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ORIGINAL PAPER

EVALUATION OF PHOSPHORUS AND POTASSIUM CONTENT IN PLANT ORGANS AS A RESULT OF DIFFERENTIATED FERTILIZER RATIOS

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Abstract

The aim of the experiment was to assess the impact of unbalanced mineral fertilization on the content of phosphorus and potassium in winter oilseed rape (*Brassica napus* L.) cv. Kana, winter wheat (*Triticum aestivum* L.) cv. Sukces and in spring barley (*Hordeum vulgare* L.) cv. Justina. The experiment was established on brown soil developed from loess with the textural composition of clay dust, which in the Polish soil taxonomy belonged to the agronomic category of heavy soil, the second valuation class and the agricultural usefulness complex of good wheat. Two experimental factors were applied: unbalanced mineral fertilization (five variants), and meteorological conditions (four levels). The doses of individual fertilizer components were adjusted to the nutritional requirements of tested plants. The phosphorus content was determined by the vanadate-molybdate method and potassium was assayed by atomic absorption spectrometry. Before determinations, the plant material was digested in concentrated sulfuric (VI) acid with addition of 30% hydrogen peroxide. Both meteorological conditions and unbalanced mineral fertilization significantly affected the content of phosphorus and potassium in winter forms of oilseed rape and wheat as well as in spring barley. Excluding nitrogen from fertilization is associated with a significantly decrease in the phosphorus content in the straw of tested plants. The absence of potassium in fertilization is associated with a decrease in its content in generative and vegetative organs of test plants. Omission of sulfur in fertilization is associated with a decrease in the potassium content in the straw and increase in the test plants grain.

Keywords: mineral fertilization, phosphorus content, potassium content, macroelements, crops.

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INTRODUCTION

Phosphorus is an important element for plant nutrition (Bagyaraj et al. 2015, George et al. 2016). It is part of ATP and other nucleotides, nucleic acids and phospholipids. In addition, it participates in many physiological processes, primarily photosynthesis, respiration, carbohydrate metabolism and nucleic acid synthesis. The optimal phosphorus content in plants affects the proper development of the root system, which determines easier absorption of other nutrients. Plants well fed with phosphorus are more resistant to diseases, drought and frost (Balemi, Negisho 2012). Potassium affects the regulation of water management in plants (Cakmak 2005). Among others, it is responsible for cell turgor. It activates over fifty enzymes and also participates in the biosynthesis of macromolecular compounds, which include starch, cellulose, proteins, nucleic acids, pectinsetc. Like phosphorus, a good supply of potassium to plants strengthens their resistance to drought (Nieves-Cordones et al. 2016). Potassium also affects the quality parameters of the plant yield. In the case of cereals, it increases the number of grains per ear and thousand grain mass (TGM). It also stimulates fat synthesis in oilseed rape seeds (Prajapati, Modi 2012).

Higher efficiency and effectiveness of mineral fertilization is possible through constant monitoring of the plant nutrition degree, optimization of fertilization, as well as development and improvement of methods for mineral content assessment in crops. Appropriate nutrition of plants affects their proper growth and development as well as the feed value. Both excess and deficiency of macro- and micronutrients can have a negative effect on animal organisms. In addition, adequate fertilization is of great importance for environmental protection issues (Gaj 2012).

The aim of the experiment was to assess the effect of unbalanced mineral fertilization on the content of phosphorus and potassium in winter forms of oilseed rape and wheat as well as in spring barley.

