https://doi.org/10.17221/809/2017-PSE

Sugar beet response to different K, Na and Mg ratios in applied fertilizers

Przemysław BARŁÓG*, Witold SZCZEPANIAK, Witold GRZEBISZ,
Radosław POGŁODZIŃSKI

Department of Agricultural Chemistry and Environmental Biogeochemistry,
University of Life Sciences, Poznan, Poland
**Corresponding author: przembar@up.poznan.pl*

ABSTRACT

Barłóg P., Szczepaniak W., Grzebisz W., Pogłodziński R. (2018): Sugar beet response to different K, Na and Mg ratios in applied fertilizers. Plant Soil Environ., 64: 173–179.

Potassium (K) in sugar beet can be partly replaced by magnesium (Mg) and sodium (Na). This hypothesis was verified based on 12 field experiments conducted on four farms in Poland during the seasons 2010–2012. The effect of different K, Na and Mg ratios in fertilizers applied in the total rate of 3205 mol/ha on beet yield (BY), storage root quality and white sugar yield (WSY) was determined. The tested K:Mg:Na cation ratios were as follows: 1:0:0; 1:0.11:0.09; 1:0.16:0.54 and 1:0.33:2.19. BY and WSY were affected by the total rate of the applied cations. The optimum ratio of K:Mg:Na was different with respect to the site and the growing season. The K rate reduction from 125 to 24 kg/ha combined with the simultaneous increase in the rate of Mg and Na did not result in lower BY. However, a too narrow K:Na ratio in applied fertilizers resulted in a decrease of sucrose content in storage roots. The fertilization cost for sugar beet production could be reduced through the application of fertilizers that contain fixed amounts of Na on soils rich in available K.

Keywords: amino-nitrogen; *Beta vulgaris* L.; potassium substitution; sucrose in molasses

Sugar beet is a crop with high demand for potassium (K) and requires 2.9–6.8 kg of K per one tonne of storage roots (Christenson and Draycott 2006). Potassium is essential for the photosynthetic process, transport of sugars from the leaves to the roots and reduction of oxidative damage (Oosterhuis et al. 2013). Another very important K function is the maintenance of plant osmotic potential, cell turgor and regulation of the opening and closure of stomata. Therefore, K shortage in the soil has a negative effect on beet yield (Scherer et al. 2003). An adequate content of K in sugar beet ensures also a high beet quality (Römer et al. 2004). However, excess K in storage roots has a negative influence on beet quality, because the amount of sugar crystallized from the extracted juice decreases (Buchholz et al. 1995).

The maintenance of osmotic potential in vacuoles, a nonspecific function of K, can be compensated by other cations such sodium (Na), calcium (Ca) and magnesium (Mg). Sodium is more efficient than the other elements, because it is structurally and chemically very similar to K (Subbarao et al. 2003). Sugar beet is a natrophile plant and in contrast to glycophytes, it does not create a barrier against the flow of Na^+ ions from the true roots to the leaves (Kronzucker et al. 2013). Subbarao et al. (1999) found that Na can safely replace even 95% of the normal tissue K without decreasing the production of some red beet cultivars. Additionally, Na has beneficial effects on the water balance, leaf area and thickness due to an increased rate of cell expansion, and the number and activity of sugar beet stomata (Wakeel et al. 2011). The role of Mg should not be ignored, because it is an important factor regulating efficiency of nitrogen fertilization (Grzebisz 2013) and yield of different crops (Zlámalová et al. 2015).

https://doi.org/10.17221/809/2017-PSE

The hypothesis of this study assumed that the yield and quality of sugar beet depends on the total amount of cations instead of the ratios of K, Mg and Na in the applied fertilizers. To verify the hypothesis, an extensive field studies were conducted to determine the effect of different ratios of K, Na and Mg on beet yield and quality, under a constant rate of total cations in the applied fertilizers.

