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SUGAR BEET RESPONSE TO BALANCED NITROGEN FERTILIZATION WITH PHOSPHORUS AND POTASSIUM. PART II. DYNAMICS OF BEET QUALITY

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Abstract

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The key objective of the study was to evaluate the seasonal course of quality characteristics of storage root of sugar beet to imbalanced fertilization. The field trial arranged as one-factorial design was consisted of eight treatments: $N_0P_0K_0$; $N_0P_1K_1$; $N_1P_0K_1$; $N_1P_1K_0$; $N_1P_{0.25}K_{0.25}$; $N_1P_{0.5}K_1$; $N_1P_1K_1$ and $N_1P_1K_1$+Ca; where 1 is recommended level of NPK fertilization and Ca means that phosphorus applied as partially acidulated phosphate rock, (PAPR). The consecutive sampling of sugar beet was conducted at following days after sowing: 92, 113, 134, 155 and 175. At each sampling date concentration of sucrose (SC) and molassigenic compounds such as α-amino-N, K and Na were determined. The course of SC during vegetation was best described by the Tangh regression model. Based on it, the optimum day after sowing for the maximum SC concentration was fixed at 172 and at 18.6%, respectively. Beet concentration of K showed a linear trend. The in-season courses of α-amino-N and Na were highly specific, being optimal for the fully balanced treatment, i.e., $N_1P_1K_1$. The in-season assessed relationships between SC and α-amino N, and K underwent at 155 DAS a change from positive to negative. This period of sugar beet growth can be, therefore, considered as the borderline between the phase sucrose accumulation sink build-up and its fill-up. The lowest white (extractable) sugar concentration of 0.8% was noted for the $N_1P_1K_0$ as compared to the $N_1P_{0.5}K_1$ treatment. This dependency implicitly indicates on importance of K current fertilizing for sucrose accumulation. The slightly lower effect of $N_1P_1K_1$ treatment (-0.3%), indirectly indicates on non-suitable conditions for sugar beet growth, limiting sucrose accumulation in the late-season. The main reason was drought in two of tree years of study, reducing the yield forming effect of P.

Key words: sucrose concentration, α-amino nitrogen, potassium, sodium, sugar losses

Introduction

The quality of sugar beets delivered by farmers to the sugar factory is one of the most important indicators of sugar production efficiency. In general, quality characteristics of storage roots are simply divided into two main groups: outer and internal - chemical (Anonim, 1995). The first one refers to morphological parameters of the storage root, share of mineral impurities and pathogens' infection. The second one comprises set of characteristics such as sucrose concentration (SC) and numerous non-sugars, termed as molassigenic compounds. In the standard factory procedure, the concentration of α-amino-N (AmN), K, and Na are considered as the most important factors of molasses sugar losses (Buchholz et al., 1995). The storage root contains numerous soluble N compounds, of which dominates amino-acids (40% of the total amount) and betaine (30%) and many others. However, in the standard procedure of sugar molasses loss calculation only the AmN is determined (Hoffmann and Märländer, 2005). All these compounds, including K and Na, termed as non-sugar impurities increase the molasses sugar losses, in turn decreasing efficiency of white sugar recovery from beets during processing (Barłóg and Grzebisz, 2001; Hoffmann, 2005; Macăk et al., 2007). The determined

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content of these four compounds is a basis for calculation synthetic indices as criteria of sugar beet quality evaluation. The most frequently used indices are i) the standard sugar molasses loss (SML), ii) sugar recovery rate (SRR), and finally iii) white sugar concentration (WSC) (Anonim, 1995; Bucholz et al., 1995).

The quality of sugar beets is, in general, defined by its genotype (Bell et al., 1996). However, the storage root chemical composition, in spite of strong genetic background, is highly sensitive to impact of environmental factors (Hoffmann and Märländer, 2005). Effect of soil properties and agronomic factors is the best investigated for N. It is well recognized that beet yield is highly sensitive to supply of N, responding quantitatively to its rate. At the same time, the beet quality shows high inconsistency. The application of fertilizer N, especially above its optimum for maximum yield results in reduced SC and increased concentration of impurities, such as AmN, K and Na (Jaggard et al., 1999; Hoffman, 2005; Malnou et al., 2008). Therefore, the most important challenge for sugar beet growers is to develop an efficient strategy of N application, keeping both yield and the quality of the storage root (Märländer et al., 2003; Grzebisz et al., 2012).

