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EFFECT OF DIFFERENT TILLAGE SYSTEMS ON THE MACRONUTRIENT CONTENT AND UPTAKE IN SUGAR BEETS

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Abstract

The study, carried out in 2012-2013, intended to determine effects of different cultivation systems on the uptake and content of macronutrients (nitrogen, phosphorus, potassium, magnesium, calcium and sodium) in sugar beets at the technological maturity stage. A conventional tillage system (SO) was compared to simplified technologies of soil cultivation. The following conservation tillage systems were analyzed: (2) tillage to a depth of 35 cm and sowing into stubble mulch (MS35); (3) shallow tillage to a depth of 15 cm and sowing into stubble mulch (MS15); (4) tillage to a depth of 15 cm and sowing into white mustard mulch; (5) strip-till on stubble mulch to a depth of 25 cm and instantaneous beet seed sowing (STS); (6) strip-till to a depth of 25 cm on white mustard mulch and instantaneous beet seed sowing (STG). Mineral nutrient concentrations in beets varied depending on the cultivation system applied and the plant organ analyzed. The experimental factor significantly differentiated the content of P, K, Ca, Mg and Na in both beet leaves and roots, having no effect on the nitrogen content. When compared to the conventional tillage system, a decreasing trend for phosphorus and calcium in beet leaves and a significant increase of sodium both in beet leaves and roots was observed in the simplified cultivation systems. Cultivation simplifications provided some equivocal evidence implicating differences in the nutrient content between the study years. The analysis of correlations between root yields and the total accumulation of nutrients indicated significant relationships for N, P, K, Ca, Mg only in the conventional tillage system and in the treatment with 35 cm deep tillage (soil ripping) along with sowing into stubble mulch (MS35). In the other treatments, strong relationships were observed only for individual nutrients.

Keywords: sugar beets, conservation tillage, nutrient content, nutrient uptake.

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INTRODUCTION

The amount of accumulated mineral nutrients in the plant serves as the basis for selecting an appropriate fertilization technology for cultivated plants. Sugar beet is a plant species with specific nutrient requirements, as it produces large biomass, which necessitates intensive nutrient uptake (WIŚNIEWSKI 1994). Therefore, sugar beet cultivation is feasible only on sites rich in macro- and microelements. Root and sugar yields depend directly on received amounts of nutrients (MILFORD et. al. 2000). During the plant-growing period, an important role is played by the nutrient accumulation rate, a decisive factor shaping the plant's growth efficiency. Mineral and organic fertilization treatments are the main factors that determine sugar beet yielding and technological quality. Natural fertilizers and plant debris applied into soil induce a number of changes in plant cultivation sites, including the nutrient supply to crops (BŁAZIAK et al. 1996, TIWANA, NARANG 1997). Furthermore, both root yield and technological quality depend on numerous natural and agricultural factors, such as a crop's variety or protection management practice (WERKER, JAGGARD 1998, KUC, ZIMNY 2005). At present, the key issue in sugar beet cultivation is to design new technologies which would cost-effectively enhance the maximal sugar production. Practically, each cultivation technique applied in sugar beet production has already been subject to technical and technological improvement, nonetheless most progress has been made in soil cultivation as well as sowing and harvesting methods. Many European countries, including Poland, have witnessed a growing interest in the application of simplified cultivation methods, which have already been widespread for years in agricultural practice throughout the USA and Canada (HARTWIG, AMMON 2002, SOANE et al. 2012). Implementation of conservation tillage of soil dedicated to growing sugar beets as well as other crops has now become an overriding objective in an attemtpt to ensure soil's sustainable productivity, e.g. by preventing soil erosion. Additionally, conservation tillage is a good alternative to conservative ploughing systems, which enables farmers to achieve cost-effective performance of agricultural treatments (VERCH et al. 2009, SIP at al. 2013). Despite wide-range studies, literature data prove that the use of conservation tillage in Europe is limited to just 3.9% of tilled soil, whereas in South America and North America it covers 47% and 39% of arable soil, respectively (VAN DEN PUTTE et al. 2010, SOANE et. al. 2012). A type of conservation farming is the strip-till technology, which combines advantages of traditional and zero soil cultivation. An application of the strip-till conservation system in beet production reduces harsh intrusion into the natural environment and spares some economic effort. Unfortunately, relevant literature lacks information on detailed research on the effects of simplified cultivation technologies on nutrient availability and their content in plants.

