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ORIGINAL PAPER

CONTENT OF MACRONUTRIENTS IN WINTER WHEAT GRAIN DEPENDING ON THE SOWING DATE AND LEVEL OF NPK FERTILIZATION*

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Abstract

The mineral composition of cereal grains has a direct impact on the health of people and farm animals. This consideration encourages making constant efforts to improve both productivity of cereal crops and quality of their grains, including an increased grain content of minerals. The research objective has been to determine the effect of sowing date and level of NPK fertilization on the yield and content of macronutrients (N, P, K, Mg, Ca) in grain of the winter wheat cultivar Arkadia. The first factor consisted of the time of sowing (4 dates): from mid-September to the end of October. The second factor consisted of NPK fertilization levels (kg ha^{-1}): 1 NPK (310 kg ha^{-1}), composed of 140 N, 70 P and 100 K, and 1.5 NPK (465 kg ha^{-1}), composed of 210 N, 105 P and 150 K. The wheat grain content of macronutrients (N, P, K, Mg, Ca) was analyzed according to well-established methods. The sowing date winter wheat did not have any distinct, annually repeatable effect on changes in the content of the determined macronutrients in wheat grain. The NPK fertilization levels had an unequivocal effect on the content of nitrogen, which accumulated the most in the grain of wheat supplied the higher NPK dose. Neither a delay in the sowing date nor the applied NPK fertilization caused an unambiguous decrease in the content of macronutrients, nor did they depress the quality of wheat grain as a potential ingredient in food for people or in concentrated feeds for animals. Overall, concentrations of the analyzed macronutrients in winter wheat grain varied between the years of the experiment.

Keywords: winter wheat, macronutrients, sowing date, NPK fertilization.

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INTRODUCTION

Wheat is a staple bread cereal, although much of harvested wheat grain is used for producing animal feeds or for other human consumption purposes. Cereal products are an essential component in human nutrition, where they act as important sources of valuable minerals (Klikocka et al. 2018). They also play a role in maintaining the proper course of metabolic processes in a human or animal body. These minerals are not synthesized in human or animal bodies, and therefore must be supplied in adequate amounts and proportions with food. Deficiency of macronutrients in an organism may occur due to various causes, including their insufficient content in food and feeds, or their interaction with other elements. The concentration of minerals in cereal grain is important because these elements have a direct influence on the health of people and farm animals (Shewry, Hey 2015). Some researchers claim that minerals contained in natural food products achieve better availability than the ones supplied in dietary supplements, where their availability depends on the properties of compounds in which they occur and on characteristics of an organism (Villegas et al. 2009). Hence, there is a need to constantly improve both the productivity of cereals and the quality of their grain, including a higher content of minerals.

Numerous authors point to the fact that the quality of grain depends on the genotype of a plant as well as the environmental conditions and agrotechnical treatments (Wajid et al. 2004, Woźniak 2006, Gondek, Gondek 2010, Stępień, Wojtowiak 2016). It is assumed that the chemical composition of cereal grain is a dynamic trait, which depends on the natural conditions and applied agronomic practice, for example the sowing date and plant fertilization. Ruža, Kreita (2008) show in their study that significantly higher yields of winter wheat in Lithuania were harvested when it was sown in late September (8.95 t ha^{-1}) than in late August (7.66 t ha^{-1}). In Pakistan, on the other hand, the highest grain yield (5.59 t ha^{-1}) was obtained only when wheat was sown on the optimal date (around 10 November), in contrast to the earlier sowing dates (5.20 t ha^{-1}) and ones delayed by two weeks (5.29 t ha^{-1}) (Anwar et al. 2015). Smith et al. (2018) report that volumes of grain yields harvested may have some influence on the content of nutrients. These researchers conclude that a depressed level of nutrients in grain could be a consequence of obtaining high yields under conditions favourable to the growth of crops. Hence, agrotechnical factors, including the proper sowing date and NPK fertilization, by increasing grain yield, may cause differences in the content of macronutrients, including their depressed levels. Delayed sowing tends to have an adverse effect on cereal yielding, but does not need to depreciate the mineral composition of cereal grains (Kumar 2012, Schwartea et al. 2005). Jarecki et al. (2017) report that higher NPK fertilization of spring wheat increased the grain content of nitrogen and potassium, but did not differentiate the content of phosphorus or magnesium. Considering this assumption, the following experiment was performed in order to determine the effect of the sowing date and NPK fertilization level on the grain yield and content of macronutrients (N, P, K, Mg, Ca) obtained from the winter wheat qualitative cultivar Arkadia. This variety was entered in the National Register of Agricultural Plant Varieties in 2011and it is recommended for cultivation throughout Poland, being useful for late sowing (Danko… 2011).

