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EFFECT OF DIFFERENT TILLAGE METHODS ON THE NUTRITIONAL STATUS, YIELD AND QUALITY OF SUGAR BEETS

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Abstract

Optimal nutrition of sugar beets at critical growth stages is one of the crucial factors for the achievement of their highest yield potential. In the present study, it was presumed that reduced systems of sugar beet cultivation had no effect on the plants' nutritional status at critical growth stages, on their yield or technological quality. In 2012-2013, two series of one-factorial field experiments with different beet crop husbandry were carried out in order to verify this hypothesis. The cultivation systems of sugar beet crops differed in the postharvest cultivation technology, mulch types and seedbed tillage. Conservation tillage systems were compared with the control treatment, which represented the conventional cultivation system with an application of manure and 35 cm deep autumn ploughing. The plant nutritional status assessment was carried out at two dates corresponding to the following growth stages: BBCH 16/17 (6-8 fully unfolded true leaves) and BBCH 39/40 (row closing). Regardless of the methods of tillage or the year of observation, the results showed that the plants at BBCH16/17 stage were well-nourished with macroelements but malnourished with microelements, mainly iron and zinc. The microelement deficiency in the plants was a result of adjusted soil reaction, which varied from slightly acidic to neutral. At the BBCH 39/40 stage, there was a decreasing trend in the content of leaf macronutrients in the no-tillage systems treatments compared to the conventional tillage with the ploughing depth to 35 cm and manure application. The reduced tillage systems in sugar beet cultivation did not result in either a yield decrease or a worse technological quality of roots. The experimental factor had no significant effect on the content of molassegenic compounds in beet roots. A decreasing trend was observed in the content of α-amino nitrogen and potassium when compared to the traditional cultivation system.

The study showed that the choice of a cultivation technology is of secondary importance as long as the plant grows in optimal conditions resulting from an appropriate site selection.

Keywords: sugar beet, mineral nutrition, tillage systems.

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INTRODUCTION

Ecological and economic problems in sugar production stimulate the search for new solutions in sugar beet cultivation technologies, with an aim of reducing the number of agricultural practices and lowering fertilization levels (Koch et al. 2009). The system of simplified cultivation envisages the elimination of winter tilling and abandonment of spring farming or else the limitation of the latter to one shallow treatment in order to mix harvest residues of intercrop plants with soil. These practices cut costs incurred by soil cultivation and fertilization, but even more importantly they increase amounts of organic matter in soil (Freibauer et al. 2004, Holland 2004) and enhance soil microbial activity (Bending et al. 2000, 2002). Recent estimates have shown that about 7% of arable land is now cultivated with no-tillage technologies (Kassam et al. 2009). Reduced tillage introduced into soil cultivation under sugar beet plantations has become an overriding objective for the maintenance of field productivity while protecting soil against erosion. At the same time, low tillage is a good alternative to traditional tilling systems. It is common knowledge that tillage systems differing in depth and intensity modify chemical and physical soil properties, thus affecting plant growth (Peigne et al. 2007, Soane et al. 2012). In the last two decades, an alternative cultivation system has been developed based on direct sowing into stubble mulch. This, as well as strip-till cultivation, responds well to pro-ecological requirements. In addition, it appears to be economical owing to lower costs of soil cultivation and sowing when compared to the conventional tillage method.

Soil selected for sugar beet cultivation should be distinguished by a biologically active humus layer and naturally high content of nutrients (Hergert 2010). Nitrogen is a nutrient that is almost certainly most often analyzed in sugar beet research because of its direct relationship with yield and strong limiting effect on plant productivity (Loomis, Conor 1992). Sugar beet requires an accurate assessment of the amount of N to be supplied as a fertilizer, as the negative effects of unbalanced N dosage ultimately mean less income for the farmer, diminished sugar production and inferior root technological quality (Marchetti, Castelli, 2011). Subsequent to nitrogen, potassium is another nutrient whose large amounts are required by plants. Yields of sugar beet can benefit from K fertilization, especially when native soil phytoavailable K concentrations are low (Zörb et al. 2014). In agricultural practice, exploitation of plant yield potential relies not so much on nutrient amounts added into soil as mineral fertilizers, but on physical and chemical conditions which influence their uptake by plants. An appropriate choice of the critical stages of sugar beet growth ought to facilitate plant nutritional status analysis as well as subsequent nutritional adjustments so that the crops could promptly produce a large leaf area.

