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THE EFFECT OF DIFFERENT PHOSPHORUS AND POTASSIUM FERTILIZATION ON PLANT NUTRITION IN CRITICAL STAGE AND YIELD OF WINTER TRITICALE

Wpływ zróżnicowanego nawożenia fosforem i potasem na odżywienie pszenżyta ozimego w fazie krytycznej oraz plon ziarna

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ABSTRACT

Research was carried out in the years 2008-2010 on the objects of stationary experiment established in 2000 at the Research Station Brody - Poznań University of Life Sciences. *Hortenso* variety of winter triticale was cultivated in the conditions of one-factor experiment. The factor investigated was a differential level of mineral fertilization with phosphorus and potassium. The aims of the study comprised: (1) determination of winter triticale response with reference to the optimal fertilizer rate as well as reduced levels of P and K fertilization, (2) evaluation of winter triticale nutritional status at the stage BBCH 31 in the conditions of differential fertilization with phosphorus and potassium, (3) assessment of yield diagnostic methods based on nutritional status and biomass produced during the analyzed development stages. Triticale response in the experimental conditions indicated that this plant is more sensitive to potassium deficiency when compared with phosphorus. Evaluation of plant nutritional status with the use of PIPPA software indicated that plant yield was constrained by deficiency of numerous elements. In the group of mineral nutrients limiting triticale yield, the effects of calcium, magnesium and potassium were most evident.

Keywords: critical stage, nutritional status, potassium and phosphorus rate, winter triticale

STRESZCZENIE

Badania przeprowadzono w latach 2008-2010 na obiektach statycznego doświadczenia założonego w 2000 roku w Rolniczym Zakładzie Doświadczalnym Brody, należącym do Uniwersytetu Przyrodniczego w Poznaniu. Pszenżyto ozime odmiany *Hortenso* uprawiano w warunkach doświadczenia jednoczynnikowego. Czynnikiem badawczym był zróżnicowany poziom nawożenia mineralnego fosforem i potasem. Interpretację wyników stanu odżywienia roślin przeprowadzono w oparciu o niemiecki program PIPPA (Professional Interpretation Program for Plant Analysis). Celem przeprowadzonych badań polowych było: (1) określenie reakcji plonotwórczej pszenżyta ozimego rozważanej w aspekcie dawki optymalnej oraz zredukowanego poziomu nawożenia P i K; (2) ocena stanu odżywienia pszenżyta w fazie BBCH 31 w

warunkach zróżnicowanego nawożenia fosforem i potasem; (3) ocena metod diagnozowania plonu na podstawie stanu odżywienia oraz wytworzonej biomasy w analizowanych fazach rozwojowych.
Reakcja plonotwórcza pszenżyta w warunkach prowadzonego doświadczenia wykazała, że roślina ta jest bardziej wrażliwa na niedobór potasu niż fosforu. Dziesięcioletni brak nawożenia P i K spowodował spadek plonów pszenżyta wynoszący odpowiednio 4,6% i 12,8%. Czynnik doświadczalny istotnie różnicował także zawartość azotu, fosforu, manganu i żelaza w liściach pszenżyta w fazie wykształconego pierwszego kolanka (BBCH 31) określanej jako faza krytyczna. Ocena stanu odżywienia roślin przeprowadzona z użyciem programu PIPPA, wykazała, że plon roślin ograniczał niedobór wielu pierwiastków. W grupie składników mineralnych ograniczających plon pszenżyta w największym stopniu zaznaczył się wpływ wapnia, magnezu, potasu. Analiza regresji potwierdziła, że zmienność plonu pszenżyta w 76% określana była przez stan odżywienia roślin potasem w fazie początku strzelania w pęd.

