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ORIGINAL PAPERS

INFLUENCE OF DIFFERENT POTASSIUM FERTILIZATION LEVEL ON NUTRITIONAL STATUS OF WINTER WHEAT AND ON YIELD DURING CRITICAL GROWTH STAGE

Renata Gaj

Chair of Agricultural Chemistry
Poznań University of Life Sciences

Abstract

An optimum plant crop nutrition status during critical stages of growth is one of the most important factors shaping their ability to yield. It has been assumed that plant nutrition during the spring wheat stem elongation stage has a significant influence on the growth and yield of this crop. In Poland, potassium is a critical nutrient for plant growth and yielding. In order to verify this hypothesis, three series of one factorial experiment were conducted in 2003-2005 that involved reduced rates of potassium applied to cv. *Zyta* winter wheat. The following rates of potassium were applied: 0, 25, 50 and 100 kg ha^{-1}. The assessment of wheat nutritional status was conducted at the beginning of stem elongation (BBCH30/31) using a German model called PIPPA. It had been hypothesized that this particular stage was decisive for wheat growth and yielding. Wheat plants showed deficiency in Ca, K, P and N irrespective of the applied potassium rate. Calcium and potassium deficiencies were crucial for the final grain yield. However, the relationships that occurred between nitrogen and main nutrients, i.e. pairs of nutrients such as N: P, N: K, N: Ca, showed a much better prognostic value, i.e. the relationship with grain yield, than the levels of nutrients in separation. The nitrogen content in leaves at the beginning of shooting showed its limiting effect on grain yield, provided that Ca was deficient, an event which appeared when N: Ca was wider that 34: 1. The same correlation was noticed for potassium, but there the excess of nitrogen revealed its harmful effect when the N:K ratio was above 1.0.

Key words: winter wheat, potassium rate, nutritional status, the beginning of shooting.

dr hab. Renata Gaj, Chair of Agricultural Chemistry, Poznań University of Life Sciences, Wojska Polskiego str. 71F, 60-625 Poznań, Poland, e-mail: grenata@up.poznan.pl

WPŁYW ZRÓŻNICOWANEGO POZIOMU NAWOŻENIA POTASEM NA STAN ODŻYWIENIA W KRYTYCZNEJ FAZIE WZROSTU I PLONOWANIE PSZENICY OZIMEJ

Abstrakt

Optymalne odżywienie roślin uprawnych w krytycznych fazach wzrostu jest jednym z najważniejszych czynników realizacji ich potencjału plonotwórczego. Przyjęto założenie, że odżywienie roślin w fazie BBCH31 istotnie wpływa na wzrost i plonowanie pszenicy. W Polsce składnikiem krytycznym dla wzrostu i plonowania roślin uprawnych jest potas. Celem sprawdzenia tej hipotezy w latach 2003-2005 przeprowadzono 3 serie jednoczynnikowych doświadczeń polowych ze zróżnicowanymi dawkami potasu stosowanymi w uprawie pszenicy ozimej odmiany Zyta. Potas aplikowano w dawkach: 0, 25, 50 i 100 kg ha^{-1}. Stan odżywienia pszenicy ozimej oceniano na początku strzelania w źdźbło (BBCH31) na podstawie niemieckiego programu PIPPA. Rośliny, niezależnie od zastosowanej dawki potasu, wykazały stan niedożywienia Ca, K, P i N. Niedobory wapnia i potasu okazały się kluczowe dla kształtowania plonu ziarna. Jednakże relacje między zawartościami dla par składników: N : P, N : K oraz N: Ca wykazały znacznie większą wartość prognostyczną, czyli związek z plonem ziarna, niż zawartości składników rozważane oddzielnie. Nadmiar azotu w liściach w fazie początku strzelania w źdźbło wykazał ujemny wpływ na plon ziarna w warunkach niedoboru wapnia, który ujawnił się dopiero dla N:Ca > 34. Tę samą prawidłowość zanotowano dla potasu, lecz nadmiar azotu ujawnił swe hamujące działanie, gdy stosunek N:K przyjął wartości większe od 1,0.

