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IMPACT OF NITROGEN FERTILISATION ON THE TECHNOLOGICAL VALUE OF SUGAR BEET CULTIVAR ROOTS

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ABSTRACT

The present field experiment and lab investigations analysed the effect of nitrogen fertilisation at the rates of 0, 80, 160 and 240 kg·ha^{-1} on the technological root value of the following cultivars 'Action', 'Amelia', 'Atair', 'Cordelia', 'Dojana', 'Evita', 'Fontana', 'Gala', 'Hanna', 'Jupiter', 'Nilla', 'PN Mono 4' 'Sofie' and 'Sonja'. 80 and 160 kg·ha^{-1} of N resulted in a significant increase in the single root weight, root yield and the biological sugar yield. Technological sugar yield justified only the application of 80 kg·ha^{-1} of N. The increase in the technological sugar yield at 160 kg·ha^{-1} of N was insignificant, while an increase in N rate up to 240 kg·ha^{-1} made the yield correspond to that obtained for 80 kg·ha^{-1} of N. With rates increasing by further 80 kg·ha^{-1} of N, there were observed increases in the contents of alpha-amino N, sodium and potassium and decreased content of sucrose. The quality of roots depended on the genotype. Sugar beet cultivars differed in their contents of sucrose, alpha-amino N, sodium and potassium and also in the technological sugar yield. The highest yield of white sugar was obtained for homogeneous group cultivars of high sucrose content – 'Hanna', 'Jupiter', 'Sonja' and 'Evita'.

Key words: nitrogen, sugar beet root

INTRODUCTION

Nitrogen applied to sugar beet cultivation remains an essential yield-formation element. Sugar beet nitrogen fertilisation enhances root yield but high nitrogen rates deteriorate the technological quality. Results of numerous studies showed that high-rate nitrogen fertilisation decreases the sucrose content and increases the content of molasses-forming compounds, especially the amount of alpha-amino N. [1,5,7,9,10]. Additionally, intensive nitrogen fertilisation increases the contents of the total nitrogen and nitrate nitrogen in roots. High nitrogen rates increase the share of mineral nitrogen in plants and decrease the ratio between the total nitrogen and nitrate nitrogen, while roots are less physiologically ripe and show a lower processing value. Contemporary sugar beet breeding has been developing new cultivars which would show high root quality [2]. According to Szota [8], the selection of lower-nitrogen-content cultivars is less effective as the nitrogen content in roots depends considerably on nitrogen availability in soil and only reasonable nitrogen sugar beet fertilisation, based on soil analysis, can assure an adequate nitrogen content in roots. There are considerable differences in technological value of new sugar beet cultivars which also show decreased, as compared to earlier cultivars, foliage coefficient, which could suggest a lower demand for nutrients, including nitrogen.

Assuming that fertilisation of those cultivars should account for their technological features as well as genetically determined morphological and physiological properties, the present research was taken up to establish the impact of a varied nitrogen fertilisation on the technological value of several sugar beet cultivars.

MATERIAL AND METHODS

Over 1997-1999 a strict field sugar beet experiment was carried out on good-wheat-soil-suitability complex, II and IIIa soil quality class, brown soil, heavy loamy sand grain size composition in Agricultural Company at Głubczyce. The soil pH in 1M KCl amounted to 5.6-5.9, while K, P and Mg soil richness was medium. After forecrop harvest, the intercrop, white mustard, was sown and autumn-ploughed along with 20 t·ha^{-1} of manure. The phosphorus and potassium fertilisation amounted to 70 kg of P_2O_5 and 180 kg·ha^{-1} of K_2O, respectively.

The experiment was set up in split-plot design in 4 replications. The plot covered 29.8 m^2. The first factor included four N rates: 0, 80, 160 and 240 kg·ha^{-1} and the second one – fourteen sugar beet cultivars: 'Action', 'Amelia', 'Atair', 'Cordelia', 'Dojana', 'Evita', 'Fontana', 'Gala', 'Hanna', 'Jupiter', 'Nilla', 'PN Mono 4' 'Sofie' and 'Sonja'. The organic and 240 kg·ha^{-1} of N fertilisation applied followed the sugar beet agricultural practices of the Agricultural Company.

