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The influence of comparative fertilization on the yield and quality of sugar beet, the nutrient balances. The evaluation of long-term field experiments in the Czech Republic

Agricultural research on plant nutrition cannot be supported without results of long-term field experiments. The Central Institute for Supervising and Testing in Agriculture established four long-term field experiments in four experimental places of the sugar beet production region of the Czech Republic, in the years 1972–1979. Each experiment comprised 12 combinations of fertilization and had an eight years crop rotation. The following five combinations were used for evaluation of yields of sugar beet (roots and leaves) and quality of the products: the control treatment without fertilization, the treatment with farmyard manure (FYM) and three treatments with FYM applied together with comparative mineral fertilization at three different levels. In the control treatment, average yield of the main product (roots) was 52.0 tons·ha^{-1} with sugar content 18.5%. In the other treatments increase of fertilization caused gradual rising of the roots and leaves yield (for roots: from 57.5 to 68.3 tons·ha^{-1}) and, on the other hand, the decrease of sugar content (from 18.6 to 16.8%). The nitrogen and potassium balances were negative, except for the highest level of mineral fertilization. The phosphorus balance was highly positive at all levels of mineral fertilization.

Key words: fertilization, nutrient balance, sugar beet

Badania rolnicze nad odżywianiem roślin nie mogą rozwijać się bez wyników długoterminowych doświadczeń polowych. W latach 1972–1979, w Centralnym Instytucie Nadzoru i Badań w Rolnictwie założono cztery takie długoterminowe eksperymenty w czterech stacjach doświadczalnych rejonu uprawy buraka cukrowego w Republice Czeskiej. Każde z doświadczeń obejmowało 12 kombinacji nawożenia i miało ośmioletni płodozmian. Następujące pięć kombinacji wykorzystano do oceny plonów buraka cukrowego (korzeni i liści) oraz jakości produktów: kontrolną — bez nawożenia, kombinację z obornikiem oraz trzy kombinacje (tzw. porównawcze) z obornikiem, uzupełnione trzema różnymi poziomami nawożenia mineralnego. W wariancie kontrolnym średni plon korzeni wyniósł 52,0 t·ha^{-1}, przy zawartości cukru 18,5%. W pozostałych wariantach zwiększenie nawożenia spowodowało stopniowy wzrost plonów korzeni i liści (dla korzeni: od 57,5 t/ha do 68,3 t·ha^{-1}), a z drugiej strony zmniejszenie zawartości cukru (z 18,6% do 16,8%). Bilans składników był negatywny dla azotu i potasu, z wyjątkiem kombinacji z najwyższą dawką nawożenia mineralnego. Bilans fosforu był wysoce pozytywny dla wszystkich poziomów nawożenia mineralnego.

Słowa kluczowe: bilans składników odżywczych, burak cukrowy, nawożenie

INTRODUCTION

In the process of transformation of agricultural production and within the frame of the strategy before admission of the Czech Republic to the European Union the attention is paid to ways of reducing additional energetic inputs to technologies of cultivation of individual crops. However, from the standpoint of sustainable soil fertility the economics cannot be the only major criterion. In the situation of so-called „enforcement of extensity", accepted in many agricultural enterprises, complying with agrotechnical demands of the grown crops must be in the centre of attention.

Sugar beet is one of the most effective crops of the temperate zone in respect of bio-energy accumulation. There is a number of reasons, here in CR and in Europe, for maintenance of sugar production from sugar beet and protection of the market in face of import of sugar. One of them is a high agronomical improvement of soil, high photosynthetic and energetic efficiency in the form of sugar, feed and industrial raw materials, high performance of oxygen and, last but not least, its high ability to utilize the nutrients from fertilization and soil reserves.

The present state of sugar beet growing in the Czech Republic shows an upward trend of average yields and improving quality of the crop. However, there are still considerable differences persisting among producers. Therefore, the productivity of sugar beet growing in the Czech Republic drops behind all the time in comparison with states of EU.

It stands to reason that there are still reserves in the sugar beet growing, in yield increase and profitability of cultivation. On the bases of top quality of agronomical practices, careful and rigorous protection of sugar beet against injurious agent, the nutrition and fertilization will be the groundwork of intensive sugar beet and sugar production in CR. It is one of the most important intensification factors, significantly influencing yield and harvest quality of this crop.