It is, in general, assumed that sugar beet responds positively to application of P and K (Draycott and Christenson, 2003). This view on sugar beet quality is supported by numerous facts, underlying a positive effect of both nutrients on N metabolism, in turn decreasing concentration of soluble N compounds (Beringer, 1987; Herlihy, 1992; Römer et al., 2004). Field experiments, concerning the sugar beet responses to application of P and K, however, are inconsistent. The final effect of P and K on beet quality depends on interaction of soil properties (pH, content of available P and K), and the degree of N balancing by P and K during the critical stages of yield formation (Giroux and Tran, 1989; Macăk et al., 2007; Barłóg et al., 2010).

The main aim of the conducted study was to evaluate the dynamics of sugar beet technical quality characteristics over the course of the growing season on the background of constant rate of fertilizer N and imbalanced rates of P and K.

Materials and Methods

The conducted study basis on data obtained from the field static experiment, which was carried out in private farm at Wieszczyczyn (52°02'N; 17°05'E) during three consecutive growing seasons 2001, 2002, 2003. The basic information about weather and soil condition the conducted experiments are described in details in the first part of this study (Barłóg et al., 2013). A completely randomized experimental design was employed with four replications and area of 54 m^2 per plots. The field trial, arranged as one-factorial design, replicated four times, consisted of eight following treatments:

A. absolute control, i.e. no applied fertilizers (acronym $N_0P_0K_0$)
B. nitrogen control, 100% of recommended level of P and K ($N_0P_1K_1$)
C. phosphorus control, 100% of recommended level of N and K ($N_1P_0K_1$)
D. potassium control, 100% of recommended level of N and P ($N_1P_1K_0$)
E. 100% of recommended level of N but 25% of P and K ($N_1P_{0.25}K_{0.25}$)
F. 100% of recommended level of N and K but 50% of P ($N_1P_{0.5}K_1$)
G. 100% of recommended level of NPK ($N_1P_1K_1$)
H. 100% of recommended level of NPK, P applied as PAPR ($N_1P_1K_1$+Ca).

The recommended level of each nutrient in the successive years of study (2001/2002/2003) amounted to: 150/150/120 kg N ha^{-1}; 60/60/80 kg P_2O_5 ha^{-1} and 180/180/300 kg K_2O ha^{-1}. The rate of N, P and K was calculated both on agrochemical properties of soils and nutrient requirements of sugar beets yield at the level of 60 Mg·ha^{-1}. Phosphorus was applied as single superphosphate (20% P_2O_5), except $N_1P_1K_1$+Ca treatment – P was applied as 50% partially acidulated phosphoric rock (PAPR); K as muriate of potash (60% K_2O), and N as ammonium nitrate (34% N). Phosphorus and K fertilizers were applied in autumn, after the harvest of the fore-crop (winter wheat). Nitrogen was applied at two dates: i) before sugar beet sowing (60% of recommend levels) and ii) at the 4-6 leaf growth stage.

Sugar beet plants (Kassandra variety) were sampled at 92, 113, 134, 155 and 175th day after sowing (DAS) within an area of 3.6 m^2 and 7.2 m^2 at the last date. At each date beet samples (25-30 storage roots per treatment) were transferred to the factory's tare house for determination of the standard beet quality characteristics, i.e. concentration of sucrose (SC), α-amino-N (AmN), K and Na on the fresh matter (FW) basis. Analyses were conducted by a Venema automatic beet laboratory system (Typ IIG). Samples of beet were washed; next beet brei was prepared and clarified with 0.3% $Al_2(SO_4)_2$ solution. The K and Na concentrations were determined by flame photometry and AmN was analyzed by the fluorometric ortho-phthaldialdehyde (OPA) method. The SC was determined by polarimetry. Standard sugar molasses loss (SML) and sugar recovery rate (SRR) were calculated according to formulas (Bucholz et al., 1995):

$$SML = 0.12\,(K + Na) + 0.24\,AmN + 1.08 \qquad (1)$$

$$WSC = SC - SML \qquad (2)$$

$$SRR = WSC \cdot 100 / SC, \qquad (3)$$

where SML is standard molasses loss (%); K + Na is sum of potassium and sodium concentration in beet (mM 100 g^{-1} in beet fresh matter); AmN is α-amino-N concentration in beet (mM 100 g^{-1} in beet fresh matter); SC is sucrose concentration (% in beet fresh matter); WSC is white sugar concentration (% in beet fresh matter); SRR is sugar recovery rate (%).