The aim of the present study was to determine the effects of reduced tillage systems on the nutritional status of sugar beets at critical growth stages as well as their yield and root quality.

MATERIAL AND METHODS

The study was carried out in 2012-2013 at the Żołędnica Animal Breeding Station (51.65°N 16.90°E), located in the vicinity of Rawicz (central Poland). The experiment was arranged in a completely randomized block design.

Six technologies with differentiated tillage methods and mulch materials constituted an experimental factor. The conventional tillage treatment with soil ploughing to the depth of 35 cm was the control treatment (SO). For comparison, the following conservation tillage systems were analyzed, each comprising either shallow or deep soil ripping: (2) tillage to the depth of 35 cm and sowing into stubble mulch (MS35); (3) tillage to the depth of 15 cm and sowing into stubble mulch (MS15); (4) tillage to the depth of 15 cm and sowing into white mustard mulch (MG); (5) strip-till on stubble mulch to the depth of 25 cm and instantaneous beet seed sowing (STS); (6) strip-till to the depth of 25 cm on white mustard mulch and instantaneous beet seed sowing (STG).

Beet seeds were sown in rows 18 cm apart. In both years, winter wheat was used as the preceding crop for sugar beets. Wheat straw was removed from the field after harvesting, which was followed by postharvest activities. Strip-till with instantaneous beet seed sowing was performed as a single-step procedure in the spring, after shallow tillage to the depth of 15 cm carried out in the previous autumn. The experiments were established on very loamy sandy soils with a high content of available phosphorus and medium content of available potassium and magnesium. The soil reaction was slightly acid in the first year of observations and neutral in the second year. The soil's physicochemical data are presented in Table 1. Phosphorous was applied as a compound fertilizer, type PK (10:30), and potassium was additionally supplied as 40% potassium salt (type Korn-Kali). Phosphorus and potassium fertilizers were applied in the autumn. Magnesium was applied twice in a foliar treatment with Epsom salt ($MgSO_4 \cdot 7H_2O$). Nitrogen fertilizers were incorporated into soil before sowing as ammonium nitrate. Additionally, a foliar treatment was performed twice with liquid fertilizer. Fertilization levels are shown in Table 2. Differences in the fertilization doses applied in

Table 1

Basic physical and chemical properties of studied soils

Years	P available (mg P kg^{-1})	K available (mg K kg^{-1})	Mg available (mg kg^{-1})	Sand (%)	Silt (%)	Clay (%)	Organic C (g kg^{-1})	pH 1M KCl
2012	130	106	68	78	20	2	9.3	6.2
2013	88	165	72	81	17	2	8.8	7.0

Table 2

Mineral fertilization levels (kg ha^{-1}) in the two trial years

Years	Nutrients			
	N	P	K	Mg
2012	90	11	129	4
2013	125	9	33	4

the two years were resulted from satellite positioning (GPS) monitoring and the subsequent adjustment of fertilization to the actual soil production potential and plant needs in the second year.

The application of fertilizers as well as herbicides and pesticides was the same for all the treatments. The assessment of sugar beet nutritional status was performed at two growth stages: when at least 6 true leaves were fully unfolded (BBCH 16/17) and as soon as the rosette growth reached the stage when leaves covered almost 90% of the ground (BBCH 39/40; at the turn of June and July). At the first growth stage, overall aerial biomass (total leaf mass) was analyzed, whereas at the second one, the content of mineral nutrients was assessed in laminas of young, well-developed leaves collected randomly from middle parts of the plants. The content of nitrogen in plant tissues was assessed by the Kjeldahl method (Auto Distillation Unit Kjeltec 2200 FOSS). In order to assess the total content of P, K, Ca, Mg and micronutrients, leaf samples were ground and mineralized at 550°C for 6h, and the ash was dissolved in 2 cm^3 of diluted HNO_3 (65% HNO_3 diluted 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 and micronutrients were determined with atomic absorption spectroscopy (SpectraAA-250Plus Varian). The plant nutritional status evaluation carried out with an aid of PIPPA software (Professional Interpretation Program for Plant Analysis) created by Schnug and Haneklaus (2008). The evaluation of quantitative parameters (the content of α-amino nitrogen, K and Na) was carried out at the Sugar Refinery in Środa Wielkopolska (central Poland) in a Venema autoanalyzer IIG (Pfeifer & Langen Co.). Root yield was determined based on the weight of 500 sugar beet roots and final population density of plants, following the methodology elaborated by the International Sugar Beet Institute (Vandergeten et al. 2004). Plant density per 1 ha was 95.000 and 98.560 in 2012 and 2013, respectively. The plot's gross size was 1200 m^2. From each plot, 20-30 whole roots were collected for beet quality evaluation based on pulp analyses.

