was significant in both years (Table 4). In the first year, the K values ranged between 2.94% (K_4Mg_6) and 3.58% (K_8Mg_2), and in the second year they ranged between 3.65% (K_4Mg_4) and 4.41% (K_8Mg_2) (Table 5). Compared to the control, an application of K_8Mg_2 increased the K content of the leaves by 3.2% and 13.1% in the first and second years, respectively, indicating that both K and Mg needed to be added to the soil to improve the K-Ca-Mg balance, which was poor due to the high Ca content of the soil. In both years, symptoms of K deficiency were not visible in the sunflower plants in any of the plots. According to the reported normal total K limits (3-4.5%) for sunflower leaves (Jones et al. 1991), the measured total K contents of the leaves were either slightly deficient or sufficient. The K contents of the leaves were lower in the first year, when the exchangeable Ca was higher, than in the second year.

Table 5
Effects of potassium and magnesium on the total nitrogen, phosphorus and potassium contents of sunflower leaves.

Fertilizer	Doses (kg K_2O-MgO da^{-1})	N (%)[a]		P (%)		K (%)	
		2009	2010	2009	2010	2009	2010
Mg	0	4.26	2.99	0.23	0.38 ab	3.47	3.90
	Mg_2	4.31	2.75	0.22	0.34 ab	3.39	3.96
	Mg_4	4.16	3.45	0.24	0.44 a	3.51	3.87
	Mg_6	3.97	2.65	0.21	0.30 b	3.35	4.18
	LSD (P < 0.05)	-	-	-	0.106	-	-
K	0	4.26	2.99	0.23	0.38 a	3.47	3.90
	K_4	4.34	3.50	0.23	0.36 a	3.32	3.97
	K_8	4.47	3.45	0.20	0.34 a	2.96	4.28
	K_{12}	4.40	2.69	0.25	0.31 b	3.25	3.67
	LSD (P < 0.05)	-	-	-	0.06	-	-
KxMg	K_0Mg_0	4.26	2.99 abcd	0.23	0.38	3.47 ab	3.90 bc
	K_4Mg_2	4.07	2.61 d	0.22	0.36	3.14 cd	3.76 bc
	K_4Mg_4	4.34	3.45 a	0.26	0.45	3.42 abc	3.65 c
	K_4Mg_6	4.13	2.55 d	0.19	0.43	2.94 d	3.76 bc
	K_8Mg_2	4.24	2.70 cd	0.23	0.31	3.58 a	4.41 a
	K_8Mg_4	4.17	2.78 bcd	0.22	0.35	3.32 abc	3.69 c
	K_8Mg_6	4.41	2.78 bcd	0.22	0.31	3.23 bc	3.68 c
	$K_{12}Mg_2$	4.12	3.11 abc	0.24	0.38	3.42 abc	3.93 bc
	$K_{12}Mg_4$	4.55	3.41 a	0.24	0.49	3.43 ab	4.16 ab
	$K_{12}Mg_6$	4.41	3.22 ab	0.23	0.47	3.44 abc	3.91 bc
	Lowest	3.97	2.55	0.19	0.31	2.94	3.65
	Highest	4.55	3.50	0.26	0.49	3.58	4.41
	LSD (P < 0.05)	-	0.474	-	-	0.284	0.403

[a] Mean values followed by the same letters within the same group in a column were not significantly different (P < 0.05)

The ratio of Ca:K in the soil was 13.92 and 11.39 in the first and second years, accordingly, since the optimal Ca:K should be 12 (Jokinen 1981), in 2010 the ratio was closer to the optimal one than in 2009. Zengin et al. (2008a and 2009), who investigated the effects of K and Mg fertilizers on sugar beet growing in similar soil conditions, demonstrated that K and Mg fertilization was necessary to establish appropriate balances for Ca-K and

Ca-Mg in soils with higher exchangeable Ca, and that nutrient levels in the leaves were increased by achieving the optimal balances. Furthermore, Zengin et al. (2008b) reported that K and Mg applications, in addition to those of N and P, increased K, Mg and S contents in potato leaves and these exhibited a high positive correlation with the tuber yield. The excessive Ca in the soil results in an antagonistic interaction between it and other cations, which reduces plant uptake of K (Aktaş and Ateş 1998). Increasing the application dose of K fertilizer reduced the total K contents of the leaves, while increasing the Mg dose reduced them. Conflicting results, i.e. the changeable or inconsistent effects of K fertilizer applications on leaf K content, has been noted by others including Hermans et al. (2004), Kacar and Katkat (2007), Zengin et al. (2008a, 2008b, 2009) and Szulc (2009). Furthermore, Sepehr et al. (2002) reported that a K application might decrease the K content in corn and sunflower plants, whereas Karaman et al. (1999) emphasized that K and Mg should be applied proportionately in order to attain proper levels of K in the leaves of corn.

