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Effects of potassium, magnesium, and sulphur containing fertilizers on yield and quality of sugar beets (*Beta vulgaris* L.)

Mehmet ZENGİN[1,*], Fatma GÖKMEN[1], M. Atilla YAZICI[2], Sait GEZGİN[1]

[1]Selçuk University, Faculty of Agriculture, Dept. of Soil Sci., 42031 Konya - TURKEY

[2]Sabancı University, Faculty of Engineering and Natural Sciences, 34956 İstanbul - TURKEY

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Abstract: Effects of potassium (K), magnesium (Mg), and sulphur (S) containing fertilizers on root yield, refined sugar yield, and K, Mg, and S concentrations of leaf of sugar beet (*Beta vulgaris* L.) were studied on 3 different locations in Konya province, namely Kuzucu, Karaarslan, and Alakova, in 2004, 2005, and 2006. In the trails, a uniform diammonium phosphate (DAP) + urea application was used as the control treatment, while potassium sulphate and Mg containing Kalimagnesia, were applied at varying rate combinations. Compared to the control treatment (DAP + urea), all fertilizer treatments containing K, Mg, and S increased root yield in the Kuzucu and Alakova locations, while in the Karararslan location only potassium sulphate treatment improved root yield. The Kalimagnesia fertilizer containing all 3 nutrients, namely K, Mg, and S, enhanced root yield by 42% and 39% in the Kuzucu and Alakova locations, respectively. But, this yield-stimulating effect of the Kalimagnesia fertilizer was rate-dependent. Kalimagnesia was also effective in improving the sugar content of the root, while the amino-N levels were not consistently affected by the fertilizer treatments. Despite increases in the leaf concentrations of K, Mg, and S by the tested fertilizers, the changes in the leaf concentrations of these nutrients could not fully explain the increases in root yields. In the discussion of the results, the possible role of basic cation saturation ratios of soils was also taken into consideration. The results indicate that a fertilizer treatment including 81 kg K_2O ha^{-1}, 27 kg Mg ha^{-1}, and 46 kg S ha^{-1} may be recommendable in fertilization of sugar beets, together with regular nitrogen and phosphorus applications, under similar conditions, in order to achieve a balanced mineral nutrition and sustain better root and sugar yields.

Key words: Kalimagnesia, magnesium, potassium, sugar beet, yield

Potasyum, magnezyum ve kükürtlü gübrelerin şeker pancarının (*Beta vulgaris* L.) verim ve kalitesine etkileri

Özet: Konya ilinde 2004, 2005 ve 2006 yıllarında üç farklı lokasyonda (Kuzucu, Karaarslan ve Alakova) şeker pancarının (*Beta vulgaris* L.) kök verimi, arıtılmış şeker verimi ve yaprağın K, Mg ve S konsantrasyonlarına potasyum (K) ve magnezyum (Mg) ve kükürt (S) içeren gübrelerin etkileri araştırılmıştır. Denemelerde potasyum, sülfat ve Mg içeren kalimagnesia değişik oranlı kombinasyonlarda uygulanırken üniform bir diamonyum fosfat (DAP)+üre uygulaması kontrol muamelesi olarak kullanılmıştır. Kontrol uygulaması (DAP + üre) ile karşılaştırıldığında, kök verimini Kuzucu ve Alakova lokasyonlarında azot ve fosforlu gübrelere ilaveten verilen tüm K, Mg ve S'lü gübreleri içeren uygulamalar önemli düzeyde ($P < 0.01$) artırırken, Karaarslan lokasyonunda kök verimini sadece potasyum sülfatı içeren uygulama artırmıştır. Üç besin elementini de (K, Mg ve S) içeren Kalimagnesia gübresi Kuzucu ve Alakova lokasyonlarında kök