A one-way ANOVA was carried out to determine the effects of NPK fertilization. The year-to-year variability has been evaluated by standard error of the mean (SE) and coefficient of variability (CV, %). Linear regression was performed in order to find out relationships between beet K concentration and DAS. In order to describe the relationship between SC and DAS, two statistical models were fitted: quadratic (Q) and Tanh (T). From the estimated coefficients a, b and c, following variables were calculated: SC_{max} – maximum of sucrose concentration (% FW) and DAS_{opt} – number of days after sugar beet sowing for SC_{max}. All these parameters were computed using the formulas presented below:

a. the quadratic model (Q):

$$SC = a + b\ DAS + c\ DAS^2 \quad (4)$$

$$DAS_{opt} = - b/2c \quad (5)$$

$$SC_{max} = -\Delta/4c \quad (6)$$

b. the Tangh model (T):

$$SC = a + b\ [\ \tanh (c \cdot DAS)\ ] \quad (7)$$

$$SC_{max} = a + b \quad (8)$$

$$DAS_{opt} = \ \rightarrow \infty \text{ (it's really 175 DAS).} \quad (9)$$

Results and Discussion

Concentration of sucrose

Sucrose concentration in the storage root is positively related to the number of rings in root cambium but negatively with the size of a parenchyma cell (affecting diameter of a root). The first characteristic is genetically fixed, and the second undergoes a modification via action of environmental factors (Bell et al., 1996). The SC in the cell, i.e., into the vacuole, is a result of its balance with other active osmotic compounds (K and Na ions). Throughout vegetation, there is an exchange between osmotic compounds and progressively allocated sucrose (Bloch and Hofmann, 2005). The study implicitly corroborated the progressive increase of SC in beets over the growing season (Figure 1). The experimental data fitted fairly well two regression models, quadratic (Q) and Tanh (T):

$$\text{Q. } SC = -2.381 + 0.217\ DAS - 0.00057\ DAS^2; \ R^2 = 0.67; n = 120 \quad (10)$$

$$\text{T. : } SC = -11.53 + 30.45\ [\ \tanh (0.0117 \cdot DAS)]; \ R^2 = 0.71; n = 120 \quad (11)$$

The main advantage of the first regression model is the ease of an optimum number of days after sowing (DAS_{opt}) for the maximum sugar concentration (SC_{max}) calculation. According to the Q model, the DAS_{opt} occurred at 189 DAS, i.e., far beyond the growing season. According to the second model (T), in spite of its complicity, the DAS_{opt} occurred at 172 DAS, resulting in SC_{max} of 18.61%.

The main factor affecting SC was a year, i.e., weather course during the growing season. This is in agreement with the opinion presented by Mäck and Hoffmann (2006). Sucrose concentration in beets at 92 DAS was 11.8%, 11.8%, and 13.8% for 2001, 2002 and 2003, correspondingly. This trend was highly conservative quality characteristic, as corroborated by SC at harvest, i.e., at 175 DAS, reaching 17.3%, 17.4%, and 19.4%, respectively. In each of the sampling dates, there was, a significant difference between 2001–2002 and 2003 ($P \leq 0.001$). The elevated SC in 2003 was a result of plant's adaptation to extended drought and concomitant high temperatures (Hajiboland et al., 2009). The factory threshold value of 16% SC was achieved, almost irrespectively of the treatment, at 134 DAS.