The aim of the present study was to determine the effect of conservation tillage on the content and accumulation of macronutrients in leaves and roots of sugar beets at technological maturity when compared to the conventional tillage system.

MATERIAL AND METHODS

In 2012-2013, two series of trials on sugar beets were carried under field conditions. The experiment was arranged in a completely randomized block design. The trial was established at the Żołędnica Animal Breeding Station (51.6°N 16.9°E), situated in the vicinity of Rawicz (central Poland). Comparative analyses were performed with reference to (1) the conventional tillage system with soil ploughing to a depth of 35 cm after previous application of manure at a dose of 30 t ha^{-1} (SO) and 5 simplified tillage systems (conservation tillage). These were: (2) tillage to a depth of 35 cm and sowing into stubble mulch (MS35); (3) tillage to a depth of 15 cm and sowing into stubble mulch (MS15); (4) tillage to a depth of 15 cm and sowing into intercrop white mustard mulch (MG); (5) strip-till on stubble mulch to a depth of 25 cm and instantaneous beet seed sowing (STS); (6) strip-till to a depth of 25 cm on white mustard mulch and instantaneous beet seed sowing STG).

Detailed information on the experimental design was presented in the first part of the study **(**Gaj et. al. 2015**).** At the stage of technological maturity (BBCH49), 500 sugar beets per plot were collected following the methodology elaborated by the International Sugar Beet Institute (Vandergeten et al. 2004). After weighing leaves and roots of the plants collected, random samples of 1.5-2.0 kg of leaves and roots were taken for examination of water and nutrient content. The plant material was dried out at 55°C and homogenized in a laboratory blender. The content of nitrogen in plant tissues was assessed by Kjeldahl (Auto Distillation Unit Kjeltec 2200 FOSS). In order to determine the total content of P, K, Ca, Mg and Na, leaf and root samples were ground and mineralized at 550°C for 6h, and the ash obtained was dissolved in 2 cm^3 of diluted HNO_3 (65% HNO_3 dissolved in distilled water at a 1:1 ratio). Next, the solution was transferred into 15 ml test tubes. The concentration of phosphorous in the solution was determined with the vanadium-ammonium molybdate colorimetric method. Potassium, calcium and magnesium were determined with atomic absorption spectroscopy (SpectraAA-250 Plus Varian).

The content of all the nutrients analyzed was expressed as g kg^{-1} of air-dry mass. The macronutrient uptake (kg ha^{-1}) was computed by multiplying the nutrient concentrations in the leaves and roots and their biomass at the stage of sugar beet technological maturity (Gaj et. al. 2015).

The effects of the experimental factor on the content of mineral nutrients, their accumulation in plant organs and the rate of nutrient uptake were tested by the Anova procedure. The estimated value y_{ijk} of the analyzed variables (individual nutrient content in beet leaves and roots, nutrient accumulation, specific uptake) was obtained from i-th block (i = 1,...,4), j-th year (j = 1,2) and k-th cultivation treatment (k = 1,...,6) (Caliński et. al. 1987).

The multivariate linear model can be written in the form:

$$y_{ijk} = \mu + \alpha + \beta_j + \gamma_k + (\beta\gamma)_{jk} + e_{ijk},$$

where:

μ – general mean;

α_i – i^{th} block effect (i = 1, 2, 3, 4);

β_j – j^{th} year effect (j =1, 2);

γ_k – k^{th} treatment effect (k = 1, 2, ..., 6);

e_{ijk} – random error.

The Tukey's multiple comparisons test was used to compare average beet root and technological sugar yields obtained in the different cultivation systems as well as to identify homogenous groups (Kala 2000).

In order to evaluate cause-effect relationships between the parameters examined (simple correlation analysis), the Pearson correlation coefficient and principal component analysis (PCA) were performed. The PCA was used to reveal regularities between independent variables and to determine the components as linear combinations of the tested variables. A comprehensive analysis of principal components enables one to indicate the initial variables which constitute data for the other variables.