MATERIALS AND METHODS

Terms of field experiment

The research hypothesis presumed that inadequately balanced fertilizer mixtures would affect the content of phosphorus and potassium in test plants. Clear differentiation of this impact was expected depending on a plant species and its preferences in relation to the analyzed elements. Evaluation of the influence of fertilizer mixtures on the accumulation of elements in crops was made on the basis of a four-year field experiment. The experiment was based on a crop rotation sequence of three plant species: winter oilseed rape (*Brassica napus* L.) cv. Kana, winter wheat (*Triticumae-*

stivum L.) cv. Sukces, and spring barley (*Hordeum vulgare* L.) cv. Justina. The trials were carried out at the Experimental Station (50°42′N, 23°12′E) in Zamość, in 2006 - 2009. The experiment was established on brown soil (a Cambissol according to WRB 2015 classification) developed from loess with the textural composition of clay dust, which belonged to the agronomic category of heavy soil, the second valuation class and the agricultural usefulness complex of good wheat soil. The soil before the experiment was characterized by slightly acid reaction (pH 6.02) and was very rich in available phosphorus (159.5 mg P kg^{-1}), rich in potassium (218.5 mg K kg^{-1}), moderately rich in magnesium (72.0 mg Mg kg^{-1}) and poor in sulfur (11.9 mg S kg^{-1}).

Experimental factors

Experimental factors consisted of unbalanced mineral fertilization applied in five variants, and years of research. The doses of individual fertilizer components were adjusted to the nutritional requirements of the test plants. In control object, doses of N:P:K:Mg:S (kg ha^{-1}) were: 140:31:133:18:60 for winter oilseed rape, 150:17:66:18:24 for winter wheat, 100:17:66:18:24 for spring barley, and 120:26:149:36:48 for sugar beet. In the second fertilizer variant, nitrogen fertilization was not used, in the third one there was no potassium, the fourth one did not contain magnesium, and in the fifth one lacked sulfur. Fertilization was carried out in accordance with the applicable agrotechnical principles. Characteristics of mineral fertilizers used in the experiment are presented in Table 1. The total surface area of a test plot was 30 m^2 (5 m × 6 m), while the plot for plant harvesting was correspon-

Table 1

Characteristics of mineral fertilizers

Treatments	Fertilizer component	Fertilizer
With sulfur fertilization	N	ammonium sulphate – NH_4NO_3 – 33,5% N
	P	simple superphosphate – $Ca(H_2PO_4)_2$ – 19% P_2O_5 + 12% S
	K	potassium sulphate – K_2SO_4 – 50% K_2O + 18% S
	Mg	magnesium sulphate – $MgSO_4 \times H_2O$ – 25% MgO + 20% S
	S	simple superphosphate – $Ca(H_2PO_4)_2$ – 19% P_2O_5 + 12% S potassium sulphate – K_2SO_4 – 19% P_2O_5 + 12% S magnesium sulphate – $MgSO_4 \times H_2O$ – 25% MgO + 20% S
Without sulfur fertilization	N	ammonium nitrate – NH_4NO_3 – 33,5% N
	P	enriched superphosphate – $Ca(H_2PO_4)_2$ – 40% P_2O_5
	K	potassium salt – KCl – 60% K_2O
	Mg	magnesium chloride – $MgCl_2$ – 20% MgO
	S	–

dingly smaller, i.e. 20 m[2] (4 m × 5 m). The phosphorus content was determined by means of the vanadate-molybdate method and potassium was measured by atomic absorption spectrometry (AAS) after prior mineralization of plant material in concentrated H_2SO_4 with addition of 30% H_2O_2.

The second experimental factor (B) consisted of the research years, set on four levels. In order to more fully characterize the meteorological conditions, the Selyaninov hydrothermal coefficient was calculated (Table 2),

Table 2

Selyaninov's coefficient values throught the field research period

Year	Months						
	April	May	June	July	August	September	October
1st year	1.840	1.200	0.620	0.390	2.460	0.020	0.310
2nd year	0.730	0.760	1.030	1.380	0.550	3.340	1.130
3rd year	2.230	1.610	0.840	2.220	1.560	2.440	1.410
4th year	0.460	1.620	1.780	0.330	0.460	0.960	3.420

which indicates the state of plant supply with water during the growing season. Division into the following classes of the Selyaninov hydrothermal coefficient values is as follows: $k \leq 0.4$ – extremely dry conditions, $0.4 < k \leq 0.7$ – very dry conditions, $0.7 < k \leq 1.0$ – dry conditions, $1.0 < k \leq 1.3$ – quite dry conditions, $1.3 < k \leq 1.6$ – optimal conditions, $1.6 < k \leq 2.0$ – quite humid conditions, $2.0 < k \leq 2.5$ – humid conditions, $2.5 < k \leq 3.0$ – very humid conditions, $k > 3.0$ – extremely humid conditions (Skowera et al. 2014).