Spring N fertilisation was carried out as pre-planned. 80 kg·ha^{-1} of N was applied before sowing, 160 kg·ha^{-1} of N was divided into two – 80 kg – prior to sowing and 80 kg – over 2-4 leaf phase in the second decade of May. 240 kg·ha^{-1} of N was split into three rates – the first and second ones were applied as 160 kg rate, while the third of 80 kg·ha^{-1} of N - over 6-8 leaf phase in the first decade of June.

The essential criteria defining the impact of the factors studied included mean single-root weight, root yield, biological sugar yield and technological sugar yield – calculated following the Reinefeld formula [3,4], sugar content – with the polarimetric method as well as alpha-amino N, potassium and sodium contents – with photocolorimetric method (CECIL CE 2010 photocolimeter). Sucrose-processing losses due to an increase, due to increasing nitrogen rates, in alpha-amino N as well as potassium and sodium contents were calculated following the Reinefeld formula. The results were statistically analysed with Statgraphics 5.0 and tested with the Tukey test at p=0.05.

RESULTS

The rainfall and its distribution over 1997-1999 differed considerably. Over successive vegetation periods of 175, 169 and 182 days, the rainfall of 438.8, 346.8 and 277.9 mm was recorded. Under the experimental soil conditions, however, there were observed no essential plant vegetation disturbances due to weather conditions. Similarly there were noted no significant changes in the technological root value over the research period.

The weather conditions and plant vegetation affected the sugar beet root yield significantly. The highest root yield was obtained in 1998 - 70.83 t·ha^{-1} and the lowest one in 1999 - 58.45 t·ha^{-1}. The factors examined did not cause variation in the plant density which amounted to 94 – 99 thousand plants per ha. The technological value of roots, used in the sugar industry, depended on the nitrogen fertilisation and genetically-conditioned cultivar properties. The highest-sugar-content (more than 19%) (Table 1) homogenous group consisted of ‘Hanna’, ‘Jupiter’, ‘Sonja’ and ‘Evita’, while a more numerous lowest-sugar-content (17.52 - 18.41%) group - ‘Fontana’, ‘Action’, ‘Atair’, ‘Sofie’, ‘Cordelia’, ‘Dojana’, ‘Amelia’, ‘PN Mono 4’ and ‘Gala’. The difference in sugar content across cultivars, ‘Fontana’ through ‘Hanna’, amounted to about 2%. The sugar content in roots of the cultivars examined was affected by nitrogen fertilisation. As for non-fertilised objects, the difference between the highest (‘Jupiter’ - 20.51%) and the lowest (‘Action’ -18.56%) sugar contents amounted to 1.95%. A considerably greater sugar content difference, 3.19%, was observed across cultivars fertilised with 80 kg·ha^{-1} of N, where ‘Jupiter’ contained 20.23% of sugar and ‘Atair’ - 17.04%. A double N rate, 160 kg·ha^{-1} resulted in a respective cross-cultivar sugar content difference of 2.04%, while 240 kg·ha^{-1} - of 3.18%. The highest decrease in the sugar content, as compared with the control, due to increased fertilisation up to 240 kg·ha^{-1} of N was recorded for ‘Amelia’ (3.78%) and ‘Dojana’ (3.43%). The lowest insignificant sugar content difference due to nitrogen fertilisation was noted for the national sugar beet cultivar ‘PN Mono 4’.