RESULTS AND DISCUSSION

Nutrient content

The results showed that the mineral nutrient content varied in the roots and leaves of sugar beets at the stage of technological maturity, depending on the technology of soil cultivation applied, the nutrient and the organ analyzed. The experimental factor differentiated the content of phosphorus, potassium, magnesium, calcium and sodium in beet roots and leaves (Tables 1 and 2). The cultivation simplifications resulted in decreasing trends for the content of phosphorus and calcium in beet leaves, while a reverse regularity was observed for the other nutrients. In the roots of beets cultivated in soil after conservation tillage (simplified cultivation), decreasing trends were observed for calcium and magnesium when compared to beets grown in traditionally ploughed soil. Sodium was unique in that no definite regularity was observed for this element. In all the conservation tillage treatments, Na was noticed to have increased in beet leaves, whereas its content in roots followed a decreasing trend. In the study years, conservation tillage had an ambigu-

Table 1

Nutrient content in leaves at sugar beet technological maturity according to cultivation systems (g kg^{-1})

Years	Treatments	Nutrients					
		N	P	K	Ca	Mg	Na
2012	SO*	24.2^{a}	1.91^{a}	30.2^{bc}	10.6^{ab}	4.29^{bc}	17.8^{a}
	MS35	25.9*a*	1.87^{ab}	28.9^{bc}	8.23^{bcd}	4.77^{abc}	19.3^{a}
	MS15	25.1^{a}	1.82^{ab}	28.2^{bc}	9.08^{abc}	4.10^{c}	18.1^{a}
	MG	25.4^{a}	1.82^{ab}	30.9^{b}	10.8^{a}	5.81^{a}	18.1^{a}
	STS	26.2^{a}	1.89^{a}	30.0^{bc}	10.2^{ab}	5.12^{abc}	18.1^{a}
	STG	25.9^{a}	1.74^{a}	31.7^{b}	10.3^{ab}	5.25^{ab}	19.3^{a}
2013	SO	27.9^{a}	1.63^{ab}	15.8^{d}	6.12^{de}	4.60^{bc}	6.84^{e}
	MS35	27.1^{a}	1.42^{bc}	28.7^{bc}	5.22^{e}	4.55^{bc}	12.4^{bc}
	MS15	25.8^{a}	0.99^{c}	31.1^{b}	5.81^{e}	4.90^{abc}	8.86^{de}
	MG	24.1^{a}	1.04^{c}	24.8^{c}	4.47^{e}	4.55^{bc}	9.28^{cde}
	STS	24.9^{a}	1.59^{ab}	33.3^{ab}	4.83^{e}	4.56^{bc}	10.3^{cd}
	STG	26.3^{a}	1.71^{ab}	38.0^{a}	6.79^{cde}	4.40^{bc}	13.7^{b}

Means with the same letter are not significantly different; $\alpha = 0.05$ (Tukey's test);
* SO – control treatment; MS35 – tillage to a depth of 35 cm and sowing into stubble mulch; MS15 – tillage to a depth of 15 cm and sowing into stubble mulch; MG – tillage to a depth of 15 cm and sowing into white mustard mulch; STS – strip-till on stubble mulch to a depth of 25 cm and instantaneous beet seed sowing; STG – strip-till to a depth of 25 cm on white mustard mulch and instantaneous beet seed sowing.

Table 2

Nutrient content in roots at sugar beet technological maturity according to cultivation systems (g kg^{-1})

Years	Treatments	Nutrients					
		N	P	K	Ca	Mg	Na
2012	SO*	7.68^{a}	0.95^{bc}	7.16^{a}	0.69^{a}	1.31^{a}	0.86^{a}
	MS35	6.13^{ab}	1.22^{a}	5.96^{ab}	0.63^{ab}	1.25^{a}	0.72^{ab}
	MS15	5.68^{b}	1.13^{ab}	5.56^{ab}	0.57^{bc}	1.23^{a}	0.68^{b}
	MG	5.11^{b}	1.04^{ab}	5.57^{ab}	0.54^{bcd}	1.09^{abc}	0.71^{ab}
	STS	5.73^{b}	1.07^{ab}	6.11^{ab}	0.49^{cde}	1.23^{a}	0.69^{b}
	STG	5.88^{b}	1.01^{abc}	5.21^{ab}	0.48^{cde}	1.14^{ab}	0.70^{ab}
2013	SO	5.48^{b}	0.57^{d}	3.80^{b}	0.43^{ef}	0.71^{e}	0.58^{b}
	MS35	5.55^{b}	0.77^{cd}	4.48^{b}	0.42^{de}	0.71^{e}	0.62^{b}
	MS15	6.06^{b}	0.92^{bc}	4.08^{b}	0.40^{ef}	0.84^{de}	0.57^{b}
	MG	5.31^{b}	0.74^{cd}	5.11^{ab}	0.24^{g}	0.97^{bcd}	0.59^{b}
	STS	4.99^{b}	0.86^{bc}	4.37^{b}	0.23^{g}	0.91^{cde}	0.60^{b}
	STG	5.62^{b}	0.95^{bc}	4.33^{b}	0.32^{fg}	0.71^{cde}	0.56^{b}