The technological yield of sugar (*ST*) was computed from the algorithm below (Buchholz et al. 1995):

$$ST = Sc - [0.177(K + Na) + 0.247(N - amin) + 1.08],$$

$$Y_{ST} = (Y_{RY} \cdot ST) : 100,$$

where:

Sc – sugar content (%);

K, Na, N – amin K – the content of potassium, sodium and α-aminonitrogen (mmol 100 g^{-1});

Y_{RY} – root yield (Mg ha^{-1});

Y_{ST} – technological sugar yield.

The results of the trial were tested with Anova (Calinski et al. 1987). The estimated value (y_{ijk}) of the analyzed variables (the content of individual nutrients in beet leaves, root yield, technological sugar yield) was obtained from i-block (i = 1,...,4), j-year (j = 1,2) and k-cultivation treatment (k = 1,...,6). The model on which the experiment was based was described by the following linear equation:

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

where:

μ – general mean;

a_i – i-block effect, i = 1,2,3,4;

β_j – j-year effect, j = 1,2;

γ_k – k-treatment effect, k = 1,2,...,6;

e_{ijk} – random error.

The average beet root yields as well as those of technological sugar obtained from the differentiated tillage systems were compared with multiple comparison tests following the Tukey's method. Simple correlation analysis and multiple regressions were performed in order to evaluate the cause and effect relationships between the investigated parameters. Regression analysis was carried out until all variables in the equation were significant at $p < 0.05$.

RESULTS AND DISCUSSION

During a beet growing season, two critical growth stages corresponding to the beet phenological development stages, BBCH16/17 and BBCH 39/40, were observed. The results of evaluation carried out at the first stage enabled us to assess the plants' nutritional status, idicated whether or not adjustment treatments would be necessary and consituted a good yield forecaster. The results of the assessment of sugar beet nutritional status carried out at BBCH16/17 and BBCH39/40 growth stages, corresponding to 6-8 true leaves unfolded and the last rosette growth phases, respectively, were separated depending on the nutrient analyzed, the year of observation and the plant growth stage. The reduced tillage systems significantly differentiated the content of the nutrients in sugar beet leaves at BBCH 16/17 stage growth (Table 3). On the other hand, the effect of a cultivation system on the

Table 3

Content of macro- and micronutrients in sugar beet leaves at BBCH 16/17 according to tillage system

