ROW METHOD OF SUGAR BEET (BETA VULGARIS L.) FERTILIZATION WITH MULTICOMPONENT FERTILIZER BASED ON UREA-AMMONIUM NITRATE SOLUTION AS A WAY TO INCREASE NITROGEN EFFICIENCY

NAWOŻENIE RZĘDOWE BURAKA CUKROWEGO (BETA VULGARIS L.) WIELOSKŁADNIKOWYM NAWOZEM PŁYNNYM NA BAZIE ROZTWORU SALETRZANO-MOCZNIKOWEGO JAKO CZYNNIK ZWIĘKSZAJĄCY EFEKTYWNOŚĆ AZOTU

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ABSTRACT

Sugar beet is the main crop commonly cultivated for sugar production in temperate regions of the World. Actual yields in main Central Europe producing countries are much lower, due to many limiting factors. Among them, nutrients supply is of great value, especially referring to efficiency of nitrogen, which is generally low. In the conducted study two methods of nitrogen application were compared (i) broadcast of calcium saltpeter and (ii) row application of the multicomponent fertilizer based on urea-ammonium-nitrate (UAN) solution. The basic amount of the applied N was 75 kg ha^{-1}. The highest yields of both taproots and refined sugar were harvested on the plot receiving 75 kg N^{-1} as UAN liquid multicomponent fertilizer and 50% of the recommended P and K rates. The positive effects of row application of liquid N fertilizer on taproot and sugar yields were also corroborated by high values of indices of agronomic efficiency for both N as well as P and K. However this method of sugar beets fertilization has some possibilities, as indicated by still high contents of melassogenic substances.

KEY WORDS: multicomponent liquid fertilizer based on UAN, sugar beet, P and K rates, yield of roots and its quality

STRESZCZENIE

Burak cukrowy jest podstawowym surowcem do produkcji cukru w strefie klimatu umiarkowanego. W krajach centralnej Europy, w których uprawia się buraki cukrowe, aktualny poziom plonowania tej rośliny znacznie odbiega od potencjalnych możliwości. Wśród różnych przyczyn takiego stanu rzeczy, koniecznie należy wymienić małą efektywność nawożenia azotem. W badaniach własnych porównano dwie metody nawożenia azotem: i) rzutowe - saletrą wapniową oraz ii) rzędowe - wieloskładnikowym nawozem otrzymanym na bazie roztworu mocznika i saletry amonowej (UAN). Podstawowa dawka azotu, niezależnie od przyjętego systemu, wynosiła 75 kg ha^{-1}. Największy plon korzeni, i plonu cukru technologicznego, uzyskano przy jednoczesnym zastosowaniu 75 kg N kg^{-1} w formie wieloskładnikowego nawozu płynnego (UAN) oraz 50% rekomendowanej dawki fosforu oraz potasu. Pozytywny efekt nawożenia rzędowego na plon korzeni i cukru wynikał ze wzrostu efektywności agronomicznej zarówno azotu, jak i zastosowanego równocześnie P i K.

SŁOWA KLUCZOWE: wieloskładnikowy nawóz płynny na bazie RSM, burak cukrowy, dawki P i K, plon i jakość korzeni

STRESZCZENIE SZCZEGÓŁOWE

Potencjał plonowania buraka cukrowego mieści się w zakresie 70-80 t ha^{-1}, lecz plony zbierane przez rolników w Europie Środkowej kształtują się na dużo niższym poziomie. Jednym z podstawowych przyczyn niskich plonów jest niedostateczny poziom zasobności gleby w składniki podstawowe (P, K, Mg), a także niedoskonały system nawożenia, oparty o duże dawki azotu. Podstawowym celem przeprowadzonych badań było porównanie efektywności plonotwórczej dwóch systemów nawożenia azotem w dawce 75 kg N ha^{-1}, w których składnik ten stosowano rzędowo w formie nawozu płynnego (wzbogaconego w inne składniki mineralne) oraz w formie saletry wapniowej, stosowanej powierzchniowo. W latach 1997-1999 przeprowadzono 3-letnią serię doświadczeń polowych, w których badano wpływ systemu aplikacji azotu (powierzchniowy, rzędowy), stosowanego w dawce 75 kg N ha^{-1} w formie nawozu wieloskładnikowego, wytworzonego z RSM (wzbogaconego w P, Na, Mg, B, Mn) (L) na tle dawek P i K (0, 50% i 100% dawki zalecanej). Przeprowadzone badania wykazały, że oba czynniki doświadczalne wywierały istotny wpływ na i) plon korzeni, ii) jakość technologiczną korzeni i, iii) efektywność agronomiczną azotu oraz PK, rozpatrywanych łącznie. Najlepszy efekt produkcyjny, a jednocześnie efektywnie wykorzystujący azot z nawozów, uzyskano w wariancie, w którym zastosowano rzędowo nawóz wieloskładnikowy, płynny na bazie RSM, pod warunkiem redukcji zalecanej dawki azotu do 50% zalecanej dawki. Uzyskany w tym wariancie nawozowym plon korzeni wyniósł średnio dla trzech lat 72,3 t ha^{-1}, a wzrost plonu w stosunku do analogicznego wariantu, lecz z saletrą wapniową kształtował się na poziomie 18,7%. Plony liści wykazały analogiczną, jak plony korzeni reakcję na zastosowane czynniki doświadczalne. W obu porównywanych kombinacjach nawozowych plony kształtowały się jak 47,2 i 36,5 t ha^{-1}. Jakość technologiczna korzeni, wyrażona zawartością i) cukru oraz ii) związków melasotwórczych (azot α-amonowy, K, Na) nie wykazała istotnego zróżnicowania na testowane warianty nawozowe. Plon cukru technologicznego determinował plon korzeni, przyjmując dla obu wcześniej przedstawionych kombinacji nawozowych wartości, jak 10,27 i 8,80 t ha^{-1}. System nawożenia azotem istotnie kształtował zarówno efektywność agronomiczną samego azotu, jak i PK, wskazując na istotnie większą produktywność azotu stosowanego rzędowo w formie płynnej. w odniesieniu do poziomów nawożenia PK, zdecydowanie największa efektywność N i PK stwierdzono dla poziomu zredukowanego o 50%. Interakcja obu czynników wskazała na istotną przewagę wariantu z nawozem płynnym z jednoczesną redukcją dawki PK na efektywność agronomiczną N i PK, zarówno dla plonów korzeni, jak i cukru technologicznego. Przedstawione wyniki badań wskazują na rezerwy plonotwórcze zawarte zarówno w technice stosowania nawozów azotów, jak i w sposobie bilansowania azotu poprzez wzbogacenia nawozu w składniki oraz optymalizację poziomu P i K.