Słowa kluczowe: faza krytyczna, pszenżyto, stan odżywienia roślin, fosfor, potas

STRESZCZENIE SZCZEGÓŁOWE

Popularność uprawy pszenżyta w Polsce wynika z większego potencjału plonowania w stanowiskach średnich i słabych w stosunku do pszenicy oraz większej odporności na zakwaszenie gleby, choroby liści, czynniki abiotyczne jak również mniejszych wymagań względem przedplonu i nawożenia. Istotne znaczenie w zapewnieniu plonów zbliżonych do plonów potencjalnych, odgrywa odpowiednie odżywienie pszenżyta fosforem i potasem. Brak zbilansowania składników względem potrzeb pokarmowych roślin jest przyczyną zaburzeń funkcjonowania poszczególnych składników oraz ich niskiego wykorzystania przez roślinę
Podstawowym celem przeprowadzonych badań polowych było: (1) określenie reakcji plonotwórczej pszenżyta ozimego rozważanej w aspekcie dawki optymalnej oraz zredukowanego poziomu nawożenia P i K; (2) ocena stanu odżywienia pszenżyta w fazie BBCH 31 w warunkach zróżnicowanego nawożenia fosforem i potasem; (3) ocena metod diagnozowania plonu na podstawie stanu odżywienia oraz wytworzonej biomasy w trzech analizowanych fazach rozwojowych. W latach 2008-2010 przeprowadzono 3-letnią serię doświadczeń polowych w układzie jednoczynnikowym. Czynnikiem badawczym był zróżnicowany poziom nawożenia mineralnego fosforem i potasem. Na podstawie zasobności gleby, pobrania jednostkowego i spodziewanego plonu ustalono poziom nawożenia mineralnego określony jako RBF (ang. Recommended Balanced Fertilization), który odpowiadał optymalnej dawce fosforu i potasu wynoszącej 180 kg azotu (N), 17.5 kg fosforu (P), 90 kg potasu (K) i 15 kg magnezu (Mg) · ha^{-1}. W oparciu o wyznaczony optymalny poziom nawożenia fosforem i potasem ustalono pozostałe dawki składnika, redukując odpowiednio poziom nawożenia P i K do 25% i 50% względem wariantu optymalnie zbilansowanego, zachowując jednocześnie stały poziom nawożenia N, P, Mg. W okresie wegetacji, w trzech terminach przypadających na następujące fazy rozwojowe: BBCH31, BBCH55, BBCH65 określono biomasę nadziemną roślin. Czynnik doświadczalny istotnie różnicował plon ziarna pszenżyta oraz zawartość analizowanych składników w fazie BBCH 31. Szczególną uwagę zwracają obiekty od 10 lat nienawożone fosforem i potasem (RBF-P i RBF-K). Dziesięcioletni brak nawożenia w porównaniu do obiektu optymalnie nawożonego spowodował spadek

plonów pszenżyta wynoszący odpowiednio 4.6% i 12.8%. Istotny spadek plonu odnotowano także w wariancie, na którym redukowano dawki potasu i fosforu do 25% względem wariantu optymalnie zbilansowanego. Ocena stanu odżywienia pszenżyta przeprowadzona w fazie BBCH 31 w oparciu o wartości standardowe wyznaczone przez Bergmanna (1992) wykazała, że niezależnie od poziomu nawożenia P i K rośliny były niedożywione potasem, wapniem i miedzią. Zredukowane dawki fosforu znacznie w większym stopniu niż potasu, istotnie różnicowały zawartość P w liściach pszenżyta. Różnice te szczególnie zaznaczyły się w stanowiskach, na których fosfor stosowano w dawce obniżonej do 25 i 50% względem obiektu optymalnie nawożonego. W diagnostyce prognozowania plonu najbardziej przydatna jest wczesna faza rozwoju roślin (BBCH 31). Potwierdzeniem tego faktu jest wysoka zależność plonu zarówno od wytworzonej biomasy jak również zależność plonu od akumulacji składników w fazie początku strzelania w źdźbło.