Means with the same letter are not significantly different; $\alpha = 0.05$ (Tukey's test);
* Explanation below Table 1.

ous effect on the content of the tested nutrients in the plant organs examined. When compared to the control treatment, in the simplified cultivation systems, an increasing trend in the leaf nitrogen content was observed in the first study year, whereas in the second year of our observations, the N leaf content decreased. The analysis of the correlations between yield and mineral nutrient content in sugar beet roots at the stage of technological maturity showed significant relationships for all the nutrients except sodium only in the conventional tillage system (Table 3). Relationships between the nutrient content in the roots and technological sugar yield as well as other quality parameters were also tested. No evident relationships between the content of nutrients and that of sugar and α-amino nitrogen were found. However, in the conventional tillage system, significant relationships were noted both between the elements tested and the nitrogen and sugar content (Figure 1*a*). In general, an increase of the nitrogen content in the roots resulted in a decrease of the sugar content and an increase of the α-amino nitrogen content. This relationship has been well documented in literature (Marchetti, Castelli 2011). Graphical interpretation of the relationship analyzed is demonstrated by principal component analysis. A different regularity was indicated in MS15 treatment (Figure 1*b*), namely there was a positive correlation between nitrogen and sugar contents in the roots but no relationship with *α*-amino nitrogen was found.

The analysis of the relationships between the mineral nutrient content in beet roots indicated, regardless of the cultivation system used in this study, a strong relationship between the content of calcium and sodium. For the cultivation treatments tested, Ca and Na correlation coefficients were as follows: SO – 0.852, MS35 – 0.691, MS15 – 0.948, MG – 0.680, STS – 0.697 and STG – 0.847. A similar relationship for K and Na was observed by Barłóg et. al. (2013). The role of these elements in maintaining osmotic potential in sugar beet roots has been well documented in subject literature (Bell et al. 1996). The research by Barłóg (2009) showed that sugar beet high yielding can be achieved only when a specific relationship is maintained between the content of sodium and the concentrations of other nutrients.

Nutrient uptake

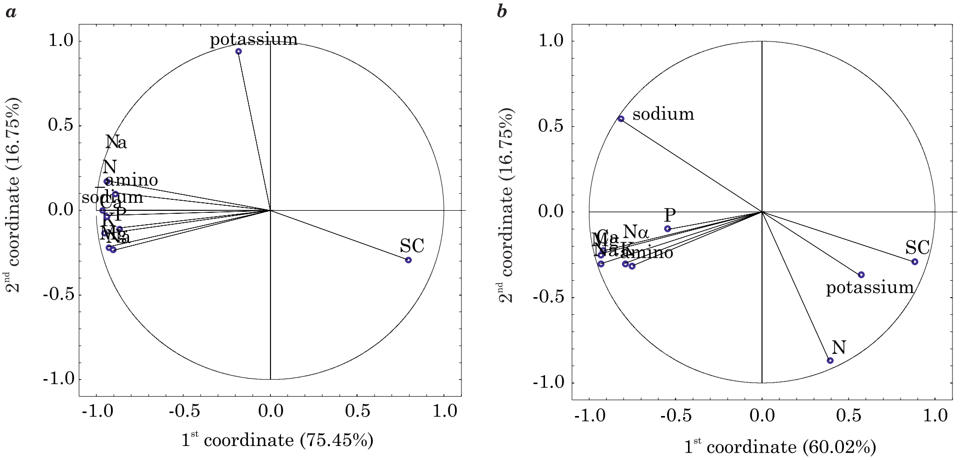
The study results showed that the mineral nutrients analyzed accumulated predominantely in beet leaves (Table 4), except for phosphorus, whose accumulation in leaves ranged from 19-30% of the total uptake, depending on the cultivation system. Special attention should be paid to sodium, whose accumulation in beet leaves was 6-fold higher than in roots. A similar Na and leaf relationship was observed by Barłóg (2009), who found a 7-fold accumulation difference between leaves and roots. According to Hasegawa and Yoneyama (1995), sugar beet has no specific barriers against the transportation of Na^+ ions from its roots up to leaves. The accumulation of Ca in leaves was on average 5-fold higher than in roots and differed depending on the cultivation system applied. All cultivation simplifications resulted in an in-