INTRODUCTION

Sugar beet (Beta vulgaris L.) is next to sugar cane, the second crop plant supplying raw material for sugar production and in the nearest future for bioethanol [10, 24]. As reported from the latest investigations carried out in Europe, potential yields of sugar beets vary from 110 to 145 t□ha^{-1} of taproots, what corresponds to 16 – 24 t□ha^{-1} of sugar [14]. The given range of yields reflects the duration of the vegetation as the main yield-forming determinant of taproot yields. Real, maximum yields are diversified and vary within a large scale from 70 to 80 t□ha^{-1}. Such high yields may require i) a maximal duration growth at the field, ii) good thermal conditions for growth at the first growth period (60-65 days) (iii) optimal supply of nutrients at the first growth period up to closed canopy [4, 7, 14, 15].

The technological progress in the area of fertilization, with respect to their rate, type and application techniques is a prerequisite for the realization of sugar beets yielding potential. Therefore the most important target of sugar beet growers appears to be related to the increase of nitrogen use efficiency. Contrary to popular belief broadly expressed by sugar beet growers, this plant is not physiologically nitrophilous. The increasing tendency of the nitrogen yield forming efficiency results from two basic factors, i.e. cropping of sugar beets at sites rich in nutrients which balance the effect of soil and fertilizer nitrogen and the systematic measurement of soil mineral nitrogen [16].

One of the ways to reduce the amounts of used up mineral fertilizers is to introduce such a method of fertilizer application which enables a maximal utilization of any applied nutrient. As compared to classical broadcast methods, some alternative row application techniques based mainly on solid fertilizers, are emerging [19, 22]. In the case of the row method of fertilizer application, the fertilizer is not applied on the whole but only a part of the soil or even incorporated in a precisely defined place and at a given depth [5].

Sugar beet are generally cultivated on soils rich in mineral elements, mainly P and K and also frequently on sites earlier previously fertilized with manure [8, 23]. Simultaneously, the low quality of taproots resulting of the excess of melassogenic compounds, α-amino-nitrogen, mainly, still remains the critical component [3, 12]. For such situation the problem of the choice of the nutrient for row application may be turned away and resumed to mobile nutrient, i.e. nitrogen. This method has been implemented in Poland at the middle of the 90s of the XX century and is currently applied on an area of ca 5000 ha, yearly. The problem to solve in the case of this method is a part of the elaboration of the rate of nitrogen, but also the effective balancing of rates of main macronutrients, i.e. phosphorus and potassium.

The aim of investigations was to compare i) the yield forming effects of two nitrogen fertilization systems – row and broadcast application under three levels of phosphorus and potassium fertilization, ii) agronomic nitrogen efficiency simultaneously applied phosphorus and potassium.

MATERIALS AND METHODS

Field investigations were conducted during the consecutive years 1997-1999 at an agricultural farm settled in Gorzyczki (52°06'N; 16°49'E, Poland). The area of the experimental field was 0.336 ha (3360 m^2) and was consisted of plots of 67.5 m^2 (25m x 2.7m). The soil used for this experiment is, according to FAO/WRB classified as albic luvisols originating from loamy sands underlined by loam. For ach experimental year, winter wheat was the fore crop for sugar beets. The experimental site was characterized by an optimal soil reaction (pH) mainly at the soil layer 0 – 0.3 m depth and mean soil, fertility for phosphorus, potassium and magnesium (Table 1).