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* E-mail: mzengin@selcuk.edu.tr

verimini sırasıyla %42 ve %39 oranlarında yükseltmiştir. Ancak bu etki uygulama oranına bağlı olmuştur. Gübre uygulamalarının kökün amino-N kapsamı üzerine etkileri farklı olup Kalimagnesia gübresi kökün şeker oranını artırıcı etkide de bulunmuştur. Denenen gübrelerin uygulanması yaprağın K, Mg ve S konsantrasyonlarını artırmasına rağmen, yapraktaki söz konusu besin elementleri konsantrasyonlarının değişimlerinin kök verimindeki artışlara etkileri tam olarak açıklanamamıştır. Sonuçların tartışılmasında, toprakların bazik katyonlarca doygunluk oranının olası rolleri de dikkate alınmıştır. Sonuç olarak, benzer iklim ve toprak özelliklerine sahip yerlerde şeker pancarının dengeli mineral beslenmesini sağlayarak optimum kök ve arıtılmış şeker verimi elde etmek için azot ve fosfor uygulamasının yanında hektara 81 kg K_2O, 27 kg Mg ve 46 kg S sağlayan gübre uygulaması önerilebilir.

Anahtar sözcükler: Kalimagnesia, magnezyum, potasyum, şeker pancarı, verim

Introduction

Nearly 20% (66,000 ha) of the total sugar beet-cultivated area (310,000 ha) of Turkey is located in the Konya province. The sugar beet root yields in Konya and Turkey are very similar, about 43 t ha^{-1}, that is less than that in the EC countries (52 t ha^{-1}) (TÜİK 2006; USDA 2007). The reason for this difference in root yield values between EC countries and Turkey is not clearly known. Yet, one of the important factors affecting the crop production is the application of a balanced fertilization program having all essential nutrients based on soil analyses. Currently, in many countries application of nitrogen (N) and phosphorus (P) fertilizers is very common, while many other mineral nutrients are not applied leading to nutrient depletion problems in soils (Tan et al. 2005). The nutrient depletion is pronounced in agricultural areas where high-yielding cultivars are increasingly planted (Hartemink 2006).

High yielding cultivars are very nutrient-responsive and result in significant nutrient depletion by removing large amounts of elements from the soils, especially under intensive monotonous cropping systems (Çakmak 2002; Tan et al. 2005; Hartemink 2006). Soil nutrient depletion problem is a growing issue in intensively cultivated soils seriously affecting crop production and threatening the food security. In order to sustain high crop yield and maintain a better soil fertility, the nutrients depleted from soil must be replenished. However, as indicated above, according to the widely used current practice, farmers generally apply nitrogen and phosphorus fertilizers and do not pay attention to the depleted nutrients in soils, that leads to an imbalanced nutrition of plants and decline in soil fertility. This is a well-documented problem in monotonous rice-wheat cropping systems in South Asia and China, resulting deficiency of potassium (K), sulphur (S), and zinc (Zn) deficiencies in plants (Çakmak 2002; Ladha et al. 2003). In India, the deficit between the removed and applied mineral nutrients is estimated to be reaching 5×10^6 t in soils subjected to monotonous wheat and rice cultivation (Singh 1998).

To our knowledge, for Turkish soils, published data about the magnitude of the nutrient depletion problem is scarce, and very few data are available about the role of K, Mg, and S on the crop production. Soil survey studies have shown that there is an important decline in plant available K concentration of soils, and plants are responsive to K fertilizers (Özgümüş et al. 1997). Field trails in Niğde and Nevşehir with potatoes showed that this crop is very responsive to fertilizers containing Mg, K, and S (Zengin et al. 2008). K, Mg, and S have particular roles in plant metabolism and in improving nutritional quality of the edible parts of crop plants (Marschner 1995). K and Mg have critical functions in photosynthesis, phloem loading of sucrose, and biomass distribution among the plant parts (Çakmak 2005; Hermans et al. 2006). When plants suffer from K and Mg deficiency, translocation of photo assimilated from leaves into actively growing parts of plants is severely reduced leading to reduced growth and development as shown in sugar beet and bean plants (Hermans et al. 2006; Çakmak and Kirkby 2008). Therefore, absence of these mineral nutrients in a balanced fertilization program will result in significant adverse effects on growth and development of plants.