Table 3

Correlation matrix of root yield, technological sugar yield and mineral nutrient content in sugar beet roots at technological maturity stage, $n = 8$

Nutrient	Treatments											
	SO		MS 35		MS15		MG		STS		STG	
	root yield	techno-logical yield	root yield	techno-logical yield	plon root yield	techno-logical yield	root yield	techno-logical yield	root yield	techno-logical yield	root yield	techno-logical yield
N	0.934**	0.575	0.479	0.302	-0.275	-0.072	-0.436	0.406	0.418	-0.213	0.044	-0.343
P	0.887**	0.654	0.837**	0.697	0.366	0.189	0.772**	-0.664	0.734**	-0.209	0.460	0.840**
K	0.943**	0.819**	0.253	0.002	0.615	0.289	0.040	-0.386	0.62	-0.276	0.749**	0.423
Ca	0.873**	0.741**	0.849**	-0.001	0.884**	-0.003	0.882**	-0.817**	0.920**	0.330	0.943**	0.420
Mg	0.823**	0.839**	0.795**	0.426	0.805**	0.353	0.478	-0.674	0.827**	-0.015	0.911**	0.576
Na	0.687**	0.809**	0.424	-0.107	0.789**	0.028	0.384	-0.409	0.834**	-0.167	0.861**	0.1267

** significant at $p < 0.01$



SC – sucrose content, N α-amino – a_amino nitrogen

Fig. 1. Two-dimensional space image of variable nutrient content in sugar beet roots and quality parameters

Table 4

Nutrient accumulation in leaves at sugar beet technological maturity according to cultivation systems (kg ha^{-1})

Years	Treatments	Nutrients					
		N	P	K	Ca	Mg	Na
2012	SO*	160.9^{a}	12.8^{a}	200.5^{abc}	69.9^{a}	28.4^{ab}	117.1^{ab}
	MS35	165.6^{a}	11.9^{ab}	184.1^{abcd}	54.3^{ab}	30.5^{ab}	122.5^{ab}
	MS15	171.1^{a}	12.5^{ab}	193.0^{abcd}	61.8^{a}	27.6^{ab}	123.5^{a}
	MG	158.9^{a}	11.4^{abc}	194.4^{abcd}	67.6^{a}	36.3^{a}	113.5^{ab}
	STS	141.8^{a}	10.1^{abcd}	161.0^{bcd}	55.4^{ab}	27.7^{ab}	97.66^{bc}
	STG	179.5^{a}	12.0^{ab}	219.8^{a}	71.7^{a}	36.3^{a}	134.1^{a}
2013	SO	148.6^{a}	8.44^{cde}	83.67^{e}	32.6^{c}	24.3^{b}	35.54^{e}
	MS35	136.5^{a}	7.10^{de}	114.6^{cd}	26.3^{c}	22.9^{b}	62.41^{d}
	MS15	145.7^{a}	5.51^{e}	176.4^{abcd}	32.5^{c}	27.5^{b}	49.59^{e}
	MG	135.9^{a}	5.70^{e}	139.2^{de}	24.9^{c}	25.4^{b}	52.18^{de}
	STS	150.2^{a}	9.56^{abcd}	198.4^{abc}	28.7^{c}	27.2^{b}	61.26^{de}
	STG	140.8^{a}	9.32^{bcd}	206.5^{ab}	36.8^{bc}	23.9^{b}	74.03^{cd}

Means with the same letter are not significantly different; α = 0.05 (Tukey's test);
* Explanation below Table 1.

crease of the Ca accumulation in beet leaves and Ca decrease in roots when compared to the conventional cultivation system (Table 5). Among all the nutrients examined, Ca and Na were the elements that least accumulated in beet roots (16% and 13%, respectively). Regardless of the cultivation treat-

Table 5

Nutrient accumulation in roots at sugar beet technological maturity according to cultivation systems (kg ha^{-1})