MATERIAL AND METHODS

The study was conducted in 2010–2012 on four farms in western Poland: Bodzewo (51°50'N, 17°04'E), Donatowo (52°05'N, 16°52'E), Jasień (52°13'N, 16°71'E) and Wieszczyczyn (52°02'N, 17°05'E). On each farm, univariate experiments were conducted in which the response of sugar beet (*Beta vulgaris* L.) to different rates of K, Mg and Na was assessed. The cations were supplied as potassium salt (49.8% K), potassium salt with magnesium and sodium (33.2% K + 3.6% Mg + 3.0% Na + 6.3% S), and raw potassium salt (magnesium kainite) with magnesium and sodium (9.1% K + 3.0% Mg + 20.0% Na + 5% S). The rates of fertilizers were calculated to apply the same amount of moles of total cations per hectare in each experimental variant. Each treatment as shown in Table 1 had a different K:Mg:Na ratio for the same total rate of cations.

The experiments were conducted in a randomized block design, with four replications. The total area of a plot was 100 m^2. Winter triticale was the fore crop in each year and location. Fertilizers with K, Mg, Na and P (35 kg P/ha; triple superphosphate 17.4% P) were applied in autumn. Nitrogen in the form of ammonium nitrate (34% N) was applied twice: before sowing and at the stage of 4(5)-leaf (65 + 60 kg N/ha). The Janowa sugar beet cultivar was tested in all experimental locations. A standard plant protection was applied.

According to the World Reference Base for Soil Resources, the soils were classified as Luvisols. They are characterized by low-clay sand and sandy clay textures. The content of available K in the soils in Bodzewo, Jasień and Wieszczyczyn was high or very high, whereas in Donatowo it was moderate. The content of available Mg ranged from high to very high (Table 2).

The long-term average total yearly precipitation in the area of study is about 550 mm. During the study, total annual precipitation amounted to 676 (2010), 449 (2011) and 595 mm (2012). It should be noted that in the two critical months for sugar beet growth (July and August) the amount of rainfall was 122 (2010), 213 (2011) and 226 mm (2012). The requirements for water by the sugar beet canopy in both months are fixed at the level of ca 180 mm (Kenter et al. 2006). The average annual temperature ranged from 7.8°C to 9.9°C.

Sugar beet was hand-harvested at the stage of technological maturity (BBCH 49) from an area of 10.8 m^2 (4 rows × 6 m). The evaluation of qualitative parameters of beet was performed using a Venema auto-analyser IIIG (Groningen, the Netherlands). Representative storage root samples were first washed, then ground to obtain a uniform pulp and clarified with 0.3% $Al_2(SO_4)_3$ solution. Potassium and Na contents were determined by flame photometry, and α-amino-N (AmN) was analysed by the fluorometric ortho-phthaldialdehyde (OPA) method. Sucrose content (SC) in fresh taproots was determined by polarimetry. White sugar yield (WSY) was calculated according to the Brunswick formula (Buchholz et al. 1995):

$$\text{SML} = 0.12\ (\text{K} + \text{Na}) + 0.24\ \text{AmN} + 1.08$$

$$\text{WSC} = \text{SC} - \text{SML}$$

$$\text{WSY} = (\text{BY} \times \text{WSC})/100$$

Where: SML – standard molasses loss (%); K + Na – sum of potassium and sodium (mmol/100 g); AmN – α-amino-N

Table 1. Experimental design

Treatment		Sum of cations		Cation (kg/ha)			K:Mg:Na ratio
		(mol/ha)	(kg/ha)	K	Mg	Na	
A	NP	–	–	–	–	–	–
B	NPK	3205	125	125	0	0	1:0:0
C	NPK + Mg + Na	3205	114	95	10	9	1:0.11:0.09
D	NPK + Mg + Na	3205	97	57	9	31	1:0.16:0.54
E	NPK + Mg + Na	3205	84	24	8	52	1:0.33:2.19

Table 2. Soil physical and chemical properties before setting of the experiments – mean values and standard deviation for three years (2010–2012)