INTRODUCTION

Winter triticale belongs to fodder cereals cultivated all over Poland. For last 10 years, this species has shown bulky growth tendency with regard to sowing. According to data of the Central Statistical Office (GUS 2009), the share of triticale in the total cereal area was 17.1%, which is 1.45 million ha. Popularity of triticale cultivation results from its higher yield potential than that of wheat when grown on medium and weak sites as well as its higher resistance to soil acidification, leaf diseases, abiotic factors, and also its lower demands with regard to forecrop (Buraczyńska and Ceglarek, 2009; Grzebisz, 2009; Liu, et al., 2004; Mikhailova et al., 2009; Radzka et al., 2008; Ścigalska and Łabuz, 2008). Sufficient nutrition of triticale with phosphorus and potassium plays an important role in securing accomplishment of yields close to potential. Both elements fulfill important physiological functions in the plant by taking part in the processes of photosynthesis, transportation of assimilates and protein synthesis (Marschner, 1995). In the mid-nineties of the 20th century, Marschner et al. (1996) stated a thesis that plant growth was optimal only when the plant is lavishly fed with potassium. Lack of balance with regard to plant nutrition needs is the reason of disturbances in functioning of particular nutrients and their low utilization by the plant as well as it increases risk of unnecessary accumulation of potentially environment threatening constituents in soil (Öborn, et al., 2005; Roberts, 2005; Zhang, et al., 2007). The structure of P and K utilization in Poland justifies a thesis of unwise fertilization of triticale and other crop plants (Grzebisz and Gaj, 2009). Achievement of higher efficacy and efficiency of mineral fertilization is possible through searching for and improving the methods of assessment of plant nutritional status as well as aiming at optimalization of fertilizing. Plant nutrition is also important for the fodder value since both deficiency and excess of micronutrients can unfavorably impact metabolism of animal organisms (Szynal and Sykut, 1992). Knowledge on factual needs of plants concerning mineral nutrients is an important aspect of reducing agriculture negative effects on environment (Mankin and Fynn, 1996). The aims of conducted field study comprised: (i) determination of winter triticale response with reference to the optimal fertilizer rate as well as reduced levels of P and K fertilization, (ii) evaluation of triticale nutritional status at the stage BBCH 31 in the conditions of differential fertilization with phosphorus and potassium, (iii) assessment of yield diagnostic methods based on nutritional status and biomass produced during the analyzed development stages.

MATERIALS AND METHODS

Experiments were conducted in the years 2008-2010 on the objects of stationary experiment established in 2000 at the Research Station Brody (52°26'N, 16°18' E) which belongs to Poznań University of Life Sciences. *Hortenso* variety of winter triticale was cultivated in the conditions of one-factor experiment with four replications for each experimental object. The investigated factor was a differential level of mineral fertilization with phosphorus and potassium. A level of mineral fertilization, i.e. Recommended Balanced Fertilization (RBF) was determined based on soil richness, individual sampling and expected yield. This was equivalent to the optimal rate of phosphorus and potassium and amounted to 180 kg nitrogen (N), 17.5 kg phosphorus (P), 90 kg potassium (K) and 15 kg magnesium (Mg) per 1 ha. Based on the fixed optimal level of fertilization with phosphorus and potassium other nutrient rates were determined by respective reduction of P and K fertilization to 25% (1/4PK) and 50% of the optimally balanced variant (RBF1/2P and RBF1/2K) while maintaining the constant level of fertilization with N. Additionally, control variants RBF-K (NPMg) and RBF-P (NKMg) were introduced, to which respectively potassium or phosphorus were not applied. Fertilization with phosphorus, potassium, and magnesium according to the design of the experiment, was carried out in one dose after forecrop harvest. Potassium was applied in the form of potassium chloride (60% K_2O), phosphorus in the form of single superphosphate, and magnesium in the form of kieserite (27% MgO). In the case of the plot RBF-PAPR, phosphorus was applied in the form of partially acidulated phosphate rock (PAPR), regarding the post RBF-PAPR as an alternative source of phosphorus in relation to single superphosphate. In the studies, phosphate with the content of the total phosphorus of 10.2% P and 50% acidity was used (which means that the amount of sulphuric acid used in the technological process for obtaining the product amounted to 50% of the amount necessary for producing single superphosphate). Fertilization with nitrogen in the form of ammonium nitrate at the dose of 180 kg $N \cdot ha^{-1}$ was carried out at three different times: before sowing in the autumn – 30 kg, before the onset of spring growth – 80 kg $N \cdot ha^{-1}$, three weeks after the application of the second nitrogen dose – 70 kg $N \cdot ha^{-1}$.

The field experiment has been started on podsolic soil containing 15 to 20% of clay particles - bonitation class IVa, which was characterized by a light acid reaction, high content of available phosphorus (103 mg P kg^{-1}), medium availability of potassium (169 mg K kg^{-1}) and magnesium (37 mg Mg kg^{-1}). Every year the winter triticale was cultivated after winter wheat.

During the vegetation period, triticale above-ground biomass at plant development stages BBCH31, BBCH55, BBCH65 [36] was assessed after collecting plants from 1m long sections. The content of nutrients was determined in the plant material taken at the first node stage (BBCH31). The results were interpreted with the use of German software PIPPA (Professional Interpretation Program for Plant Analysis), (Schnug and Haneklaus, 2008). The detailed description of software is provided by Gaj (2008). In general, in the first step software computers the value of potential yield at a given plant nutrient content and at all other conditions as constant. Then it sorts out and arranges elements in the order from the most yield limiting one to the one with the content sufficient for obtaining maximum yield. This mode reflects authentic arrangement of yield limiting nutrients.