Evaluation of results of long-term experiments has proven to be an effective way to check effect of fertilization intensity on yield and other characters of cultivated crops.

MATERIAL AND METHODS

The Central Institute for Supervising and Testing in Agriculture (CISTA) established long-term experiments in four experimental places (Pusté Jakartice, Sedlec, Uherský Ostroh, Žatec) of the sugar beet production region, in the years 1972–1979.

The aim of the long-term field experiments was to observe effects of different levels of nutrients on yields of cultivated crops, quality of products and development of agrochemical soil properties.

Each long-term field experiment had the same crop rotation system. The first two crop rotations (1972–1980 and 1981–1989) lasted nine years each. Duration of the last crop rotation, finished in 1997, was eight years. It contained 50% of cereals, 25% of root crops and 25% of fodder crops. The sugar beet was cultivated within the frame of crop rotations in the years 1979, 1982, 1988 and 1996.

The experimental design included as a whole 12 combinations of fertilization. Nitrogen, phosphorus and potassium fertilizers were applied in three levels — low (1st marked as 1), medium (2nd marked as 2), high (3rd marked as 3) (Table 1). The combinations with application of mineral fertilizers we designate as a comparative mineral fertilization, i.e. 1st level is a basic application rate of mineral nutrients, 2nd level is basic application rate multiplied 1,5 times and 3rd level is basic application rate multiplied 2 times.

Organic manures were applied two times during a crop rotation cycle before root crops. The application rate was 35 tons of farmyard manure (FYM) per hectare in the years 1972–1989 and 40 tons FYM·ha^{-1} in the last crop rotation (since 1990).

For observation of the effect of fertilization intensity on the yield of sugar beet, sugar content and balance calculation the following 5 combinations were used: combination without fertilization (control), combination with farmyard manure (FYM) application, combination with FYM + 1st level of mineral nutrients ($N_1P_1K_1$) application, combination with FYM + 2nd level of mineral nutrients ($N_2P_2K_2$) application and combination with FYM + 3rd level of mineral nutrients ($N_3P_3K_3$) application.

Table 1

Application rates of farm yard manure (FYM) and mineral nitrogen, phosphorus and potassium for sugar beet in the years 1979, 1982, 1988, 1996

Sugar beet in crop rotation	Combinations of fertilization	FYM in t·ha^{-1}	Mineral nutrients in kg·ha^{-1}		
			N	P	K
1979	without fertilization	0	0,0	0,0	0,0
	FYM	35	0,0	0,0	0,0
	FYM + $N_1P_1K_1$	35	150,0	82,5	224,2
	FYM + $N_2P_2K_2$	35	225,0	130,0	332,1
	FYM + $N_3P_3K_3$	35	300,0	165,0	448,4
1982	without fertilization	0	0,0	0,0	0,0
	FYM	35	0,0	0,0	0,0
	FYM + $N_1P_1K_1$	35	120,0	48,0	108,0
	FYM + $N_2P_2K_2$	35	180,0	72,0	162,0
	FYM + $N_3P_3K_3$	35	240,0	96,0	216,0
1988	without fertilization	0	0,0	0,0	0,0
	FYM	35	0,0	0,0	0,0
	FYM + $N_1P_1K_1$	35	120,0	72,0	162,0
	FYM + $N_2P_2K_2$	35	180,0	109,0	245,0
	FYM + $N_3P_3K_3$	35	240,0	144,0	323,8
1996	without fertilization	0	0,0	0,0	0,0
	FYM	40	0,0	0,0	0,0
	FYM + $N_1P_1K_1$	40	53,0	26,2	66,5
	FYM + $N_2P_2K_2$	40	80,0	52,4	133,0
	FYM + $N_3P_3K_3$	40	106,0	104,7	266,0
	without fertilization	0	0,0	0,0	0,0
∅	FYM	36,25	0,0	0,0	0,0
application	FYM + $N_1P_1K_1$	36,25	110,8	57,2	140,2
rate	FYM + $N_2P_2K_2$	36,25	166,3	90,9	218,0
	FYM + $N_3P_3K_3$	36,25	221,5	127,4	313,6

For nutrient balance calculation the content of 0.4% N; 0.2% P_2O_5; 0.5% K_2O in FYM was used, considering the 45% useful effect in the first year after manuring

RESULTS

Yields of sugar beet

The Table 2 and Figure 1 show average yields of the main product (roots) and by-product (leaves) for the period under consideration. The results are expressed as average values for all the experimental places.