	Soil depth (cm)	Soil particles[1] (mm)			pH^2	Nutrient (mg/kg)		
		1–0.1	0–0.02	< 0.02		P^3	K^3	Mg^4
Bodzewo	0–30	60 ± 2	17 ± 8	16 ± 3	6.5 ± 0.2	89 ± 10	174 ± 71	101 ± 34
	30–60	61 ± 3	15 ± 3	24 ± 7	6.3 ± 0.6	53 ± 18	126 ± 61	111 ± 43
	60–90	47 ± 9	20 ± 3	33 ± 13	6.4 ± 0.2	39 ± 11	126 ± 53	110 ± 36
Donatowo	0–30	66 ± 3	24 ± 6	10 ± 2	6.8 ± 0.3	66 ± 15	136 ± 26	56 ± 6
	30–60	68 ± 7	21 ± 5	11 ± 2	6.5 ± 0.8	53 ± 22	106 ± 29	60 ± 22
	60–90	68 ± 4	23 ± 7	9 ± 3	6.4 ± 0.7	38 ± 14	80 ± 23	61 ± 34
Jasień	0–30	62 ± 3	20 ± 1	18 ± 3	6.5 ± 0.8	106 ± 32	238 ± 83	94 ± 18
	30–60	58 ± 1	19 ± 3	23 ± 3	6.6 ± 0.7	96 ± 24	211 ± 27	90 ± 20
	60–90	51 ± 1	29 ± 12	20 ± 13	6.7 ± 0.7	63 ± 28	152 ± 19	80 ± 11
Wieszczyczyn	0–30	61 ± 3	21 ± 1	18 ± 3	6.9 ± 0.1	104 ± 20	188 ± 43	135 ± 57
	30–60	44 ± 15	32 ± 1	24 ± 14	6.6 ± 0.2	80 ± 17	118 ± 34	131 ± 59
	60–90	61 ± 5	17 ± 3	22 ± 2	6.6 ± 0.5	34 ± 15	80 ± 32	124 ± 54

[1] Casagrande's aerometric method in Prószyński modification; [2] 1 mol/L KCl (1:2.5 m/v ratio); [3] Double Lactate method, pH 3.6 (1:50 m/v ratio); [4] 0.0125 mol/L $CaCl_2$ (1:10 m/v ratio)

(mmol/100 g); SC – sucrose content (%); BY – beet yield (t/ha); WSC – white sugar content (%); WSY – white sugar yield (t/ha).

The effect of individual research factors (year, location and treatment) and of their interaction was assessed using the three-way ANOVA for a completely randomized design. Differences between the mean values were compared with the Tukey's *HSD* (honest significant difference) test ($\alpha = 0.05$). Pearson correlation, linear regression, and stepwise regression analysis were applied to investigate the relationships between the studied characteristics. Statistica 12 software was used for statistical analyses (StatSoft, Inc. 2013).

RESULTS AND DISCUSSION

The dominant effect of a seasonal factor (year) on beet yield (BY) was confirmed in this study ($F_{2,180} = 224.2$; $P < 0.001$). Average BY was high, amounting to 65.5, 63.5 and 80.3 t/ha in 2010, 2011 and 2012, respectively. The effect of K-Mg-Na application was governed by the interaction 'year × location × cations' ratios' ($F_{24,180} = 1.63$; $P < 0.05$). In Bodzewo, a significant effect of K-Mg-Na was observed in 2011 with the highest BY in treatment E. In Donatowo, the effect of these sets of nutrients was important in two years: 2010 and 2011. The highest BYs were recorded in treatments C and D. In Jasień, the influence of K-Na-Mg was significant in 2012. The highest BY was observed in treatment D. In Wieszczyczyn, BY was significantly influenced by the applied set of fertilizers in two years: 2010 and 2011. In the first year, the highest BYs were obtained in treatments C and E, and in the second in B and E (Table 3).

On average, for all experiments, compared with the NP control (A), applied K-Mg-Na increased BY significantly by 10.7–16.3%, regardless of the cation ratios:

A (63.3) < B (70.7) < C (71.7) < D (71.1) < E (72.0 t/ha).

Based on these results, the key role of the total dose of cations affecting BY was clearly demonstrated, regardless of the specific effect of each individual cation. The reduction of the K dose from 125 kg/ha (treatment B) to 24 kg/ha (E) combined with the simultaneous increase in the contribution of the other cations did not decrease BY and even resulted in a slight increase. Compared with the treatment B, on average, BY in the treatment E with the highest rate of Na increased by 1.9%.