Słowa kluczowe: pszenica ozima, dawki potasu, odżywienie roślin, początek strzelania w źdźbło.

INTRODUCTION

During the early stage of growth of cereal plants, their nutritional status decides about the future yields. The nutritional status of grain plants in the early stages of their vegetation period enables to predict the yield level. In a given growth phase, plants need proper levels of nutrients. For obtaining the expected grain yield (1), the nutrient content in crops should be higher than critical (2); moreover, nutrients should be available in proper ratios. The proper ion ratios of nutrients in soil and in plants is one of the most important factors determining the metabolism and yield quality or level. Mineral fertilization may be more effective if we have more information about the crop's nutritional status. The agricultural extension service for plant producers relies on critical values proposed in the 1970s by BERGMANN (1986). These values may be less valid for present cultivars and yields. It seems that new critical values enabling prediction of plant nutritional status given in the German model PIPPA are much better (SCHNUG, HANEKLAUS, 2008).

In this paper, the potassium nutritional status of winter wheat was studied in a field experiment in respect of the optimal potassium fertilization. It was assumed that the prognostic PIPPA model may be useful for winter wheat in Polish soil and climatic conditions.

MATERIAL AND METHODS

Field experiments were conducted within years 2003-2005 in the Brody Agricultural Experimental belonging to the Poznań University of Life Sciences. Winter wheat (*Triticum aestivum* L., Zyta) was the tested plant. The experiment was conducted in one-factor trial in four replications, and the following potassium treatments: 0, 25, 50, 100 kg K ha^{-1}. As background was applied the following mineral fertilization: N–180, P–22, Mg–15 kg ha^{-1}. The highest potassium dose 100 kg ha^{-1} was assumed as optimal for chosen N P Mg doses. The control without potassium (NPMg) and any fertilizers (CA) were also regarded. 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 105 mg P $kg^{-1}$and medium availability of potassium 125 mg K kg^{-1} and magnesium 37 mg Mg kg^{-1}. In every year the winter wheat was cultivated after winter oilseed rape.

The PIPPA program (Professional Interpretation Program for Plant Analysis) as developed by SCHNUG and HANEKLAUS (2008) in the Institute of Plant Nutrition and Soil Science (FAL) in Braunschwick was used for plant nutritional level evaluation.

As the base of model PIPPA is used the boundary line expressing the dependence between the relative yield and the nutrients content in particular plant organs. The boundary line concept was originated more than 30 years ago (WEBB 1972) however its use is developing slowly. EVANYLO, SUMNER (1987) and SCHNUG, HANEKLAUS (1998) have developed the critical levels of different nutrients in winter wheat and have described them in mathematical way as curve line. The points sprayed behind the line show the effect of factors not connected with the nutrient. The maximal possible yield at given nutrient content is calculated.

The weather conditions in the years of the field experiment were different. The precipitations in 2003 year were especially unadequate; in the months April-July were 20% below average (Table 1). The statistical analysis according to Anova calculation for one factor experiment was used at the $p<0.05$.

RESULTS AND DISCUSSION

The nutritional status evaluation was done for the beginning of straw shooting stage BBCH30/31 described in the literature as critical stage (BERGMANN 1992, REINER 1992). The increasing potassium dose had real effect on the content of nitrogen, copper and iron in the plant (Table 2). The nitrogen

Table 1

Weather conditions during vegetation of winter wheat

Vegetation season	Months											
	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	Apr	May	June	July
Temperature (^{o}C)												
2002/2003	20.9	13.8	7.5	3.7	-3.4	-1.6	-3.2	3.4	8.2	16	19.8	19.6
2003/2004	20.8	14.8	6.1	5.3	2.0	-3.5	2.2	5.1	10.0	13.6	16.3	17.3
2004/2005	19.1	13.7	9.6	4.1	1.9	2.1	-1.5	1.8	8.8	12.8	16.4	19.7
Multi-year	17.4	13.1	8.5	3.4	-0.2	-1.8	-0.6	2.8	7.7	13.1	16.3	17.8
Rainfall (mm)												
2002/2003	129	49	127	69	13	60	74	20	21	20	35	97
2003/2004	9	31	40	28	42	73	32	21	23	44	59	60
2004/2005	57	43	49	69	54	49	66	23	19	86	40	127
Multi-year	62	50.3	41.8	44.7	47.1	36.5	30.6	38.8	38	54.7	65.7	56