Field trials consisted of two factors tested at three levels:

1. Method of application and nitrogen rate (N):
- row, multicomponent liquid fertilizer − 75 kg N$\cdot$ha^{-1} (L-N_1)
- broadcast, calcium saltpeter − 75 kg N$\cdot$ha^{-1} (C-N_1)
- broadcast, calcium saltpeter − 75 + 50 kg N$\cdot$ha^{-1} (C-N_2)

2. Phosphorus and potassium rates (PK):

Table 1. Chemical and physical properties of soil
Tabela 1. Fizyczne i chemiczne właściwości gleby

Year /rok	Soil layer / warstwa gleby (m)	Clay / Ił koloi-dalny %	pH_{KCl}	Nmin 1) kg ha^{-1}	P_2O_5 2) mg 100g^{-1}	K_2O 2) mg 100g^{-1}	Mg 3) mg 100g^{-1}
1997	0.0 – 0.3	4	6.7	67.0	16.7	14.5	4.8
	0.3 – 0.6	8	6.0	40.2	6.4	14.0	5.3
1998	0.0 – 0.3	6	6.8	70.2	13.4	12.9	5.5
	0.3 – 0.6	8	6.8	56.6	5.8	9.0	5.0
1999	0.0 – 0.3	4	6.6	42.7	12.9	14.2	4.5
	0.3 – 0.6	6	5.6	66.0	5.0	12.6	4.6

1) – extracting solution / roztwór ekstrakcyjny: 0.01 mol $CaCl_2$;
2) – extracting solution / roztwór ekstrakcyjny: lactate buffer / bufor mleczanowy, pH 3.55
3) – extracting solution / roztwór ekstrakcyjny: 0.0125 mol $CaCl_2$

Table 2. Chemical composition of liquid fertilizer (UAN) and nutrient amounts incorporated in soil together with nitrogen, at the rate 75 kg N ·ha^{-1}
Tabela 2. Skład chemiczny płynnego nawozu (UAN) oraz dawki składników pokarmowych wniesione do gleby z dawką 75 kg N ·ha^{-1}

Nutrients / Składniki	Expressed in the form: / wyrażone w formie:	Concentration / Stężenie %	Rate of nutrients Dawka składnika kg ha^{-1}
Nitrogen / Azot	N	14.6	75.0
Phosphorus / Fosfor	P_2O_5	1.22	6.7
Sodium / Sód	Na	5.30	29.0
Magnesium / Magnez	MgO	0.22	1.2
Manganese / Mangan	Mn	0.15	0.8
Boron / Bor	B	0.05	0.3

- control, without P i K (P_0K_0)
- 40 kg P_2O_5 + 80 kg K_2O · ha^{-1} (P_1K_1)
- 80 kg P_2O_5 + 160 kg K_2O · ha^{-1} (P_2K_2)

The chemical composition of the multicomponent liquid fertilizer (urea-ammonium-nitrate solution, UAN) and the amounts of nutrients incorporated into the soils at the rate 75 kg N·ha^{-1} (level N_1) are reported in Table 2.

The liquid fertilizer was applied simultaneously with seeding of sugar beet (variety Saskia) at the following dates: 10.04.1997; 14.04.1998 and 16.04.1999. The application of the liquid fertilizer was done by a 6-band seeder (Kleine - Unicorn 3) with a liquid fertilizer applicator. Solid nitrogen fertilizers (calcium saltpeter, 15.5%) were applied at two separate rates, first one week before seeding and the second one at the 9 leaf growth stage (BBCH 19) according to Meier [18]. Manure was applied a year earlier, after winter wheat harvest at the rate 40 t ha^{-1}. Phosphorus and potassium fertilizers - superphosphate (46% P_2O_5) and muriate of potash (60% K_2O) were applied at fall. Phosphorus and potassium basic rates for the P_2K_2 treatment corresponded to nutrients requirements of sugar beets for taproot yield leveled at 60 t·ha^{-1}.

Climatic conditions during sugar beet growth are presented in Table 3. It can be observed that, the first two years (1997-1998) were characterized by best weather conditions for sugar beets as compared to the year 1999, with drought which took place from August.

Sugar beet plants were harvested from 16.20 m^2 (6 rows per 6 m) in September or October (calendar dates: 26.09.97; 28.09.98; 02.10.99). The technological value of the beet (polarimetric sugar content, α-amino-N, potassium and sodium) was determined using a Venema auto-analyzer. These basic beet characteristics were then used to calculate technological parameters of the raw material (taproots) [2]:

a) Overall processing loss (m_{OPL}, in %):

$m_{OPL} = 0{,}12 \cdot w'_{(K+Na)} + 0{,}24 \cdot w'_{\alpha\text{-}N} + 1.08$

b) Recoverable sugar content (m_{RS}, in %): $m_{RS} = m_S - m_{OPL}$

c) Recoverable sugar yield (m_{RSY}, in t·ha^{-1}):

$$m_{RSY} = m_B\,(m_S - m_{OPL}) \times 100^{-1}$$

where:

w'_K – content of potassium in mmol·100^{-1} g of fresh taproots

w'_{Na} – content of sodium in mmol·100^{-1} g of fresh taproots

$w'_{\alpha\text{-}N}$ – content of α-amino-N in mmol·100^{-1} g of fresh taproots

m_B – taproots yield in t ha^{-1}

$m_S = w_{S,\ pol}$ – polarimetric determined sugar content in beet in %

The efficiency of N or PK fertilization was calculated on the basis of the following parameters:

$$AE_T = \frac{m_B}{R}$$

and

$$AE_S = \frac{m_{RSY}}{R}$$

where,

AE_T – agronomic efficiency [kg of taproots · 1 kg^{-1} of N or PK]