The results obtained were tested with one-factor ANOVA. The analysis of straight correlation and multiple regression were applied to evaluate cause-effect

relationships between analyzed parameters. Regression analysis was conducted until all variables in the equation were significant at $p < 0.05$
Weather conditions during the experimental period were different (Table 1). In the springtime of the years 2008-2009 there were observed strong precipitation deficits in May and June (2008) and April (2009). The least favorable weather conditions were observed in last experimental year (2010), when there occurred considerably lower temperatures at much increased precipitation when compared to long-term averages.

Table 1. Weather conditions during the growth of winter triticale
Tabela 1. Warunki meteorologiczne w sezonie wegetacyjnym uprawy pszenżyta ozimego

Vegetation season	Months, Miesiące											
	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Temperature, Temperatura (°C)												
2007/2008	18.1	13.2	8.2	3.1	2.1	2.3	4.2	4.1	8.7	15.2	19.1	20
2008/2009	18.8	13.9	10	5.7	1.6	-2.4	0.1	4.6	11.7	13.4	15.7	19.7
2009/2010	19.7	15.6	7.9	6.7	-0.4	-9.5	-3.9	0.3	3.8	8.5	11.4	15.6
Long-term Wielolecie	17.4	13.1	8.5	3.4	-0.2	-1.8	-0.6	2.8	7.7	13.1	16.3	17.8
Rainfalls Opady, (mm)												
2007/2008	70.9	48.8	21.3	68	53	113	30.5	75.7	120	19.5	8.6	80.1
2008/2009	171.5	29.8	74.9	34.3	36.6	22.6	52.6	65.1	13.3	85.3	79.3	68.1
2009/2010	31.4	50	73.3	45.4	41.4	46.8	19.9	56.3	38.9	92.7	17	98.2
Long-term, Wielolecie	62	50.3	41.8	44.7	47.1	36.5	30.6	38.8	38	54.7	65.7	56

RESULTS AND DISCUSSION

Triticale response under differential phosphorus and potassium fertilization levels was significantly different when compared with the absolute control as well as it differed among observed fertilized objects (Figure 1). The objects which were not fertilized with phosphorus and potassium for 10 years (RBF-P and RBF-K) require special attention. Ten-year-long lack of fertilization with phosphorus and potassium resulted in the decrease of yield by 4.6% and 12.8%, respectively, when compared with the object fertilized at the optimal level. A significant difference was observed only for the variant without potassium. Triticale response indicates that this plant is more sensitive to potassium deficiency than that of phosphorus. The decrease of yield was 57% when compared with the absolute control. The results of research conducted by Kunzova and Hejcman, (2010) on wheat during long-term stationary fertilization experiment indicated plant reaction to lack of fertilization only after 20 years. Triticale also showed a significant decrease of yield under the influence of reduced rates of potassium and phosphorus, and this reaction was more than ever strongly indicated at the site where 25% of optimal P and K needs were fulfilled.