Table 2

Average yields of the main product (roots) and by-product (leaves)

Combinations of fertilization	Sugar beet — roots		Sugar beet — leaves	
	yield in $t \cdot ha^{-1}$	rel. valuation in %	yield in $t \cdot ha^{-1}$	rel. valuation in %
without fertilization	51,95	100,0	20,94	100,0
FYM	57,48	110,6	22,66	110,6
FYM + $N_1P_1K_1$	65,26	125,6	32,38	154,6
FYM + $N_2P_2K_2$	67,32	129,6	35,41	169,1
FYM + $N_3P_3K_3$	68,25	131,4	39,69	189,6

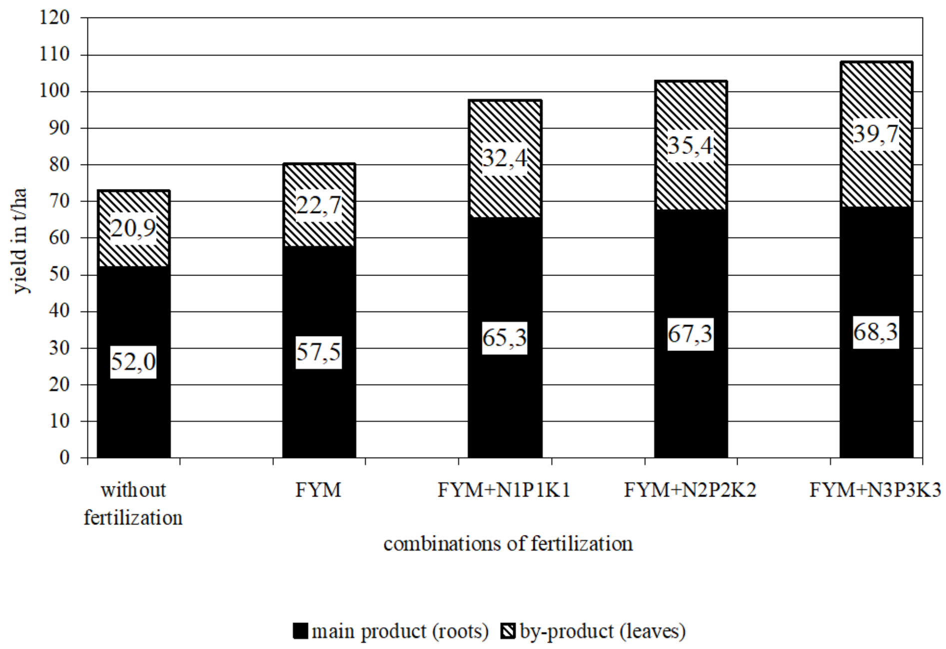

Fig. 1. Average yields of sugar beet in the long-term experiments

The effect of comparative nutrient fertilization was related to the combination without fertilization. In respect of evaluation this combination presents 100%.

Generally, the comparative nutrient fertilization effects were more distinct for the yield of leaves (almost 90% above control for the highest fertilization level) than for the yield of roots.

The highest yields (roots and leaves) were achieved at the 3rd level of mineral fertilization. However, the increase of root yield in comparison with the 2nd level was minimal — less than 2%, therefore the 3rd level of fertilization was uneconomical. The increased mineral fertilization caused higher yield of the by-product (leaves), which mostly remains on a field and eventually increases reserves of nutrients (P and K) in soil.

For the statistical evaluation, the criterion of 95 percent LSD was used. The significant differences of the root yield were determined between combinations without fertilization and those with applied FYM. Further significant differences were found between combinations with application of FYM only and the FYM+2nd or 3rd level of mineral fertilization. The significant differences of the yield of leaves were found for the same combinations as for roots and, additionally, between combinations with application of FYM and FYM+1st level of mineral fertilization and next between 1st and 3rd level of mineral fertilization (Table 4).