Years	Treatments	Nutrients								
		N	P	K	Mg	Ca	Zn	Mn	Cu	Fe
		(g kg^{-1})					(mg kg^{-1})			
2012	SO	48.7^{a}	4.63^{ab}	42.4^{abc}	15.1^{a}	8.97^{abc}	78.9^{a}	41.6^{a}	13.1^{ab}	147.2^{ab}
	MS35	45.7^{abc}	4.61^{ab}	44.2^{abc}	14.3^{a}	9.36^{abc}	60.1^{b}	35.8^{ab}	14.2^{ab}	130.5^{ab}
	MS15	44.1^{abc}	4.42^{ab}	46.4^{ab}	14.8^{a}	11.1^{a}	56.9^{bc}	35.6^{ab}	14.1^{ab}	140.6^{ab}
	MG	40.7^{bc}	4.75^{a}	43.8^{abc}	11.8^{ab}	9.90^{abc}	56.6^{bc}	33.7^{abc}	14.5^{ab}	149.9^{a}
	STS	38.4^{c}	4.34^{ab}	47.0^{a}	12.4^{ab}	10.8^{ab}	54.1^{bc}	29.8^{bcd}	13.3^{ab}	121.8^{ab}
	STG	47.6^{ab}	3.94^{b}	47.8^{ab}	10.3^{abc}	10.5^{ab}	43.7^{c}	22.4^{cd}	10.9^{b}	97.4^{b}
2013	SO	39.5^{c}	3.12^{c}	37.0^{bc}	9.15^{bc}	7.99^{bcd}	10.97^{d}	21.1^{d}	16.7^{ab}	120.4^{ab}
	MS35	41.1^{bc}	2.68^{c}	35.8^{c}	8.51^{bc}	6.93^{cd}	11.87^{d}	29.5^{bcd}	19.4^{a}	159.4^{a}
	MS15	41.9^{abc}	2.93^{c}	40.8^{abc}	6.88^{c}	5.36^{d}	8.32^{d}	32.7^{abcd}	18.6^{a}	168.5^{a}
	MG	38.5^{c}	2.98^{c}	44.9^{abc}	8.35^{bc}	7.77^{bcd}	9.37^{d}	31.9^{abcd}	19.0^{a}	129.6^{ab}
	STS	41.3^{abc}	2.93^{c}	44.0^{abc}	8.86^{bc}	8.68^{abc}	9.37^{d}	21.1^{d}	17.5^{a}	144.8^{ab}
	STG	41.3^{abc}	2.85^{c}	25.2^{d}	9.12^{bc}	9.81^{abc}	10.5^{d}	27.2^{bcd}	17.8^{a}	157.4^{a}

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.

nutrient content was not unambiguous. In this study, the content of nutrients was for the most part differentiated reliant upon the cultivation system applied and the years of observations as in the case of zinc. Taking into account the effect of the experimental factor, it was detected that reduced tillage on the whole reduced the content of Zn in sugar beet leaves when compared to the conventional tillage system. The differences in zinc contents in the years of observations were due to changing soil reaction. In 2013, the site designated for sugar beet cultivation showed neutral soil reaction, whereas it was slightly acidic during the experiment carried out a year before. Soil reaction was also a basic factor determining low contents of iron in sugar beet leaves, irrespective of the tillage system applied.

Regardless of the tillage system applied and the year of observations, the plants were very well nourished with nitrogen, phosphorous, potassium, calcium, magnesium and copper. On the other hand, a big shortage of iron was observed in both years of observations, and that of zinc in the year 2013. According to literature data (Barłóg 2009), optimal contents of Fe and Zn in beet leaves at BBCH 17/16 should be within a range 480-760 mg kg^{-1} and 25-50 mg kg^{-1}, respectively.

At the second critical growth stage (BBCH 39/40), beet plant finishes the phase of leaf rosette formation, achieves the optimal leaf area index (LAI), and then starts the phase of intensive root growth. In contrast to BBCH16/17 stage, the evaluation of plant nutritional status at this stage has primarily prognostic implication, and not diagnostic for potential modification of plant nutritional status. At BBCH 39/40 stage, there was a decreasing trend in the contents of leaf macronutrients for no-till treatments when compared to conventional conventional tillage with ploughing depth adjusted to 35 cm and manure application (Table 4). This regularity was distinctive for nitrogen, phosphorus and potassium notwithstanding the year of observation. Anova showed a significant effect of the tillage systems tested on P contents only in the second year of the trial. It was found that beet plants cultivated in stubble mulch (STS) were distinctively P malnourished and STS treatment significantly differed from other treatments tested. The reason of this relationship can be the effect of soil density. The latter is an indirect factor shaping physical soil conditions, which directly affects the so called soil mechanical resistance. With regard to phosphorous, the higher is soil density, the worse are soil physical properties, and consequently P uptake by plants is restricted. The structure of plant root system, especially in the case of sugar beets plays an important role in P uptake because the latter is closely dependent on low mobility of this nutrient in soil (Holford 1997, Lynch 1995). The contents of N and P observed at BBCH 39/40 (40-60 g kg^{-1} N and 2.7-4.8 g kg^{-1} P) were below threshold values reported in the literature (Barłóg 2009, Haneklaus, Schnug 1996). The lowest nitrogen contents in beet leaves (regardless of the year of observation) were observed for the treatment with strip-till sowing into stubble mulch (STS) and MS35 At BBCH 39/40 stage, simplification of soil cultivation resulted in significantly differentiated contents of calcium and