AE_S – agronomic efficiency [kg of refined sugar · 1 kg^{-1} of N or PK]

m_B – yield of taproots [kg·ha^{-1}]

m_{RSY} – yield of refined sugar [kg·ha^{-1}]

R – rate of N (or PK treated together) [kg·ha^{-1}].

The assessment of the effect of PK fertilization was made on the basis of two additional parameters:

$$NAE_T = \frac{m_{B(PK)} - m_B}{R}$$

and

$$NAE_S = \frac{m_{RSY(PK)} - m_{RSY}}{R}$$

where,

NAE_T – net agronomic efficiency [kg of taproots · 1 kg^{-1} of PK]

NAE_S – net agronomic efficiency [kg of refined sugar · 1 kg^{-1} of PK]

m_B – yield of taproots on the treatment without PK [kg·ha^{-1}]

$m_{B(PK)}$ – yield of taproots on the treatment with PK [kg·ha^{-1}]

m_{RSY} – yield of refined sugar on the treatment without PK [kg·ha^{-1}]

$m_{RSY(PK)}$ – yield of refined sugar on the treatment with PK [kg·ha^{-1}]

R – rates of PK (together) [kg·ha^{-1}].

Table 3. Weather conditions during the growth of sugar beet
Tabela 3. Warunki pogodowe w trakcie wegetacji buraka cukrowego

Months Miesiąc	Long term / Wielolecie		1997		1998		1999	
	Temp. Temp. °C	Rainfall Opady mm	Temp. Temp. °C	Rainfall Opady mm	Temp. Temp. °C	Rainfall Opady mm	Temp. Temp. °C	Rainfall Opady mm
IV	8.7	46.6	8.7	38.2	10.0	38.2	9.2	73.1
V	14.2	66.0	11.7	78.3	14.9	20.8	14.1	50.0
VI	18.0	82.0	18.0	55.0	17.5	107.0	17.8	82.3
VII	19.8	64.5	19.5	151.9	18.6	65.0	20.7	40.1
VIII	18.9	48.7	20.8	127.7	17.5	62.0	19.5	20.0
IX	12.5	42.0	11.9	21.0	12.6	101.5	18.0	23.0
X	7.6	39.8	6.7	29.3	8.0	94.0	9.7	42.8
Sum / Suma	-	588.2	-	617.7	-	664.1	-	530.1

Table 4. Taproot yields of sugar beet in relation to interaction between systems of nitrogen fertilization and level of PK fertilization (t·ha^{-1})
Tabela 4. Plon korzeni buraka cukrowego w zależności od współdziałania systemu nawożenia azotem oraz poziomu nawożenia PK (t·ha^{-1})

Year / Rok	System of N fertilization System nawożenia azotem	Level of P and K fertilization Poziom nawożenia P i K		
		P_0K_0	P_1K_1	P_2K_2
1997	L–N_1	58.6 a	82.6 b	65.3 a b
	C–N_1	55.2 a	64.0 a b	57.0 a
	C–N_2	64.1 a b	62.3 a	67.7 a b
1998	L–N_1	66.3 a	73.6 a	51.6 a
	C–N_1	61.8 a	64.6 a	52.8 a
	C–N_2	53.5 a	58.2 a	68.6 a
1999	L–N_1	54.0 a	60.6 a	59.3 a
	C–N_1	51.5 a	54.1 a	52.5 a
	C–N_2	46.4 a	49.3 a	48.6 a
Mean / Średnia	L–N_1	59.6 a b	72.3 b	58.7 a
	C–N_1	56.3 a	60.9 a	54.1 a
	C–N_2	54.7 a	56.6 a	61.6 a b

Values followed by the same letter are not significantly different at $\alpha = 0.05$ Wartości zaznaczone tą samą literą nie różnią się istotnie na poziomie $\alpha = 0.05$

All experimental data were elaborated by using analysis of variance (Fisher-Snedocor's method) for each year separately and for interaction year x treatments, using computer software STATISTICA 8. For F-test showing significant differences, Tukey's test (HSD) at the probability level $\alpha = 0.05$ was additionally performed to compare mean values.