METHODS

In 2014-2016, a field experiment was conducted at the Experimental Station in Tomaszkowo (53°42′N; 20°26′E), which belongs to the University of Warmia and Mazury in Olsztyn. The winter wheat cultivar Arkadia was cultivated after winter wheat. The soil tillage was carried out as recommended. The experiment was set up in a design of random sub-blocks, in 3 replications, on proper heavy eutrophic brown soil (Polish Soil Classification 2011), which in the WRB taxonomy (IUSS Working Group WRB 2015) belonged to Haplic Combisols (Eutric). This soil had a moderate content of humus (1.86-2.16%), high and moderate abundance of available phosphorus (P): 64-85 mg kg^{-1} of soil and potassium (K):181-220 mg kg^{-1} of soil, as well as moderate abundance of available magnesium (Mg): 92-121 mg kg^{-1} of soil and slightly acidic reaction (pH 6.1-6.4). The surface area of a single plot was 16 m^2. The first experimental factor corresponded to the of sowing date (4 dates, every two weeks): I – 15-16 September, II – 29-30 September, III – 14-15 October, IV – 28-29 October. The density of sown seeds was 400 seeds m^{-2}. The second factor consisted of two levels of NPK fertilization (kg ha^{-1}): 1 NPK (310 kg ha^{-1}), composed of 140 N, 70 P and 100 K, and 1.5 NPK (465 kg ha^{-1}), composed of 210 N, 105 P and 150 K. Nitrogen fertilizers were applied on 3 dates (Table 1).

Samples of grain for determination of the content of macronutrients (N, P, K, Mg, Ca) were collected during combine harvesting. Analyzes were made at the Agricultural Chemistry Station in Olsztyn, using the following methods: nitrogen – by potentiometric titration, after digestion in sulphuric acid, phosphorus – by spectorphotometry on a Spectrocolorimeter Specol

Table 1

Regimes of winter wheat nitrogen fertilization

Dates of nitrogen application	Type of fertilizer	1 NPK	1.5 NPK
After resumed vegetative growth (BBCH 12-21)	ammonium nitrate 34%	70	100
Stem elongation (BBCH 32-33)	urea 46%	40	60
Inflorescence emergence (BBCH – 52-53)	urea 46%	30	50

11, magnesium – by flame atomic absorption spectormetry on an AAS1 Atomic Absorption Spectrometer, potassium and calcium – by flame photometry on a Flavo 4 apparatus. All analyzes were accredited by the Polish Centre of Accreditation, certificate number AB 277.

Statistical analyzes

The research data were processed statistically by applying an analyzis of variance for two-factorial experiments of sowing date, NPK fertilization levels) for individual years of the experiment, and for three-factorial experiments (years, of sowing date, levels of nitrogen fertilization). The processed data originated from three years of field trials in a split-block random sub-blocks design. Significance of differences was verified with the Duncan's test, at the probability of error set at 0.05. The dependence between the yield of winter wheat grain and content of macronutrients in grain, as well as their mutual correlations were expressed with the linear correlation coefficient (*r*). All calculations were supported by the software programme Statistica (StatSoft, Inc. 2010).

Meteorological conditions

The research period (2014–2016) was characterized by highly variable weather (Table 2). The first two seasons (2013/2014 and 2014/2015) were favourable to the emergence of plants regarding the soil moisture in autumn and the wintering conditions. The winters were warmer than the multiannual average winter. In the third season, following modest rainfalls in August and October 2015, large water deficits appeared during the consecutive of sowing date winter wheat, which resulted in the delay of plant emergence and thinning of plants. The situation was made aggravated by the shortage of precipitations in spring 2016 and their excess in July (rainfall higher by 73% compared to the multiannual average), as a result of which the yield parameters scored low.