Table 1. Effect of N fertilisation on sugar beet root sugar content, %

Cultivar	N rate, kg·ha^{-1}				Mean	Homogeneous groups
	0	80	160	240		
Fontana	18.78	17.53	17.23	16.54	17.52	a
Action	18.56	17.70	17.55	16.46	17.57	a

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Atair	19.16	17.04	17.87	16.35	17.60	a b
Sofie	19.36	17.91	17.40	16.29	17.74	a b
Cordelia	19.37	18.94	17.25	16.62	18.04	a b
Dojana	19.87	17.96	18.12	16.43	18.09	a b c
Amelia	19.65	19.25	17.88	15.87	18.16	a b c
PN Mono 4	18.95	18.07	18.24	18.32	18.39	a b c d
Gala	19.25	18.71	18.25	17.42	18.41	a b c d
Nilla	19.77	18.81	17.76	17.85	18.54	b c d e
Evita	19.95	19.62	19.27	17.29	19.03	c d e f
Sonja	20.35	20.16	18.48	17.77	19.10	d e f
Jupiter	20.51	20.23	18.84	18.36	19.48	e f
Hanna	20.48	19.87	18.74	19.05	19.53	f
Mean	**19.57**	**18.70**	**18.06**	**17.16**	**-**	**-**
$LSD_{0.05}$	0.38* 1.53 *** 1.65****				0.94**	

LSD * for nitrogen rate; ** for cultivar; * for interaction between nitrogen and cultivar;**
****** for interaction between cultivar and nitrogen**

The cultivar genotype and nitrogen rates also affected the alpha-amino N content (Table 2) whose lowest content was recorded in ‘Hanna’ roots (1.67 mval·100 g^{-1}) and highest – in ‘PN Mono 4’ and ‘Fontana’ roots (2.89 and 2.94 mval·100 g^{-1}). Analysing the control, N non-fertilised objects, the lowest alpha-amino N content was recorded in ‘Hanna’ roots whose low content of this N form was also true for higher nitrogen rates.

Cross-cultivar alpha-amino N content variability depended on the nitrogen rates; non-fertilised object - 0.51 mval·100 g^{-1}, 80 kg·ha^{-1} of N – 1.32 mval·100 g^{-1}, 160 kg·ha^{-1} of N – 1.95 mval·100 g^{-1}, while 240 kg·ha^{-1} of N – 2.70 mval·100 g^{-1} of alpha-amino N. The greatest increase in alpha-amino N content, more than 3-times – for 240 kg·ha^{-1} of nitrogen was observed for ‘Fontana’.

The nitrogen rate affected sodium and potassium content in the cultivar roots (Tables 3 and 4). The content of potassium ranged from 3.91 mval for ‘Gala’ up to 4.87 mval for ‘Nilla’. The lowest increases, as compared with the control, in potassium content for 240 kg·ha^{-1} of N were observed for ‘Gala’ - 0.51 mval, ‘Dojana’ and ‘Evita’ - 0.71 mval, while the highest values for ‘Sonja’ - 2.05 mval. The sodium content increased significantly only when treated with 240 kg·ha^{-1} of N. The lowest sodium content was identified in ‘Hanna’ - 0.66 mval, while twice as much - 1.34 mval in ‘Dojana’ roots. The control root sodium content ranged from 0.54 mval in ‘Hanna’ and ‘Sonja’ up to 1.27 mval in ‘PN Mono 4’. As for 240 kg·ha^{-1} of N, the sodium content range was from 0.90 mval in ‘Hanna’ to 1.92 mval in ‘Fontana’. There was observed no significant sodium content increase due to nitrogen fertilisation in ‘Hanna’, ‘Nilla’ and ‘PN Mono 4’.

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Table 2. Effect of nitrogen fertilisation on alpha-amino N content, mval·100 g^{-1} of root

Cultivar	N rate, $kg \cdot ha^{-1}$				Mean	Homogeneous groups
	0	80	160	240		
Hanna	1.10	1.23	1.82	2.52	1.67	a
Gala	1.40	1.81	1.90	2.42	1.88	a b
Amelia	1.41	1.68	2.07	3.08	2.06	a b
Jupiter	1.44	1.65	2.21	2.87	2.04	a b c
Sonja	1.21	1.81	2.54	3.30	2.22	a b c d
Sofie	1.45	2.23	2.59	2.75	2.25	a b c d
Action	1.56	2.28	2.63	2.75	2.30	a b c d
Nilla	1.43	2.35	2.68	2.86	2.33	a b c d
Atair	1.49	2.30	2.27	3.42	2.37	a b c d
Dojana	1.29	1.75	2.12	4.65	2.45	a b c d
Evita	1.53	1.81	2.50	4.43	2.57	b c d
Cordelia	1.61	2.55	2.68	4.01	2.71	c d
PN Mono 4	1.37	2.37	3.77	4.06	2.89	d
Fontana	1.61	1.91	3.12	5.12	2.94	d
Mean	**1.42**	**1.98**	**2.49**	**3.40**	**-**	**-**
$LSD_{0.05}$	0.32* 0.87*** 1.05****				0.78**	-

