Yields and root technological quality of sugar beet grown in crop rotation and long-term monoculture

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ABSTRACT

The paper presents the findings of 6-year (1993–1998) investigations obtained in the field static experiment continued since 1967. This experiment concerned the estimation of the crop yield and its structure, and root technological quality under the conditions of crop rotation and extreme shortening of the rotation, i.e. monoculture. Investigations have proved that under agroclimatic conditions of north-eastern Poland it is possible to obtain 60 t of roots per ha in a naturally correct crop rotation, while in a long-term monoculture – 33 t, and 36 t and 19 t of top, respectively. The differences in monoculture crops occurred as a result of a plant loss during germination by 5.6%, and a smaller unit weight per root by 41.6%. The applied procedures of plant protection by herbicides and fungicides improved the root and top crop and favored the maintenance of plant density. A lowering of saccharose content in roots from 15.7% in the crop rotation to 15.0% in monoculture was recorded, and of sugar yield in the technological process from 13.0 to 12.3%, respectively. A high white sugar yield was obtained in crop rotation – 7.89 t per ha, while in monoculture it was only 4.06 t, i.e. 48.5% less.

Keywords: sugar beet; long-term experiment; crop rotation; monoculture; chemical protection; root yield; white sugar yield; molasses forming substances

Sugar beet belongs to species of high crop-generating abilities. Among cultivated plants, it distinguishes itself by the highest energy index *E* – measured by the quotient of the energy obtained in crops in relation to energetic expenses incurred in the production process (Gutmański 1986, Zawiślak and Tyburski 1992). A good soil quality and the proximity of the market – sugar factories – is a stimulus to grow sugar beet. Under the condition of balanced organic and mineral fertilization, the size and quality of root yields depends on the frequency of cultivating sugar beet in the same field and using crop-protective agents against agrophages rather than on forecrops (Osińska and Szymczak-Nowak 1980, Niewiadomski and Zawiślak 1982, Kuś 1992, Pačuta et al. 2000). Agricultural practice expects science to devise crop rotation models including a permissible specialization limit, which, while guaranteeing real and valuable crops, will protect the bioenergetic potential and soil fertility (Niewiadomski 1995, Heyland and Lohmann 1997, Krejčíř 1997).

Field static research carried out in northeastern Poland aimed at determining the root crop size and the quality of sugar beet cultivated in crop rotation and long-term monoculture, as well as at estimating the crop-protective effectiveness of herbicides and fungicides.

MATERIAL AND METHODS

The paper presents the findings of 6-year (1993–1998) investigations, obtained in northeastern Poland, in the Olsztyn region, Experimental Farm of Bałcyny, belonging to the University of Warmia and Mazury. The vegetation period of the region during a 6-year period was characterized by day-and-night air temperatures of 13.5°C and total rainfall of 383 mm.

The field static experiment has been carried out since 1967 on soil lessivé (Orthic Luvisols) developed from silty light loam. Within the discussed research cycle, the cultivated soil layer was characterized by slightly acidic reaction, the organic matter content of 1.2–1.3%, high phosphorus and magnesium content and medium potassium content. Sugar beet was cultivated in a 6-field crop rotation: sugar beet (manure) – maize – spring barley – peas – winter rape – winter wheat and in 26–31-year monoculture. Three levels of plant protection were used: 0 – no protection (control object), H – protection by herbicides (chlorydazon – 4 kg per ha), H + F – protection by leaf herbicides and fungicides (chlorydazon – 4 kg per ha + copper oxychloride 5 kg per ha). The experiment was conducted with the method of random subblocks in three replications. The size of plots for cultivation, sowing, and harvest was 27 m^2. The land was cultivated using the plough system. Manure was applied in autumn and covered with pre-winter ploughing. Its dose in crop rotation amounted to 30 t per ha, and in the sugar beet monoculture, it was used twice in the amount of 15 t per ha each time over the period of 6 years. Mineral fertilization amounted to 340 kg NPK including 120 kg N per ha. In spring, a cultivation unit was used for mixing mineral fertilizers with soil and for land cultivation. Sugar beet seeds, Colibri cultivar, were sown at 45-cm row spacing in the third decade of April. The roots were harvested in the second decade of October.

The final planting was counted and the root and top yields were determined during the harvest. A raw material technological evaluation on Venem line was made annually based on root samples from each object. The analysis included the saccharose, potassium, sodium, and alpha-amino nitrogen contents. Then, the white sugar yields were calculated on the basis of the alkalinity index value (K + Na/N-amino) developed by Reinefeld et al. (1974) and by Trzebiński (1986).