RESULTS AND DISCUSSION

Yield of taproots

Weather conditions have strongly differentiated the harvested yields of sugar beets, which amounted for the consecutive years of field trials, on average 64.1 t□ha^{-1} – 1997; 61.2 t□ha^{-1} – 1998; and 52.9 t□ha^{-1} – 1999. The last year was characterized not only by the lowest amount of precipitations but also by unfavorable for sugar beet cropping, distribution of rainfalls (Table 3, 4). The seasonal variability is the overriding factor as compared to remaining others. Even in Great Britain weather course is reported to influence sugar yield from 26 up to 79% [6]. The growth rate of sugar beet at the start of vegetation depends on the temperature and the intensity of solar radiation, but good growing conditions during this period do not ensure maximal yields of taproots [14]. Mean temperature and precipitations during summer months (i.e., July and August) and the duration of the vegetation are the important climatic factors which determine the final yields of sugar beets [6, 14]. Kertner's et al. (2006) hypothesis about the limited impact of weather conditions during the first period of vegetation and its influence on the prognosis of the final yields, seems to be controversial, since the whole strategy of sugar beet cropping in Europe relays basically on the acceleration of the growth rate for the first two months of growth [1, 7].

For years 1997 and 1999, taproot yields depended significantly on the interaction of both experimental factors. The highest yield was harvested from the treatment L-$N_1P_1K_1$, i.e. for the fertilization system, where the UAN-based multicomponent liquid fertilizer was used. Yields in this treatment were not only high but even significantly higher than those harvested from the remaining treatments. No significant differences were obtained in 1998 between the tested nitrogen fertilization systems, however a distinct tendency for greater yielding was also observed in the treatment L−$N_1P_1K_1$ (Table 4).

The yield forming effect of PK rates depended closely and more on the rate of nitrogen than the system of nitrogen application. For the rate of 75 kg N□ha^{-1}, highest taproot yields were obtained on the treatment P_1K_1, whereas for the rate 125 kg N□ha^{-1}, properly, for the treatment P_2K_2, irrespective of the system of fertilizer application. The interaction of the experimental factors revealed the specific role of the method of nitrogen application and the magnitude of PK. The mean taproots yield harvested in the treatment L−$N_1P_1K_1$ was significantly higher than that obtained from other tested treatments: L−$N_1P_2K_2$; C−$N_1P_0K_0$; C−$N_1P_1K_1$; C−$N_1P_2K_2$; C−$N_1P_0K_0$ and C−$N_1P_1K_1$. The mean difference between sugar beet yield in treatment L−$N_1P_1K_1$ and above mentioned ones, amounted on average 27%. The yield of taproots fertilized with L−$N_1P_1K_1$ did not however differ significantly from those harvested in other two treatment, i.e., L−$N_1P_0K_0$ and C−$N_2P_2K_2$ (Table 4).

The analysis of leaves biomass confirmed the regularities reported for taproots, i.e. significant influence of the interaction of both experimental factors (Table 5). The maximal mean leaves yield (47.2 t□ha^{-1}) was produced by plants grown in the treatment L−$N_1P_1K_1$. This yield was significantly different of most of mean yields, except for the treatment receiving the highest nutrients rate (C−$N_2P_2K_2$) with 42.1 t□ha^{-1}. The other variants did not differ significantly, and the lowest leaves yield, ca ¾ of the maximal yield, was produced in the treatment C−$N_1P_2K_2$ (Table 5). None of the experimental factors and the interaction between the factors did not influence the value of the canopy index (considered leaves : taproot mass ratio), which was on average 0.65:1.0, i.e., relatively narrow.

It is generally supposed, under medium growing conditions, maximal taproots yield is obtained frequently at nitrogen rate ranging from 120 to 160 kg N □ha^{-1} [16]. In the practice, on account of the necessity for keeping adequate taproot quality and simultaneously sugar yield, nitrogen rates lower than 125 kg N □ha^{-1} are most frequently applied. Our results revealed that row application of nitrogen at the rate 75 kg N □ha^{-1} yielded more taproots than the same rate being applied by the broadcast system. The rate 125 kg N □ha^{-1} was found to be markedly high, but under conditions of lack or ½ suggested P and K rates. Highly positive effect was recorded for the UAN-based multicomponent liquid fertilizer, as nitrogen carrier. This was attributed to the technique of application as well as its chemical composition, since apart of nitrogen, this fertilizer contained phosphorus, manganese, boron, and mainly sodium. The virtue of UAN relies on acidifying property in the soil of the amide and amine form, a feature that induces a reflexive effects as a result of a mobilization of some macro and microelements. This is a very important process in a soil characterized by an initial soil reaction (pH) varying from slightly acid to neutral.

Several studies have reported that the application of nutrients directly to the rhizosphere have a positive effect on plant yield [5, 22]. The tested liquid fertilizer contained small amounts of phosphorus, also. This nutrient is slowly mobile in the soil and only a high concentration in the rhizosphere covers sugar beet requirements at the beginning of the growth. The yield forming role of sodium and other remaining elements is based on their physiological functions, which control nitrogen transformation and water management in the plant, basically [4, 9].