Table 2

Content of macro- and micronutrients in winter wheat during BBCH 31 stage versus the level of potassium fertilization (mean for 3 years)

Treatments	Nutrients								
	N	P	K	Mg	Ca	Zn	Mn	Cu	Fe
	(g kg^{-1})					(mg kg^{-1})			
Absolute control	25.3	3.27	21.03	0.99	1.05	21.62	47.30	3.934	129.4
NPMgK0	31.3	3.36	22.80	1.06	1.29	25.69	49.43	4.617	192.7
NPMg 25% K	30.5	3.27	23.10	1.05	1.21	23.48	50.40	3.845	101.3
NPMg 50% K	34.7	3.35	22.59	0.98	1.15	24.08	47.77	3.875	142.9
NPKMg100% K	32.7	3.40	23.54	1.01	1.16	22.48	47.93	4.255	150.9
LSD $_{0.05}$	2.5	ns	ns	ns	ns	ns	ns	0.5091	17.19

content in the plant was increasing only to potassium dose responding to 50% of maximal potassium dose. Every potassium dose caused the decrease of copper and iron content in winter wheat leaves. At different potassium doses the potassium content in wheat leaves was similar ~23 g in kg. The obtained nutrients content in the wheat was much lower than critical levels of BERGMANN (1992) 45 g of potassium, 4-10 g of calcium, 1.2-2.5 g of magnesium, 6 mg of copper in 1 kg of wheat. Some authors as critical potassium content in the wheat regard 20 to 50 g kg^{-1} (LEIGH, JONES 1984).

The real correlations are stated for next nutrients pairs: N: K, N: P, N: Ca (Table 3). The mechanisms of these correlations for N: K and N: P described in the literature (MARSCHNER et al. 1996). The uptake and the transport in the plant of nitrate ions depends on potassium supply. The correlation analysis of N: K pair for control object without potassium fertilization

Table 3

Correlation coefficient between nutrients content in leaves during BBCH 31 stage and grain yield of winter wheat (n = 60)

Variable	Nutrients (g kg^{-1})				
	N	P	K	Ca	Mg
Yield (t ha^{-1})	-0.307*	-0.536*	0.132	-0.576*	0.306*
N	1	0.479*	0.476*	0.827*	-0.109
P	-	1	0.259*	0.748*	-0.264*
K	-	-	1	0.400*	0.360*
Ca	-	-	-	1	-0.165
Mg	-	-	-	-	1

*corelation significant at $p < 0.05$

shows the grain yield decrease (Figure 1). Similar trends show other objects. It means the yield decrease may be expected if N: K ratio increases above 1.0. This supports the MARSCHNER et al. (1996) hypothesis that only plants well supplied with potassium may uptake sufficient nitrogen amounts necessary for growth. It means both potassium and nitrogen supply must be adequate simultaneously. The level of potassium fertilization had also real effect on the N: Ca and N: P indexes of grain yield (Table 4). Special attention may be paid to N: Ca pair for 25% potassium dose in comparison to maximum 100% dose. The optimal N: Ca ratio enabling the yield 7.8 t from ha as calculated on regression equation is 34 to 1 (Figure 2). The correlation analysis (Table 4) shows that pairs N: P; N: K; N: Ca are more usefull for predicting the winter wheat grain yielding than relation between each nutrient content and grain yields.