Statistical analysis

The results obtained from the experiment were statistically verified with the ANOVA module (for factor systems) of Statistica 9.0 PL software, while LSD values were determined applying the Tukey LSD test at significance $\alpha = 0.05$. The relationships between content of minerals in the analyzed plants were expressed by a linear correlation coefficient (r). Interactions between the variables were assessed through simple correlation (StatSoft Inc. 2010).

RESULTS AND DISCUSSION

The content of phosphorus and potassium in the generative and vegetative organs of the studied plants was clearly influenced by the experimental factors. There were significant changes in the content of the elements studied, both under the influence of variable fertilization, weather conditions, as well as under the influence of the interaction of both experimental factors (Tables 3, 4, 5, 6).

Table 3

Content of phosphorus and potassium in seeds and straw of winter rape (g kg^{-1})

Specification	Mineral fertilization (A)	Year of experiment (B)										Linear correlation coefficient (r)
		1st	2nd	3rd	4th	$\bar{x}$	1st	2nd	3rd	4th	$\bar{x}$	
		phosphorus					potassium					
Seeds	NPKMgS	8.132	4.535	8.011	7.836	7.129	8.800	7.950	9.513	10.80	9.266	0.656
	PKMgS	8.072	4.973	7.780	8.053	7.220	6.800	7.345	6.563	9.500	7.552	0.159
	NPMgS	7.870	4.577	8.144	7.644	7.059	8.425	7.730	7.550	10.43	8.534	0.297
	NPKS	8.078	4.588	8.091	7.733	7.123	8.150	7.740	9.038	11.13	9.015	0.456
	NPKMg	8.096	4.456	8.199	7.372	7.031	8.675	7.830	10.48	10.41	9.349	0.637
	$\bar{x}$	8.050	4.626	8.045	7.728	7.112	8.170	7.719	8.629	10.45	8.743	–
$LSD_{0.05}$		A – 0.143 B – 0.120 AxB – 0.376					A – 0.474 B – 0.398 AxB – 1.247					
Straw	NPKMgS	1.366	0.589	1.591	1.418	1.241	18.30	18.88	29.39	10.63	19.30	0.210
	PKMgS	1.204	0.602	1.169	1.457	1.108	10.18	13.30	22.73	7.525	13.43	-0.184
	NPMgS	1.473	0.699	1.974	1.438	1.396	13.95	15.54	20.11	8.188	14.45	0.258
	NPKS	1.385	0.662	1.789	1.393	1.307	16.95	15.82	31.70	9.925	18.60	0.556
	NPKMg	1.534	0.593	1.693	1.549	1.342	14.78	15.40	28.59	10.08	17.21	0.278
	$\bar{x}$	1.392	0.629	1.643	1.451	1.279	14.83	15.79	26.50	9.270	16.60	–
$LSD_{0.05}$		A – 0.078 B – 0.065 AxB – 0.205					A – 2.002 B – 1.682 AxB – 5.271					

Table 4

Content of phosphorus and potassium in grain and straw of winter wheat (g kg^{-1})