In this study, field experiments have been established to study the roles of mineral fertilizers containing K, Mg, and S in root yield, refined sugar yield, and K, Mg and S concentrations of leaf of sugar beets grown in the Konya province. The experiments were conducted at 3 locations in 2004, 2005 and 2006.

Materials and methods

A series of field trails have been conducted on sugar beets (*Beta vulgaris* L.) in the Konya province-Turkey in the following manner: at the Kuzucu village of Çumra in 2004, at the Research Farm of Konya Soil and Water Research Institute in Karaarslan in 2005, and at the Production Farm of the Sugar Institute in Alakova in 2006.

The fertilizer materials used in the trials were diammonium phosphate (DAP), urea, Kalimagnesia, and potassium sulphate. Kalimagnesia is a granule potassium magnesium sulphate fertilizer containing 30% K_2O (25% K), 10% MgO (6% Mg), and 42.5% SO_4 (17% S) as soluble in water (Table 1).

The experimental area is situated at an altitude of 1010 m. The climate of the experimental area is characterized by hot and dry summers and cold and rainy winters with an average annual precipitation of 320 mm. Total precipitations during the sugar beet growth period (April through September) at the experimental sites were about 67 mm in 2004 and 100 mm in both 2005 and 2006 (Table 2). Table 2 also shows the air temperatures (°C) and relative humidity (%) values for the same period.

Some physical and chemical properties of the soil samples taken from the experimental sites are given in Table 3. According to the analyses with 3 parallels, these soils are slightly alkaline, low in organic matter,

Table 1. Fertilizer materials and treatments used in the experiments.

Treatment	**Rate kg ha^{-1}**	**Source**	**Treatment**	**Rate kg ha^{-1}**	**Source**
1	180 kg N 105 kg P_2O_5 81 kg K_2O 46 kg S	DAP+ urea DAP P. sulphate P. sulphate + S	**4**	180 kg N 105 kg P_2O_5 121.5 kg K_2O 69 kg S 40.5 kg Mg	DAP + urea DAP Kalimagnesia Kalimagnesia Kalimagnesia
2	180 kg N 105 kg P_2O_5 40.5 kg K_2O 23 kg S 13.5 kg Mg	DAP + urea DAP Kalimagnesia Kalimagnesia DAP	**5 (Control)**	180 kg N 105 kg P_2O_5	DAP + urea DAP
3	180 kg N 105 kg P_2O_5 81 kg K_2O 46 kg S 27 kg Mg	DAP + urea DAP Kalimagnesia Kalimagnesia Kalimagnesia			

Table 2. Meteorological data for the experimental sites.

Loc.	**Parameters**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Average**
Kuzucu	**Temp. (°C)**	9.8	14.6	19.1	22.2	21.9	17.1	17.4
	Relative hum. (%)	57.0	56.2	52.7	41.7	49.0	44.5	50.2
	Precipitation (mm)	37.6	11.1	9.7	1.2	7.6	0.0	Total 67.2
Karaar.	**Temp. (°C)**	10.16	15.08	19.16	22.96	22.98	16.15	17.75
	Relative hum. (%)	56.8	51.7	44.4	39.1	42.1	59.0	48.8
	Precipitation (mm)	29.6	24.0	6.0	14.0	-	27.0	Total 100.6
Alakova	**Temp. (°C)**	11.3	15.1	20.8	22.0	25.1	17.3	18.6
	Relative hum. (%)	60.3	58.1	39.1	39.4	34.3	53.7	47.5
	Precipitation (mm)	48.8	14.2	9.8	4.4	11.8	12.4	Total 101.4

Table 3. Some chemical and physical properties of the experimental soils.