Effect of tested fertilizing variants was low as indicated by the lack of the significant R^2 coefficient variability in the Tangh model. However, a positive trend on SC for some treatments has been observed: $N_0P_0K_0$, $N_0P_1K_1$, $N_1P_0K_1$, $N_1P_{0.25}K_{0.25}$ and $N_1P_{0.5}K_1$. The slight negative impact of $N_1P_1K_0$ can be attributed to the N imbalance due to insufficient supply of K, which is in agreement with data reported by (Giroux and Tran, 1989; Herlihy, 1992). In two other treatments, i.e., $N_1P_1K_1$ and $N_1P_1K_1$+Ca supply of N was balanced, but only under ample water conditions, as in 2001. In dry years, it sup-

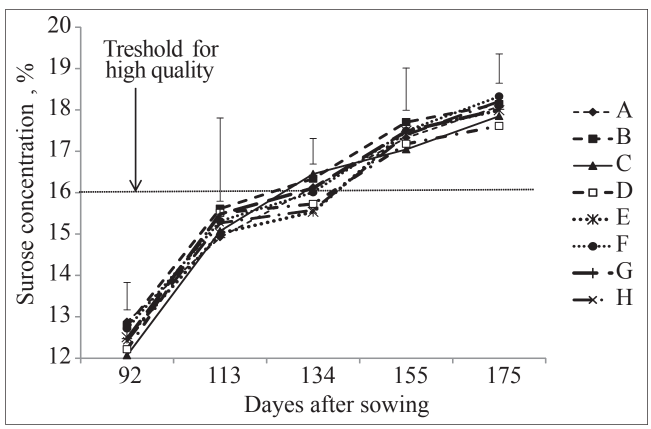

Fig. 1. Dynamics of sucrose concentration (SC) in the beets under different conditions of N imbalance as imposed by P and K fertilizing

In Material and Methods section is detailed explanation of treatment symbols. The vertical bars represent ±SE of the mean plies was too high, in turn reducing, but only slightly sucrose concentration in beets, and corroborates other studies (Mäck and Hoffmann, 2006).

Concentration of α-amino nitrogen

The course of AmN in beets during the growing season, averaged over years, was treatment-specific (Figure 2). It is, in general assumed, that AmN decreases along the storage root maturation (Rother, 1998). However, in this case, its concentration was measured since the 92 DAS, when the root reached the highest absolute rate of growth (Grzebisz et al., 2012). The course of AmN was evaluated by three criteria. The first describes the stage of the AmN maximum. There were found two maxims: i) at 113 DAS for $N_1P_0K_1$ and $N_1P_{0.5}K_1$, and ii) at 134 for all others. The second criterion describes the order of treatments based on AmN at 134 DAS. It was as follows:

$N_0P_1K_1 < N_0P_0K_0 < N_1P_0K_1 = N_1P_{0.5}K_1 < N_1P_1K_0 = N_1P_{0.25}K_{0.25} = N_1P_1K_1 < N_1P_1K_1$+Ca.

The third criterion describes the course of AmN during the declining phase. Three patterns have been distinguished based on the shape of the trend:

1) constant decrease: $N_0P_0K_0$, $N_1P_{0.25}K_{0.25}$, $N_1P_1K_1$;
2) decrease and stagnation since 155 DAS onwards: $N_1P_0K_1$ and $N_1P_{0.5}K_1$;
3) decrease and secondary increase since 155 DAS onwards: $N_0P_1K_1$, $N_1P_1K_0$, $N_1P_1K_1$+Ca.

We formulated a hypothesis, that AmN in the storage root is an N reserve, used by a plant for the root growth. It has also been assumed that values of AmN below 14.5 mM kg^{-1} of FW mean plant N malnutrition (Anonim, 1995). The study

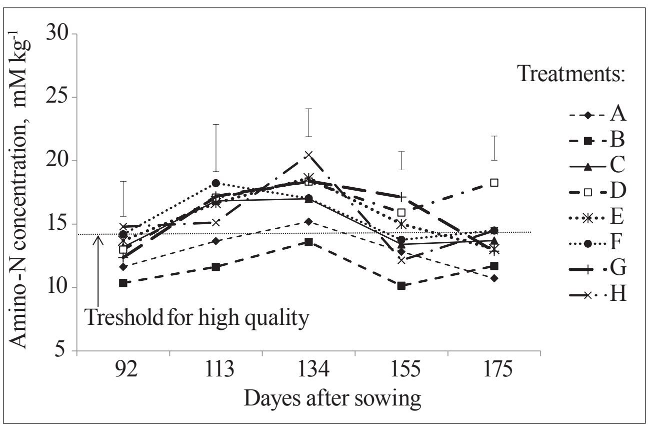

Fig. 2. Dynamics of α-amino-N concentration (AmN) in the beets under different conditions of N imbalance as imposed by P and K fertilizing.