RESULTS AND DISCUSSION

In the analyzed experiment, on average for the three years, wheat sown on the first three dates (I, II, III), from 15 September to 15 October, produced yields which reached 7.65 t ha^{-1}, 7.43 t ha^{-1} and 7.63 t ha^{-1}, respectively, with no significant differences (Table 3). The last sowing date (end of October) resulted in lower grain yields, on average 5.0% less compared to date I, and 4.7% compared to date III, but without any significant difference relative to date II. It is always difficult to be able to sow winter cereals on optimal dates in Poland, especially in north-eastern Poland, as maintained by Oleksiak (2014). The long-term studies carried out by this

Table 2

Air temperatures and rainfall in the plant growing season for winter wheat in 2013-2016, according to the Meteorological Station in Tomaszkowo

Month	Air temperature (°C)				Rainfalls (mm)			
	average of many years	mean of month			mean sum of many years	sum of month years		
	1961-2010	2013-2014	2014-2015	2015-2016	1961-2010	2013-2014	2014-2015	2015-2016
Aug	17.3	17.4	17.3	19.9	68.7	37.6	86.1	14.3
Sept	12.6	11.3	13.6	13.5	57.1	101.1	25.9	63.8
Oct	7.7	8.9	8.8	6.1	46,0	16.0	15.1	19.4
Nov	2.8	5.0	3.7	4.8	47.9	18.0	34.0	84.5
Dec	-1.2	2.2	-0.3	3.5	36.6	27.7	61.8	56.6
Jan	-2.9	-3.7	0.4	-4.1	31.2	48.4	46.8	24.7
Feb	-2.3	1.2	0.7	2.3	21.9	8.1	6.8	57.1
March	1.2	5.1	4.2	2.9	28.5	57.7	45.1	21.6
Apr	7.0	8.8	6.7	7.4	34.2	26.0	38.2	28.8
May	12.7	12.9	11.8	13.6	54.6	32.7	29.7	56.9
June	15.9	14.4	15.5	17.1	79.0	50.8	29.5	69.3
July	18.0	20.4	17.6	18.1	75.4	37.3	81.9	130.4
Aug	17.3	17.3	19.9	17	68.7	86.1	14.3	70.4
Mean or sum (Apr-July)	13.4	14.1	12.9	14.1	243.2	146.8	179.3	285.4

Table 3

Yields of winter wheat grain depending on the sowing date and level of NPK fertilization (t ha^{-1})

Specification	Year of research			Mean
	2014	2015	2016	
Sowing date				
I	8.56	8.00	6.38	7.65
II	8.08	8.16	6.04	7.43
III	8.68	7.45	6.75	7.63
IV	8.13	7.33	6.35	7.27
$LSD_{(0.05)}$	0.38	0.47	n.s.	0.27
Level of fertilization NPK				
1 NPK	8.21	7.56	6.01	7.26
1.5 NPK	8.51	7.91	6.75	7.72
$LSD_{(0.05)}$	0.17	n.s.	0.38	0.17
Mean for years	8.36	7.74	6.38	7.49
$LSD_{(0.05)}$ for years - 0.48				

n.s. – not significant

researcher (1986-2003 and 2008-2013) suggest that over 80% of the farmland cropped with winter wheat is sown after the recommended date, which significantly depresses the yields, by 2.5 - 4.5%. This observation is confirmed by Weber and Podolska (2008), who concluded that a two-week delay of sowing wheat relative to the optimal date significantly lowered the yields. As reported by Wajid et al. (2004), earlier sowing dates of wheat in Pakistan ensured higher grain yields than delayed sowing. Plants seeded on an optimal sowing date proceed through a longer biological activity period, mainly the vegetative growth season. Some authors draw attention to the fact that premature sowing favours more intensive tillering of plants in autumn, more rapid development, and occurrence of mould in spring, which diminishes wheat yields (Ruža, Kreita 2008). Others express an opinion that the relationship between winter cereal yields and sowing dates is affected by the sensitivity of cultivars to this agronomic factor, and by the meteorological conditions during the vegetative growth of plants (Jaśkiewicz 2009).

In the experiment reported herein, the date of sowing produced a significant but varied influence on the content of the analyzed macronutrients in grain (Table 4). As for nitrogen, the mentioned factor significantly affected the three-year average results as well as the content determined in the third year of the experiment, when the highest accumulation of nitrogen was detected: on average 24.0 g kg^{-1} d.m., which was by 18.2 and 10.6% more than in the first and second year, respectively. In 2014 and 2016, and with respect to the three-year average results, most nitrogen (22.6 g kg^{-1} d.m. on average) accumulated in grain of wheat sown at the end of September. The highest concentration of this element was determined in the grain harvested in 2016, from the second of sowing date, where it reached 25.0 g kg^{-1} d.m. In an American study, winter triticale contained significantly more nitrogen in grain (18.5 g kg^{-1} d.m.) when sown in 2002 in mid-October than two weeks earlier (end of September), when the nitrogen content equalled 17.5 g kg^{-1} d.m. (Schwarte et al. 2005).