Parameters	Kuzucu	Karaarslan	Alakova	Analysis methods (Kacar, 1997)
pH (1:2.5 s:w)	8.05	7.56	7.63	pH meter
EC (1:5 s:w; µS cm^{-1})	105.6	196.7	124.3	EC meter
Org. matter (%)	1.8	2.2	0.83	Walkley-Black method
Lime (%)	21.3	20.56	5.25	Scheibler Calcimeter
Texture class	Sandy clay loam	Sandy clay loam	Sandy clay	Texture triangle
P (mg kg^{-1})	21.6	39.9	60	$NaHCO_3$ method
K (mg kg^{-1})	185	439	331	Extraction with NH_4OAc
Ca (mg kg^{-1})	4120	2249	3648	Extraction with NH_4OAc
Mg (mg kg^{-1})	164	273	262	Extraction with NH_4OAc
K (me 100 g^{-1})	0.47	1.12	0.85	-
Ca (me 100 g^{-1})	20.6	11.24	18.24	-
Mg (me 100 g^{-1})	1.37	2.28	2.18	-
Ca/Mg	15	4.93	8.37	-
Ca/K	43.8	10.03	21.46	-
Mg/K	2.9	2.03	2.56	-
Ca saturation (%)	91.8	76.77	85.75	-
Mg saturation (%)	6.1	15.57	10.2	-
K saturation (%)	2.1	7.65	4.0	-
S (mg kg^{-1})	0.37	13.66	28.28	Extraction with KH_2PO_4
Fe (mg kg^{-1})	0.73	4.63	4.91	Soltanpour and Workman (1981)
Cu (mg kg^{-1})	0.51	0.72	0.79	Soltanpour and Workman (1981)
Mn (mg kg^{-1})	2.80	5.69	5.84	Soltanpour and Workman (1981)
Zn (mg kg^{-1})	0.23	0.45	0.18	Soltanpour and Workman (1981)
B (mg kg^{-1})	0.42	0.40	1.14	Kacar (1997)

calcareous, and varying in texture. In all locations, extractable calcium and magnesium concentrations of soils were sufficient, while extractable sulphur was adequate in Karaarslan and Alakova soils and low in Kuzucu (Table 3) (Ülgen and Yurtsever 1974; FAO 1990).

Completely randomized field experiments with 3 replications were utilized in this investigation. A uniform diammonium phosphate (DAP) + urea application to all experimental plots was used as control treatment, while potassium sulphate and Mg containing Kalimagnesia were superimposed on this base application at 4 different combinations, making up 5 treatments (Table 1). Plots had dimension of 2.25 m by 8.00 m (18 m^2) with 45 cm row spacing and 20 cm planting interval. Field operations at the 3 locations are given in Table 4.

In all trails, fully expanded leaves were sampled and transported to laboratory for analysis of mineral nutrients. Leaf samples were first washed under tap water and then with deionized water. Following drying at 70 °C, leaf samples were ground and subjected to digestion by HNO_3 using a microwave system (CEM, Mars 5). The amounts of K, Mg, and S in the extracts were determined by ICP-AES (Varian, Vista Axiel Simultaneous) as described by Soltanpour and Workman (1981). The leaf specimens were analyzed with 3 parallels.

At the harvest, 3 rows in the middle were taken into consideration. The net weights of roots were determined by a steelyard scale after cleaning with pressured water and reported in t ha^{-1} units. Refined sugar content (RSC), refined sugar yield (RSY), and the level of amino-N were determined in the extracts

Table 4. Timetable of the field operations.

Field operation	Experimental site		
	Kuzucu	Karaarslan	Alakova
Sowing	28.04.2004	13.04.2005	21.04.2006
Hoeing and topdressing 1	03.06.2004	29.05.2005	02.06.2006
Hoeing and topdressing 2	01.07.2004	19.06.2005	14.07.2006
Irrigation starting	24.06.2004	15.06.2005	15.06.2006
Number of irrigation	7	9	6
Irrigation interval	13	11	13
Sampling	09.08.2004	25.07.2005	27.07.2006
Harvest	08.10.2004	04.10.2005	04.10.2006

following the methods routinely employed by the Sugar Factory Laboratory of Konya (Kubadinow and Wieninger 1972).