In Material and Methods section is detailed explanation of treatment symbols. The vertical bars represent ±SE of the mean

showed the highest average beet yield in-growth in August, from 113 to 134 DAS (Barłóg et al., 2014). Based on these two sets of data the temporary yield of roots (BY_{134}) was regressed against AmN:

$$BY_{134} = 90.59 - 22.94\ \text{AmN}; \quad R^2 = 0.60;\ P \leq 0.001;\ n = 18 \qquad (12)$$

The obtained equation implicitly corroborates the presented above hypothesis. Therefore, much higher concentration of AmN in beets, as found in dry years (2002, 2003), resulted from too slow rate of the root biomass in-growth. It is supposed that N reserves were not used for cell's growth, in turn limiting the space for sucrose accumulation. In can be, thus, chosen a conclusion that secondary increase in AmN is an indicator of technical immaturity of the root. This was the most pronounced for the $N_1P_1K_1$+Ca treatment. In this particular plot, the root showed, the highest average AmN of 20.5 mM kg^{-1} of FW and the highest in-season variability (CV = 26%). Such high concentration is typical for the upper stem, indirectly indicating a status of N resources for the root growth (Mahn et al., 2002). The $N_1P_1K_1$ plot can be considered as the standard of AmN course during the growing season. This conclusion is corroborated by following facts: i) elevation at 134 DAS, i.e., at the stage of the highest rate of storage root in-growth, ii) sufficiently high concentration at 134 DAS, indicating N reserves, decisive for growth of the root sugar accumulation sink, iii) low in-season variability (CV ≈ 4%). The variability of AmN in the root at 134 DAS above the standard, defined by the $N_1P_1K_1$, was due to insufficient supply of N, in turn decreasing the size of the sugar sink, as found for plots without N fertilizer. In other treatments, N management was disturbed due to its imbalance, caused not only by K and P, but also by Ca. The last nutrient implicitly corroborates the importance of Ca for N management in sugar beet.

Concentration of potassium

Potassium concentration in the storage root showed since the beginning of observation, i.e., following the 92 DAS a constant declining trend (Figure 3). This tendency clearly proves that sucrose accumulation in beet parenchyma cells occurred in expense of potassium replacement (Bell et al., 1996). In the mead-season concentration of K in beets was, in general, higher than the threshold of 45 mM kg^{-1} FW (Anonim, 1995), indicating a good K supply condition. At 134 DAS effect of seasonal variability was low, as indicated by the coefficient of variation (CV), which ranged from 3% for the $N_1P_{0.25}K_{0.25}$ to 11% for the $N_0P_1K_1$. At harvest, beet reached the lowest K concentration, but it showed year-to-year variability. In 2001, it was, averaged over treatments, the highest, amounting to 46 mM kg^{-1} FW.

The lowest of 35 mM kg^{-1} FW was noted in 2002 ($P \leq 0.01$). These two figures clearly underlined the fact, that water shortage significantly decreases K uptake by sugar beets from soil resources, in turn negatively impacting the root physiological sink for sucrose accumulation (Barłóg et al., 2013).

The trend of K concentration has been evaluated using the linear regression model (Table 1). The fit-goodness, as indicated by the R^2 coefficient, was significant, but ranging from 0.71 for $N_1P_1K_1$ down to 0.34 for $N_1P_1K_1$+Ca. In addition the directional coefficient of the trend (the parameter b in equation), for the balanced treatment was the highest, indirectly indicating a high rate of sugar accumulation in parenchyma cells. Moreover, both characteristics of the developed equation, circuitously underlined the importance of P for molassigenic compound's management. The lowest value of R^2, as found for $N_1P_1K_1$+Ca results from its high year-to year-variability, especially in the mead-season. In addition, the directional coefficient b was low, at the level noted for $N_0P_0K_0$. This relationship suggests a slow K/sucrose exchange due to Ca action. The analysis of the obtained trends showed the highest differences in K concentrations between two treatments $N_0P_1K_1$ and $N_1P_1K_0$. This result implicitly corroborated a hypothesis of interaction of N and K, and indirectly indicating a phenomenon termed as the dilution effect.