Specification	Mineral fertilization (A)	Year of experiment (B)										Linear correlation coefficient (r)
		1st	2nd	3rd	4th	$\bar{x}$	1st	2nd	3rd	4th	$\bar{x}$	
		phosphorus					potassium					
Grain	NPKMgS	3.860	2.109	4.249	4.176	3.599	4.300	4.175	6.825	3.975	4.819	0.397
	PKMgS	3.818	2.143	3.847	4.095	3.476	4.550	4.450	6.475	4.138	4.903	0.189
	NPMgS	3.808	2.109	4.216	4.017	3.538	4.200	4.110	6.425	4.113	4.712	0.436
	NPKS	3.767	2.098	4.246	4.080	3.548	4.500	4.185	5.950	4.100	4.684	0.443
	NPKMg	3.861	2.095	4.083	4.223	3.566	4.300	4.230	6.800	4.250	4.895	0.348
	$\bar{x}$	3.823	2.111	4.128	4.118	3.545	4.370	4.230	6.495	4.115	4.803	–
$LSD_{0.05}$		A – 0.144 B – 0.121 AxB – 0.380					A – n.s. B – 0.315 AxB – n.s.					
Straw	NPKMgS	1.113	0.525	1.448	1.739	1.206	4.240	10.58	35.71	20.01	17.64	0.537
	PKMgS	1.217	0.438	1.065	1.514	1.059	2.300	6.045	27.66	10.86	11.72	0.107
	NPMgS	0.983	0.645	1.518	1.850	1.249	3.623	10.51	30.58	20.05	16.19	0.580
	NPKS	0.997	0.625	1.468	1.661	1.188	3.325	12.74	32.25	21.30	17.40	0.646
	NPKMg	0.900	0.515	1.468	1.340	1.056	3.365	10.84	32.48	19.96	16.66	0.768
	$\bar{x}$	1.042	0.550	1.393	1.621	1.151	3.37	10.14	31.74	18.44	15.92	–
$LSD_{0.05}$		A – 0.137 B – 0.115 AxB – 0.360					A – 1.636 B – 1.375 AxB – 4.308					

Table 5

Content of phosphorus and potassium in grain and straw of spring barley (g kg^{-1})

Specification	Mineral fertilization (A)	Year of experiment (B)										Linear correlation coefficient (r)
		1st	2nd	3rd	4th	$\bar{x}$	1st	2nd	3rd	4th	$\bar{x}$	
		phosphorus					potassium					
Grain	NPKMgS	4.447	2.076	3.680	4.593	3.699	4.138	5.010	5.475	6.450	5.268	0.179
	PKMgS	4.217	2.070	3.465	4.320	3.518	4.313	5.210	6.813	6.213	5.637	0.029
	NPMgS	4.425	2.129	3.736	4.558	3.712	3.825	5.160	6.413	6.625	5.506	0.080
	NPKS	4.510	2.148	3.663	4.549	3.718	3.938	5.175	6.325	6.638	5.519	0.038
	NPKMg	4.463	2.043	3.446	4.577	3.632	4.050	4.970	6.700	6.338	5.515	0.044
	$\bar{x}$	4.412	2.093	3.598	4.519	3.656	4.053	5.105	6.345	6.453	5.489	–
$LSD_{0.05}$		A – 0.129 B – 0.108 AxB – 0.339					A – 0.279 B – 0.234 AxB – 0.724					
Straw	NPKMgS	1.211	0.168	1.160	3.659	1.550	6.525	17.30	14.08	21.23	14.78	0.472
	PKMgS	0.827	0.117	1.175	3.245	1.341	4.863	13.05	9.800	15.16	10.72	0.476
	NPMgS	1.348	0.167	1.252	3.898	1.666	5.938	15.52	13.14	23.45	14.51	0.630
	NPKS	1.319	0.181	1.374	4.027	1.725	6.250	17.72	12.10	25.53	15.40	0.604
	NPKMg	1.358	0.120	1.480	3.562	1.630	5.850	17.82	13.31	22.10	14.77	0.402
	$\bar{x}$	1.213	0.151	1.288	3.678	1.582	5.890	16.28	12.49	21.49	14.04	–
$LSD_{0.05}$		A – 0.149 B – 0.163 AxB – 0.511					A – 0.856 B – 0.720 AxB – 2.254					