This experiment showed that the sowing date had a highly significant effect on the grain content of the other determined macronutrients, although the effects were not unequivocal, neither between the years nor as three-year means. On average for the three years of the study, the impact of this factor was the strongest in the case of the second and first of sowing dates, except for potassium, which reached the highest content in grain of wheat sown on the third date (mid-October). In a study conducted in India, when the sowing of wheat was postponed by two weeks relative to the optimal date, the nitrogen content in grain rose by an average of 6.7%, while P and K decreased by 11.0% and 4.3%, respectively (Kumar 2012).

In our experiment, significantly greater wheat grain yields were obtained in response to the NKP fertilization level raised by 50%, (7.72 t ha^{-1}), i.e. 6.3% more than in the basic fertilization dose (Table 3). Similar differences were reported by Pszczółkowska et al. (2018), where an increase in nitrogen supply from 120 to 180 kg ha^{-1} raised the wheat grain yield by 0.55 t ha^{-1}

Table 4

Content of macronutrients in winter wheat grain depending on the sowing date (g kg^{-1} d.m.)

Macronutrient	Sowing date	Year of research			Mean
		2014	2015	2016	
Nitrogen (N)	I	19.3	21.0	23.4	21.2
	II	21.0	21.8	25.0	22.6
	III	20.4	21.6	23.8	21.9
	IV	20.5	22.2	23.8	22.2
	$LSD_{(0.05)}$	n.s.	n.s.	0.9	0.5
	mean for years	20.3	21.7	24.0	22.0
	$LSD_{(0.05)}$ for years - 0.5				
Phosphorus (P)	I	2.98	2.54	3.49	3.00
	II	2.81	2.53	3.60	2.98
	III	2.75	2.57	3.54	2.95
	IV	2.77	2.49	3.48	2.91
	$LSD_{(0.05)}$	0.10	n.s.	0.08	0.05
	mean for years	2.83	2.53	3.53	2.96
	$LSD_{(0.05)}$ for years - 0.02				
Potassium (K)	I	5.22	5.28	5.91	5.47
	II	5.04	5.08	6.06	5.39
	III	5.35	5.21	6.29	5.62
	IV	5.00	5.07	6.40	5.49
	$LSD_{(0.05)}$	0.08	0.08	0.12	0.05
	mean for years	5.15	5.16	6.17	5.49
	$LSD_{(0.05)}$ for years - 0.07				
Magnesium (Mg)	I	1.45	1.52	1.69	1.55
	II	1.59	1.60	1.69	1.63
	III	1.57	1.52	1.69	1.59
	IV	1.46	1.47	1.74	1.56
	$LSD_{(0.05)}$	0.07	n.s.	0.04	0.04
	mean for years	1.52	1.53	1.70	1.58
	$LSD_{(0.05)}$ for years - 0.02				
Calcium (Ca)	I	0.45	0.57	0.53	0.52
	II	0.50	0.49	0.55	0.51
	III	0.45	0.48	0.51	0.48
	IV	0.49	0.49	0.55	0.51
	$LSD_{(0.05)}$	0.02	0.02	0.02	0.01
	mean for years	0.47	0.51	0.54	0.51
	$LSD_{(0.05)}$ for years - 0. 02				

n.s. – not significant

(5.5%). Boquet et al. (1987) demonstrated that elevated nitrogen fertilization tended to diminish the content of P and K, while phosphorus and potassium fertilization did not differentiate the mineral composition of wheat grain. In our study, the three-year averaged results proved a significantly beneficial effect of the NPK fertilization increased by 50% only with respect to nitrogen (22.7 and 21.3 g kg^{-1} d.m., respectively) – Table 5. The tested fertilization levels also affected, albeit not unambiguously, the content of phosphorus and potassium in individual years, although they did not differentiate the content

Table 5

Content of macronutrients in winter wheat grain depending on the level of NPK fertilization (g kg^{-1} d.m.)