According to Christenson and Draycott (2006), Na application should result in the highest efficiency of BY in soils with low content of available K. Under such conditions, the simple mechanism of replacing K with Na can explain the favourable in-

Table 3. Beet yield (t/ha) depending on the experiment location and fertilization treatments

Location	Year	Treatment				
		A	B	C	D	E
Bodzewo	2010	53.9	57.5	57.0	59.5	59.6
	2011	67.7^{b}	73.2^{ab}	71.6^{ab}	66.7^{b}	78.5^{a}
	2012	81.1	85.9	82.4	86.5	80.0
	mean	67.6	72.2	70.3	70.9	72.7
Donatowo	2010	53.6^{b}	64.0^{ab}	66.3^{a}	63.5^{ab}	63.4^{ab}
	2011	52.5^{b}	63.4^{ab}	64.1^{ab}	64.7^{a}	60.0^{ab}
	2012	83.9	87.8	90.4	86.5	87.0
	mean	63.3^{b}	71.7^{a}	73.6^{a}	71.6^{a}	70.1^{a}
Jasień	2010	76.6	75.9	78.7	78.5	81.5
	2011	49.3	61.2	59.0	58.3	58.2
	2012	85.1^{c}	89.1^{bc}	95.1^{ab}	99.0^{a}	94.0^{abc}
	mean	70.3^{b}	75.4^{ab}	77.6^{a}	78.6^{a}	77.9^{a}
Wieszczyczyn	2010	52.9^{c}	58.6^{bc}	72.7^{a}	64.2^{ab}	71.7^{a}
	2011	48.1^{b}	71.7^{a}	63.8^{ab}	64.1^{ab}	72.9^{a}
	2012	54.9	59.8	59.2	61.9	57.4
	mean	52.0^{b}	63.4^{a}	65.2^{a}	63.4^{a}	67.3^{a}

Different letters (in rows) indicate statistically significant differences between treatments at $P < 0.05$

fluence of Na on BY (Wakell et al. 2011). However, in our study, beet was grown on soils rich in available K. Moreover, the positive effect of Na fertilization occurred in two locations with the highest K fertility level (Jasień and Wieszczyczyn). To explain the beneficial effect of Na on BY, mechanisms of ionic balance regulation (K/Na, K/Mg, etc.) and the resulting modification of N metabolism was likely (Barłóg et al. 2017). Our study indicated also a positive reaction of sugar beet to increasing rates of Na in the driest growing season (year 2010).

The BY increase in response to Mg was observed in one location. Magnesium applied in a narrow Na/Mg ratio (treatment C) caused the highest increase in BY in Donatowo, with the lowest content of soil available Mg. This fact corroborates the previous study concerning sugar beet response to Mg application (Barłóg and Grzebisz 2001). Probably, the excess of Na^+ ions in the soil (treatments D and E) decreased the rate of Mg^{2+} ions uptake (Zhang et al. 2010).

The SC variability depended on the interaction between K-Mg-Na ratios and location ($F_{12,180}$ = 3.70; $P < 0.001$). Application of fertilizers rich in Na significantly reduced SC in Bodzewo. Sodium treatment resulted in higher SC in one location (Wieszczyczyn), but only to the rate of 31 kg Na/ha. Those results might be explained by dilution of sucrose due to the increased water content in storage roots (Tsialtas and Maslaris 2009). The content of melassogenic substances such as K and Na in storage roots were significantly modified by interaction between K-Mg-Na ratios and locations ($F_{12,180}$ = 1.97; $P < 0.05$ and $F_{12,180}$ = 6.24; $P < 0.001$). On average, the sugar beet plants grown on plots with Na applied showed a substantially higher Na concentration in storage roots than in the plot without this nutrient (B). This is in line with data reported by Haneklaus et al. (1998). Simultaneously, the more Na was applied, the higher the SML and AmN contents in storage roots were recorded (Bodzewo, Wieszczyczyn). The K content in beets was the least dependent on the K:Mg:Na ratio in the applied fertilizers (Table 4).

In two locations (Bodzewo, Wieszczyczyn), SC was positively correlated with K (R^2 = 0.55 and 0.42; $P < 0.01$ for n = 15). Apart from that, SC increased along with the K/Na ratios in storage roots. Only in Jasień, a negative correlation was revealed between the K/Na ratio and SC (Figure 1). These results corroborate the opinion that the excess of available K in the soil may negatively affect the partitioning of carbohydrates between tops and storage roots, resulting in lower SC (Giroux

