YIELD AND TECHNOLOGICAL QUALITY OF SUGAR BEET AFTER EXTRARADICAL NUTRITION

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Abstract: This small-plot field experiment was aimed at testing the effects of extraradical nutrition on the quality of sugar beet production. The experiment also included the monitoring of root growth dynamics and changes in the root's technological quality. The growth of taproots during the vegetation period corresponded with the development of the weather conditions. The sugar content in the taproots gradually increased up to an average harvest value of 18.1%. When monitoring the variants, the content of alpha-amino nitrogen did not undergo significant changes, staying in the rather positive values of 15–20 $mg \cdot 100g^{-1}$. Similarly positive was the low content of noxious potassium at the point of harvest. The best results were obtained after repeated application of the *Carbon Si* fertilizer. This variant reached the highest taproot yield, polarization sugar yield and refined sugar yield per hectare. The highest sugar content was reached after repeated application of the *Carbonbor Zn, Cu, S* spray in combination with *Insenol*. The experiment has shown that extraradical nutrition promotes taproot yield and has a positive influence on technological quality as well.

Key Words: sugar beet, extraradical nutrition, yield, quality, sugar content

INTRODUCTION

Sugar beet is a strategic and energy crop due to its ability to amplify the energy received most successfully. It serves as an excellent pre-crop. Currently, it is also being used as an energy crop (Jirkovský et al. 2013). The area where sugar beet is currently grown in the Czech Republic ranges between 40–60 000 ha when including the areas where sugar beet is grown for the production of fermented alcohol. Sugar production is performed in 7 sugar refineries, where a total of approximately 380 000 tonnes of white sugar is produced per year. The production quota set by the EU for the Czech Republic is 372 459 tonnes (Jůzl, Elzner 2014).

Sugar beet is a very demanding crop in terms of nutrients required. For a total of 1 t of taproot, 4.4 kg of N, 5.6 kg of K, 2 kg of Ca, 0.9 kg of Na, 0.8 kg of Mg and 0.7 kg of P is consumed. The choice of location for growing sugar beet is essential. The crop requires deep, medium-weight soil with neutral to slightly alkaline soil reaction (pH 6.3–7.4). Controlled nutrition affects primarily the taproot yield, which is also influenced by the ratio between taproot and beet top weight, the sugar content and other technological parameters (Hřivna et al. 2014[a]).

Well-balanced nutrition can figure significantly into the process of yield production and product quality. The plants receive nutrients mainly through the root surface and partially through the leaf surface. Extraradical nutrition is an important tool for adjusting the nutrition status of the plant during the vegetation period. It is especially essential when applying micronutrients (Hřivna, Cerkal 2009).

An important intensification factor when growing sugar beet and producing sugar are thus foliar liquid fertilizers. These enrich the plant with the macro and, above all, microelements the plant currently requires. In addition, they are economically more viable than their soil-based counterparts (Urban et al. 2003). Yield production and sugar beet quality can also be greatly affected by the weather conditions (Bittner 2012).

The experiment focused on the evaluation of the changes in the technological quality of sugar beet during extraradical nutrition. The possibilities of using extraradical nutrition and the effects on the technological indicators of sugar beet (sugar content, soluble ash, alpha-amino nitrogen) and its yield were observed. The potassium and calcium content in beet juice was also determined, as it plays an important role in the calculation of sugar content in molasses.

MATERIAL AND METHODS

Material

The small-plot experiment studied the application of fertilizers intended for foliar nutrition of sugar beet in combination with an *Insenol* supporting agent (Table 1). The taproot yield production and quality was observed during the vegetation period.

The field experiment was performed on the Panorama variety, which falls within the transitional NC type group. It is one of the most universal varieties, which is characterized by high sugar yield, excellent technological qualities and low content of ash and noxious nitrogen. It is also resistant to rhizomania and nematodes.