Table 6

Effects of potassium and magnesium on the total calcium, magnesium and sulphur contents of sunflower leaves.

Fertilizer	Doses (kg K_2O-MgO da^{-1})	Ca (%)[a]		Mg (%)		S (%)	
		2009	2010	2009	2010	2009	2010
Mg	0	3.02 a	3.80	0.41	0.54	0.11	0.35
	Mg_2	2.94 a	3.51	0.35	0.57	0.11	0.35
	Mg_4	2.95 a	2.90	0.34	0.51	0.12	0.36
	Mg_6	2.68 b	3.91	0.41	0.58	0.11	0.46
	LSD (P < 0.05)	0.302	-	-	-	-	-
K	0	3.02	3.80	0.41	0.54	0.11	0.35
	K_4	2.91	3.06	0.37	0.50	0.12	0.41
	K_8	2.72	3.74	0.34	0.57	0.10	0.38
	K_{12}	3.10	3.85	0.37	0.61	0.11	0.36
	LSD (P < 0.05)	-	-	-	-	-	-
KxMg	K_0Mg_0	3.02	3.80 ab	0.41	0.54 cd	0.11	0.35 b
	K_4Mg_2	3.12	3.88 a	0.40	0.64 a	0.12	0.37 b
	K_4Mg_4	2.58	2.66 d	0.34	0.47 e	0.12	0.35 b
	K_4Mg_6	2.92	3.61 abc	0.36	0.62 ab	0.11	0.37 b
	K_8Mg_2	3.03	3.53 abc	0.36	0.58 bc	0.12	0.35 b
	K_8Mg_4	2.49	3.17 cd	0.41	0.52 d	0.11	0.35 b
	K_8Mg_6	2.85	3.60 abc	0.38	0.61 ab	0.11	0.34 b
	$K_{12}Mg_2$	2.98	3.59 abc	0.35	0.52 d	0.10	0.36 b
	$K_{12}Mg_4$	2.72	3.46 abc	0.35	0.55 cd	0.12	0.48 a
	$K_{12}Mg_6$	2.70	3.34 bc	0.40	0.52 d	0.12	0.36 b
	Lowest	2.49	2.66	0.34	0.47	0.10	0.34
	Highest	3.12	3.91	0.41	0.64	0.12	0.48
	LSD (P < 0.05)	-	0.513	-	0.049	-	0.065

[a] Mean values followed by the same letters within the same group in a column were not significantly different (P < 0.05)

The effect of Mg fertilizer on the total Ca content of the leaves was statistically significant in the first year and, in the second year, the effects of Mg and of KxMg interactions were significant (Table 4). In the first and second years, the Ca values ranged between 2.49% (K_8Mg_4) and 3.12% (K_4Mg_2), and between 2.66% (K_4Mg_4) and 3.91% (Mg_6), respectively (Table 6). In comparison with the control, the Ca content was increased by 3.3% with K_4Mg_2 fertilization and by 2.9% using Mg_6 fertilizer in the first and second years, respectively. These Ca contents were excessive according to the reported normal total Ca limits (0.8-2%) for sunflower leaves (Jones et al. 1991). The reason was mostly due to the relatively higher amounts of exchangeable Ca in the soil.

In both years, changes in Ca content of the leaves with K and Mg applications were related to the K-Ca-Mg balance in the soil. According to Doll and Lucas (1973), the cation exchange complex of a soil should be saturated with approximately 3-5% K, 65-85% Ca, and 6-12% Mg ions in order to nourish the plants adequately with K, Ca and Mg. Similarly, Jokinen (1981) recommended that K saturation should be 5%, Ca saturation 10%, and Mg saturation about 60% to give ideal ratios of exchangeable cations of Ca:K = 12, Ca:Mg = 6, and Mg:K = 2 in order to ensure that plants could uptake adequate levels of K, Ca and Mg from the soil. Yet the balance between these elements in each of the two local soils where the experiment was carried out differed from these recommended values.