Macronutrient	NPK fertilization level	Year of research			Mean
		2014	2015	2016	
Nitrogen (N)	1 NPK	19.7	20.8	23.3	21.3
	1.5 NPK	20.9	22.4	24.7	22.7
	$LSD_{(0.05)}$	0.5	0.7	0.7	0.3
	mean for years	20.3	21.6	24.0	22.0
	$LSD_{(0.05)}$ for years - 0.5				
Phosphorus (P)	1 NPK	2.79	2.49	3.62	2.97
	1.5 NPK	2.86	2.57	3.43	2.95
	$LSD_{(0.05)}$	0.05	n.s.	0.07	n.s.
	mean for years	2.83	2.53	3.53	2.96
	$LSD_{(0.05)}$ for years - 0.02				
Potassium (K)	1 NPK	5.08	5.25	6.17	5.50
	1.5 NPK	5.23	5.07	6.15	5.48
	$LSD_{(0.05)}$	0.08	0.05	n.s.	n.s.
	mean for years	5.16	5.16	6.16	5.49
	$LSD_{(0.05)}$ for years - 0.07				
Magnesium (Mg)	1 NPK	1.54	1.52	1.68	1.58
	1.5 NPK	1.52	1.53	1.72	1.59
	$LSD_{(0.05)}$	n.s.	n.s.	n.s.	n.s.
	mean for years	1.53	1.53	1.70	1.59
	$LSD_{(0.05)}$ for years - 0.02				
Calcium (Ca)	1 NPK	0.48	0.51	0.50	0.50
	1.5 NPK	0.46	0.51	0.57	0.51
	$LSD_{(0.05)}$	0.02	n.s.	0.02	n.s.
	mean for years	0.47	0.51	0.54	0.51
	$LSD_{(0.05)}$ for years - 0. 02				

n.s. – not significant

of magnesium or calcium in wheat grain. In a study conducted by BORKOWSKA (2004), different nitrogen fertilization levels did not affect the content of magnesium and potassium in winter wheat grain, whereas the share of phosphorus increased under the influence of a higher nitrogen supply. In turn, a study by CHWIL (2000) showed that the content of magnesium in wheat grain increased owing to more intensive NPK fertilization.

Supplying crops with proper quantities of nutrients, under suitable soil conditions, is the basic factor that helps to obtain expected yield volume and quality (GONDEK, GONDEK 2010). A team of researchers from Croatia (KOVAČEVIĆ et al. 2013) observed that when an NPK dose was increased from 170 kg ha^{-1} (including N 103) to 363 kg ha^{-1} (including N 133), it raised the yields by 17% and the content of Mg by 17%, while the concentrations of P and K remained on similar levels. When the fertilization dose was further increased to 580 kg NPK (including N 183), the content of macronutrients rose as follows: Mg by 20 %, phosphorus by 11%, and potassium by 6%. In another experiment into the impact of NPK fertilization on quality of grain of winter wheat grown in Romania, CRISTA et al. (2012) proved that higher nitrogen doses led to a higher nitrogen concentration in grain, while elevated amounts of phosphorus and potassium fertilizers did not have any significant effect on the grain content of nitrogen. GAJ and GÓRSKI (2014) showed that different doses of P and K, regardless of the year of experiments, had no significant effect on the accumulation of N, whereas the content of phosphorus, potassium, magnesium and calcium in wheat grain depended mostly on the weather conditions. In an experiment by PSZCZÓŁKOWSKA et al. (2018), nitrogen supplied in increasing doses (60, 120 and 180 kg N ha^{-1}) did not modify the content of phosphorus, magnesium or calcium in winter wheat grain, although it considerably improved the wheat's yielding compared with the control plots (by 2.03, 3.47 and 4.02 t ha^{-1}, respective to the increasing doses) and the content of nitrogen (higher by 0.10, 0.20, and 1.20 mg kg^{-1} d.m. respectively). BOBRECKA-JAMRO et al. (2013) report that the nitrogen fertilization increased from 40 to 120 kg ha^{-1} caused an increase in the grain content of magnesium from 0.76 to 1.01 g kg^{-1} d.m., and calcium from 0.26 to 0.35 g kg^{-1} d.m., while failing to affect the content of phosphorus and potassium in wheat grain. DUCSAY and LOŽEK (2004) maintain that nitrogen nourishment of winter wheat has a positive influence on the accumulation of main macronutrients (N, P, K, Ca, Mg and S) in grain. In a study by JASKULSKA et al. (2018), a nitrogen dose of 200 kg N ha^{-1} did not affect the grain content of P, K and Mg, although it raised the concentration of Ca in grain from 0.18 to 0.23 g kg^{-1} d.m., compared with the effects noted in response to a nitrogen dose of 100 kg ha^{-1}. GAJ and GÓRSKI (2014) draw attention to the fact that the quality of grain depends not only on concentrations of macronutrients but also on proper ratios between them, as these are crucial in an evaluation of grain's value as human food or animal feed. Mutual interactions between bioelements have a considerable effect on their availability in the digestive tract and on cellular absorption. According to Łabądź et al. (2017), both a deficit and an excess of any of the elements causes changes in concentrations of other elements. In the analyzed research, significant and negative correlations were determined between the content of macronutrients in grain and grain yields. The strongest correlation was detected between yield and potassium, phosphorus and nitrogen, where it reached r = -0.681*, -0.678*, and -0.668*, respectively. The weakest correlation occurred between yield and calcium (-0.368 *), which can probably be explained by the smallest variation in the calcium content between years of the research. On the other hand, significant but positive correlations were identified between pairs of elements, except the pair composed of phosphorus and calcium, and the strongest correlation occurred between the content of phosphorus and potassium (r = 0.826*) – Table 6.