Table 1 Foliar fertilizers used

Fertilizer	*Composition*	*Properties*
Carbon Si	15% SiO_2 5% K_2O 1% C	eliminates silicon deficits while also supplying the plant with potassium and carbon
Carbonbor Zn, Cu, S	6% C 5% B 3.5% Cu 2% S 1% Zn	suitable for the elimination of boron, zinc, copper and sulphur deficits while also supplying carbon
Insenol	PVP	contains polyvynilpyrrodlidone as an active substance, which possesses excellent wettable properties and easily creates a film

Characteristics of the Plot and Agrotechnical Data

The taproot yield production and quality was monitored during the experiment. The experiment was based on a plot of land belonging to the cooperative farm Agrospol Velká Bystřice. The land is located in a mildly warm and mildly humid climate region. The soil is medium-weight brown earth.

In the autumn, the post-harvest remnants were ploughed in by medium ploughing (winter wheat). Sowing was carried out on the 20. 3. 2014. The sowing rate was 1.17 seed units per hectare at an exact distance of 18.8 cm. The harvest was performed on the 24. 10. 2014.

The experiment variants and the doses and dates of fertilizer application are listed in Table 2. The fertilizer application was performed twice during the experiment by spraying onto the leaves.

Table 2 Agents and application dates

	Variant	*Dose in $l \cdot ha^{-1}$*	*Date of application*	
1	Default variant	-	-	-
2	Carbon Si (1x)	1 l	6. 8. 2014	-
3	Carbon Si (2x)	1 l	6. 8. 2014	19. 8. 2014
4	Carbonbor Zn, Cu, S	2 l	6. 8. 2014	19. 8. 2014
5	Carbonbor Zn, Cu, S 2x + Insenol	2.0 l + 0.75 l	6. 8. 2014	19. 8. 2014

Samplings and Analyses

During the vegetation period, samples of the plants were taken. Sampling was performed on the following dates: 24. 7., 5. 8., 19. 8., 5. 9., 19. 9. and 10. 10. 2014, with 3 plants being taken from each variant. The weight of the beet tops and the taproots was determined. The sugar content, soluble ash content and alpha-amino nitrogen content was established from the technological parameters. The harvest took place on the 10. 10. 2014. 10 samples in 3 repetitions were taken from each variant. The harvest area was determined and the yield per hectare was calculated.

The root was subjected to technological analyses. The digestion and alpha-amino nitrogen (α-N) content was measured. The alpha-amino nitrogen content was determined on a Konica Minolta CM 3500d spectrophotometer. The soluble ash content in the beet was determined using an Inolab Level 1 WTW conductometer. Digestion was measured on a POLAMAT – S machine. Aside from the above mentioned technological parameters, the potassium content (c_K) and sodium content (c_{Na}) in the beet juice was measured. Based on these criteria, a calculation the proportion of sugar in molasses was determined (PCM).

The results of the samplings performed during the vegetation period were compiled into tables. The harvest itself was then statistically evaluated and the results were expressed using graphs. The statistical evaluation of the results was performed using the ANOVA method. The evaluation utilized the Statistica 12.0 software (StatSoft, Inc.).

RESULTS AND DISCUSSION

Evaluation of the Dynamics of Growth and Changes in the Sugar Beet Quality during the Vegetation Period

The first application of the agents was intentionally performed only in the first ten days of August. At this time, sugar beet has the most extensive foliage apparatus and it can thus be assumed that the agents and fertilizers applied would be directed through the leaf into the plant and utilized to the maximum. Late application ensured that the fertilizer solution impacted the largest surface of the plant (Hřivna et al. 2012). In this, we work with the assumption that the mechanism for the entry of nutrients into the plant through the above-ground organs is similar to entry through the roots (Vaněk et al. 2002).

It is generally known that beet tops grow mainly in the first half of the vegetation period, after which intensive growth of the root occurs, and the weight of the beet tops decreases. The sugar content in the beet taproot grows extensively only in the second half of the vegetation period (Pulkrábek et al. 2007).

Hřivna et al. (2014)[a] states that extraradical nutrition leads to an increase in the yield and in sugar content. This was confirmed already at the third sampling (19. 8. 2014), i.e. approximately 2 weeks after the first application of foliar fertilizers, by the noticeable effect on the taproot yield. The results of the analyses of this sampling are listed in Table 3. The differences in taproot weight in comparison to the default variant reached up to 200 g. The application of fertilizers also positively affected the sugar content in the taproots, which increased by 1 to 2% when compared to the default variant. The measurements also disproved the suspicion that the content of noxious alpha-amino nitrogen content could increase after the application of fertilizers, as proposed by Hřivna et al. (2014)[a]. The content of alpha-amino nitrogen was very low and almost equal in all the variants.