LSD * for nitrogen rate; ** for cultivar; * for interaction between nitrogen and cultivar;**
****** for interaction between cultivar and nitrogen**

Table 3. Effect of N fertilisation on potassium content, mval·100 g^{-1} of root

Cultivar	N rate, $kg \cdot ha^{-1}$				Mean	Homogeneous groups
	0	80	160	240		
Gala	3.85	3.85	3.59	4.36	3.91	a
Dojana	3.85	3.85	3.85	4.62	4.04	a b
Evita	3.85	3.85	3.85	4.62	4.04	a b
Atair	3.59	3.59	4.87	4.62	4.17	a b
Hanna	3.59	4.10	4.62	4.36	4.17	a b
Jupiter	3.85	3.59	4.36	5.13	4.23	a b
Amelia	3.85	4.18	3.51	5.38	4.23	a b
Fontana	4.10	4.36	4.36	4.62	4.36	a b c
PN Mono 4	3.85	4.10	5.13	4.62	4.42	a b c
Sonja	3.33	4.36	4.87	5.38	4.49	b c
Cordelia	4.36	4.36	4.62	4.87	4.55	b c

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Action	3.85	4.62	4.62	5.38	4.62	c
Sofie	4.10	4.87	5.13	5.13	4.81	c
Nilla	4.10	4.62	5.64	5.13	4.87	c
Mean	**3.85**	**4.10**	**4.62**	**4.87**	-	-
LSD $_{0.05}$	0.24* 1.01*** 1.30****				0.57**	-

LSD * for nitrogen rate; ** for cultivar; * for interaction between nitrogen and cultivar;**
****** for interaction between cultivar and nitrogen**

Table 4. Effect of N fertilisation on sodium content, mval·100 g^{-1} of root

Cultivar	Nitrogen rate, kg·ha^{-1}				Mean	Homogenous groups
	0	80	160	240		
Hanna	0.54	0.55	0.63	0.90	0.66	a
Sonja	0.54	0.87	0.96	1.25	0.91	a b
Nilla	0.75	0.95	0.96	0.96	0.91	a b
Jupiter	0.67	1.01	0.89	1.27	0.96	a b c
Amelia	0.63	0.79	0.81	1.86	1.02	a b c d
Evita	0.70	0.90	1.02	1.52	1.04	a b c d
Action	0.93	0.93	0.93	1.39	1.05	b c d
Cordelia	0.78	0.94	1.44	1.02	1.05	b c d
Gala	0.80	0.94	1.18	1.31	1.06	b c d
Atair	0.81	1.05	1.33	1.30	1.12	b c d
Sofie	0.85	1.17	1.28	1.55	1.21	b c d
Fontana	0.97	1.16	1.10	1.92	1.28	b c d
PN Mono 4	1.27	1.41	1.22	1.35	1.31	c d
Dojana	0.96	1.04	1.55	1.80	1.34	d
Mean	**0.80**	**0.98**	**1.09**	**1.39**	**-**	**-**
LSD $_{0.05}$	0.29* 0.43*** 0.56****				0.38**	-

LSD * for nitrogen rate; ** for cultivar; * for interaction between nitrogen and cultivar;**
****** for interaction between cultivar and nitrogen**

The research showed that the technological white sugar yield (Table 5), most significant criterion in the evaluation of the factors studied, was significantly diversified depending on the nitrogen rate and cultivar properties. The increase in the technological white sugar yield was obtained only for 80 kg·ha^{-1} of N, as compared with the control. The increase in the fertilisation by another 80 kg·ha^{-1} of N, namely up to 160 kg·ha^{-1} of N, gave an insignificant increase in the technological white sugar yield by another 0.5 t·ha^{-1}, while 240 kg·ha^{-1} of N decreased the sugar yield by about 0.6 t·ha^{-1}, which corresponds to the yield obtained for 80 kg·ha^{-1} of N.