Table 4

Content of macro- and micronutrients in sugar beets at the beginning of BBCH 39/40 according to tillage system

Years	Treatments	Nutrients								
		N	P	K	Mg	Ca	Zn	Mn	Cu	Fe
		(g kg^{-1})					(mg kg^{-1})			
2012	SO*	41,8^{a}	3.15^{a}	53.6^{a}	8.87^{b}	13.8^{ab}	56.8^{abcd}	47.8^{a}	11.1^{ab}	94.8^{ab}
	MS35	39.7^{a}	2.86^{abc}	51.9^{a}	8.97^{ab}	12.4^{ab}	61.4^{ab}	40.7^{a}	10.6^{abc}	94.5^{ab}
	MS15	40.0^{a}	2.88^{abc}	52.3^{a}	8.35^{bc}	11.3^{abc}	66.6^{a}	53.4^{a}	11.7^{a}	108.1^{a}
	MG	41.4^{a}	2.96^{ab}	54.1^{a}	11.6^{a}	14.2^{a}	68.7^{a}	47.4^{a}	10.9^{abc}	79.4^{abc}
	STS	40.1^{a}	2.76^{abcd}	48.9^{ab}	7.79^{bcd}	11.0^{bc}	58.8^{abc}	39.4^{a}	8.8^{bc}	76.5^{abcd}
	STG	40.5^{a}	2.89^{abc}	49.7^{ab}	8.17^{bcd}	12.8^{ab}	60.8^{ab}	37.8^{a}	10.1^{abc}	81.1^{abc}
2013	SO	25.2^{b}	2.35^{bcde}	39.9^{c}	6.47^{bcde}	6.90^{de}	20.6^{e}	48.7^{a}	7.6^{c}	41.1^{e}
	MS35	22.7^{b}	2.35^{bcd}	41.9^{bc}	5.86^{cdef}	8.28^{cd}	23.9^{cde}	48.3^{a}	9.4^{abc}	58.1^{cde}
	MS15	24.6^{b}	2.16^{de}	38.0^{c}	5.59^{def}	9.73^{de}	38.1^{abcde}	47.5^{a}	7.7^{c}	43.2^{de}
	MG	22.2^{b}	2.31^{cde}	36.9^{c}	4.93^{ef}	6.21^{de}	21.9^{de}	52.1^{a}	9.4^{abc}	48.8^{cde}
	STS	21.7^{b}	2.04^{e}	39.1^{c}	4.59^{ef}	5.08^{e}	35.5^{abcde}	36.4^{a}	8.3^{bc}	72.0^{bcde}
	STG	24.4^{b}	2.39^{bcde}	35.8^{c}	3.27^{f}	5.15^{e}	28.6^{bcde}	36.1^{a}	8.8^{abc}	68.8^{bcde}

Means with the same letter are not significantly different; $\alpha = 0.05$ (Tukey's test);
* Key below Table 3.

magnesium in the leaves tested. Regardless of the year of observation, the lowest nutrient contents were observed for the treatments where strip sowing was applied (STS and STG). On the other hand, it should be noted that in any case Ca and Mg contents were considerably higher than the optimum (Ca – 3.0 g kg^{-1}; Mg – 1.5 g kg^{-1}) determined by HANEKLAUS and SCHNUG (1998) for BBCH 39/40 stage of sugar beet growth. The effect of tillage depth and cultivation intensity on physical and chemical soil properties in sugar beet cultivation has been well documented in subject literature (ATKINSON et al. 2007, KRAUSE et al. 2009, ARVIDSSON et al. 2012).

The sugar beet nutritional status assessment performed with the use of PIPPA software at BBCH 39/40 growth stage showed that in the group of mineral nutrients with a limiting effect on yields iron and copper produced a noticeable impact, which was irrespective of the the years of observations. In the control treatment (SO) as well as the simplified cultivation treatment with sowing into stubble mulch (MS35), a Zn limiting effect on sugar beet root yield appeared. The PIPPA software enabled us to determine nutrient deficts as well as the contribution of individual nutrients to the overall limiting impact. The result interpretation is illustrated in Figure 1. Regardless of the cultivation system applied, iron was the element which limited