The effect of fertilizers on the total Mg contents of the sunflower leaves was statistically insignificant in the first year; however, in the second year the effects of Mg and of KxMg interactions ($P < 0.01$) were significant (Table 4). In the first year, measured total Mg contents ranged between 0.34% (Mg_4, K_8, K_4Mg_4) and 0.41% (K_0Mg_0, K_8Mg_4) and, in the second year, between 0.47% (K_4Mg_4) and 0.64% (K_4Mg_2) (Table 6). Generally although there were clear trend on effect of fertilizer on leave nutrient content, one may note that in the first year, only increasing doses of the applications of Mg alone showed a reducing or increasing effect on the total Mg of leaves, while increasing doses of K alone or in the KxMg applications exhibited a decreasing trend. However, in the second year, increasing the doses of applications of Mg alone tended to increase the total Mg contents of the leaves, while increasing the doses of applications of K alone or of Mg for K_4 and K_8 (but not for K_{12}) in the KxMg treatments exhibited reductions followed by increases in the leaf Mg contents. The measured Mg contents of the leaves were all sufficient according to reported normal total Mg limits (0.3-0.8%) for sunflower leaves (Jones et al. 1991). This was supported by the absence of any visible symptoms of Mg deficiency in the sunflowers grown in any of the plots in either of the study years.

The greater deviation of the balances between exchangeable K-Ca-Mg in the soil in the first year were likely the cause of the lower total Mg contents of the leaves in plants grown in that year than in the second year. Combinations of K and Mg applied in different doses increased the Mg contents of the leaves to higher levels than those observed in the control by reducing the antagonistic interaction of these cations with Ca. The Mg contents of the leaves were reduced with increasing doses of K in the first year but were both reduced and increased in the second year. Sepehr et al. (2002), Zengin et al. (2008b), Szulc (2009) and Silva et al. (2010), among others, have noted that increasing the doses of K applications reduces the Mg content of the leaves due to the antagonistic effect.

The effect of the K and Mg fertilizers on the total S contents of the sunflower leaves was statistically insignificant in the first year; however, in the second year, the KxMg interactions were significant ($P < 0.01$) (Table 4). In the first year, the measured S contents ranged between 0.10% (K_2, $K_{12}Mg_2$) and 0.12% (Mg_4, K_4, K_4Mg_2, K_4Mg_4, K_8Mg_2, $K_{12}Mg_4$, $K_{12}Mg_6$) but, in the second year, they ranged between 0.34% (K_8Mg_6) and 0.48% ($K_{12}Mg_4$) (Table 6). In the first year, when compared with the control, the leaf S content was increased by 9.1% in the K_4Mg_4 treatment while, in the second year, it was increased by 37.1% in the $K_{12}Mg_4$ treatment.

In the first year, leaf S contents exhibited a non-significant rising-decreasing trend for some application treatments, whereas the effects of separate applications of Mg tended to increase the leaf S content in the second year. Nabi et al. (1995), Reddy and Singh (1996) and Zengin et al. (2008a and 2008b) reported similar findings. Therefore, the plant absorbed more sulphate ions during its growth when the balance between the important macro-nutrients (K, Ca, Mg) in the soil was adjusted to be closer to the optimal balance.

The effect of the KxMg interactions on the total Fe content of the sunflower leaves was significant ($P < 0.01$) in both years (Table 4). In the first year, the measured Fe values ranged between 100.26 mg kg^{-1} ($K_{12}Mg_4$) and 150.54 mg kg^{-1} (K_{12}), while in the second year they ranged between 311.93 mg kg^{-1} (K_8Mg_6) and 794.21 mg kg^{-1} (Mg_6) (Table 7). In the first year, the leaf Fe content was increased by 27.8%, when compared with the control, in the K_{12} treatment, which had the highest observed value, and, in the second year, it was increased by 83.6% in the Mg_6 treatment.