The technological sugar yield also depended on the cultivar properties and interaction between cultivar and nitrogen fertilisation. Irrespective of the nitrogen rate, the highest

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technological sugar yield, 12.2 t·ha^{-1}, was obtained for 'Sonja', while the lowest sugar yield, 9.26 t·ha^{-1}, for 'PN Mono 4'. The technological white sugar yield of the cultivar studied depended significantly on nitrogen fertilisation. Analysing the non-fertilised and 80 kg·ha^{-1} of N objects, it was 'PN Mono 4' which showed the lowest technological sugar yield. Due to the application of 160 and 240 kg·ha^{-1} of N, 'Atair' and 'Amelia' showed the lowest sugar yields.

Table 5. Technological yield of white sugar, t·ha $^{-1}$

Cultivar	Nitrogen rate, kg·ha^{-1}				Mean	Homogenous groups
	0	80	160	240		
Sonja	10.97	11.93	12.78	12.40	12.21	a
Jupiter	9.75	12.73	12.24	12.24	11.85	a
Gala	10.42	12.06	12.41	11.46	11.65	a b
Evita	8.80	11.83	13.19	11.73	11.54	a b
Hanna	9.53	10.85	11.64	12.46	11.20	b
Fontana	8.22	11.28	12.59	11.37	11.03	b c
Amelia	10.85	12.15	11.48	9.05	10.97	c
Cordelia	8.87	10.63	11.61	11.71	10.90	c d
Dojana	9.76	11.12	11.91	10.23	10.90	c d
Action	10.48	11.07	10.92	10.46	10.79	c d e
Nilla	10.19	10.45	10.49	10.99	10.60	c d e
Sofie	9.63	9.77	11.02	10.26	10.30	d e
Atair	10.24	10.16	10.39	9.91	10.24	e
PN Mono 4	6.52	8.88	10.58	10.85	9.26	f
Mean	**9.59**	**11.06**	**11.66**	**11.08**	-	-
LSD $_{0.05}$	1.02* 1.35*** 2.50****				0. 65**	-

LSD * for nitrogen rate; ** for cultivar; * for interaction between nitrogen and cultivar;**
****** for interaction between cultivar and nitrogen**

The impact of increasing N rate fertilisation, by 80 kg·ha^{-1} on yielding, mean root weight and biological sugar yield expressed in relative values, as compared with the non-fertilised object, is presented in Fig. 1. 80 and 160 kg·ha^{-1} of N significantly increased the root yield by 23.7% and 14.8%, respectively. No such relationship was observed when the nitrogen rate increased by another 80 kg, namely from 160 to 240 kg·ha^{-1} of N. Nitrogen fertilisation affected the mean weight of a single root. As compared with the control, nitrogen rate of 80 kg·ha^{-1} increased the root weight by 23%, while an increase in the N rate up to 160 kg·ha^{-1} increased the root weight by another 28.9%. 80 and 160 kg·ha^{-1} of N increased the biological sugar yield by 18.1% and 26.0%. An increase in the biological sugar yield when 160 was replaced by 240 kg·ha^{-1} of N was insignificant.