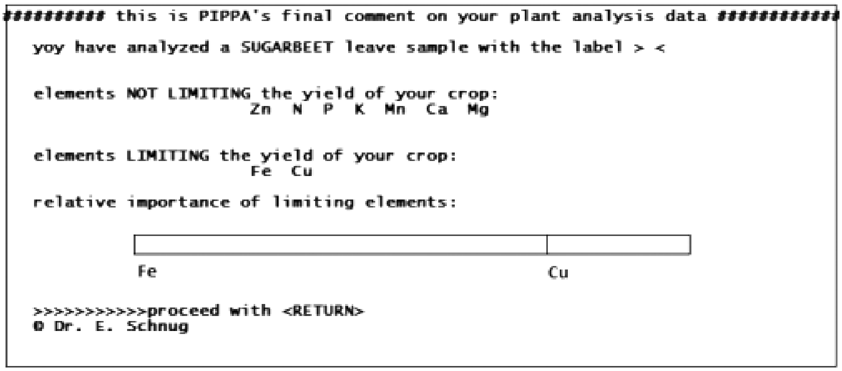

Fig. 1 The share of nutrients limiting sugar beet yield at BBCH 39/40 growth stage

yields of sugar beet roots the most, while copper decreased the yield to a small extent. Although the assessment carried out based on the threshold values (BARŁÓG 2009) showed that the plants were well-nourished with copper, this nutrient was classified to the group of nutrients with a limiting effect on root yield. The regression analysis indicated that the content of zinc, iron and copper significantly determined root yield when the rosette growth reached the stage of leaves covering almost 90% of the ground (BBCH 39/40).

$$Y = 0.349(Zn) - 0.006(Fe) - 0.098(Cu) + 103.6,\ R^2 = 0.65,\ p < 0.001,$$

Y – root yield.

In agricultural practice, beet root yield is a basic and measurable criterion for the evaluation of yield value of the applied production factors. The Anova results showed the significant effect of the simplified cultivation systems on sugar beet yielding only in 2012 (Table 5).

Compared to the conventional tilling, an increase of root yields was observed for all the treatments except the postharvest cultivation to the depth of 15 cm and strip-till sowing into stubble mulch with mustard intercropping (STG). Lower root yields (by 11%) in the system of beet seeds sown into mulch versus the traditional system were also reported by KORDAS and ZIMNY (1997). The study by KORDAS and ZIMNY (1997), which had been carried out for several years, showed that direct sowing resulted in a significant increase of soil compaction, especially at the beginning of the plant growing season, which was then manifested by a yield reduction. ARVIDSSON et al. (2014), who tested various crops (beets, potatoes, cereals) cultivated with the use of reduced tillage technologies, showed yield reductions only for root crops, and this confirmed a higher sensitivity of the latter to soil density when compared to cereals. One of the basic measures in the assessment of growth conditions and yielding of the tested plant is the cross-referencing of the results with the potential yield. The standard yield potential of the tested sugar beet varieties was 86.9 t ha^{-1} in 2012 and 78.6 t ha^{-1} in 2013. In the present study, the beet root yields were 30% (2012) and 25% (2013) higher than the standard values for the tested varieties. During the whole experiment, the weather conditions were particularly beneficial for sugar beets in 2012, which stimulated the content of nutrients and, consequently, the yields of roots and technological sugar. The research conducted by FRECKLETON et al. (1999) showed that even in the rainly climate of England, precipitation patterns in

Table 5

Sugar beet root yield (Y_{SB}) and technological sugar yield (Y_{ST}) according to tillage system (t ha^{-1})

Years	Treatments	Y_{SB}	Y_{ST}
2012	SO*	112.5^{ab}	16.3^{ab}
	MS35	115.2^{ab}	16.3^{ab}
	MS15	111.6^{b}	16.5^{ab}
	MG	111.8^{b}	15.6^{ab}
	STS	124.9^{a}	16.9^{a}
	STG	111.0^{b}	16.6^{ab}
2013	SO	89.4^{c}	14.8^{b}
	MS35	93.5^{c}	15.8^{ab}
	MS15	95.7^{c}	16.0^{ab}
	MG	97.3^{c}	16.6^{ab}
	STS	97.5^{c}	16.6^{ab}
	STG	94.9^{c}	15.9^{ab}

Means with the same letter are not significantly different; α = 0.05 (Tukey's test);
* Key below Table 3.