https://doi.org/10.17221/809/2017-PSE

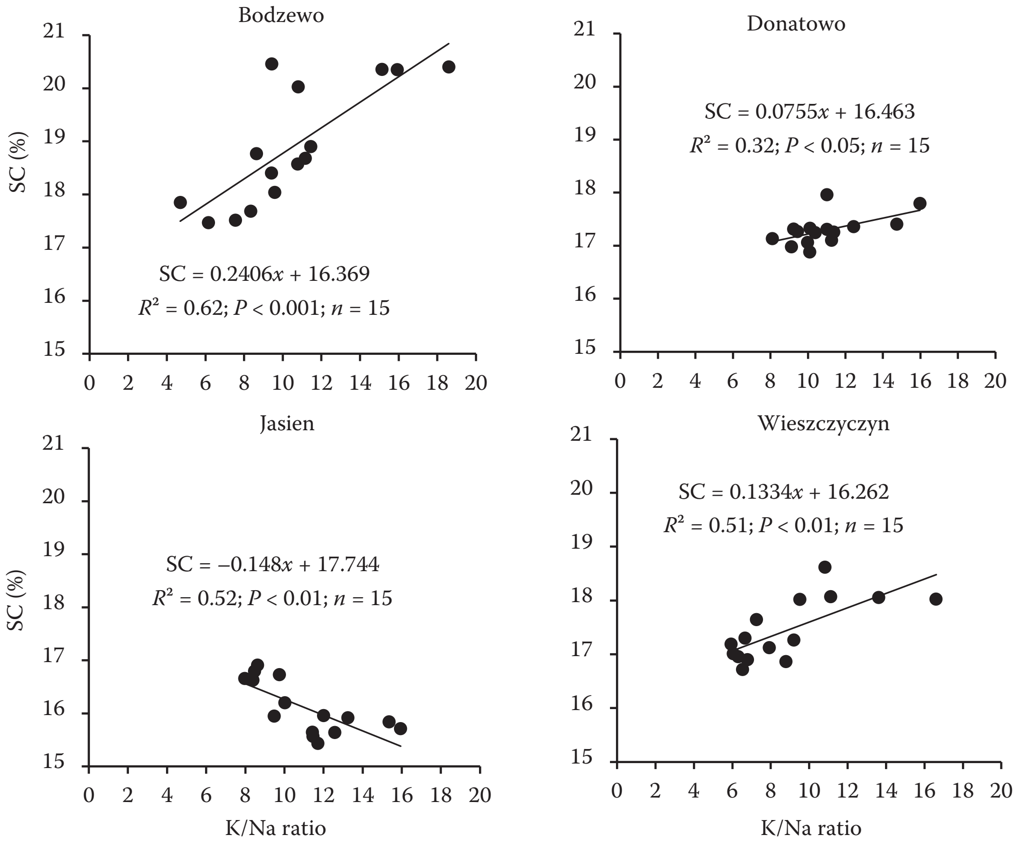

Figure 1. Sucrose content (SC) as a function of K/Na ratios in storage roots depending on the experiment location

and Tran 1989). Moreover, in our study, K was the primary cation affecting the AmN content (R^2 from 0.34 and $P < 0.05$ to $R^2 = 0.70$ and $P < 0.001$ for $n = 15$).

The effect of different K-Mg-Na ratios in the applied fertilizers on WSY was site-specific ($F_{12,180} = 2.22$; $P < 0.05$). As a result, different treatments were recognized as optimal for a given location. The highest average increase in WSY with respect to NP was recorded for treatment B, C, D and E in Bodzewo, Donatowo, Jasień and Wieszczyczyn, respectively (Figure 2). These differences might