Concentration of sodium

The course of Na concentration in fresh biomass of the storage root was both year-to-year variable and treatment-specific (Figure 4). According to Bloch and Hofmann (2005), beet Na concentration decreasing during season, but lees compared to K concentration. In our study, the highest Na concentration and its variability revealed at 113 DAS. At this

Table 1
Models of beet K concentration during vegetation season (n = 15)

Treatment	Equation	R^2 ($P \leq 0.01$)	DASt
$N_0P_0K_0$	K = 71.930 – 0.182 DAS	0.57	148
$N_0P_1K_1$	K = 64.886 – 0.150 DAS	0.64	132
$N_1P_0K_1$	K = 74.960 –0.207 DAS	0.67	146
$N_1P_1K_0$	K = 76.543 – 0.229 DAS	0.59	138
$N_1P_{0.25}K_{0.25}$	K = 83.349 – 0.257 DAS	0.62	149
$N_1P_{0.5}K_1$	K = 77.844 – 0.221 DAS	0.45	149
$N_1P_1K_1$	K = 77.844 – 0.270 DAS	0.76	148
$N_1P_1K_1$+Ca	K = 71.721 – 0.181 DAS	0.34	148

K is beet potassium concentration, mM kg^{-1}; DAS is number days after sowing; DAS_t is number of days after sugar beet sowing for threshold = 45 mM K kg^{-1} of FW

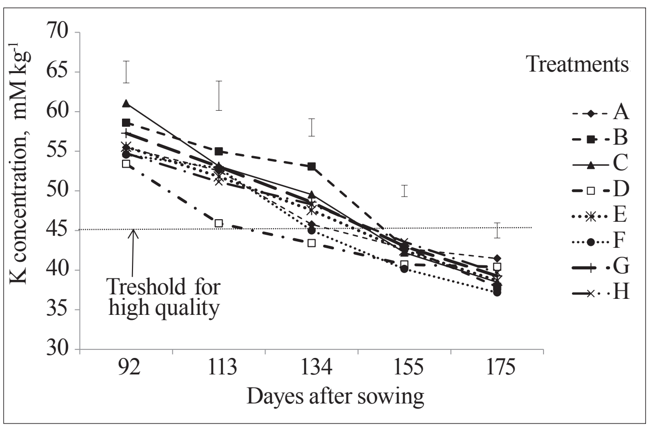

Fig. 3. Dynamics of K concentration in the beets under different conditions of N imbalance as imposed by P and K fertilizing

In Material and Methods section is detailed explanation of treatment symbols. The vertical bars represent ±SE of the mean

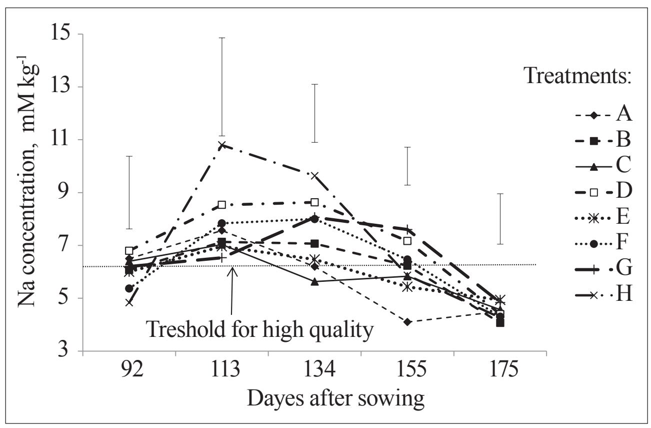

Fig. 4. Dynamics Na concentration in the beets under different conditions of N imbalance as imposed by P and K fertilizing

In Material and Methods section is detailed explanation of treatment symbols. The vertical bars represent ±SE of the mean sampling date, the variation coefficient ranged from 10% for $N_0P_0K_0$ and $N_1P_1K_1$ to 86% for $N_1P_1K_1$+Ca. At harvest, Na concentration dropped down below the threshold value of 6.5 mM kg^{-1}. At this particular date, its year-to-year variability was much lower, ranging from 44% for the absolute control ($N_0P_0K_0$), through 37% for unbalanced N treatments such as $N_1P_0K_1$ and $N_1P_1K_0$ down to 10% for the $N_0P_1K_1$. Effect of fertilizing treatments on Na concentration course has been assessed by two criteria. The first describes the stage of its maximum. For $N_0P_0K_0$, $N_1P_0K_1$, $N_1P_{0.25}K_{0.25}$ and $N_1P_1K_1$+Ca the top elevation was noted at 113 DAS. For remaining four, i.e., $N_0P_1K_1$, $N_1P_1K_0$, $N_1P_{0.5}K_1$, $N_1P_1K_1$ at 134 DAS. The second criterion describes the mode of its declining from 134 DAS towards the maturity. There has been distinguished three types of response:

a. fast: $N_0P_0K_0$, $N_1P_{0.5}K_1$, $N_1P_1K_1$+Ca;
b. moderate or variable: $N_0P_1K_1$, $N_1P_0K_1$, $N_1P_{0.25}K_{0.25}$;
c. low: $N_1P_1K_0$, $N_1P_1K_1$.

The most interesting is the third group. It is well recognized that lack of K fertilizer ($N_1P_1K_0$) increased Na accumulation in beets (Herlihy, 1989). However, the course of Na concentration in $N_1P_1K_1$ treatment was different compared to all others. The highest increase of its concentration took place in August, following by stabilization up to 155 DAS. As in the case of AmN and K, Na course was for this particular treatment the most specific, characterized by the lowest CV at harvest and low declination rate at the late-season.

Relationships between quality characteristics

The key question of this part of a study is to define relationships between the main quality characteristics of beets throughout the season (Table 2). In the mead-season, i.e., the period with the highest rate of storage root growth, the SC was positively correlated with AmN. It was positive up to 155 DAS, when changed into negative. The same time-depended tendency was found for SC and K. In addition, through the whole season, the concentration of AmN was positively correlated with K. However, the coefficient of correlation declined during plant maturation. This relationship again corroborates the hypothesis of N and K impact on K uptake by plants. At the beginning of the storage root growth N is required by a plant to build-up its physiological sink, which refers to number of parenchyma rings. Potassium impacts both the rate nitrate-N uptake and size of parenchyma cells (Marschner et al., 1996). The sudden change of both relationships, which appeared at 155 DAS, indicates the end of the phase of the physiological sink for sucrose accumulation build-up.

The relationships between Na and SC were much more complicated and inconsistent during the season (Hoffmann, 2005; Bloch et al., 2006). The clear relationship with SC occurred only at 113 DAS, i.e., at the stage of the highest variability of Na concentration. Even more interesting are relationships between Na and AmN, which was positive and significant at the stage of the highest beet yield increase (Barłóg et al., 2013). These results, indirectly corroborate the hypoth-

Table 2
Coefficients of correlation between quality characteristics of the storage root in the course of the growing season (n=15)

Number days after sowing	Quality characteristics	Sucrose	AmN	K
92	AmN	0.826***		
	K	0.736***	0.768***	
	Na	-0.238	-0.312	0.005
113	AmN	0.750***		
	K	0.404	0.566**	
	Na	0.487*	0.289	-0.133
134	AmN	0.302		
	K	0.572**	0.227	
	Na	-0.100	0.422*	-0.415*
155	AmN	-0.428*		
	K	-0.801***	0.229	
	Na	-0.519**	0.586**	0.437*
175	AmN	-0.314		
	K	-0.237	0.114	
	Na	-0.273	-0.249	0.618**

Level of significance: * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$

esis about impact of sodium on N metabolism in sugar beet (Barłóg, 2013). Therefore, its effect on SC can be only explained by simultaneous evaluation of AmN variability. The analysis of K and Na relationships showed even more complicated pattern. It was negligible or negative up to the end of the mead-season (August) and suddenly change into positive in the late-season. The most negative relationship, which occurred at 134 DAS, indicates an antagonism between both nutrients (Draycott and Christensen, 2003). Analysis of data on root biomass at this particular period of sugar beet growth suggests a negative impact of Na on size of cells, in turn leading to decrease capacity of root for sucrose accumulation (Tsialtas and Maslaris, 2009). The positive relationships can be explained only by high rate of sucrose accumulation in the root in expense of both nutrients, which predominates in the late-season, provided a good supply of P.