July and August had a decisive influence on sugar yields. The effect of the course of weather conditions on shaping sugar yields has also been demonstrated by other authors (Muchova et al. 1998, Pacuta et al. 2000, Mohammadian et al. 2008, Hartmann et al. 2012). Our results clearly indicate that the choice of a cultivation technology is a secondary factor if beets are grown in areas with fertile soils and in years with suitable precipitation patterns during the plant growing season. The sugar beet's critical demand for water occurs during the intense growth of leaves, which peaks at the turn of July and August.

Sugar yield is the basic parameter used in the evaluation of a sugar beet plantation. This yield depends on three factors, i.e. the root yield, root quality and sugar extraction level. In the present study, simplification of a cultivation technology increased sugar yield relative to the control treatment (SO), although statistically significant differences were confirmed only in 2013 (Table 5).

In the alternative systems of sugar beet cultivation, particular attention should be drawn to the quality analysis of roots, which comprises an evaluation of the content of sugar as well as that of molassegenic compounds. The latter negatively affect sugar extractability from beet roots during the processing chain and, consequently, depress yields of technological sugar. The more sugar and the less of molassegenic compounds sugar beets contain, the higher the technological value they present. Regardless of the treatment tested, in each year of the observations, the content of sugar was 16% higher than the standard value (Table 6), which indirectly implcates that the plants used nitrogen effectively.

Table 6

Effect of tillage system on the quality parameters of sugar beet roots

Years	Treatments	Polarization (%)	N α-amino	Na	K
			(mmol 1000 g^{-1})		
2012	SO*	17.5^{a}	20.2^{a}	5.1^{a}	51.5^{a}
	MS35	17.6^{a}	17.5^{ab}	5.3^{a}	49.8^{a}
	MS15	18.1^{a}	15.5^{abc}	4.2^{ab}	48.3^{a}
	MG	17.6^{a}	16.2^{abc}	4.8^{a}	48.3^{a}
	STS	17.5^{a}	18.2^{ab}	5.6^{a}	51.2^{a}
	STG	17.4^{a}	16.1^{abc}	4.4^{a}	49.7^{a}
2013	SO	18.6^{b}	10.3^{bc}	2.7^{b}	50.7^{a}
	MS35	18.9^{b}	1.0^{bc}	2.5^{c}	49.4^{a}
	MS15	18.7^{b}	11.4^{bc}	2.4^{c}	52.1^{a}
	MG	19.0^{b}	9.0^{c}	2.5^{bc}	51.0^{a}
	STS	19.1^{b}	8.5^{c}	2.6^{c}	50.2^{a}
	STG	18.7^{a}	1.1^{bc}	2.5^{c}	48.0^{a}

Means with the same letter are not significantly different; α = 0.05 (Tukey's test);
* Key below Table 3.

Alpha-amino nitrogen, K and Na are considered to be molassegenic compounds, and therefore their presence in beet root pulp hinders sugar extraction (Herlihy 1992). When analyzing beet root quality parameters tested in this study, significant differences were found only between the years. In the treatments where the conservation tillage was applied, a decreasing trend was observed for the α-amino nitrogen and potassium content compared to the traditional soil cultivation system. Bell et al. (1992) states that the content of α-amino nitrogen in beet roots depends on the amount of nitrogen taken up by beet plants from soil, which in turn reflects the content of soil mineral nitrogen.

CONCLUSIONS

1. Regardless of the tillage systems, the sugar beet nutritional status assessment at the BBCH 16/17 growth stage indicated that the plants were well-nourished with macroelements (N, P, K, Mg, Ca). On the other hand, they were distinctly malnourished with iron and zinc in the second year of the experiment.

2. At the BBCH39/40 growth stage, when beet plants grow most intensively, they were found to be deficient in nitrogen and iron in all the analyzed treatments, with a decreasing tendency in the no-tillage systems.

3. No significant differences in the root and technological sugar yields were observed caused by reduced tillage, which indicates that the choice of a cultivation technology for soil under sugar beet fields is of secondary importance to the soil's high nutrient availability, its adjusted reaction and optimal growth conditions during the plant growing season.

4. The experimental factor had no significant effect on the content of molassegenic compounds in beet roots. A decreasing trend appeared in the content of α-amino nitrogen and potassium when compared to the conventional tillage system.

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