Years	Treatment	Nutrients					
		N	P	K	Ca	Mg	Na
2012	SO*	223.4^{a}	27.63^{bc}	208.2^{a}	20.03^{a}	37.75^{ab}	22.03^{a}
	MS35	187.8^{ab}	37.17^{a}	181.5^{a}	19.40^{a}	38.16^{ab}	22.04^{a}
	MS15	163.9^{bcd}	32.35^{ab}	159.9^{abc}	16.36^{ab}	35.32^{ab}	19.60^{a}
	MG	152.0^{bcd}	31.09^{ab}	165.7^{ab}	15.91^{ab}	32.35^{b}	21.16^{a}
	STS	186.4^{ab}	34.60^{ab}	198.8^{a}	15.70^{ab}	39.81^{a}	22.47^{a}
	STG	169.4^{bc}	28.85^{b}	149.9^{abcd}	13.75^{bc}	32.91^{b}	20.31^{a}
2013	SO	115.2^{d}	12.10^{e}	79.88e	8.94^{d}	15.0^{d}	12.23^{b}
	MS35	122.4^{cd}	17.11^{de}	98.49^{cde}	9.49^{cd}	15.66^{d}	13.78^{b}
	MS15	136.3^{cd}	20.28^{cd}	91.52^{de}	8.88^{d}	18.82^{cd}	12.81^{b}
	MG	122.3^{cd}	16.99^{de}	116.6^{bcd}	5.51^{d}	22.22^{c}	13.46^{b}
	STS	117.0^{d}	20.08^{cd}	101.5^{cde}	5.40^{d}	21.19^{cd}	13.99^{b}
	STG	120.2^{cd}	20.48^{cd}	93.22^{de}	6.95^{d}	18.76^{cd}	12.10^{b}

Means with the same letter are not significantly different; α = 0.05 (Tukey's test);
* Explanation below Table 1.

ment applied, the phosphorus content increased in beet roots with the highest P accumulation values for treatments MS35 and MS15 (75.7% and 75.5%, respectively). According to literature data, mineral nutrient uptake under field conditions depends on a plant's genetic traits and can be modified by the factors influencing the plant's effectiveness in nutrient absorption from fertilizers. The most important conditions are: water availability, temperature, sowing time, plant cultivation system and soil reaction (HEDLEY et al. 1995, VAN DUIVENBOODEN et al. 1996, SELLES et al. 1999, GILL et al. 2001, GREWAL et al. 2011, VALLE et al. 2011).

The total macronutrient accumulation in sugar beets at the stage of technological maturity depended on the system of pre-sowing cultivation, nutrients and the year of study (Table 6). Except for nitrogen, sugar beets in the conventional cultivation system accumulated considerably less mineral nutrients. The reason for a decreased nitrogen uptake in the conservation cultivation systems examined could be the large involvement of beet lateral roots under the conditions of mulch cultivation, which indicates some obstruction to the vertical root's growth, followed by a lower nutrient uptake from deeper soil layers. Studies conducted by KORDAS (1997) showed that direct seed sowing caused a significant increase of soil density and disturbances in nutrient uptake, especially in the early plant-growing season. In terms of the effects of the study years as well as the simplified cultivation techniques applied, in the first year of observations (2012), the lowest total

Table 6

Total nutrient accumulation at sugar beet technological maturity according to cultivation systems (kg ha^{-1})

Years	Treatment	Nutrients					
		N	P	K	Ca	Mg	Na
2012	SO*	384.3^{a}	40.38^{a}	408.7^{a}	89.87^{a}	66.18^{a}	142.1^{ab}
	MS35	353.4^{ab}	49.07^{a}	365.6^{ab}	72.75^{a}	68.66^{a}	144.6^{ab}
	MS15	335.0^{abc}	44.80^{a}	352.8^{ab}	78.21^{a}	63.17^{a}	143.1^{ab}
	MG	310.0^{abc}	42.89^{a}	360.1^{ab}	83.50^{a}	68.66^{a}	134.7^{ab}
	STS	328.1^{abc}	44.74^{a}	359.8^{ab}	71.12^{a}	67.53^{a}	120.1^{b}
	STG	348.9^{ab}	40.83^{a}	369.8^{ab}	85.42^{a}	69.24^{a}	154.4^{a}
2013	SO	263.7^{c}	20.54^{c}	163.6^{bc}	41.52^{b}	39.36^{b}	47.77^{d}
	MS35	258.9^{c}	24.21^{bc}	243.1^{bc}	35.77^{b}	38.55^{b}	76.19^{c}
	MS15	282.1^{bc}	25.99^{bc}	267.9^{c}	41.40^{b}	46.27^{b}	62.41^{cd}
	MG	258.3^{c}	22.69^{bc}	255.7^{c}	30.41^{b}	48.65^{b}	65.64^{cd}
	STS	267.2^{c}	29.64^{bc}	229.8^{bc}	34.12^{b}	48.42^{b}	65.25^{c}
	STG	261.0^{c}	29.80^{b}	299.7^{bc}	43.71^{b}	42.62^{b}	86.13^{c}