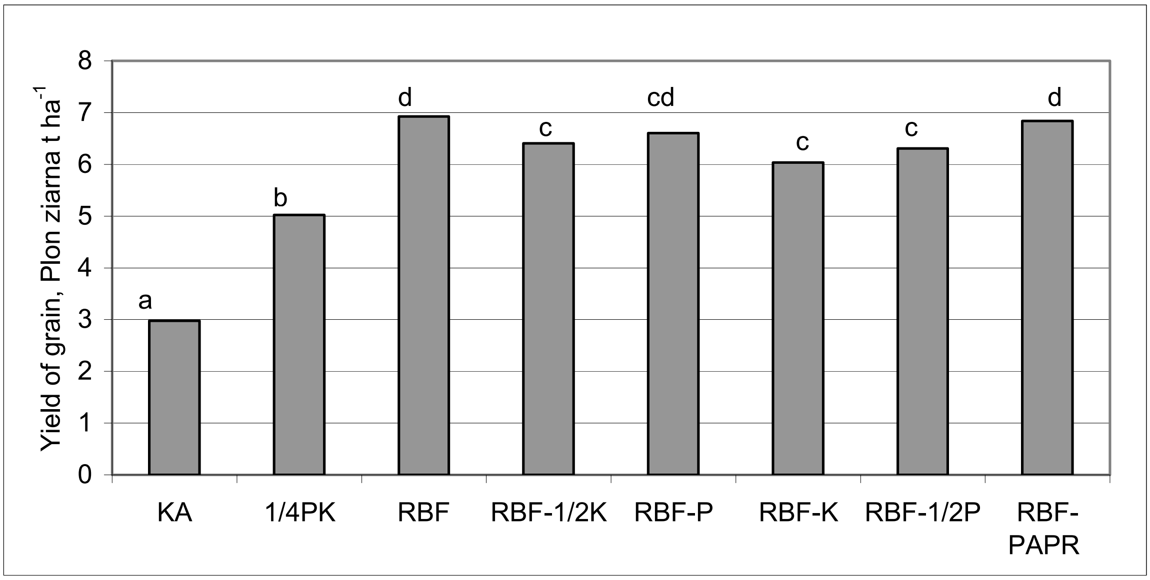

Figure. 1. Effect of differential level of phosphorus and potassium application on grain yield of winter triticale, t·ha^{-1}

Rycina. 1. Wpływ zróżnicowanego poziomu nawożenia fosforem i potasem na plon ziarna pszenżyta

Values followed by the same letter are not significantly different at α = 0.05

Wartości zaznaczone tą sama literą nie różnią istotnie na poziomie α = 0.05

In this variant, there was observed 27% yield drop off when compared with the object optimally balanced with regard to nitrogen (RBF). Literature data on issues connected with long-term experiments on phosphorus fertilization of crop plants indicate that yield reduction as a result of lack of fertilization with this element is revealed after much longer time interval (Moskal, et al., 1999; Stępień and Mercik, 1999). Shen, et al. (2004) observed plant response to lack of fertilization with phosphorus after 11 years. Absence of significant direct effects of differential rates of potassium or else of long-term discontinuation of fertilization of wheat and winter rape with this element was noted in other studies (Gaj 2010a, 2010b). In world's literature, potassium is rarely mentioned as the element limiting plant production, however it is most often pointed out as the main nutrient affecting the quality of obtained products (Usherwood, 1985; Whitehead, 2000). The risk of yield reduction can be decreased by applying balanced fertilization as regards all nutrients. In the group of yield limiting factors, there were also involved other mechanisms besides phosphorus and potassium, of which on the first place there should be listed water and temperature during the vegetation season. In studies on cereal reaction to weather conditions during vegetation there is often observed stronger influence of precipitation on plant growth and yield than that of temperature. Koziara (1996) emphasizes that the above relationship results from quality of soils designated for cereal cultivation. Weak retention abilities of soils when connected with irregular precipitation patterns have as a result crucial effects on quantity of harvested crops. In the years of the present study, a particularly adverse pattern of weather conditions was indicated in the vegetation season 2009/2010, which determined quantity of obtained yield, but at the same time did not change the direction of triticale reaction to differential rates of P and K. A decrease of yield during the last observed vegetation season in this study was 18.5% when compared with the previous years. Alike wheat, triticale is the cereal with high production potential, thus when ensuring abundance of water one can expect high yields. According to COBORU (Research Centre for Cultivar Testing) data, during the years of experiments, triticale yielding potential was 7.83 $t\cdot ha^{-1}$ on average, which means that on the experimental site which was optimally fertilized triticale yielding potential was 88%. Among main farmer's obligations there are both maximalization of water content in soil (reduction of field surface outflow through creation of conditions for good infiltration of water down the soil profile) and effective control of plant water management during the vegetation period. Successful water management by the plant is determined by good nourishment with potassium. Under the influence of mineral fertilization there significantly increased the content of all analyzed nutrients when compared with the content of elements observed in the absolute control plants (Table 2).

Table 2. Content of macro- and micronutrients in winter ttiticale at BBCH 31 stage on the background of the level of potassium and phosphorus fertilization, (mean for 3 years)
Tabela 2. Zawartość makro- i mikroskładników w pszenicy ozimej w fazie BBCH 31 na tle poziomu nawożenia potasem, (średnia z 3 lat)