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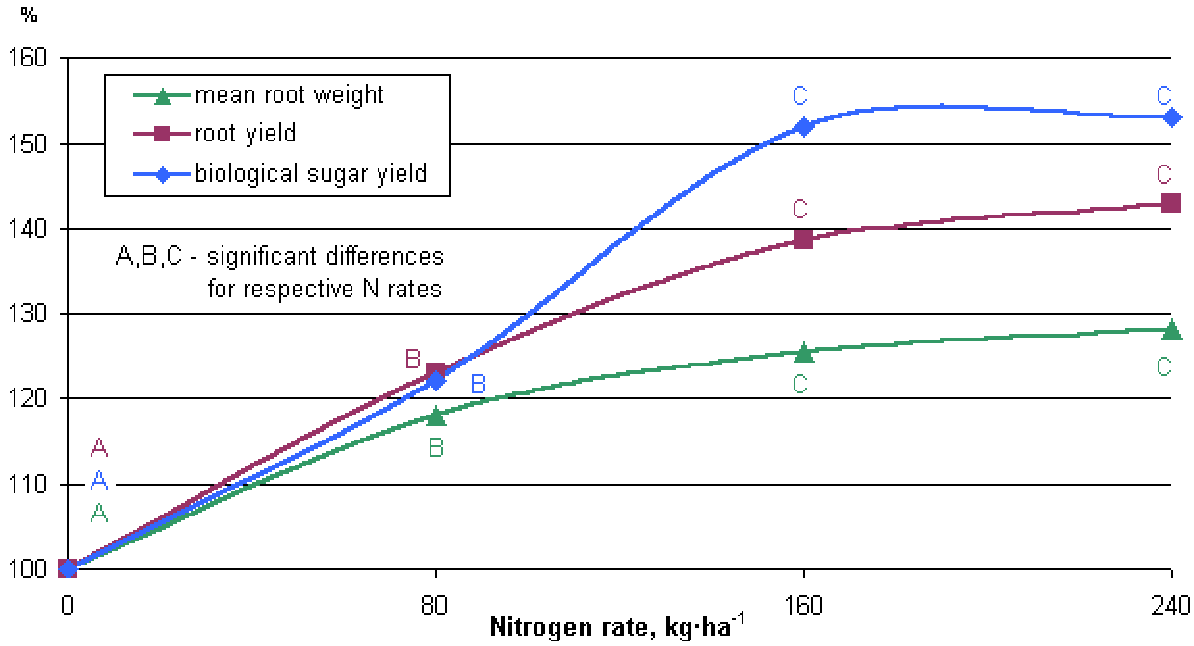
Fig. 1. Mean root weight, root yield and biological sugar yield for various nitrogen fertilisation rates (relative values as compared with the control)



The impact of nitrogen fertilisation on some technological sugar beet root properties is seen in Fig. 2. Increasing nitrogen rates brought about increased contents of alpha-amino N, sodium and potassium and decreased content of sucrose. The application of 80 kg·ha^{-1} of nitrogen significantly increased the content of alpha-amino N by 39.0%, sodium by 22.5% and potassium by 6.5%. Increased nitrogen fertilisation from 80 to 160 kg·ha^{-1} caused a further significant increase in the content of these compounds by 25.7%, 12.7% and 11.2 %, respectively. An increase in nitrogen rate by another 80 kg·ha^{-1}, namely up to 240 kg, resulted in a further significant increase in alpha-amino N by 36.5%, sodium by 27.5 % and potassium by 5.4%. Unlike the content of these compounds, the content of sucrose in beet roots changed differently; each increase in the nitrogen rate by 80 kg·ha^{-1} decreased it significantly by 4.7%; 8.4% and 14.0%, as compared with the control. Increases in the contents of alpha-amino N as well as sodium and potassium due to increasing nitrogen rates decreased the content of sucrose. Sucrose-processing losses due to increased contents of alpha-amino N, sodium and potassium are shown in Fig. 3. An increase in the contents of sodium and potassium due to the application of 80 kg·ha^{-1} of N increased the sugar losses by a real value of 0.15 %. Increase in the content of sodium and potassium affected by 160 and 240 kg·ha^{-1} of N decreased sucrose content by a further 0.22% and 0.19%. Decreased content of sucrose caused by an increased content of alpha-amino N, depending on nitrogen fertilisation rate, amounted to 0.06%, 0.1% and 0.19%.