RESULTS AND DISCUSSION

Root and top yields

Average sugar beet root yields in crop rotation amounted to 60 t per ha and were higher than those obtained in monoculture (33.1 t) by as much as 44.8% (Table 1). The yield differences, confirmed statistically, became apparent in the variants of sugar beet protection by pesticides, irrespective of the plant sequence system. In crop rotation, 58.8 t of roots per ha were obtained in control objects with no chemical protection, while the yield was only 30.5 t in monoculture. Plant protection by herbicides was more important in continuous cultivation than in crop rotation. The root yield was increased by 11%, but due to high yield variability in the next years, the differences were not confirmed statistically. The application of leaf fungicides in crop rotation had an insignificant effect on root yields, although they played a greater crop-protective role in monoculture.

The top yields of sugar beet were subject to a similar dependence as the root yields (Table 1). In the 6-field crop rotation, 36.4 t per ha were harvested, while under the conditions of continuous cultivation – only 18.5 t, which was 49% less. Unlike in crop rotation, the top yields in monoculture were depended to a higher degree on the level of plant protection. The plant foliage coefficient under the crop rotation conditions reached the value of 0.60, while in monoculture it was 0.56. A higher negative effect of incorrect plant sequence on the weight of top yields than on the weight of root yields, particularly in after-drought seasons, was previously reported by Kuś (1992), Malec (1997), Zawiślak and Rychcik (1997).

Plant density, weight per root and root deformation

Sugar beet yields were mainly dependent on the number of plants per area unit and on the average root weight. During the harvest, the average number of plants per ha amounted to 84 thousand in both systems with a lower planting tendency under the conditions of cultivation followed by the same species at a row (Table 2). The number of plants was more differentiated by the protection by pesticides. The lowest density of 82.8 thousand plants per ha was noted in the control objects with no protection due to the occurrence of black root rot (Wojciechowska-Kot and Kurowski 1988, Szymczak-Nowak et al. 1997).

The root weight per unit was dependent both on the plant sequence and on the intensity of crop-protective measures. On average, it amounted to 685 g in crop rotation, while in monoculture it was 400 g, i.e. it was lower by 42%. The root weight increased with an increase in the plantation protection inputs; in crop rotation the variations between objects amounted to 2%, while in monoculture they reached 8%.

The technological yield of sugar is largely dependent on the shape of roots. The most valuable are those with a typical wedge shape, without bifurcation. In the discussed experiment, there were significantly more bifurcated roots in monoculture where every fifth specimen was inconsistent with the adopted standard. On average, there were 18.7% of deformed roots, while in crop rotation – only 10.2%. As proved by the studies of Gutmański (1986) and the authors' studies (Adamiak et al. 1991, Zawiślak and Tyburski 1992), the causes of this phenomenon could be sought in the monoculture soil being more populated by fungi *Aphanomyces graminis*, *Phoma betae* and others, and parasitic nematodes *Heterodera schachtii*. In the soil of crop rotation, eelworm cysts oc-

Table 1. Root and top yields of sugar beet (1993–1998)

Levels of protection	Grown in crop rotation	Grown in a 26–31 year monoculture	Average
Root yields ($t.ha^{-1}$)			
0	58.8	30.5	44.6
H	60.2	34.0	47.1
H + F	60.9	34.9	47.9
Average	60.0	33.1	level of protection – 2.36*
$LSD_{\alpha = 0.05}$	crop sequence – 2.56**		
Top yields ($t.ha^{-1}$)			
0	36.0	16.7	26.3
H	36.2	18.7	27.5
H + F	37.0	20.0	28.5
Average	36.4	18.5	level of protection – n.s.
$LSD_{\alpha = 0.05}$	crop sequence – 16.6**		

Explanations to Tables 1–3 and Figure 1: n.s. = not significant, 0 = no protection, H = protection by herbicides, H + F = protection by herbicides and fungicides

Table 2. Plant density, weight per root and root deformation (1993–1998)

Levels of protection	Grown in crop rotation	Grown in a 26–31 year monoculture	Average
Plant density (t.ha^{-1})			
0	86.0	79.5	82.8
H	88.1	83.3	85.7
H + F	88.0	84.3	86.1
Average	87.3	82.4	level of protection – 2.39*
$LSD_{\alpha = 0.05}$	crop sequence – n.s.		
Weight per root (g)			
0	680	380	530
H	682	406	545
H + F	691	415	553
Average	685	400	level of protection – n.s.
$LSD_{\alpha = 0.05}$	crop sequence – 15.6**		
Deformed roots (%)			
0	10.5	20.7	15.6
H	10.1	17.7	13.9
H + F	9.9	17.6	13.8
Average	10.2	18.7	level of protection – 1.54*
$LSD_{\alpha = 0.05}$	crop sequence – 3.6**		

curred sporadically while in monoculture 9 specimens per 100 g of soil were noted on average, with the population size on the verge of harmfulness. Similar causes of root deformation have been reported by many authors (Osińska and Szymczak-Nowak 1980, Gonet and Gonet 1981, Krejčíř 1997).