The plant index parts analysis and proper interpretation of the results enable the evaluation of plants nutritional status. In this study plant nutritional status of winter wheat in BBCH31 phase was evaluated with the aid

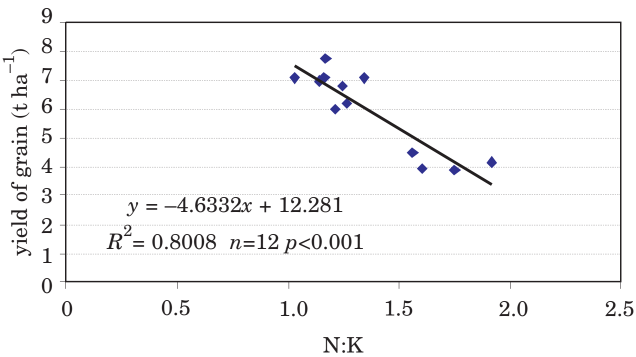

Fig. 1. Correlation between N:K concentration indices in leaves during BBCH 31 stage and grain yield of winter wheat in K_0 treatment

Table 4

Correlation coefficients between nutrient indices during the critical stage BBCH 31 and grain yield of winter wheat (n= 12)

Treatments	Indices of nutrients		
	N: P	N: K	N: Ca
Absolute control	0.689*	0.612*	-0.773*
NPMg – K0	-0.849*	-0.894*	0.877*
NPMg – 25% K	-0.535	-0.740*	0.713*
NPMg – 50% K	0.642*	-0.746*	0.685*
NPMg – 100% K	0.350	-0.851*	0.735*

*correlation significant at $p < 0.05$

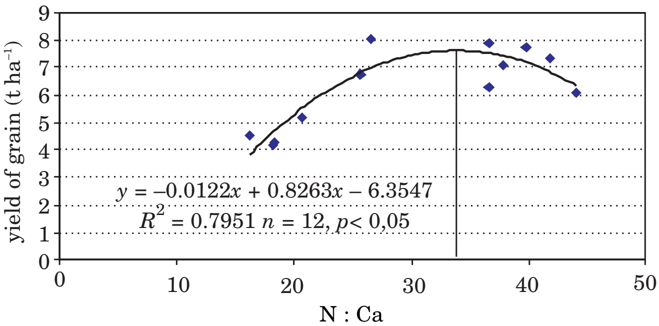

Fig. 2. Correlation between N : Ca indices in leaves during BBCH 31 stage and grain yield of winter wheat in treatment K25%

of PIPPA program. In contrast to evaluation with the aid of critical levels developed by BERGMANN (1992) it was stated that plant yield was restricted by insufficiency of many nutrients (Table 5). It is abvious that winter wheat for high yielding demands adequate supply of all nutrients. In all years of the field experiment the winter wheat yields were restricted by inadequate calcium supply meanwhile the restricting affect of other nutrients (K, N, P, Mg, Zn) was slighter. Thus the PIPPA program enabled to find the nutrients in unadequate level and simultaneouslu to evaluate their share in restricting the yields expressed in percentage (Figure 3).

Table 5

Rating of nutrients significantly limiting yield of winter wheat

Treatments	Elements											
Absolute control	Ca	Mg	K	N	Zn	P		Cu	│	Fe		Mn
K_0, NPMg	Ca	K	P	N	Mg	Zn	│	Cu		Fe		Mn
25%K, NPMg	Ca	K	P	N	Zn	Mg		Cu	│	Fe		Mn
50%K, NPMg	Ca	K	Mg	Cu	P	Zn		N	│	Fe		Mn
100%K, NPMg	Ca	K	Mg	Zn	P	N			│	Cu	Fe	Mn

K_0 – potassium control
– nutrients limiting yield
– nutrients not limiting yield

The reasons of Ca and Mg deficiency in plant may be different and may be caused by Ca Mg deficiency in the soil and by difficulties in uptake of these nutrients by plant and in their transport in the plant during the growth. Both Ca and Mg are uptaken by the youngest root tissue (RUSSELL 1977). Their uptake may be disturbed by toxic level of Alluminion ions. Such explanation may be true as soil pH after winter wheat harvest in all objects was 5 to 6 meanwheale the winter wheat for optimal growth demands neu-