As Hřivna et al. (2003) state, intensive photosynthesis, which is vital for the subsequent growth of taproots, requires a sufficiently developed and extensive leaf area. This was confirmed by our experiment as well, as the leaf area was in good condition for a long period of time. During the fourth sampling (5. 9. 2014), the lowest taproot weight was again observed on the default variant. The sugar content in the taproots with regard to the sampling time was relatively favourable, and ranged between 16.8 to 17.8%. The highest sugar content was recorded in var. 2 and 3, i.e. after the application of the *Carbon Si* fertilizer.

The last sampling before harvest was performed on the 10. 10. 2014. The results show a positive effect of the fertilizer application on the taproot yield. The results can be found in Table 4. The highest weight was achieved by the variant with repeated application of *Carbonbor Zn, Cu, S*. This variant also had the smallest beet top weight. The sugar content in all variants was between 17.6 and 18.8%. The balanced nutrition and favourable conditions also manifest themselves in the very low alpha-amino nitrogen content. Thus, the suspicions expressed by Pospíšil et al. (2005) regarding fertilization by nitrogen potentially increasing alpha-amino nitrogen content, which has strong molasses-forming properties, have not been confirmed.

Table 3 Analysis of sugar beet (19. 8. 2014)

Var.	*Taproot weight (kg)*	*Beet top weight (kg)*	*Sugar content (%)*	*α-N (mg·100g^{-1})*
1	0.590	0.493	14.6	20
2	0.677	0.460	16.8	20
3	0.780	0.737	15.8	20
4	0.793	0.583	16.0	20
5	0.770	0.630	16.4	20

Table 4 Analysis of sugar beet (10. 10. 2014)

Var.	*Taproot weight (kg)*	*Beet top weight (kg)*	*Sugar content (%)*	*α-N (mg·100g^{-1})*
1	0.803	0.397	17.8	15
2	1.023	0.410	18.2	20
3	1.160	0.437	18.8	15
4	1.267	0.367	17.8	20
5	1.100	0.497	17.6	15

Evaluation of the Harvest Results

The experiment crops were harvested on the 24. 10. 2014. The results are presented in the following graphs (Figure 1–8).

The lowest beet top weight (Figure 1) was found on variant 2 (38.2 t·ha^{-1}), where the *Carbon Si* agent was applied; the highest values were obtained from the default variant (45.2 t·ha^{-1}). Similar results have been published by Hřivna et al. (2014)[b].

The taproot yield is shown in Figure 2. After the application of extraradical nutrition, the taproot yield increased in all variants. The highest yield was detected in variants 3 (147.7 t·ha^{-1}) and 2 (140.3 t·ha^{-1}), i.e. after the application of the *Carbon Si* fertilizer. Even though the experiment is on a small-plot scale, the yields were above standard. Chochola (2010) reports significantly lower yields in their experiments.

The technological quality of the sugar beet is further determined by a set of factors which significantly influence its processability and determine the total sugar yield. Dornas et al. (2007) quote 20–22% as the obtainable levels of sugar content in taproots; however, these concentrations cannot be achieved in our conditions.

The sugar content ranged from 17.73–18.40% (Figure 3), similarly to the values reported by Pulkrábek et al. (2007). Higher sugar content was detected after extraradical nutrition by Hřivna et al. (2014)[b]. The sugar content was the highest in variant 5 with repeated application of *Carbonbor Zn, Cu, S* and *Insenol*. The higher sugar content corresponded with the fact that this variant achieved the lowest taproot yield out of all the treated variants.

Sugar content and taproot yield are the decisive factors in the calculation of the polarization sugar production per hectare. In this respect, the least effective treatment was the application of *Carbon Si* once (variant 2) during the vegetation period (Figure 4). All variants with extraradical nutrition, however, showed a significantly higher polarization sugar yield than the untreated default version. The sugar beet had very high sugar content even in high taproot yield, resulting in very high polarization sugar yield. Hřivna and Cerkal (2009) report a polarization sugar yield of 10–11 t·ha^{-1}, i.e. lower values than those found in our experiment. Similarly, Chochola (2010) has obtained a lower polarization sugar yield of approximately 15 t·ha^{-1}.