Content of molasses forming substances

The corrected sugar content is dependent on many root features: morphological – size and shape, physical – tissue elasticity, physiological – intensity of constituent roots' respiration on piles before processing, chemical –

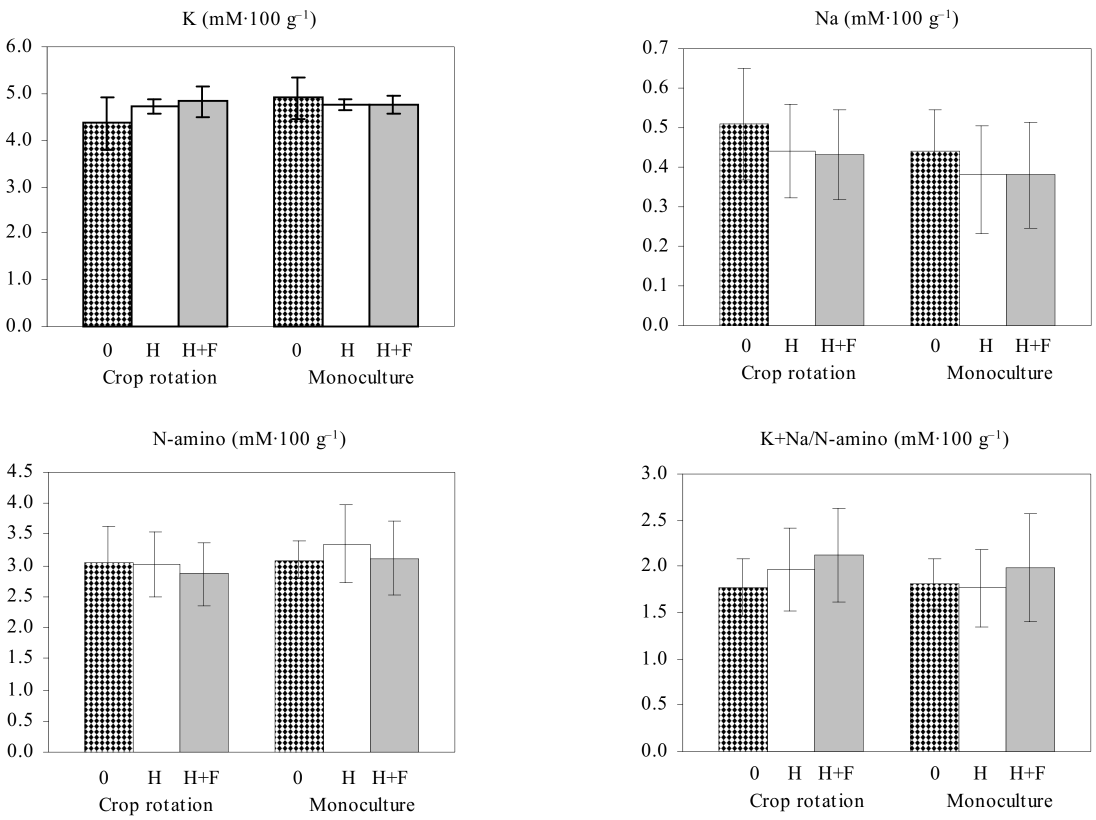

Figure 1. Content of molasses forming substances

standard deviation

Table 3. Saccharose content, corrected sugar content and yield (1993–1998)

Levels of protection	Grown in crop rotation	Grown in a 26–31 year monoculture	Average
Saccharose content (%)			
0	15.6	15.0	15.3
H	15.7	15.0	15.4
H + F	15.7	15.1	15.4
Average	15.7	15.0	level of protection – n.s.
$LSD_{\alpha = 0.05}$	crop sequence – 0.29		
Corrected sugar content (%)			
0	13.0	12.3	12.7
H	13.0	12.2	12.6
H + F	13.1	12.4	12.7
Average	13.0	12.3	level of protection – n.s.
$LSD_{\alpha = 0.05}$	crop sequence – 0.32		
Sugar yields ($t.ha^{-1}$)			
0	7.69	3.71	5.70
H	7.97	4.16	6.07
H + F	8.02	4.30	6.16
Average	7.89	4.06	level of protection – 0.32*
$LSD_{\alpha = 0.05}$	crop sequence – 2.95**		

saccharose content, and content of melassigenic substances impeding sugar extraction (Gutmański 1986, Trzebiński 1986, Zawiślak and Rychcik 1997). The main components that make it difficult to extract sugar are: potassium, sodium, and alpha-amino nitrogen in the form of amino-acids (glutamic acid and aspartic acid) and amides (glutamines, asparagines). The content of molasses forming substances in roots depends mainly on the quality of soil, mineral fertilization (mostly nitrogen and potassium), and meteorological conditions during the vegetation period (Reinefeld et al. 1974, Malec 1997, Barłóg and Grzebisz 2001).