Sugar content (SC) of roots (%) (ICUMSA 1974), RSC and RSY (t ha^{-1}), were determined by the equation below developed by Kubadinow and Wieninger (1972).

RSC (%) = SR - [0.343 (Na+K) + 0.094 amino-N + 0.29]

RSY (t ha^{-1}) = root yield (t ha^{-1}) × RSC/100

Minitab and M-Stat computer software were used in the statistical analyses of the data obtained in this investigation.

Results

Summary of the analysis of variance for the sugar beet root parameters for the 3 experimental locations are given in Table 5. Generally, treatment effects on observed root parameters were statistically significant, with the exception of RY and SC at Kararslan and SC at Kuzucu.

Compared to the control treatment (No 5: DAP + urea), all fertilizer treatments increased root yield in the Kuzucu and Alakova locations, while in the Karararslan location only the treatments No: 1 and No: 2 resulted in comparable, yet statistically insignificant, increases in root yield (Table 6). In both Kuzucu and Alakova locations, the treatment No: 3

Table 5. Summary of the analysis of variance of sugar beet root parameters for different locations.

Location	Mean squares				
	RY	SC	Amino-N	RSC	RSY
Kuzucu	255.6**	0.06933	0.7629**	0.21556*	7.246**
Karaarslan	163.21	0.4273	0.222	3.037**	4.6877*
Alakova	381.88**	0.41042*	0.18656*	0.4323*	9.7897**

RY = root yield, SC = sugar content, RSC = refined sugar content, RSY = refined sugar yield. **($P < 0.01$); *($P < 0.05$).

Table 6. The effect of different fertilizer applications on root yield and quality parameters of sugar beet.*

Loc.	Treatment	Root yield ($t\ ha^{-1}$)	SC (%)	Amino-N (me 100 g^{-1})	RSC (%)	RSY ($t\ ha^{-1}$)
Kuz.	1	66.51 ab	19.60	2.43 a	16.62 b	11.05 ab
	2	58.17 bc	19.93	2.48 a	16.86 ab	9.80 b
	3	74.01 a	19.77	1.43 b	17.20 a	12.72 a
	4	53.37 c	19.67	1.57 b	17.10 ab	9.13 b
	5	52.33 c	19.53	2.33 a	17.07 ab	9.03 b
Kar.	1	74.28	16.40	1.09	14.70 b	10.92 a
	2	64.55	17.13	1.19	16.73 a	10.80 ab
	3	56.22	16.22	1.00	14.38 b	8.09 c
	4	57.50	16.87	1.52	16.00 a	9.20 abc
	5	59.29	16.43	0.78	14.76 b	8.74 bc
Ala.	1	90.02 a	16.10 ab	2.43 b	13.85 ab	12.47 a
	2	92.49 a	15.98 ab	2.76 ab	13.78 ab	12.74 a
	3	93.10 a	16.50 a	3.00 a	14.35 a	13.36 a
	4	78.03 b	15.95 ab	2.40 b	13.78 ab	10.75 b
	5	67.20 c	15.47 b	2.57 b	13.28 b	8.92 c

*Data are average of 3 replicates. SC: sugar content, RSC: refined sugar content,
RSC (%) = SC - [0.343 (Na + K) + 0.094 amino-N + 0.29],
RSY: refined sugar yield, RSY ($t\ ha^{-1}$) = root yield ($t\ ha^{-1}$) × RSC/100.