In seeds of winter rape, unbalanced mineral fertilization was not associated with an unambiguous change in the phosphorus content. However, the phosphorus content was significantly increased in the straw in response to potassium, magnesium and sulfur deficiency in fertilization. This can be associated with a strongly antagonistic relationship between potassium and magnesium (Rietra et al. 2017). In the seeds of winter rape, the omission of nitrogen and magnesium in a fertilization dose was associated with a significantly decreased content of potassium. The content of potassium in the straw of winter rape was the highest in control objects. Exclusion of the subsequent nutrients in fertilizer doses was associated with a significant decrease in the potassium content. Nitrogen fertilization in the experiment carried out by Ngeziman and Agenbag (2014) was associated with an increase in the content of potassium in oilseed rape. Studies performed by Podleśna (2004) revealed an increase in the potassium content in oilseed rape straw with the use of sulfur fertilization, as well as a slight decrease in the phosphorus content in sulfur fertilized plants. The lack of sulfur fertilization in the experiment by Podleśna (2009) was associated with an increase in the content of phosphorus and potassium in stems, leaves and roots of winter oilseed rape. Hřivna et al. (2002) demonstrated that the potassium content in winter oilseed rape did not depend on sulphur fertilization to any degree.

Unbalanced mineral fertilization did not significantly affect the content of phosphorus in grain of winter wheat. The content of phosphorous decreased in the straw when nitrogen, magnesium and sulfur were lacking in the plant growth environment. The lack of potassium was associated with a significant increase in the phosphorus content in the straw of winter wheat. Excluding nitrogen and magnesium from fertilization doses in most cases resulted in an increase in the potassium content in grain of winter wheat, while the lack of potassium was associated with the reverse dependence. In the straw, there was a significant decrease in the potassium content when nitrogen, potassium and sulfur were absent in the fertilizer dose. In the same trial, there was no relationship between nitrogen fertilization and potassium content in spring wheat grain. Similar conclusions were drawn by Wojtkowiak et al. (2018), who found that nitrogen fertilization at a higher dose resulted in an increase in the phosphorus content in the grain of four winter wheat cultivars. Meanwhile, Jarecki et al. (2017) reported that higher NPK fertilization was associated with an increase in the potassium content in wheat grain. Kruczek and Wójtowicz (1998) showed that nitrogen fertilization did not differentiate the content of phosphorus and potassium in wheat grain.

The phosphorus content in spring barley grain did not change significantly depending on a fertilizer variant. A decreased phosphorus content was recorded in straw when nitrogen was excluded from fertilization, and the lack of potassium and magnesium was associated with an increase in the content of phosphorus. This is consistent with reports on a synergistic relationship between phosphorus and magnesium in plants (Rietra et al. 2017). The concentration of potassium in spring barley grain significantly increased in treatments without nitrogen, potassium and magnesium in the fertilizer dose. In the years of the research, the omission of sulfur resulted in the reverse dependence. In the straw, there was a decrease in the potassium content with the omission of nitrogen and potassium in fertilization. In experiments by Skwierawska et al. (2008), mineral fertilization including the use of sulfur did not significantly change the phosphorus and potassium content in spring barley grain. Research carried out by Wilczewski (2014) revealed that increasing nitrogen fertilization was associated with an increase in the content of both potassium and phosphorus in spring barley grain.

In winter oilseed rape, the content of potassium was strongly positively correlated with the content of phosphorus in control objects as well as in objects without magnesium and sulfur in fertilization. In straw, such a relationship was noted when sulfur was not included in fertilizer doses. A strongly positive correlation of the content of potassium with the content of phosphorus was observed in the grain and straw of winter wheat in control treatments and in those without the addition of potassium and magnesium to the plant growth environment. In spring barley, strong correlations were recorded only in straw, and they occurred in all variants of fertilization.

In our study, statistically significant changes in the content of elements studied were found which resulted from different course of meteorological conditions during the experiment. In particular years of research, average monthly air temperatures and the intensity and distribution of atmospheric precipitation varied during the growing seasons. Plant development in all years was at temperatures higher than the average for many years (April-October). The average monthly atmospheric precipitation showed very large variation in the months of sowing and growing of the winter forms of oilseed rape and wheat. There were both record-high (August, 1st year of research – 144.8 mm with the average of 63.9 mm for many years, September, 2nd year of research – 144.2 mm and September, 3rd year of research – 100.4 mm for the average of many years 59.1 mm), as well as extremely low precipitations in the 1st year of research in September – 0.8 mm with an average of 59.1 mm and in the 2nd year of research in August – 31.6 mm with an average of 63.9 mm for many years. The highest precipitation during spring barley sowing was recorded in the 1st year (54.8 mm) and in the 3rd year of the experiment (71.5 mm), with the average of 44.5 mm for many years. On the other hand, the 2nd and 4th year of research were characterized by much lower precipitation values: 21.7 mm and 15.5 mm, respectively.