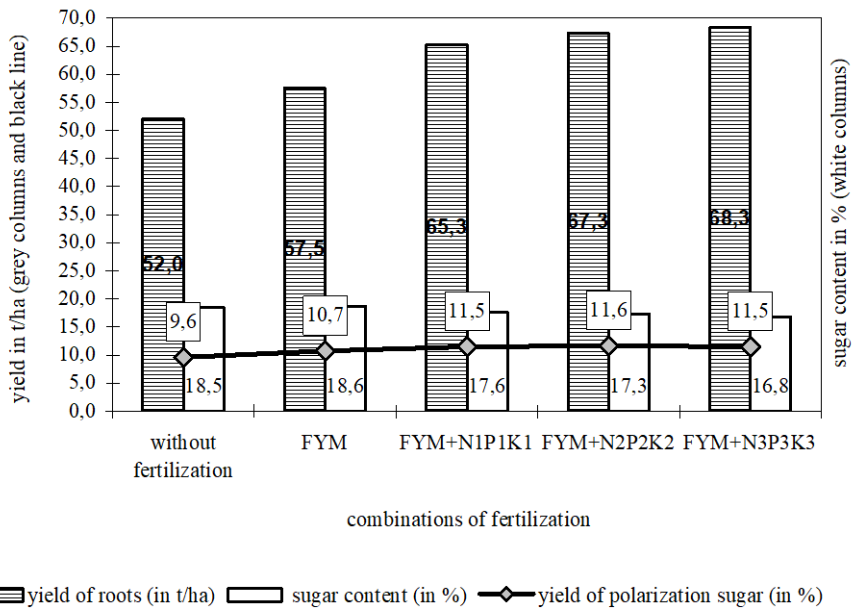

Fig. 2. Qualitative characteristics of the crop

The impact of intensity of fertilization on quality of production

The technological quality of sugar beet presents the complex of biological, chemical, physiochemical and mechanical properties of beet roots, which are decisive for their profitable storage and fabrication of high yield of white refined sugar. The main indicator of technological value of sugar beet is the percentage of sugar content.

The average sugar content values detected for the individual combinations of fertilization, across the whole period under consideration and all sites, corresponded indirectly proportionately with the yield of roots and intensity of fertilization of these combinations. It means that increasing intensity of fertilization in pursuit of higher yields declined the sugar content of beet roots.

This negative dependence between yield and sugar content is generally known and it is in particular in virtue of the type of grown variety. Therefore, to classify the real amount of sugar beet production it is necessary to observe the indicators connecting the qualitative parameter (sugar content) and quantitative parameter (yield). The „yield of polarization sugar“ (see Table 3) is an indicator of this kind. This indicator evaluates the sugar-beet production from standpoint of parameters, in accordance with these parameters the practical financial assessment of production is performed.

Table 3

The technological quality of sugar beet

Combinations of fertilization	Average roots yield ($t \cdot ha^{-1}$)	Sugar content (%)	Yield of polarization sugar ($t \cdot ha^{-1}$)	Relative comparison in % for yield of polarization sugar
without fertilization	52,0	18,5	9,59	100,0
FYM	57,5	18,6	10,70	111,6
FYM + $N_1P_1K_1$	65,3	17,6	11,47	119,6
FYM + $N_2P_2K_2$	67,3	17,3	11,62	121,2
FYM + $N_3P_3K_3$	68,3	16,8	11,49	119,8

The statistical evaluation for the sugar content (by the 95 percent LSD method) has shown that the occurrence of significant differences was identical as that stated for the yield of leaves. The first one was between combinations without fertilization and those with applied FYM. Next significant difference was found within the FYM combinations between those with and without mineral nutrition. Another significant difference was stated between the 1st and the 3rd level of mineral fertilization (Table 4).