Means with the same letter are not significantly different; α = 0.05 (Tukey's test);
* Explanation below Table 1.

accumulation of N and P was observed in sugar beets grown under MG treatment, and the total K, Ca, Mg and Na accumulation was the lowest in beets grown under STS treatment. The highest P, K and Ca accumulation appeared in beets grown under STG treatment in the second year (2013). Varied nutrient uptake is associated with the development of the root system. Studies by Khan et al. (1986) and Ishaq et al. (2001) indicate that a significant factor influencing phosphorus uptake is the mode of soil cultivation, which directly affects the development of the root system and consequently determines water and mineral nutrient uptake. The root system structure plays a particular role in P uptake because of the low mobility of this element in soil (López-Fando, Pardo 2009). A considerable increase of the root system growth (production of many lateral roots) can enhance P uptake. Brown and Biscoe (1985) found the largest beet taproot mass in a 0-10 cm soil layer. In the system of beet sowing into stubble mulch, fertilizers are mixed with a soil layer few centimeters thick, making fertilizer nutrients easily available to plants. Rasmussen (1999) showed a significant increase of available P content in a 0-5 cm soil layer as a result of mineral fertilization, whereas in deeper soil layers (10-20 cm), P content was stable, tending to decrease during the plant-growing season. The current results show that phosphorus accumulation in beets changes seasonally. Also, the accumulation of the nutrients examined was higher in 2012 than in 2013. The difference stemmed from the higher beet yields with a higher nutrient accumulation in their organs in the first study year.

In agricultural practice, specific macronutrient uptake is the most useful estimate, as it provides the grounds for assessment of sugar beet nutritional needs. The estimated values in the present study were lower than those reported by other authors (Słowiński et al. 1995, Grzebisz et al. 1998, Barłóg 2009). The simplified cultivation treatments caused a significant decrease of the rate of the uptake of nitrogen, potassium, calcium and magnesium by sugar beets when compared to the conventional tillage system (Table 7). In

Table 7

Specfic nutrient uptake (kg t root yield^{-1})