Treatment/ Wariant	Nutrients, Składniki								
	N	P	K	Mg	Ca	Zn	Mn	Cu	Fe
			$g\cdot kg^{-1}$				$mg\cdot kg^{-1}$		
Absolut control	27.01	3,02	24.57	0.95	2.30	21.66	35.00	3.61	51.60
RBF-P	30.43	3.24	28.48	1.11	2.55	25.00	42.74	3.72	58.55
RBF-K	30.92	3.26	27.99	1.15	2.53	25.48	43.08	3.87	55.65
¼ PK	31.51	2.88	27.01	1.00	2.55	25.41	33.32	3.91	61.64
RBF-1/2P	28.9	2.98	29.57	0.92	2.50	25.00	48.50	4.07	56.46
RBF-1/2K	31.54	3.41	29.57	1.11	2.55	27.80	42.42	3.93	56.05
100% PK	29.92	3.43	28.20	1.07	2.48	25.25	40.20	3.72	63.30
100% PK (P as/jako PAPR	30.51	3.19	27.70	0.91	2.33	24.47	51.80	3.82	64.41
LSD NIR, 0.05	2.016	0.162	1.892	0.114	0.298	2.672	2.67	ni	9.189

The experimental factor significantly differentiated the content of nitrogen, phosphorus, manganese and iron in triticale leaves. Reduced phosphorus rates differentiated significantly, and to a bigger extent than potassium, the content of P in triticale leaves. The differences were especially distinctive on the sites where phosphorus was applied at the rates lowered to 25% and 50% as compared to the object fertilized optimally. The content of phosphorus in triticale leaves was also differentiated by a form of applied P. Lower contents of this element were observed in the variant treated with partially acidulated phosphate rocks (RBF-PAPR).

Evaluation of triticale nutritional status based on the standard indicators established by Bergmann (1992), which was carried out at BBCH 31 stage indicated that plants were malnourished with potassium, calcium and copper, regardless P and K fertilization levels. In a view of Greenwood and Stone (1998), the content of a mineral nutrient which allows maximum plant growth rate is critical. Correlation analysis of relationships between yield and element contents at BBCH 31 stage indicated significant relations only for potassium and phosphorus (Table 3).
In order to define dominant share of potassium in shaping yield, regression analysis with the best sub-set variable selection was carried out. This relationship indicates that variableness of triticale yield was determined in 76% by nourishment of plants with potassium at the beginning of stem elongation stage, as described by the presented equation:

$$Y\ (\text{Yield}) = 7.96\ [K] - 16.309 \quad R^2 = 0.765 \quad n = 24;\ p < 0.004$$

Table 3. Correlation coefficient between nutrients' content in leaves in BBCH 31 stage and grain yield of winter triticale, n= 24

Tabela 3. Współczynniki korelacji między zawartością składników w liściach w fazie BBCH 31 a plonem ziarna pszenżyta, n = 24

Variable/ Zmienna	Nutrients/ Skladniki ($g\cdot kg^{-1}$)				
	N	P	K	Ca	Zn
Yield/Plon ($t\cdot ha^{-1}$)	-0.612	0800*	0.875*	0.662	0.683
N	1	0.521	0.620	0.620	0.862*
P	-	1	0.891*	0.760*	0.807*
K	-	-	1	0.844*	0.858*
Ca	-	-	-	1	0.789*
Zn	-	-	-	-	1

*correlation significant at p < 0,05, korelacja istotna na poziomie p < 0,05

Askegaard et al. (2004) emphasize that evaluation of potassium content in plants is a key aspect of effective management of this element and that it complements soil tests. In a view of Leigh and Johnston (1983) a low content of a given element in plant is not an adequate indicator of available potassium in soil. Plant functioning depends on balanced fertilization with all micro- and macroelements. Nutrients seldom act separately. Element concurrence can be of synergic or antagonistic character. Numerous researches indicated that firstly the interaction between nitrogen and other elements influenced yield and utilization of nitrogen (Fixen, et al., 2005; Roberts, 2008). In this study, significant correlations were shown between nourishment with phosphorus and the content of calcium, potassium and zinc as well as between potassium and calcium (Table 3). P x K concurrence comprises element participation in the process of photosynthesis, enzymatic reactions as well as enhancement of stress toleration. Concurrence of phosphorus with various micro- and makroelements is also well documented in literature, where often the interaction between phosphorous and zinc is pointed out (Korzeniowska, 2008; Summer and Farina, 1986).