In the light of our experimental results, an elucidation is needed for the controversy dealing with the reduction of taproot yields, which took place in the treatments with the highest P and K rates (80 kg P_2O_5 + 160 kg K_2O □ha^{-1}) at 75 kg N □ha^{-1} and the systematic increase of taproot yields with increasing P and K rates in the treatment fertilized with 125 kg N □ha^{-1} in the form of calcium saltpeter. Several investigations have pointed out at the significant role of potassium on the taproot yield [7, 11, 21]. This classical view, resulting directly from the effects experienced in the light of the latest studies, seems to be apparently true, only. Under English conditions, a significant and positive effect of potassium

Table 5. Yield of tops in relation to interaction between systems of nitrogen fertilization and level of PK fertilization ($t \cdot ha^{-1}$)
Tabela 5. Plon masy nadziemnej w zależności od współdziałania systemu nawożenia azotem oraz poziomu nawożenia PK ($t \cdot ha^{-1}$)

Year / Rok	System of N fertilization System nawożenia azotem	Level of P and K fertilization Poziom nawożenia P i K		
		P_0K_0	P_1K_1	P_2K_2
1997	$L–N_1$	43.7 [a]	62.6 [b]	42.7 [a]
	$C–N_1$	46.3 [a]	48.9 [a]	42.3 [a]
	$C–N_2$	53.0 [a b]	46.0 [a]	56.9 [a b]
1998	$L–N_1$	22.8 [a b]	26.4 [a b]	19.4 [a]
	$C–N_1$	24.8 [a b]	19.1 [a]	22.6 [a b]
	$C–N_2$	21.5 [a b]	28.2 [b]	27.3 [b]
1999	$L–N_1$	43.5 [a]	52.5 [a]	51.3 [a]
	$C–N_1$	44.7 [a]	41.4 [a]	39.6 [a]
	$C–N_2$	39.9 [a]	37.5 [a]	41.9 [a]
Mean / Średnia	$L–N_1$	36.7 [a]	47.2 [b]	37.8 [a]
	$C–N_1$	38.6 [a]	36.5 [a]	34.8 [a]
	$C–N_2$	38.1 [a]	37.2 [a]	42.1 [a b]

Values followed by the same letter are not significantly different at α=0,05
Wartości zaznaczone tą samą literą nie różnią się istotnie na poziomie α = 0.05

Table 6. Effect of interaction between nitrogen fertilizers and the levels of PK fertilization on the quality of sugar beet taproots (mean 1997 – 1999)
Tabela 6. Wpływ współdziałania systemu nawożenia azotem oraz poziomu nawożenia PK na jakość korzeni burka cukrowego (średnia 1997 – 1999)

Treat-ment / Wariant	Polari-zation/ Polary-zacja %	α-amin N mmol kg^{-1}	K mmol kg^{-1}	Na mmol kg^{-1}	Sugar losses / straty cukru %	Yield of refined sugar / Plon cukru techn. t ha^{-1}
$L–N_1P_0K_0$	16.61 [a]	18.6 [a]	45.7 [a]	5.8 [a]	2.40 [a]	8.62 [a b]
$L–N_1P_1K_1$	16.60 [a]	18.9 [a]	47.0 [a]	5.1 [a]	2.42 [a]	10.27 [b]
$L–N_1P_2K_2$	16.58 [a]	23.2 [a]	47.1 [a]	4.9 [a]	2.52 [a]	8.34 [a]
$C–N_1P_0K_0$	16.43 [a]	21.7 [a]	50.9 [a]	5.1 [a]	2.55 [a]	7.94 [a]
$C–N_1P_1K_1$	16.74 [a]	20.8 [a]	46.9 [a]	4.9 [a]	2.46 [a]	8.80 [a b]
$C–N_1P_2K_2$	16.48 [a]	22.3 [a]	47.6 [a]	4.4 [a]	2.50 [a]	7.66 [a]
$C–N_2P_0K_0$	16.84 [a]	20.8 [a]	47.8 [a]	4.5 [a]	2.47 [a]	7.83 [a]
$C–N_2P_1K_1$	16.56 [a]	24.6 [a]	48.0 [a]	4.4 [a]	2.37 [a]	7.94 [a]
$C–N_2P_2K_2$	16.66 [a]	19.7 [a]	47.3 [a]	5.1 [a]	2.45 [a]	8.75 [a b]

Values followed by the same letter are not significantly different at α = 0.05
Wartości zaznaczone tą samą literą nie różnią się istotnie na poziomie α = 0.05

fertilization (rates from 0 to 600 kg K ha^{-1}) was observed only at 1 of 26 tested treatments (treatment with mg K kg^{-1} soil) [20]. The optimal content of available potassium, which is needed for maximal production of sugar under field conditions amounts for 250 mg K_2O kg^{-1} soil in Germany and 220-250 mg K_2O kg^{-1} soil in Poland (DP Doppel lactate), [8, 25]. Potassium nutrition of sugar beet depends more on potassium-based soil fertility that on currently applied fertilizers [8, 20]. Moreover a positive reaction on potassium fertilization appears only under extreme conditions, soil drought, but plant yields are lowest decidedly [25].