The seeds of winter oilseed rape were characterized by a significantly higher phosphorus content in the 1st and 3rd year of experiment (Table 3). The Selyaninov hydrothermal coefficient in these years in the spring months (April-June) was close to the optimal one. In the 2nd year, the phosphorus content was significantly lower. Between April and June in that year the Selyaninov hydrothermal coefficient indicated dry conditions. Climatic conditions in Poland are a relatively unstable factor affecting the cultivation of cereals. All weather anomalies affect the size and quality of the crop (Jaczewska-Kalicka 2008, Orzech et al. 2009, Grabowski et al. 2014). At the same time, it is reported that the increase in yielding of crop plants is more affected by rainfall than the average temperature, which is explained by greater variation in precipitations than in temperatures over the recent years. A more detailed description of the impact of weather conditions on yield is difficult to provide due to many additional factors, such as the soil type and its tillage, fertilization, use of plant protection agents and other agrotechnical factors (Grabowski et al. 2014). In winter wheat grain, the highest content of phosphorus was recorded in the 3rd year of the experiment, while in straw phosphorus reached the highest level in the 4th year. Significantly less phosphorus in both generative and vegetative organs was in the 2nd year. Grain and straw of spring barley in the 4th year of experiment were characterized by the highest phosphorus content, while in the 2nd year, these values were the lowest. A significantly higher potassium content contained winter rape seeds in the 4th year; in straw, however, such a relationship was recorded in the 3rd year. In cereal plants, less phosphorus was recorded in the 2nd year of the experiment, which in the spring to summer season was characterized by the highest average temperatures. It is consistent with the study performed by Grabowski et al. (2014), which proves that the content of phosphorus in grain decreased with the increase of temperature in the spring and summer. In the research by Kraska and Pałys (2009), a lower phosphorus content was recorded in the warmest year. The 2nd yield of oilseed rape seed was characterized by a significantly lower potassium content, while in the case of straw, such values were recorded in the 4th year. Winter wheat in the 3rd year of the experiment was characterized by the highest content of potassium in grain and straw; the lowest values were obtained in the 4th year in the grain and in the 1st year in straw. Generative and vegetative organs of spring barley contained most potassium in the yield from the 4th year of research, while the lowest content of this element was in the yield from the 1st year of the experiment. This can be associated with the lowest level of precipitation during the sowing of spring barley in the 4th year and highest in 1st year respectively.

CONCLUSIONS

1. Excluding nitrogen from a fertilization regime is associated with a significant decrease in the phosphorus content in the straw of the tested plants. In the case of potassium, the lack of nitrogen results in a significant decrease in its content in the seeds and straw of winter oilseed rape and

in the straw of winter wheat and spring barley. However, the lack of nitrogen in cereal grain is associated with an increase in the concentration of potassium.

2. Potassium deficiency in the growth environment of the test plants results in an significant increase in the phosphorus content in the straw of these crops. The absence of potassium in a fertilization dose is associated with a decrease in its content in generative and vegetative organs of the test plants.

3. The lack of magnesium in fertilization results in a significant increase in the phosphorus content in the straw of winter oilseed rape and spring barley, whereas a lower content of phosphorus appears in the straw of winter wheat. Magnesium deficiency in the plant growth environment is also associated with a significant decrease in the potassium content in seeds and straw of winter oilseed rape and wheat form as well as an increase in spring barley grain and straw.

4. Omission of sulfur in fertilization is associated with a decrease in the potassium content in the straw and its increase in the grain of the test plants.

5. In the majority of control treatments with the studied plants, there were strongly positive correlations between the content of potassium and phosphorus. A similar relationship was noted in treatments without magnesium in fertilization.

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