Evaluation of plant nutritional status carried out with PIPPA software indicated that plant yield was limited by deficiency of many elements (Table 4). Similar relation was proved for other crop plants (Gaj, 2008, 2010a, 2010b). The results of this study indicate high demands of triticale with high level yields with regard to site abundance of all mineral nutrients. In the group of mineral nutrients with limiting effect on triticale yield, the effects of calcium, magnesium, potassium were most distinguished, while the effects of other elements (nitrogen, zinc) were minimal. The use of PIPPA software allows not only to determine elements which are deficient, but also their share in the group of yield limiting elements, which reflects the strength of activity of particular elements. Limiting effect of elements was decreasing in the following direction: calcium > magnesium > phosphorus >potassium > copper > nitrogen > zinc.

Table 4. Rank of components limiting yield of winter triticale (mean for 3 years)
Tabela 4. Szereg pierwiastków limitujących plon pszenżyta ozimego (średnia z 3 lat)

Treatments Warianty	Elements Składniki
Control	Ca Fe Mg K P N Zn Cu ▌ Mn
RBF–P	Ca P Mg Zn K N Fe Cu Zn ▌ Mn
RBF-K	Ca Fe P K Mg N Cu ▌ Zn Mn
1/4PK	Ca Mg P K N Cu ▌ Zn Mn Fe
RBF-1/2P	Ca Mg Fe N K P Zn ▌ Cu Mn
RBF-1/2 K	Ca Fe Mg K N P Cu ▌ Mn Zn
RBF	Ca Mg K N Cu P ▌ Zn Fe Mn
RBF (P as/jako PAPR)	Ca Mg P K N Cu Zn ▌ Mn Fe

According to other literature data (Matos, et al. 1993), the content of calcium in leaves ranging from 0.1 to 0.4% is not a factor limiting triticale yield.

Plant growth rate is simple to determine and the most credible indicator of plant nutritional status. Mineral fertilization significantly increased triticale biomass in all analyzed periods (data available from the author). The assessment of biomass together with assessment of nutrients provides a good diagnostic tool for predicting yield. In practice, most often used is the assessment of above-ground biomass since this is a measurable indicator which can be linked with a given plant development stage, i.e. indicative stage (Grzebisz, 2008). Correlation analysis taking into account relationships between biomass in the stages BBCH 31, BBCH 55 and BBCH 65 and triticale grain yield (Table 5) indicates that these can be a better diagnostic tool for predicting grain yield than relationships between the content of particular elements and yield. In a view of agricultural practice in diagnostics of yield prediction, most useful is the first node stage, and high values of correlation coefficients.
confirm this fact. Yield quantity can be predicted with high probability during examination of biomass in the early vegetation period. At the same time there exists a possibility of intervention mineral fertilizing in the situation when plants show growth restriction due to malnutrition. Cereal yield is determined by plant ability to accumulate and distribute dry mass (carbon) into its organs during the whole period of vegetation, both in the phases of vegetative and generative growth (Spiertz and Vos, 1985). In the present study, the relationship between yield and whole plant biomass or biomass of analyzed organs indicated that the values of correlation coefficients were equal or higher for the total dry mass of whole plants when compared with those for selected plant organs. Similar relationship was observed by Szczepaniak (1999).

Table 5. Correlation coefficient between yield of winter triticale and total dry matter winter triticale, n = 24

Tabela 5. Współczynniki korelacji prostej pomiędzy plonem a biomasą całkowitą pszenżyta ozimego w analizowanych fazach rozwojowych, n= 24

Growth stage Faza rozwojowa	Total biomass Calkowita biomasa	Plants organ Organ rośliny		
		Leaves	Stem	Ears
BBCH-31	0.816*	0.816*	-	-
BBCH-55	0.768*	0.6194	0.733*	0.784*
BBCH-65	0.930*	0.890*	0.854*	0.876*

- correlation significant at $p < 0.05$, $p < 0.05$; n=24

CONCLUSIONS

1. Winter triticale yielding significantly depended on a differential level of fertilization with phosphorus and potassium. Triticale response was

considerably stronger when potassium rates were reduced whilst compared to phosphorus.

2. The assessment of triticale nutritional status at the beginning of stem elongation indicated that plants were malnourished with potassium, calcium and copper.
3. Correlation analysis of nutritional status and grain yield showed significant correlation for phosphorus and potassium. The state of nourishment with potassium decided in 76% on variableness of winter triticale grain yield.
4. In yield diagnostics and prognosis most useful is plant early development stage (BBCH 31). This is confirmed by high reliance of yield both on produced biomass and plant ability to accumulate nutrients in the stage of the beginning of stem elongation.

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