However, the calculated yield of polarization sugar is not the decisive factor; it is the refined sugar production, dependent on the purity of the beet juice, that is key. The amount of losses during production is decided by the amount of soluble ash and alpha-amino nitrogen, i.e. substances with high molasses-forming properties which lower the yield of sucrose from taproots. The alpha-amino nitrogen content in all variants was at a low level (15–20 mg·100g^{-1}) during the whole vegetation period. The lowest value was detected in the variant with double *Carbon Si* application. The very low alpha-amino nitrogen values can be attributed to the N_{min} limit content in the soil and high biomass production in the root and the beet tops in the given year. Similar data is reported by Hřivna et al. (2012). On the other hand, experiments performed by Hřivna and Pechková in 2013 have shown high amounts of noxious nitrogen. The time of origin thus played a key role here.

The potassium and sodium content in the juice were also low, with potassium concentration ranging between 2.5 and 3.5 mmol·100g^{-1}; similar results were obtained by Artyszak et al. (2014). The beet-cultivating institute Semčice lists average potassium values of 3–5 mmol·100g^{-1}, which is also confirmed by Hřivna and Cerkal (2009). The decisive factor of the total sugar yield obtained when processing sugar beet in the sugar refinery is the proportion of sugar in molasses (PCM). From it stems the total production white sugar, which can also be expressed as the production of refined sugar per hectare. The losses, expressed as the proportion of sugar content in molasses (PCM), are indicated in Figure 5. The sugar content in molasses reached a maximum of under 1%, which is exceptional. The values generally range between approximately 1.3–1.5%. Hřivna and Cerkal (2009) quote even higher values of ca 1.9% and Cerkal et al. (2007) give values of up to 2.4%.

The low losses have positively reflected on the total refined sugar yield per hectare (Figure 6), which was the highest in variant 3, i.e. after repeated application of the *Carbon Si* fertilizer. Adamčínová et al. (2010) also achieved a similar refined sugar yield.