Table 6

Coefficients of linear correlation between the content of macronutrients, and the grain yield of winter wheat, mean in years 2014-2016

Macronutrients ($g\ kg^{-1}$ d.m.)	Yield ($t\ ha^{-1}$)	N	P	K	Mg
N	-0.668*	1			
P	-0.678*	0.558*	1		
K	-0.681*	0.557*	0.826*	1	
Mg	-0.547*	0.608*	0.649*	0.676*	1
Ca	-0.368*	0.530*	0.175	0.344*	0.456*

Significance of the correlation coefficient r: * p = 0.05

In our experiment, the mineral composition of wheat grain was significantly different between the years of the trials (Tables 4, 5). Grain harvested in 2016 (when the yields were the lowest, 6.38 $t\ ha^{-1}$ on average; Table 3) was characterized by the highest average content of nitrogen (24.0 $g\ kg^{-1}$), phosphorus (3.53 $g\ kg^{-1}$), potassium (6.16 $g\ kg^{-1}$ d.m.) and magnesium (1.70 $g\ kg^{-1}$ d.m.) as well as calcium (0.54 $g\ kg^{-1}$ d.m.), compared to the grain obtained in the years 2014 and 2015 (average yields: 8.36 and 7.74 $t\ ha^{-1}$). Similar relationships, although in triticale grain, were reported from western Sweden by Feil and Fossati (1995), who demonstrated that the content of minerals in grain, except Mg, was much lower in a year when the crop's yields were higher. The higher accumulation of elements in our study is likely to have been favoured by higher rainfall in July 2016, when the total precipitation was by 73% higher than the multi-year average. A similar situation appeared in an experiment reported by Bielski (2015), where winter triticale grain had the highest P, K and Ca content in a year with the highest rainfall in July. Many authors point to the relationship between the volume of harvested yields and the chemical composition of grain with the amount and distribution of precipitations as well as the course of temperatures during the vegetative development of plants, which may lead to certain differences in the content of minerals in grain between years of field trials (Ducsay, Ložek 2004, Gondek, Gondek 2010). Some researchers emphasize that the impact of environmental conditions and agritechnical practice on concentrations of minerals in grain is largely dependent on the genotype of a crop plant (Jaskulska et al. 2018). Hawkesford (2014) and Tiryakioğlu et al. (2014) draw attention to the role of remobilization of nutrients from leaves to kernels during the stage of grain filling in winter wheat. According to Hawkesford (2014), our knowledge of the process of remobilization of minerals from other organs of a plant to grain can be important for making a correct diagnosis of optimal macronutrient fertilization, which in the future may help to prevent excessive use of nutrients and their leaching into the environment.

CONCLUSIONS

1. The sowing date of the winter wheat cultivar Arkadia did not have any distinct, repeatable and significant effects on changes in the content of macronutrients in grain, especially for nitrogen and potassium. Only in the case of phosphorus did its content decrease with each delay in sowing (from 3.00 to 2.91 g kg^{-1} d.m.)

2. The level of NPK fertilization had an unequivocal effect only on the content of nitrogen in grain. The concentration of this element in grain increased in response to the higher NKP fertilization dose, on average from 21.3 to 22.7 g kg^{-1} d.m.

3. Different sowing dates and levels of NPK fertilization did not change unambiguously the quality of wheat grain as a potential ingredient of food for people or concentrated feeds for animals.

4. The content of the analyzed macronutrients in winter wheat was in most cases varied between the years of the experiment, which was mainly a consequence of different volumes of yields harvested in the consecutive years.

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