When K and Mg were applied separately, the total Fe content either increased or decreased depending on the study year (Table 7). This may be due to the synergistic effect of K and Mg in the study soils on Fe (Aktaş and Ateş 1998). Moreover, the level of lime in the soil was higher in the first year (9.07%) than in the second year (5.70%). As the amount of lime increased, the available Fe was reduced (Aktaş 1991; Eyüpoğlu et al. 1998). Izsaki (2006) found that the Fe contents of maize leaves were increased by K applications. The total Fe contents of the leaves were lower in the first year because the available Fe in the soil was also lower, by almost 3 mg kg^{-1} (Table 2).

The effect of Mg on the total Zn content of the sunflower leaves was statistically significant ($P < 0.01$) in the first year and, in the second year, the effect of K was significant ($P < 0.01$) (Table 4). In the first year, the measured Zn contents ranged between 15.15 mg kg^{-1} (K_8) and 22.97 mg kg^{-1} (K_8Mg_2) whereas, in the second year, they were between 25.06 mg kg^{-1} ($K_{12}Mg_2$) and 47.66 mg kg^{-1} (K_4Mg_4) (Table 7). In the first year, the Zn content of the leaves increased by 31.0%, as compared with the control, for the K_8Mg_2 treatment and, in the second year, by 49.3% for K_4Mg_4. The measured Zn contents were either deficient or sufficient according to the reported normal total Zn limits (30-80 mg kg^{-1}) for sunflower leaves (Jones et al. 1991).

The available Zn content in the soils was sufficient for growing sunflowers. The Zn deficiencies that resulted in the plants of some plots could be explained by an association with increased plant growth, which induced Zn deficiencies in the leaves. Hence, stem yields of these plants were above the average (Table 7) while the leaves were deficient in Zn. Actually, as plant biomass increase, leaf nutrient content decrease du to nutrient dilution. Low doses of Mg (2 kg da^{-1}) or K (4 kg da^{-1}) resulted in the highest Zn contents in the leaves, while further increasing the dosage resulted in reductions in leaf Zn contents (Table 7). Sepehr et al. (2002) and Izsaki (2006) also reported that K increased the Zn concentration of leaves.

Table 7
Effects of potassium and magnesium on the total iron and zinc contents and stem yields of sunflower leaves

Fertilizer	Doses (kg K_2O-MgO da^{-1})	Fe (mg kg^{-1}) [a]		Zn (mg kg^{-1})		Stem yield (kg ha^{-1})	
		1. Year	2. Year	1. Year	2. Year	1. Year	2. Year
Mg	0	117.75	432.37	17.54 b	31.93	15.880	17.670 a
	Mg_2	124.19	410.67	20.90 a	33.02	20.630	8.260 b
	Mg_4	106.76	445.48	18.68 ab	30.95	20.070	14.790 ab
	Mg_6	115.95	794.21	17.88 ab	27.66	16.410	18.510 a
	LSD (P < 0.05)	-	-	3.08	-	-	829,7
K	0	117.75	432.37	17.54	31.93 b	15.880	17.670 a
	K_4	101.62	635.03	19.31	40.92 a	17.740	8.820 b
	K_8	114.78	433.91	15.15	29.21 b	15.770	11.160 ab
	K_{12}	150.54	389.45	17.59	31.78 b	12.110	11.380 ab
	LSD (P < 0.05)	-	-	-	8.306	-	829,70
KxMg	K_0Mg_0	117.75 abcd	432.37 bc	17.54	31.93	15.880	17.670
	K_4Mg_2	109.56 bcd	408.71 bc	20.00	37.34	8.880	6.700
	K_4Mg_4	122.33 abc	355.45 bc	19.12	47.66	21.340	14.220
	K_4Mg_6	132.55 a	370.08 bc	18.42	36.14	13.370	6.620
	K_8Mg_2	129.97 ab	432.57 bc	22.97	29.63	15.650	11.760
	K_8Mg_4	107.21 cd	367.46 bc	18.87	28.12	14.760	13.290
	K_8Mg_6	132.06 a	311.93 c	18.01	26.15	15.710	9.440
	$K_{12}Mg_2$	118.01 abcd	448.07 ab	22.88	25.06	11.220	7.280
	$K_{12}Mg_4$	100.26 d	570.04 a	18.90	32.58	15.980	16.560
	$K_{12}Mg_6$	120.44 abcd	403.84 bc	17.47	35.35	14.870	14.160
	Lowest	100.26	311.93	15.15	25.06	8.880	6.700
	Highest	150.54	794.21	22.97	47.66	21.340	18.510
	LSD (P < 0.05)	21.52	123.9	-	-	-	