A quantitative and qualitative analysis of molasses forming substances revealed its significant variation both in the compared variants of plant sequence and protection and in particular years of study (Figure 1). Under the agroclimatic conditions of north-eastern Poland, the roots obtained in the 6-field crop rotation were characterized by a higher content of sodium – 0.06mM.100 g^{-1}, and a lower content of potassium – 0.17mM.100 g^{-1}, and alpha-amino nitrogen – 0.21mM.100 g^{-1} in the pulp compared with the roots obtained in monoculture. The alkalinity coefficient of the cell sap in the roots from crop rotation was more favorable and amounted to 1.95 while in monoculture it was 1.86. Fungicides played a positive role in reducing the content of noxious nitrogen and in forming better alkalinity of the cell sap.

Saccharose content, corrected sugar content and yield

The practically used biological sugar yield index per area unit is not equivalent to the corrected sugar yield achieved in the technological process. During the discussed 6-year period, the saccharose content in crop rotation amounted to an average of 15.7% and was 0.7% higher than that obtained in a 26–31-year monoculture (Table 3). No significant differences caused by crop-protective measures have been found. Similar relations occurred in the corrected sugar yield, and its average value in crop rotation reached 13%. There was also a significant difference to the disadvantage of monoculture. Similar dependence has been found by Trzebiński (1986), Heyland and Lohmann (1997), Zawiślak and Rychcik (1997).

A high white sugar yield was obtained in crop rotation – 7.89 t per ha, while in monoculture it was only 4.06 t, i.e. 48.5% less. Plantation protection only by herbicides as well as in combination with fungicides had a significant effect on an increase in sugar yield in crop rotation by 4% and in monoculture by as much as 14%.

CONCLUSIONS

Sugar beet cultivation in a 6-field crop rotation enabled obtaining high root yields – 60.0 t, top yields – 36.1 t, and 7.89 t of white sugar per ha, while in 26–31-year monoculture those values were 44.8, 49.2 and 48.5% less, respectively. The differences in yields were due to the decrease in planting by 5.6% and in root unit weight by 41.6%.

In either system of sugar beet cultivation, the use of herbicides and fungicides increased the yields, including the most important component – sugar. Herbicides were of greater compensating importance in this respect.

The root pulp of sugar beets from crop rotation contained less potassium and alpha-amino nitrogen and more sodium than the root pulp of sugar beets from monoculture. Pesticides had a varied effect on the content of molasses forming substances, and the calculated coefficient of cell sap alkalinity was more favorable in the crop rotation roots.

Acknowledgments

Studies on the sugar beet cultivation systems were initiated in 1967 by Full Prof. Dr. Dr. h. c. (multi) Witold Niewiadomski, member of the Polish Academy of Sciences, the then Head of the Chair. The authors would like to thank Dr. Andrzej Kosecki, the manager of the Experimental Station at Bałcyny for agrotechnical supervision during the realization of the long-term static experiment.

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Received on April 17, 2002

ABSTRAKT

Výnosy a technologická kvalita kořenů cukrovky pěstované v osevním postupu a ve víceleté monokultuře

Jsou uvedeny výsledky šestiletého výzkumu (1993–1998) získané ve stacionárním polním pokusu probíhajícím od roku 1967. Byl hodnocen výnos cukrovky a technologická kvalita kořene v podmínkách osevního postupu a extrémního zkrácení rotace, tj. monokultury. Výzkumy prokázaly, že v agroklimatických podmínkách severovýchodního Polska je možné dosáhnout u kořene 60 $t.ha^{-1}$ v běžném korektním osevním postupu, zatímco v dlouhodobé monokultuře 33 $t.ha^{-1}$ a u chrástu 36 $t.ha^{-1}$ v osevním postupu a 19 $t.ha^{-1}$ v monokultuře. Diference v monokultuře se vyskytly jako výsledek ztrát 5,6 % během klíčení a vlivem hmotnosti kořene činily 41,6 %. Aplikovaná ochrana herbicidy a fungicidy zkvalitnila kořen a chrást a zlepšila hustotu porostu. Bylo zjištěno snížení obsahu sacharózy v kořenech z 15,7 % v osevním postupu na 15,0 % v monokultuře a výtěžnosti cukru v technologickém procesu z 13,0 % na 12,3 %. Vysoké produkce bílého cukru bylo dosaženo v osevním postupu, a to 7,89 $t.ha^{-1}$, zatímco v monokultuře to bylo pouze 4,06 $t.ha^{-1}$, tj. o 48,5 % méně.

Klíčová slova: cukrovka; dlouhodobý pokus; osevní postup; monokultura; chemická ochrana; výnos kořene; výnos bílého cukru; melasotvorné látky

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