Fig. 2. Content of some compounds in sugar beet roots for increasing N fertilisation rates (relative values as compared with the control)

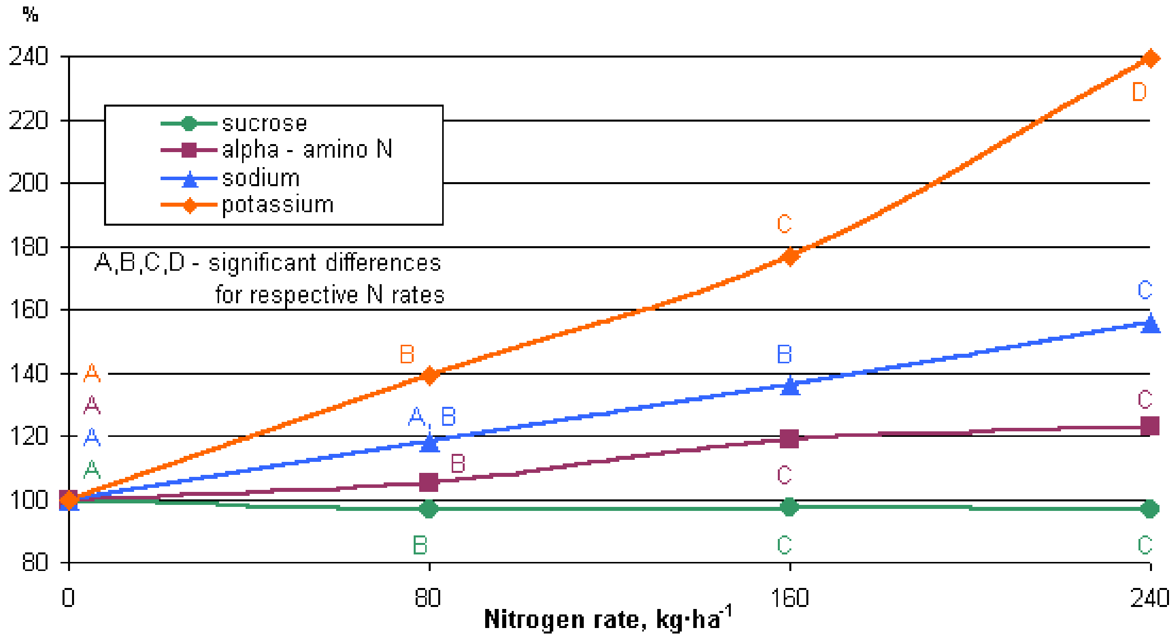
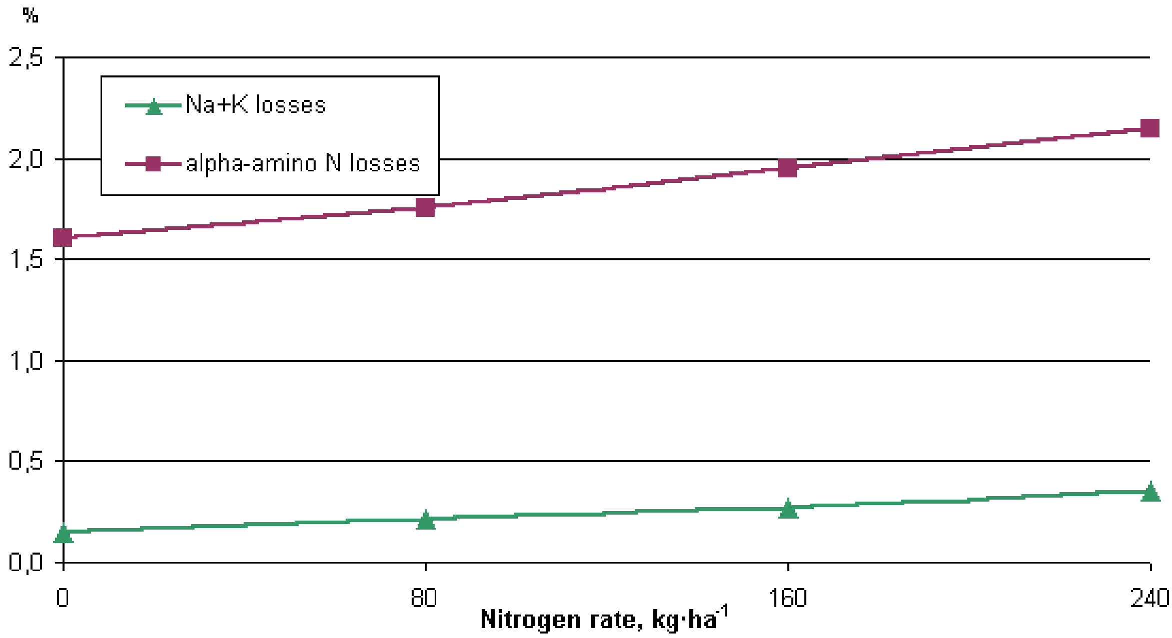