Figure 1 Beet top yield

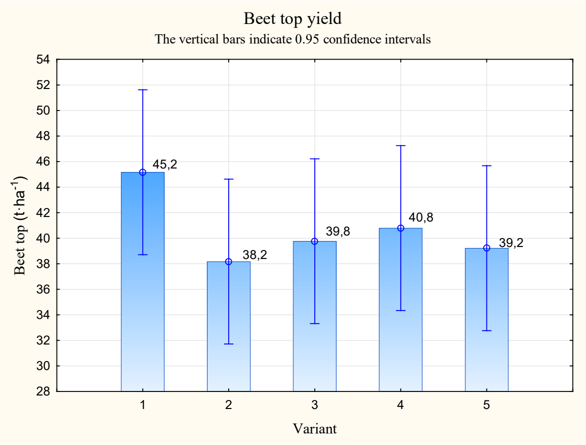


Figure 2 Taproot yield

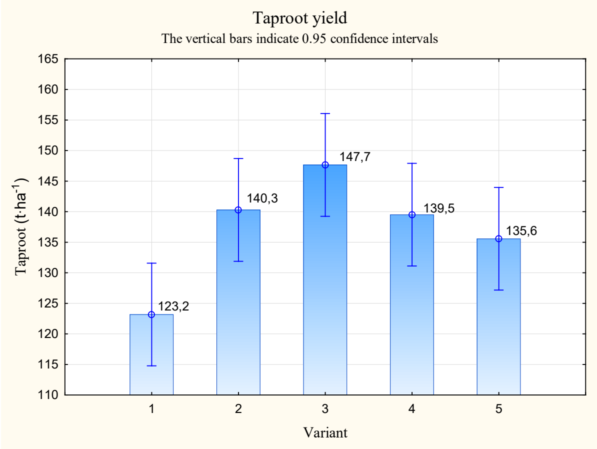


Figure 3 Sugar content

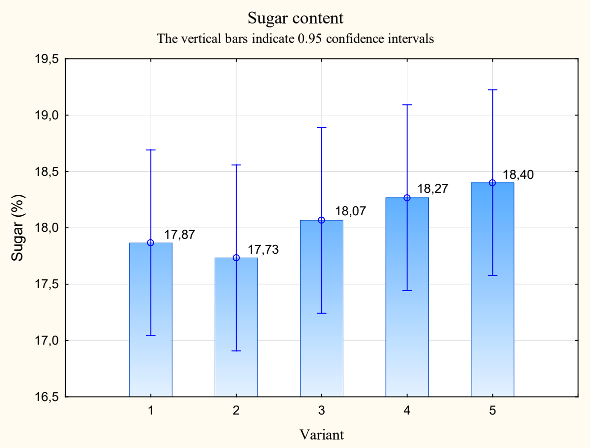


Figure 4 Polarization sugar content

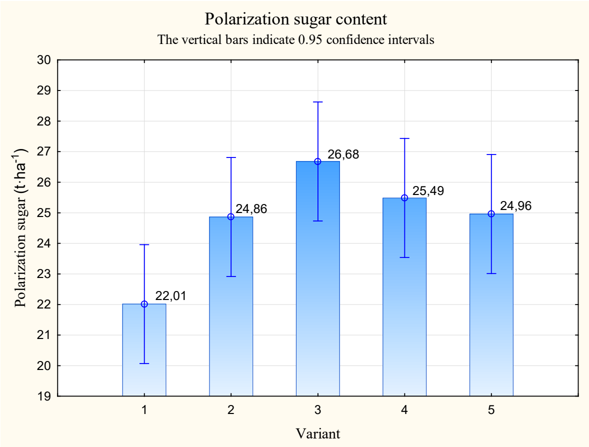


Figure 5 Proportion of sugar in molasses

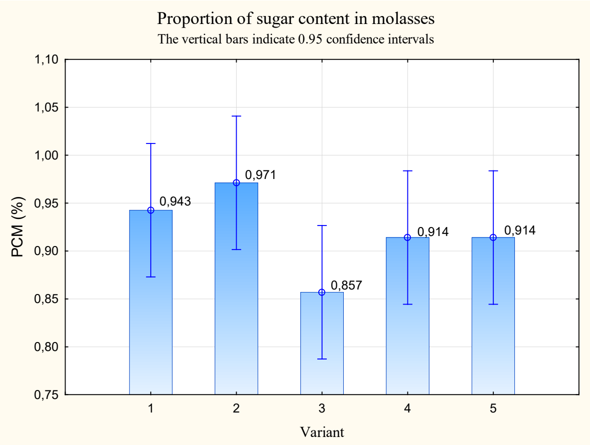
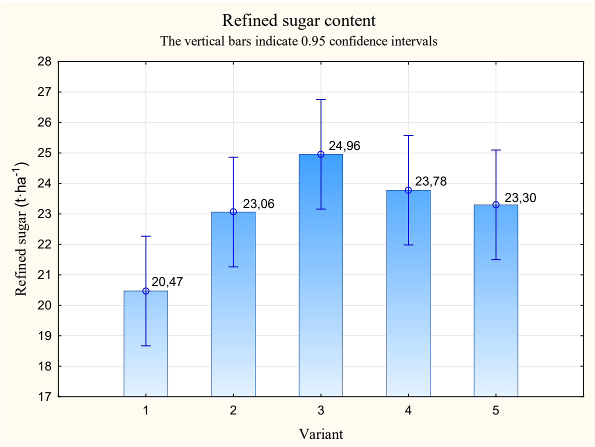


Figure 6 Refined sugar content



CONCLUSION

The aim of the experiment was to monitor the production of taproot yield and the dynamics of changes in taproot quality during the vegetation period, as well as the yield and quality of sugar beet after the harvest after the application of extraradical nutrition.

The experiment has shown that the best results have been achieved by variant 3 with repeated application of foliar fertilizer *Carbon Si*. All the variants treated have shown better results in almost all analyses and measurements when compared to the untreated default variant. The results thus confirm the influence of extraradical nutrition and its effects on yield and quality of sugar beet.

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