At the experimental sites, where nitrogen fertilization systems have been tested, soils were moderately rich

Table 7. Effect of nitrogen fertilizers and levels of PK fertilization on mean values of agronomic efficiency ($kg \cdot kg^{-1}$)
Table 7. Wpływ nawozów azotowych oraz poziomu nawożenia PK na średnie wartości efektywności agronomicznej ($kg \cdot kg^{-1}$)

Year, treatment / Rok, wariant	Agronomic efficiency of N fertilization / Efektywność agronomiczna nawożenia azotem		Agronomic efficiency of PK fertilization / Efektywność agronomiczna nawożenia PK		Net Agronomic efficiency of PK fertilization / Efektywność agronomiczna netto nawożenia PK	
	AE_T [1]	AE_S [2]	AE_T	AE_S	NAE_T	NAE_S
Mean for years / Średnia dla lat						
1997	741,8 [b]	81,3 [a]	604,2 [b]	65,6 [a]	85,8 [c]	7,6 [b]
1998	703,5 [ab]	107,3 [b]	548,9 [ab]	84,1 [a]	-1,2 [a]	-0,1 [a]
1999	610,5 [a]	98,0 [ab]	485,4 [a]	78,7 [a]	40,7 [b]	9,1 [b]
Mean for N fertilization / Średnia dla nawożenia azotem						
$L–N_1$	742,7 [b]	103,7 [b]	606,3 [b]	83,9 [b]	70,2 [a]	6,7 [a]
$C–N_1$	654,4 [a]	91,5 [a]	511,1 [a]	71,9 [a]	2,5 [a]	1,4 [a]
$C–N_2$	658,7 [a]	91,4 [a]	521,2 [a]	72,6 [a]	52,7 [a]	8,4 [a]
Mean for PK fertilization / Średnia dla nawożenia PK						
P_0K_0	757,5 [b]	105,7 [c]	--	--	--	--
P_1K_1	833,1 [c]	116,6 [b]	745,6 [b]	104,4 [b]	67,6 [a]	9,8 [a]
P_2K_2	465,2 [a]	64,3 [a]	346,7 [a]	47,9 [a]	15,9 [a]	1,3 [a]
Mean for interaction N x PK / Średnia dla współdziałania N x PK						
$L–N_1P_0K_0$	794.9 [b]	112.9 [bc]	--	--	--	--
$L–N_1P_1K_1$	963.5 [c]	134.3 [c]	862.3 [b]	120.2 [b]	150.9 [a]	19.2 [a]
$L–N_1P_2K_2$	469.9 [a]	63.9 [a]	350.2 [a]	47.6 [a]	-10.6 [a]	-5.7 [a]
$C–N_1P_0K_0$	748.7 [b]	103.8 [b]	--	--	--	--
$C–N_1P_1K_1$	781.6 [b]	110.5 [b]	699.5 [ab]	98.9 [ab]	29.5 [a]	6.0 [a]
$C–N_1P_2K_2$	432.8 [a]	60.2 [a]	322.6 [a]	44.8 [a]	-24.5 [a]	-3.1 [a]
$C–N_2P_0K_0$	729.0 [b]	100.4 [b]	--	--	--	--
$C–N_2P_1K_1$	754.2 [b]	105.1 [b]	675.0 [ab]	94.1 [ab]	22.5 [a]	4.3 [a]
$C–N_2P_2K_2$	492.9 [a]	68.7 [a]	367.4 [a]	51.2 [a]	82.9 [a]	12.6 [a]

[1] – for yield of taproots / dla plonu korzeni
[2] – for yield of refined sugar / dla plonu cukru technologicznego
Values followed by the same letter are not significantly different at $\alpha = 0,05$
Wartości zaznaczone tą samą literą nie różnią się istotnie na poziomie $\alpha = 0.05$

in potassium before the seeding of sugar beet. For soils containing on average 160 mg K_2O ·kg^{-1}, about 180 kg K_2O ·ha^{-1} were applied as manure (amount of potassium available after one year is estimated to 75%) and from 0 to 160 kg K_2O ·ha^{-1} as potassium salt. Therefore, the mean content of available potassium ranged from 220 to 270 mg K_2O ·kg^{-1}. AT all studied treatments characterized by potassium content over 250 K_2O ·kg^{-1} soil (variants P_2K_2) and receiving simultaneously 75 kg N ·ha^{-1}, a reduction of taproots and leaves biomass was registered. In media with high potassium content, an increase of a risk of antagonisms between potassium and other nutrients may occur, in turn creating unfavorable conditions and changes in the ionic equilibrium of plant cells [13]. The positive effect of the highest potassium rate on taproots yield and leaves biomass was recorded only in the treatment with double nitrogen rate (75+50 kg N ·ha^{-1}) as calcium saltpeter as nitrogen carrier. In the case of the treatment C-$N_2P_2K_2$, the increase of the nitrogen rate along with a high supply of potassium induced an increase of the biomass of both organs, i.e. leaves and taproots. For the other two remaining variants (C-$N_2P_0K_0$, C-$N_2P_1K_1$) of the same treatment, it was observed that the high nitrogen rate unbalanced by an adequate amount of potassium, has induced a decrease of the biomass of both organs. Such a specific role of potassium results in its function upon the uptake and transport of nitrates [17].