including the second rate of Kalimagnesia improved root yield by 41.4% and 38.5%, respectively. However, the average root yields of the first 3 treatments took the same letter in Alakova location. Therefore, potassium sulphate and Kalimagnesia (the first and second rate) showed similar effect on the root yield. It appears that the 3rd rate of Kalimagnesia (treatment No: 4) was not so much effective to improve root yield (Table 6). The sugar content was highest (16.50%) with the 3rd rates of the Kalimagnesia treatments in Alakova. The amino-N is not a desirable compound in the root. Therefore, the treatments resulting in the lowest levels of this compound are desirable. In this respect, the treatments 3 and 4 at Kuzucu, and 4 and 5 at Alakova seem to be the candidates, although the individual and combined effects of various rates of K_2O, S, and Mg are not sufficiently clear. Furthermore, this matter should be discussed along with effects of the treatments on RSC and RSY values. Like the sugar content values, also the RSC and RSY values are generally increased by the Kalimagnesia treatments, especially its second increment (Table 6).

Summary of the analysis of variance for the K, Mg, and S contents of the leaf for the 3 experimental locations are given in Table 7. The effects of the fertilizers on K, Mg, and S contents of sugar beet leaves were statistically significant ($P < 0.01$) at all locations, except for Mg and S at Karaarslan.

Leaf concentrations of K, Mg, and S of the plants grown at 3 locations are given in Table 8. As expected, the higher dose of the Kalimagnesia treatment

Table 7. Summary of the analysis of variance of sugar beet leaf parameters for different locations.

Location	Mean squares		
	K	Mg	S
Kuzucu	0.46104**	0.0038124**	0.0059247**
Karaarslan	0.46955**	0.0001766	0.002093
Alakova	0.09397**	0.0016994**	0.0017404**

**($P < 0.01$)

resulted in the highest nutrient concentrations compared to other treatments. Compared to the control, generally, plants had always higher Mg and S concentrations. Although the first treatment contained potassium sulphate, there was, however, no increase in the leaf K concentration by this treatment, even a decline in K concentration was present with the first treatment (Table 8). The reason of this decline in K concentration was not clearly understood. Irrespective of the treatments, plants grown at the Alakova location had less potassium than the plants grown at the Kuzucu and Karaarslan locations, while the concentrations of Mg and S were not so much different between these locations.

Discussion

Applying K, Mg, and S at different forms and levels generally resulted in increases in root yield and improved leaf concentrations of K, Mg, and S with a few exceptions (Tables 6 and 8). This result may indicate that plants grown under the mentioned conditions in Konya region were subjected to an imbalanced mineral nutrition. It is, therefore, important that the fertilizer trails described in this paper should be also extended to other regions. Potassium concentrations of the experimental plants are not adequate according to the critical concentrations reported by Marschner (1995). Commonly reported sufficient concentrations of K in sugar beet leaves range from 3% to 6% (Bergman 1992; Kadar 2001; Marschner 1995). Highest increases in root yield by application of fertilizers were found in the Kuzucu and Alakova locations where accompanying increases in leaf K concentrations were clearly present. For example, at the Kuzucu location, the plants of the control treatment had nearly 3% K in the leaves but in plants with the highest root yield K concentration was 3.56% (Treatment 3; Table 6). Nevertheless, the leaf concentrations of K cannot explain all of the variability present in root yields, for example at the Karaarslan location where the effects of treatments on RY were not significantly different (Tables 5, 6, and 8). It appears that there are factors other than leaf K concentrations which contributed to changes in root yield upon the fertilizer treatments. Based on the critical concentrations of S and Mg for sugar beet plants, the experimental plants do not suffer from Mg and S deficiency. The reported adequate Mg and S concentrations for sugar beet leaves range from 0.3% to 0.7% for Mg and 0.28% to 0.32% for S (Bergman 1992; Marschner 1995; Hoffmann et al. 2004). The Mg and S values presented in Table 8 are within the sufficiency range. Thus, the level and changes in Mg and S concentrations of leaves cannot explain the changes in root yield in relation to the fertilizer treatments.