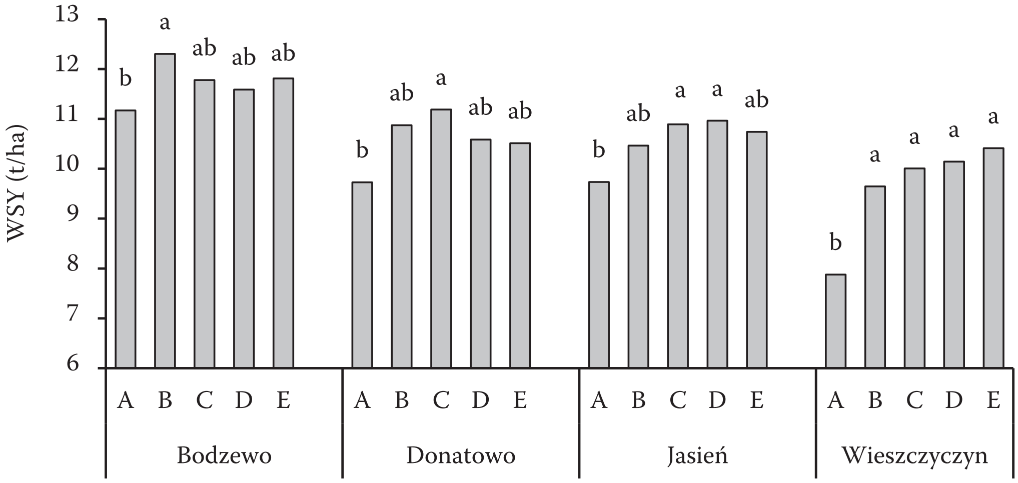

Figure 2. White sugar yield (WSY) depending on the experiment location and potassium (K) fertilization treatment. Different letters indicate statistically significant differences between treatments at $P < 0.05$

Table 4. Beet quality depending on experiment location and potassium (K) fertilization treatment (means for 2010-2012)

Location	Treatment	SC (%)	α-N	K	Na	SML (%)
			(mmol/kg)			
Bodzewo	A	18.81^{ab}	22.9	44.9^{b}	4.3^{bc}	2.22^{b}
	B	19.29^{a}	21.4	47.6^{ab}	3.7^{c}	2.21^{b}
	C	19.02^{ab}	21.5	49.2^{a}	4.2^{bc}	2.24^{b}
	D	18.77^{ab}	23.4	48.2^{ab}	5.5^{b}	2.28^{ab}
	E	18.59^{b}	25.4	49.3^{a}	7.8^{a}	2.37^{a}
Donatowo	A	17.53	17.9	46.4	4.3^{ab}	2.12
	B	17.40	18.6	48.8	4.0^{b}	2.16
	C	17.32	17.6	47.7	4.2^{b}	2.12
	D	17.04	22.9	49.8	4.9^{ab}	2.28
	E	17.17	20.3	47.7	5.2^{a}	2.20
Jasień	A	16.05	15.1	53.5	5.2^{ab}	2.15
	B	16.00	14.5	52.4	4.5^{b}	2.11
	C	16.22	15.7	53.9	4.6^{b}	2.16
	D	16.21	15.8	54.5	5.5^{a}	2.18
	E	16.03	16.8	54.8	5.4^{a}	2.20
Wieszczyczyn	A	17.11^{b}	11.1^{b}	44.2^{ab}	6.2^{a}	1.95^{b}
	B	17.25^{b}	12.5^{b}	46.9^{a}	5.8^{ab}	2.01^{ab}
	C	17.34^{b}	13.5^{ab}	43.1^{b}	4.4^{b}	1.97^{b}
	D	17.98^{a}	12.7^{b}	45.1^{ab}	5.2^{ab}	1.99^{b}
	E	17.55^{ab}	15.6^{a}	46.0^{a}	5.8^{ab}	2.07^{a}

Different letters indicate statistically significant differences between treatments at $P < 0.05$

be explained by differences in BY ($R^2 = 0.82–0.98$; $P < 0.001$; $n = 15$). However, WSYs were, depending on the location, also determined by SC and AmN ($R^2 > 0.99$; $P < 0.001$; $n = 15$):

Bodzewo:

$$\text{WSY} = -13.50 + 0.163\text{BY} + 0.751\text{SC} - 0.022\text{AmN};$$

Donatowo:

$$\text{WSY} = -11.03 + 0.155\text{BY} + 0.654\text{SC} - 0.027\text{AmN};$$

Jasień:

$$\text{WSY} = -13.44 + 0.129\text{BY} + 0.882\text{SC};$$

Wieszczyczyn:

$$\text{WSY} = -10.09 + 0.149\text{BY} + 0.656\text{SC} - 0.023\text{AmN}.$$

Based on the results of this study, it can be concluded that the total amount of cations applied in K-Mg-Na fertilizers affected BY more than the cation ratio. The observed variability in BY, resulting from different K:Mg:Na ratios, depended on the interactions of numerous factors, such as weather conditions and the content of available K and Mg in the soil. However, a noticeable lack or positive influence of Na were observed on BY. Therefore, for soils with high available K content, the fertilization costs for sugar beet could be reduced through the application of less-expensive fertilizers that contain fixed amounts of Na. However, before the choice and calculation the amount of applied K, Na and Mg fertilizers, the soil fertility level must be fully recognized, including the analysis for soil Na content. Recommendations can then be formulated to avoid lower technological quality of storage roots.