Qualitative assessment of taproots

Investigated fertilizer treatments did not significantly influence the qualitative parameters of sugar beet taproots (Table 6). Among experimental factors, nitrogen exerted the greatest and simultaneously negative effect [12]. The tested method of row application of nitrogen has significantly reduced nitrogen demand of plants, but any expected improvement of taproot quality was not observed. In spite of that nitrogen was applied at the lowest rate, its availability in the rhizosphere was probably more higher as compared to the treatment with the classical method of broadcast application of fertilizers.

The yield of technological sugar of sugar beets is a function of yield taproots and the content of sugar and molasses compounds as well [2]. Our data reveal that the yield of technological sugar (m_{RSY}) depended closely on taproots biomass (m_B). Based on the following equations it could be observed that less significant effect was attributed to the polarization (m_S) and the content of melassogenic compounds ($w'_{\alpha\text{-N}}$, w'_K) of which potassium has exerted a negative effect in two of three experimental years:

1997	$m_{RSY} = -11.0 + 0.15\ m_B + 0.66\ m_S - 0.015\ w'_K$	$R^2 = 0.99^{***}$; $n = 9$
	$m_{RSY} = 0.011 + 0.51\ m_B$	$R^2 = 0.93^{***}$; $n = 9$
1998	$m_{RSY} = -9.16 + 0.11\ m_B + 0.68\ m_S - 0.013\ w'_{\alpha\text{-N}}$	$R^2 = 0.99^{***}$; $n = 9$
	$m_{RSY} = -0.073 + 0.11\ m_B$	$R^2 = 0.90^{***}$; $n = 9$
1999	$m_{RSY} = -8.74 + 0.16\ m_B + 0.50\ m_S - 0.007\ w'_K$	$R^2 = 0.99^{***}$; $n = 9$
	$m_{RSY} = 0.81 + 0.15\ m_B$	$R^2 = 0.86^{***}$; $n = 9$

*** - significant for $p < 0.001$

Agronomic efficiency

The agronomic efficiency of applied nitrogen varied accordingly with time (years) as well as with experimental factors. Weather conditions have differently influenced the efficiency of 1 kg of the applied fertilizer nitrogen, examined for taproots and sugar. In the first case it was observed a statistically proved and negative effect of drought on taproots yield in 1999. For the second case referred to unit production of sugar, higher values were recorded for the second and third year of experimentation, resulting explicitly from a greater sugar polarization in taproots (Table 7).

The investigated nitrogen fertilization system has significantly influenced nitrogen efficiency, which increased by 13% under the liquid method for taproots and sugar yields. The second factor, i.e., P and K rates points out explicitly at the highest efficiency of nitrogen applied on the treatment with the rate of both elements reduced by 50%. Considering the interaction between the methods of nitrogen application and the rates of P and K, it could be observed a double increase of nitrogen efficiency in the treatment $L-N_1P_1K_1$ as compared to all other variants. An unusually interesting phenomenon was observed on treatments fertilized with P and K. The full rate of P and K, designated as P_2K_2, induced a decreased of nitrogen efficiency, irrespective of the method of nitrogen application; a case not observed for the treatment P_0K_0. The assessment of yield forming efficiency of phosphorus or potassium is not often mentioned in scientific investigations and even appliqué. Our investigations have shown a strong effect of weather, i.e., a seasonal variability. This factor did not allow defining the role of tested experimental factors in the aspect of the assessment of the net efficiency of applied P and K rates. The assessment of the gross efficiency for the consecutive years confirmed the disparate influence of weather conditions on taproots and sugar yields. Row application of nitrogen has distinctly increased P and K efficiency as compared to the broadcast method (Table 7).

Such explicit and proved effect of row nitrogen application indicates at the role of the fertilizer application method as well as the significance of the phosphorus starting rate contained in the liquid fertilizer. Simultaneously ca two times lower values of P and K gross agronomic efficiency in the treatment P_2K_2 confirm the necessity for optimalizing the rates of both elements. The analysis of values of the net efficiency showed that unbalancing nitrogen with P and K rates, may lead to unit depression of the production of taproots and sugar as compared to the control. This phenomenon requires further investigations, since results reported in the current paper and those available in the scientific literature do not enable an elucidation of this state.

CONCLUSION

The carried out investigations revealed that the purposes of sugar beet production reported in the introductory chapter may be fulfilled by changing not only the method of P and K application, but also nitrogen, mainly in soils intensively fertilized with organic as well as mineral fertilizers. By the row application of the liquid form of nitrogen fertilizer (UAN) at the rate 75 kg N ha^{-1}, the best productive response, expressed in terms of taproots and sugar yields was recorded, even higher than the yielding potential of the tested variety under polish conditions. In this system it should be simultaneously controlled the level of P and K fertilization, relying on a significant reduction of their rates. Excessive soil level of K reduces not only taproots yields but additionally worsens the technological quality of the raw material. The agronomic efficiency has confirmed the highly positive effect of nitrogen applied in the liquid form. Nitrogen applied according to the row method has displayed much higher effect as compared to nitrogen from calcium nitrate, incorporated mainly at the highest rate (125 kg N□ha^{-1}). The nitrogen row application method limits the size of nitrogen rates under sugar beet cropping and improves the utilization of P and K rates at fall. The tested methods of nitrogen application and P and K fertilizers did not significantly differentiate the quality of taproots.

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