Fig. 3. Sucrose-processing losses affected by contents of alpha-amino N, potassium and sodium for increasing N fertilisation rates



DISCUSSION

Generally research show a significant impact of genotype on technological sugar beet root value. The contents of sucrose, alpha-amino N, potassium and sodium can be affected by genetic cultivar properties. The technological sugar yield depends on the contents of sucrose and molasses-forming compounds - alpha-amino N, potassium and sodium and on root yield,

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while technological sugar efficiency defines the production costs. Out of 14 cultivars tested, the lowest technological sugar yield was obtained for ‘PN Mono 4’, whose roots showed average contents of sucrose and potassium and high contents of alpha-amino N and sodium. Cross-cultivar difference in the technological sugar yield in the present research reached about 3 $t \cdot ha^{-1}$.

The results obtained confirmed a significant cross-cultivar variation in the contents of potassium and sodium. According to Szota [8], it is possible to select a line showing a high yielding potential and decreased potassium and sodium contents, despite a positive correlation between these features. Szota [8] reports that the selection of and breeding the beet lines cover also the contents of sucrose and alpha-amino N. The cross-cultivar sucrose content range amounted to 2% and alpha-amino N content range - 1.27 $mval \cdot 100\ g^{-1}$ of roots.

The present research confirmed earlier findings that nitrogen fertilisation significantly affects the technological root value. Increased nitrogen rates increased the content of molasses-forming compounds and decreased the content of sucrose, which is shown by numerous authors including Gutmański et al., [5], Kalinowską-Zdun and Wyszyński [6] and others [9,10]. Nitrogen rates increasing by another 80 $kg \cdot ha^{-1}$, which increased the contents of potassium, sodium and alpha-amino N, increased sucrose-processing losses which, as shown by the present study, were generated much more by increased contents of sodium and potassium than by alpha-amino N content.

The research into the impact of sugar beet productivity showed a favourable effect of nitrogen fertilisation on yielding, weight of a single root and biological sugar yield, yet only up to 160 $kg \cdot ha^{-1}$, which, however, did not increase the technological sugar yield which increased only when 80 $kg \cdot ha^{-1}$ of N was applied. 240 $kg \cdot ha^{-1}$ of N occasionally applied in sugar beet cultivation brought about a significant increase in neither root yield nor biological sugar yield. However it decreased the technological white sugar yield up to the value obtained for 80 $kg \cdot ha^{-1}$ of N. All that was observed irrespective of sugar beet cultivar properties.

CONCLUSIONS

1. 80 and 160 kg ha^{-1} of N under the present conditions significantly increased the weight of a single sugar beet root, root yield and biological sugar yield, while their values did not change significantly for 240 kg ha^{-1} of N.
2. The technological sugar yield was enhanced by 80 kg ha^{-1} of N, only. An increase in technological white sugar yield obtained for 160 kg ha^{-1} of N was insignificant, while the increase up to 240 kg ha^{-1} of N equalled that obtained for 80 kg ha^{-1} of N.
3. Each increase in nitrogen rate by 80 kg ha^{-1} increased the contents of alpha-amino N, potassium and sodium and decreased the content of sucrose.
4. The root quality modified by nitrogen fertilisation depended also on cultivar genotype. The sugar beet cultivars differed in the contents of sucrose, alpha-amino N, potassium and sodium as well as the technological sugar yield efficiency.
5. The highest white sugar efficiency was noted for ‘Hanna’, ‘Jupiter’, ‘Sonja’ and ‘Evita’ cultivars which represented homogenous cultivar group of the highest sucrose content.

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