REFERENCES

Barłóg P., Grzebisz W., Błaszyk R. (2017): Compositional nutrient diagnosis in sugar beet with sodium supplementation. Archives of Agronomy and Soil Science, 63: 856–869.

Barłóg P., Grzebisz W. (2001): Effect of magnesium foliar application on the yield and quality of sugar beet roots. Rostlinná Výroba, 47: 418–422.

Buchholz K., Märländer B., Puke H., Glattkowski H., Thielecke K. (1995): Neubewertung des technischen Wertes von Zuckerrüben. Zuckerindustrie, 120: 113–121.

Christenson D.R., Draycott A.P. (2006): Nutrition – Phosphorus, sulphur, potassium, sodium, calcium, magnesium and micronutrients – Liming and nutrient deficiencies. In: Draycott A.P. (ed.): Sugar Beet. Oxford, Blackwell Publishing Ltd., 185–220.

Giroux M., Tran T.S. (1989): Effect of potassium fertilization and N-K interaction on sugarbeet quality and yield. Journal of Sugar Beet Research, 26: 11–23.

Grzebisz W. (2013): Crop response to magnesium fertilization as affected by nitrogen supply. Plant and Soil, 368: 23–39.

Haneklaus S., Knudsen L., Schnug E. (1998): Relationship between potassium and sodium in sugar beet. Communications in Soil Science and Plant Analysis, 29: 1793–1798.

Kenter C., Hoffmann C.M., Märländer B. (2006): Effects of weather variables on sugar beet yield development (*Beta vulgaris* L.). European Journal of Agronomy, 24: 62–69.

Kronzucker H.J., Coskun D., Schulze L.M., Wong J.R., Britto D.T. (2013): Sodium as nutrient and toxicant. Plant and Soil, 369: 1–23.

Oosterhuis D.M., Loka D.A., Raper T.B. (2013): Potassium and stress alleviation: Physiological functions and management of cotton. Journal of Plant Nutrition and Soil Science, 176: 331–343.

Römer W., Claassen N., Steingrobe B., Märländer B. (2004): Reaktion der Zuckerrübe (*Beta vulgaris* var. *altissima*) auf die Kaliumdüngung – Ein 20-jähriger Feldversuch. Journal of Plant Nutrition and Soil Science, 167: 726–735.

Scherer H.W., Goldbach H.E., Clemens J. (2003): Potassium dynamics in the soil and yield formation in a long-term field experiment. Plant, Soil and Environment, 49: 531–535.

StatSoft, Inc. (2013): Electronic Statistics Textbook. Tulsa. Available at http://www.statsoft.com/textbook/

Subbarao G.V., Wheeler R.M., Stutte G.W., Levine L.H. (1999): How far can sodium substitute for potassium in red beet? Journal of Plant Nutrition, 22: 1745–1761.

Subbarao G.V., Ito O., Berry W.L., Wheeler R.M. (2003): Sodium – A functional plant nutrient. Critical Reviews in Plant Sciences, 22: 391–416.

Tsialtas J.T., Maslaris N. (2009): Selective absorption of K over Na in sugar beet cultivars and its relationship with yield and quality in two contrasting environments of central Greece. Journal of Agronomy and Crop Science, 195: 384–392.

Wakeel A., Farooq M., Qadir M., Schubert S. (2011): Potassium substitution by sodium in plants. Critical Reviews in Plant Sciences, 30: 401–413.

Zhang J.-L., Flowers T.J., Wang S.-M. (2010): Mechanisms of sodium uptake by roots of higher plants. Plant and Soil, 326: 45–60.

Zlámalová T., Elbl J., Baroň M., Bělíková H., Lampíř L., Hlušek J., Lošák T. (2015): Using foliar applications of magnesium and potassium to improve yields and some qualitative parameters of vine grapes (*Vitis vinifera* L.). Plant, Soil and Environment, 61: 451–457.

Received on December 18, 2017
Accepted on March 13, 2018