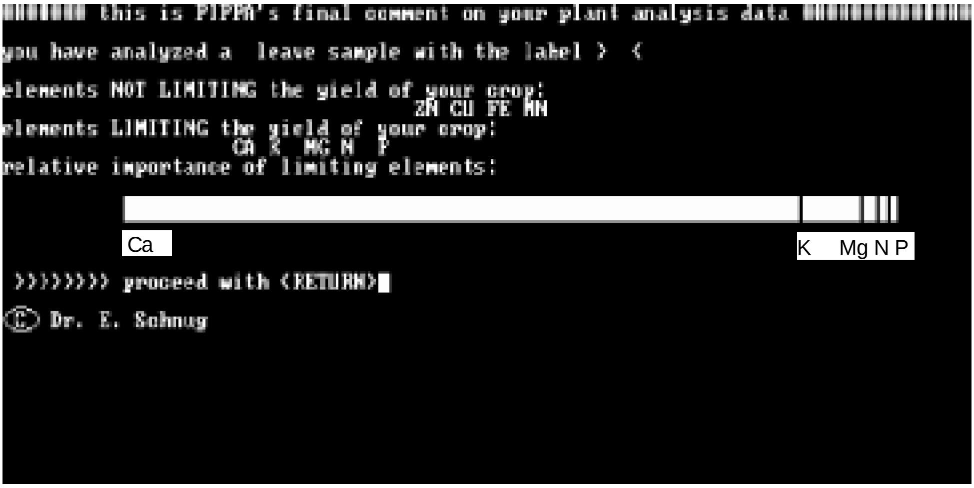

Fig. 3. Structure of share of nutrients in winter wheat at BBCH 31stage, as the index of grain yield limitation

tral soil. The soil acidity (pH below 5; 0.01 mol $CaCl_2$ in 1 dcm^3 of soil) is regarded as main factor restricting the yields (GRZEBISZ et al. 2006) and the knowledge about soil pH is very important for proper plant production. Although winter wheat showed potassium deficiency level in BBCH31 phase the influence of potassium doses on wheat yields was unsignifficant (Figure 4). According to SZCZEPANIAK (2004) the real effect of potassium fertilization on the plant yields may be expected at low K available content in the soil and at water stress during plant growth. The results of MERBACH et al.

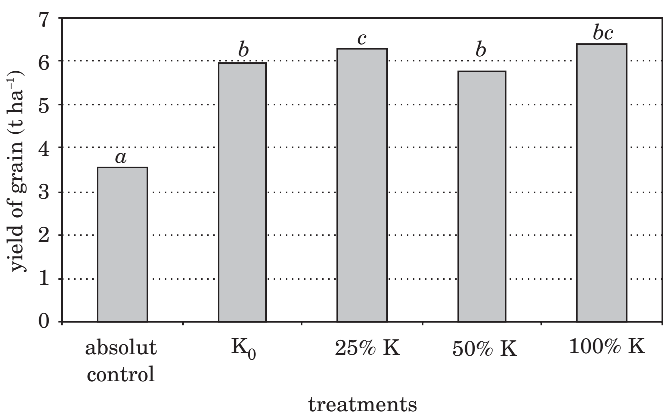

Fig. 4. Effect of the level of potassium application on grain yield of winter wheat, t ha^{-1}, *a*,*b*,*c* – letters indicate statistical differences between treatments, $p < 0.05$

(1999) show that the decrease of potassium doses at medium K available level in the soil causes the yield decrease and this decrease is the highest in root plants and the lowest in cereal plants.

CONCLUSIONS

1. The evaluation of nutritional status of winter wheat in strow shooting stage has shown at first place the insufficient level of calcium in the plant and then potassium and magnesium.

2. Pairs ratio content N: K, N: Ca, N: P in the plant enables better prediction of the yields than the content of each nutrient.

3. The winter wheat yields were restricted by Ca and K supply but calcium deficiency was more important factor.

4. Ca and K was not equilibrated with N. N excess was observed when ratio N to Ca was higher than 34 to 1 and ratio N to K higher than 1.

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