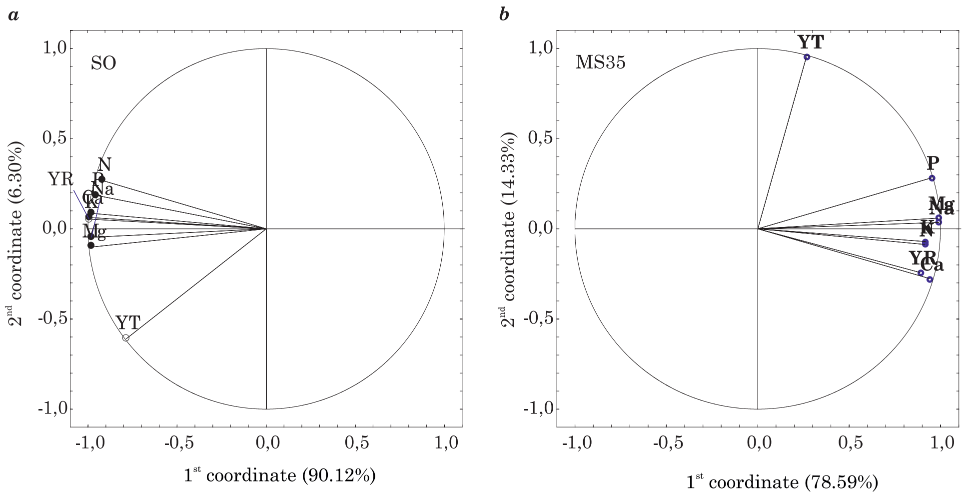
Years	Treatment	Nutrients					
		N	P	K	Ca	Mg	Na
2012	SO*	3.41[a]	0.358[ab]	3.63[a]	0.799[a]	0.591[abc]	1.27[a]
	MS35	3.06[ab]	0.426[a]	3.18[ab]	0.630[abc]	0.596[ab]	1.26[a]
	MS15	3.01[ab]	0.403[a]	3.17[ab]	0.700[ab]	0.566[abcd]	1.28[a]
	MG	2.29[ab]	0.380[ab]	3.23[ab]	0.750[ab]	0.615[a]	1.21[ab]
	STS	2.63[b]	0.358[ab]	2.89[ab]	0.561[bcd]	0.541[abcde]	0.96[bc]
	STG	3.14[ab]	0.368[ab]	3.33[ab]	0.768[a]	0.623[a]	1.39[a]
2013	SO	2.93[ab]	0.230[d]	1.82[c]	0.461[cde]	0.438[ef]	0.53[e]
	MS35	2.78[ab]	0.259[cd]	2.61[b]	0.383[e]	0.413[f]	0.82[cd]
	MS15	2.94[ab]	0.272[cd]	2.81[b]	0.433[de]	0.483[def]	0.65[de]
	MG	2.65[b]	0.234[d]	2.63[b]	0.313[e]	0.490[cdef]	0.67[de]
	STS	2.74[ab]	0.305[bcd]	3.09[ab]	0.352[e]	0.498[bcdef]	0.78[cde]
	STG	2.75[ab]	0.314[bc]	3.16[ab]	0.460[cde]	0.449[ef]	0.91[cd]

Means with the same letter are not significantly different; α = 0.05 (Tukey's test);
* Explanation below Table 1.

the latter, sugar beet macronutrient uptake per production of a yield unit was higher than in the treatments where simplified technologies of soil cultivation were applied. As for nitrogen, such a relationship indicates luxury management of this nutrient with a tendency for its accumulation in the roots and production of yield with a lower technological quality. The values of specific macronutrient uptake were also influenced by a given plant-growing season. In the study years, a particularly large difference was observed between the values of this indicator obtained for potassium, especially in the conventional tillage system.

Yield as a function of macronutrient accumulation

Principal component analysis (PCA) was used for illustration of the relationship between sugar beet root yield and the total accumulation of nutrients in the cultivation treatments tested. Significant relationships for the uptake of all the analyzed nutrients were observed only in the conventio-



YT – technological yield, YR – root yield,

Fig. 2. Two-dimensional space image of total nutrient accumulation variables and quality parameters in sugar beet roots

nal tillage (Figure 2*a*) and tillage to a depth of 35 cm with sowing into stubble mulch (MS35) – Figure 2*b*. In all the other treatments, relationships for individual nutrients were found.

The analysis of the correlations between technological sugar yield and the total accumulation of the nutrients tested showed significant relationships only in the conventional tillage system. The correlation coefficient values obtained in this treatment were as follows: N = 0.575; P = 0.654; K = 0.819; Ca = 0.741; Mg = 0.839; Na = 0.809. No such relationships were observed in the treatments where tillage simplifications were applied.

CONCLUSIONS

1. When compared to the conventional tillage system, simplification of soil cultivation based on shallow ripping without soil turning over, as well as strip-till cultivation significantly differentiated the macronutrient content in sugar beet organs. The application of simplified soil cultivation treatments caused a significant increase of the calcium content both in roots and leaves of sugar beets, and a decrease of phosphorus and sodium content in leaves.

2. The total macronutrient accumulation in beets depended on the cultivation system, the macronutrient analyzed and the study year. In the first year (2012), among the simplified technology treatments, the largest accumulation of nitrogen and phosphorus was observed in MG treatment, and that

of potassium, calcium, magnesium and sodium – in STS treatment. In 2013, the highest content of P, K, Ca was observed in beets grown under STG treatment.

3. The analysis of correlations between sugar beet root yield and the total accumulation of macronutrients showed significant relationships for N, P, K, Ca, Mg only in the conventional tillage treatment and that with tillage to a depth of 35 cm and beet seed sowing into stubble mulch (MS35).

4. Correlation coefficients for technological sugar yield and the total accumulation of macronutrients indicated significant relationships only for sugar beets cultivated in the system of conventional tillage.

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