[a] Mean values followed by the same letters within the same group in a column were not significantly different (P < 0.05) (Duncan Comparison of Means Test)

The effect of K on the total Mn contents of the sunflower leaves was statistically significant (P < 0.05) in the first year while the KxMg interactions were significant (P < 0.01) in the second year (Table 4). In the first year, the measured Mn contents ranged between 50.71 mg kg^{-1} (K_8Mg_6) and 62.31 mg kg^{-1} ($K_{12}Mg_4$) and were between 127.85 mg kg^{-1} (Mg_2) and 198.60 mg kg^{-1} (K_4Mg_2) in the second year (Table 8). In the first year, the Mn content of the leaves increased by 10.9%, when compared with the control, in the $K_{12}Mg_4$ treatment, and by 42.9% in the K_4Mg_2 treatment in the second year. Measured leaf Mn contents were sufficient or excessive according to the reported normal total Mn limit values (25-100 mg kg^{-1}) for sunflower leaves (Jones et al. 1991).

Manganese contents of the leaves were lower in the first than in the second year (Table 8). The lime content and exchangeable Ca values of the soil were greater in the first than in the second year (Table 2). Aktaş and Ateş (1998), Eyüpoğlu et al. (1998) and Güneş et al. (1999) reported that, as the lime content of the soil increases, the available Mn content is reduced. The Mn content of the leaves consistently increased as the dose of K increased in the first year (Table 8), which may be due to the synergic effect between K and Mn (Aktaş and Ateş 1998).

The effects of K, Mg and the KxMg interactions on the total Cu content of the leaves were all statistically significant ($P < 0.01$) in the first year (Table 4). However, in the second year, the significant effects were those of K ($P < 0.01$) and the interaction of KxMg ($P < 0.05$). In the first year, the measured Cu values ranged between 12.47 mg kg^{-1} (K_8) and 20.11 mg kg^{-1} (Mg_6), and were between 26.55 mg kg^{-1} (control) and 44.61 mg kg^{-1} (K_8) in the second year (Table 8). In the first year, the Cu contents of the leaves increased by 0.7%, as compared with the control, in the Mg_6 treatment and, in the second year, by 68.0% in the K_8 treatment. Measured leaf Cu contents were sufficient or excessive according to the reported normal total Cu limits (10-20 mg kg^{-1}) for sunflower leaves (Jones et al. 1991).

Table 8
Effects of potassium and magnesium on the total manganese, copper and boron contents of sunflower leaves

Fertilizer	Doses (kg K_2O-MgO da^{-1})	Mn (mg kg^{-1})		Cu (mg kg^{-1}) [a]		B (mg kg^{-1})	
		1. Year	2. Year	1. Year	2. Year	1. Year	2. Year
Mg	0	56.19	138.96	19.97	26.55	128.13	75.20
	Mg_2	59.32	127.85	15.49	30.71	109.07	80.01
	Mg_4	59.28	137.53	18.69	29.71	98.83	77.48
	Mg_6	55.57	180.34	20.11	29.60	111.89	103.71
	LSD ($P < 0.05$)	-	-	-	-	-	-
K	0	56.19 b	138.96	19.97	26.55	128.13	75.20
	K_4	59.07 a	141.65	19.79	30.48	123.94	79.20
	K_8	54.76 b	146.48	12.47	44.61	102.30	99.80
	K_{12}	59.82 a	173.53	12.58	30.57	84.83	90.82
	LSD ($P < 0.05$)	2.990	-	-	-	-	-
KxMg	K_0Mg_0	56.19	138.96 bc	19.97 a	26.55 c	128.13 a	75.20 de
	K_4Mg_2	59.46	198.60 a	14.21 de	40.37 a	104.78 bc	134.70 a
	K_4Mg_4	59.87	138.06 bc	19.97 a	38.92 a	121.85 ab	88.28 cde
	K_4Mg_6	57.94	164.71 b	13.30 e	31.03 bc	100.26 c	113.57 abc
	K_8Mg_2	61.18	147.40 bc	15.29 cde	37.06 ab	117.75 abc	99.70 bcd
	K_8Mg_4	50.84	132.72 c	18.53 ab	33.41 abc	104.23 bc	75.70 de
	K_8Mg_6	50.71	136.58 bc	16.66 bcd	34.61 ab	120.88 abc	121.63 ab
	$K_{12}Mg_2$	62.19	135.30 bc	15.88 cde	38.03 ab	100.35 c	72.66 e
	$K_{12}Mg_4$	62.31	149.81 bc	19.75 a	33.54 abc	109.49 abc	83.05 de
	$K_{12}Mg_6$	59.34	139.23 bc	17.67 abc	35.62 ab	104.00 bc	84.22 de
	Lowest	50.71	127.85	12.47	26.55	84.83	72.66
	Highest	62.31	198.60	20.11	44.61	128.13	134.70
	LSD ($P < 0.05$)	-	31.60	2.649	7.155	21.44	26.03