Standard molasses loss and sugar recovery

Based on quality characteristics, there have been calculated three synthetic parameters: sugar molasses loss (SML), sugar recovery rate (SRR), white sugar concentration (WSC). With respect to SML, its values showed a high conservancy during the growing season, ranging from 2.17% at 113 DAS down to 1.93% at 175 DAS. Therefore, the average technical quality of processed beets represents over the whole season the good class (Anonim, 1995). On the average, the SRR index showed an increasing trend throughout the season. It raised from 82.9% at 92 DAS, through 88.4% at 155 DAS up to 89.2 at 175 DAS. The last values represent "the very good" class of beet's technical quality (Anonim, 1995). At this particular stage, among the studied treatment, slightly worse SRR value was found for roots harvested in the $N_1P_1K_0$ treatment (Table 3).

The white sugar concentration (WSC) increased throughout the course of sugar beet maturation, rising from 10.4% at 92 DAS to 16.1% to 175 DAS). At harvest, the highest WSC index was found for beets harvested in the $N_1P_{0.5}K_1$ (16.4%) and the lowest for $N_1P_1K_0$ (15.6%) (Table 3). This result indirectly corroborates the importance of K in formation of sugar beet quality (Beringer, 1987; Wiebel and Orlovius, 1997; Nikolova, 1999; Römer et al., 2004). Plants grown in $N_1P_1K_1$ treatment showed the WSC index lower by 0.3%. This decrease can be explained by unfavourable weather conditions in two of three years with study, which disturbed beet's capability to accumulate in the late-season. The only sufficiently large size of a root is a prerequisite for efficient use of P (Table 3).

Conclusion

The course of SC, in spite of year-to-year variability, was only slightly affected by the structure of applied nutrients. It shape was the best described by the Tangh regression model. The optimum day, calculated based on this function, revealed at 172 DAS with SC_{max} of 18.6%. Each of the studied standard molassigenic compounds showed a specific course during the growing season. The only K concentration in beet brei declined linearly since 92 DAS onwards. For AmN and Na, there were found fixed maxims. The optimum course for all three compounds was found for plants grown in the $N_1P_1K_1$ treatment. In this particular treatment, the concentration of AmN showed an elevated peak in the mead-season, following by a gently decrease in the late-season. Another its attribute was very low year-to-year variability of molassigenic compounds in the late-season. The high significant correlations between α-amino-N and K, which occurred in the mead-season, indicate functions of both nutrients, as factors responsible for physiological sugar sink build-up. At 155 DAS, SC in beets showed a sudden change in relation to both nutrients. This date of growth should, thereby, consider as the borderline between phases of the sucrose accumulation sink build-up and the final fill-up. The importance of Na for sugar beet quality

Table 3
Effect of fertilizing treatments on the mean values of standard molasses loss (SML), white sugar concentration (WSC) and sugar recovery rate (SRR) at harvest of sugar beet (at 175 DAS)

Treatment	SML, %		WSC, %		SRR, %	
	Mean	CV, %	Mean	CV, %	Mean	CV, %
$N_0P_0K_0$	1.89	2.52	16.2	8.4	89.5	1.1
$N_0P_1K_1$	1.86	3.54	16.3	8.6	89.7	0.8
$N_1P_0K_1$	1.93	6.89	15.9	6.6	89.2	1.4
$N_1P_1K_0$	2.06	7.23	15.6	8.9	88.3	1.8
$N_1P_{0.25}K_{0.25}$	1.92	7.23	16.1	10.6	89.3	1.5
$N_1P_{0.5}K_1$	1.93	5.23	16.4	5.6	89.5	1.1
$N_1P_1K_1$	1.92	9.02	16.1	8.0	89.3	1.1
$N_1P_1K_1$+Ca	1.95	7.50	16.3	7.4	89.2	1.6

formation, due to its high year-to-year and in-season variability, is difficult to evaluate. However, its positive relationships with α-amino N suggest an impact of Na on sugar beet N metabolism. Among the studied nutrients, a special attention should be devoted to K. Its lack in the fertilizing program, in spite of high K soil fertility level, resulted in significantly lower white sugar concentration (WSC). Based on the WSC index, it can be concluded that the best-quality material was obtained in the treatment with the full recommended rate K and 50% rate of P. The slightly worse result for the treatments with full of both nutrients was due to extended drought in two of three seasons. As a result of water shortage, occurring in the mead-season, the size of beet storage for SC significantly decreased, in turn negatively affecting WSC.

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