A complementary explanation of the increases in yield by fertilizer applications might be related to the cation saturation ratio of soils. Currently, the basic cation saturation ratio (BCSR) concept is being used for a better understanding and interpretation of soil analyses and plant response to fertilizer applications (Kopittke and Menzies 2007). According to Albrecht (1975) for a balanced mineral nutrition, soils should have 60% to 75% Ca saturation, 10% to 20% Mg saturation, and 2% to 5% K saturation. According to the report by Kopittke and Menzies (2007), following ratios has been recommended for a better plant growth in an ideal soil: Ca/Mg ratio: 6.5; Ca/K ratio:

Table 8. Effect of different fertilizers on the nutrient concentration (%) of sugar beet leaves.*

	Kuzucu			Karaarslan			Alakova		
Treatment	**K**	**Mg**	**S**	**K**	**Mg**	**S**	**K**	**Mg**	**S**
1	2.97 c ± 0.13	0.33 b ± 0.01	0.37 c ± 0.01	3.12 b ± 0.05	0.31 ± 0.01	0.43 ± 0.04	2.65 ab ± 0.02	0.28 c ± 0.01	0.34 b ± 0.01
2	3.10 c ± 0.06	0.37 a ± 0.00	0.35 c± 0.01	2.35 c ± 0.03	0.31 ± 0.01	0.38 ± 0.03	2.43 bc ± 0.21	0.32 b ± 0.00	0.32 c ± 0.01
3	3.56 b ± 0.14	0.38 a ± 0.01	0.38 b± 0.01	3.03 b ± 0.09	0.31 ± 0.01	0.38 ± 0.01	2.58 ab ± 0.01	0.32 b ± 0.01	0.34 b ± 0.00
4	3.89 a ± 0.03	0.39 a ± 0.01	0.43 a± 0.02	3.44 a ± 0.02	0.30 ± 0.01	0.43 ± 0.03	2.71 a ± 0.06	0.34 a ± 0.01	0.37 a ± 0.01
5	3.08 c ± 0.05	0.31 b ± 0.01	0.31 d± 0.01	2.99 b ± 0.04	0.30 ± 0.01	0.42 ± 0.03	2.27 c ± 0.01	0.32 b ± 0.00	0.30 d ± 0.01

*Data are average of 3 replicates and leaf samples were analyzed with 3 parallels.

13, and Mg/K ratio: 2. In terms of the cation saturation values and the ratios between cations, the most suitable location seems to be Karaaraslan (Table 3). In this location, the Ca saturation and Mg saturation values and the Ca/Mg, Ca/K, and Mg/K ratios are very close to the values given for an ideal or balanced mineral nutrition of plants (Kopittke and Menzies 2007; Table 3). In well agreement with these suggestion, plants grown in the Karaarslan location responded to the fertilizer applications much less compared to other locations.

The treatment 3, which was associated with the highest root yield values and also RSY values in the Kuzucu and Alakova locations, represents application of 81 kg K_2O, 27 kg Mg, and 46 kg S ha^{-1}. These values should be taken into consideration in establishment of a balanced mineral nutrition and maintaining a better soil fertility and crop production. In the target regions with low soil pH, applying K, Mg, and S (e.g., acid soils) together with N and P fertilizers is required to ensure and sustain high yield capacities of plants, especially when high-yielding cultivars are planted.

References

Albrecht WA (1975) The albrecht papers. Vol. 1. Foundation Concepts. Acres USA, Kansas City.

Bergmann W (1992) Nutritional Disorders of Plants, Development, Visual and Analytical Diagnosis. Gustav Fisher Verlag Jena, Stuttgart, NY. ISBN 3-334-60422-5.

Çakmak İ (2002). Plant nutrition research: Priorities to meet human needs for food in sustainable ways. Plant and Soil 247: 3-24.

Çakmak İ (2005). The role of potassium in alleviating detrimental effects of abiotic stresses in plants. J. Plant Nutr. Soil Sci 168: 521-530.

Çakmak İ, Kirkby EA (2008). Role of magnesium in carbon partitioning and alleviating photooxidative damage. Physiologia Plantarum 133: 692-704.