Table 4

Effect of fertilization on roots yield, leaves yield and sugar content in sugar beet

The comparison of combinations of fertilization	The yield of roots the limit value is 7,99081 difference	The yield of leaves the limit value is 6,38562 difference	The sugar content the limit value is 0,74456 difference
without fertilization — FYM	-5,52625	-1,72000	-0,15000
without fertilization — FYM+$N_1P_1K_1$	-13,31060*	-11,44120*	0,87500*
without fertilization — FYM+$N_2P_2K_2$	-15,36500*	-14,47690*	1,20625*
without fertilization — FYM+$N_3P_3K_3$	-16,30000*	-18,75310*	1,63750*
FYM — FYM+$N_1P_1K_1$	-7,78438	-9,72125*	1,02500*
FYM — FYM+$N_2P_2K_2$	-9,83875*	-12,75690*	1,35625*
FYM — FYM+$N_3P_3K_3$	-10,77380*	-17,03310*	1,78750*
FYM+$N_2P_2K_2$ — FYM+$N_1P_1K_1$	2,05437	3,03563	-0,33125
FYM+$N_2P_2K_2$ — FYM+$N_3P_3K_3$	-0,93500	-4,27625	0,43125
FYM+$N_1P_1K_1$ — FYM+$N_3P_3K_3$	-2,98937	-7,31188*	0,76250*

* — Denotes a statistically significant difference

The best results were achieved for the combination FYM+$N_2P_2K_2$ with middle intensity of fertilization by all nutrients, the average yield of polarization sugar was from 1,4 to 21,2% higher in comparison with the other combinations. On the contrary, the lowest yields of polarization sugar were achieved in the control combination and with organic fertilizing only.

It is possible to state, that from the view of economic efficiency of fertilization and financial assessment of sugar beet production the fertilization on medium level of nutrients has shown to be the most optimal. It implies, that fertilization of sugar beet with excessively high level of nutrients is not economically feasible.

Nutrient balances

The figures 3, 4 and 5 show the nutrient balances in the period under consideration. The first column for every combination shows total quantity of specific nutrient off-take (in $kg{\cdot}ha^{-1}$) by the products (main + by-product). The second column represents total quantity of specific nutrient fertilization (in $kg{\cdot}ha^{-1}$). The negative nitrogen balance is brightly evident in the situation, when all production (i.e. main + by-product) goes from the field away. A slightly positive nitrogen balance was only at the 3rd level of mineral fertilization. In case of removal of the main product and leaving tops on the field, the nitrogen balance will be positive for all combinations, except for the control combination without fertilization.

The phosphorus balance was highly positive at all levels of mineral fertilization.