[a] Mean values followed by the same letters within the same group in a column were not significantly different ($P < 0.05$)

The Cu contents of the leaves were lower in the first than in the second years (Table 8). Not only was the available Cu content of the soil less in the first year (1.03 mg kg^{-1}) than in the second year (3.70 mg kg^{-1}), but the lime content was also higher (Table 2). Aktaş (1991), Güzel et al. (1992) and Eyüpoğlu et al. (1998) reported that, as the lime content in the soil increased, the Cu content in plants decreased. The Cu content of the leaves was affected to a greater degree by changes in the K than in the Mg applications. When K and Mg were applied together, the plant uptake of Cu was greater, which may be related to the improvement in the balance of K-Ca-Mg in the soil.

The effect of the KxMg interaction on the total B contents of the leaves was statistically significant ($P < 0.05$) in the first year; however, in the second year, the significant effects were those of both K and Mg ($P < 0.01$) and of the KxMg interaction ($P < 0.05$) (Table 4). The measured values of B ranged between 84.83 mg kg^{-1} (K_{12}) and 128.13 mg kg^{-1} (control) in the first year, and were between 72.66 mg kg^{-1} ($K_{12}Mg_2$) and 134.70 mg kg^{-1} (K_4Mg_2) in the second year (Table 8). In the first year, the lowest B content of the leaves occurred with the Mg_6 treatment and this was 33.8% less than that of the control for which the B content was the highest, but in the second year the highest B content occurred with the K_4Mg_2 treatment, which was 83.6% more than that of the control. Measured B contents were sufficient or excessive according to the reported normal total B limits (35-100 mg kg^{-1}) for sunflower leaves (Jones et al. 1991).

Boron contents of the leaves were lower in the first than in the second year (Table 8) because the available B in the soil was also lower (3.11 mg kg^{-1}) in the first year as compared with 4.05 mg kg^{-1} in the second year (Table 2). Furthermore, as the Ca content of the soil was higher in the first than in the second year the plant uptake of B may have been inhibited; Aktaş and Ateş (1998) reported that increases in soil Ca levels reduced B uptake by plants. When the K and Mg were applied together, the increases in the B contents of the leaves were notably greater (Table 8). This may result from the improvements in the poor K-Ca-Mg balance in the soil that occurred with the combined applications.

In conclusion, it should be noted that, even though exchangeable K and Mg levels were sufficient in Konya soils, the uptake of K and Mg by sunflower were insufficient because of the high lime (Ca) content, which caused antagonistic interactions among the macronutrients. Synergic relationships between K in the soil and Fe or Mn in the leaves were found since the nutrient contents in the leaves increased with increasing doses of K. Synergic relationships between Mg in the soil and Mn or B in the leaves were found, as the nutrient contents in the leaves increased with increases in Mg applications. In general, when K and Mg were applied together at certain levels, the antagonistic effect among the exchangeable cations was reduced since the poor K-Ca-Mg balance in the soil was improved and, due to improved nutrient uptake, sufficient amounts of nutrients in the leaves were obtained. Long-term field experiments on various plant species using more fertilizer types and amounts should be established and continued to obtain results that are more specific.

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