FAO (1990) Management of Gypsiferous Soils. Soils Bulletin 62. Rome, Italy.

ICUMSA (1974) Report of the Proceedings. 16th Session, Subj. 12, Rec. (1): 156.

Hartemink AE (2006) Assessing soil fertility decline in the tropics using soil chemical data. Advances in Agronomy 89: 179-225.

Hermans C, Hammond JP, White PJ, Verbruggen N (2006) How to plants respond to nutrient shortage by biomass allocation? Trends Plant Sci 11: 610-617.

Hoffmann C, Stockfisch N, Koch HJ (2004) Influence of sulphur supply on yield and quality of sugar beet (*Beta vulgaris* L.)-determination of a threshold value. European J Agron 21: 69-80.

Kacar B (1997) Chemical Analysis of Plant and Soil. III. Soil Analysis. Foundation of Univ. of Ankara, Fac. of Agric. Education, Research and Developing Publ. No: 3, Ankara. (In Turkish)

Kadar I (2001) Estimation of the nutrient status of sugar beet (*Beta vulgaris* l.) using plant analysis. Novenytermeles 50: 107-121.

Kopittke MP, Menzies, NW (2007) A Review of the use of the basic cation saturation ratio and the 'ideal' soil. SSSAJ 71: 259-265.

Kubadinow N, Wienninger L (1972) Comp. Rent. XIV. Ass. Comm. Int. Teach Sucr. (Cits) Brussel, 1971, 539: S.A. Zucker. 25: 43.

Ladha JK, Dawe D, Pathak H, Padre AT, Yadav RL, Singh B, Singh Y, Singh P, Kundu AL, Sakal R, Ram N, Regmi AP, Gami SK, Bhandari AL, Amin R, Yadav CR, Bhattarai EM, Das S, Aggarwal HP, Gupta RK, Hobbs PR (2003) How Extensive are yield declines in long-term rice-wheat experiments in Asia? Field Crops Res 81: 159-180.

Marschner H (1995) Mineral Nutrition of Higher Plants. 2nd Edn. Academic Press, San Diego, Ca.

Özgümüş A, Atalay, İZ, İrget ME (1997) Potassium status in soils and crops, recommendations and present use in Turkey. Pages: 33-47. In Food Security in the WANA Region, the Essential Need for Balanced Fertilization (Ed: A.E. Johnston) Regional Workshop of the International Potash Inst. In Coop. with the Ege Univ. Fac. of Agric., Dept. of Soil Sci. (26-30 May, İzmir) Turkey.

Singh MV (1998) Micronutrients in Indian soils and plants. Progress Report of AICRP Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants 28: 1-122.

Soltanpour PN, Workman SM (1981) Use of inductively-coupled plasma spectroscopy for the simultaneous determination of macro and micro nutrients in NH_4HCO_3-DTPA extracts of soils. In Barnes R.M. (ed). Developments in Atomic Plasma Analysis, USA. pp. 673-680.

Tan ZX, Lal R, Wiebe KD (2005) Global soil nutrient depletion and yield reduction. J. of Sustainable Agric 26: 123-146.

TÜİK (2006) www.tuik.gov.tr. Türkiye İstatistik Kurumu web sitesi. Erişme tarihi 2006.

USDA (2007) http://www.fas.usda.gov/WAP/circular/ 1996/96-11/nov96wap2. html. Birleşik Devletler Tarım Departmanı web sitesi. Erişme tarihi 2007.

Ülgen N, Yurtsever N (1974) Guide of Turkey Fertilizer and Fertilizing. Ministry of Village Works and Cooperatives, Research Inst. of Soil Fertilizer Publ. No: 28, Ankara. (In Turkish)

Zengin M, Gökmen F, Gezgin S, Çakmak İ (2008). Effects of different fertilizers with potassium and magnesium on the yield and quality of potato. Asian J. Chem 20: 663-676.