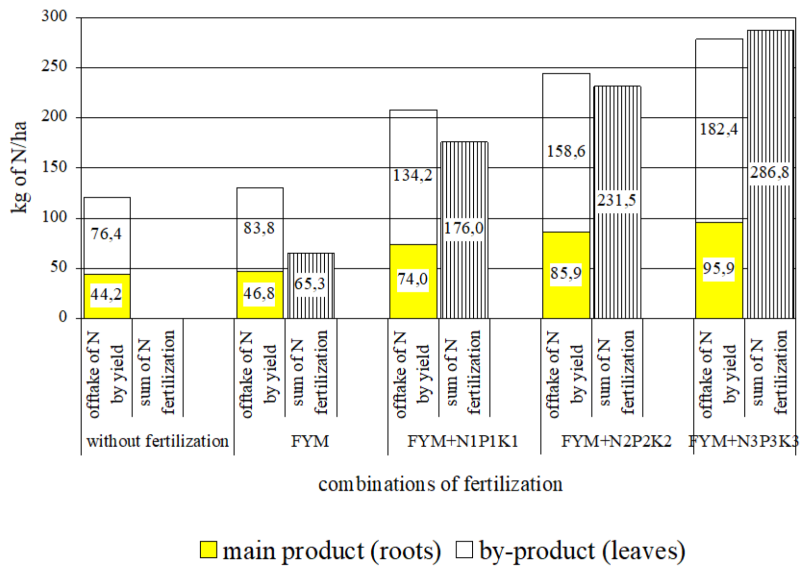

Fig. 3. The nitrogen balance of the long-term experiments at sugar beet

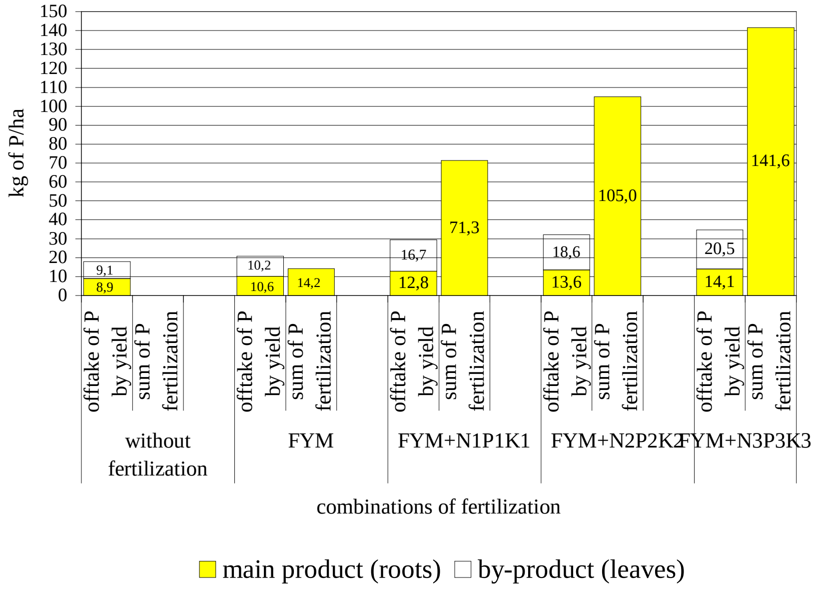

Fig. 4. The phosphorus balance of the long-term experiments at sugar beet

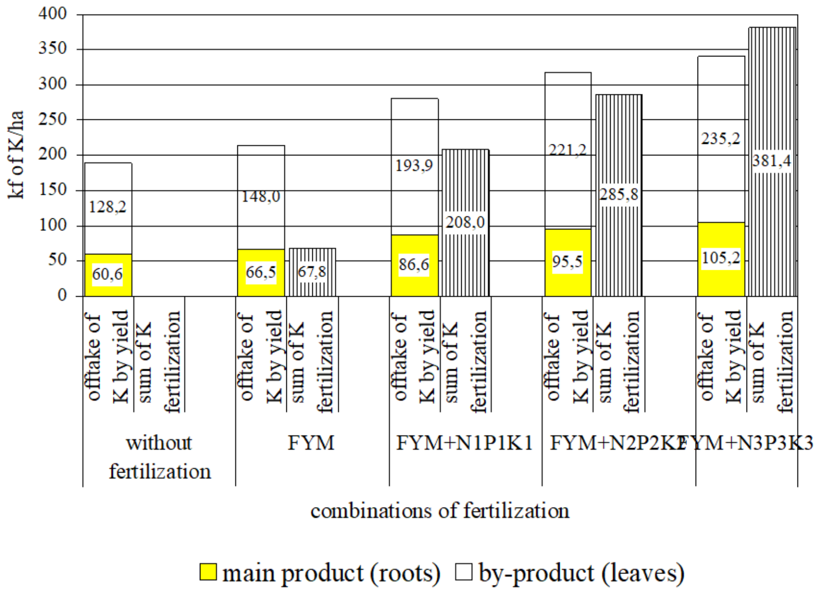

Fig. 5. The potassium balance of the long-term experiments at sugar beet

The potassium balance is much similar to that of nitrogen. Only at the 3rd level of mineral fertilization there was excess of this element. In the case of leaves ploughing under the potassium was well-balanced in the combination with application of FYM and highly positive in combinations with mineral fertilization.

On the basis of these facts it is possible to deduce the optimal application rates of nutrients for the existing technology of cultivation of sugar beet.

CONCLUSIONS

On the basis of the above results from the selected combinations of the long-term field experiments, it is possible to formulate the following conclusions concerning comparative nutrient fertilization of sugar beet:

1. The comparative nutrient fertilization caused improvement of yields of sugar beet. The comparative fertilization exerted a major effect on the yield of leaves, which usually remain on the field and are returned back into the soil. Therefore the high application rates of mineral nutrients, as those in the 3rd level of fertilization, are uneconomical.
2. From the view of economic efficiency of fertilization and financial assessment of sugar beet production with regard to average prices of fertilizers and sugar in a market the fertilization on a medium (2nd) level of nutrients has been the most close to optimal.
3. The nitrogen and potassium balances were negative at all levels of fertilization, except the highest (3rd) one, if the whole production (i.e. roots and leaves) goes from the field away. The phosphorus shows a high balance excess. Improvement of nitrogen and potassium balances without escalation of fertilization rates is possible to manage by returning leaves of sugar beet to the soil.

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