Journal of Elementology ISSN 1644-2296

Brzozowska I., Brzozowski J. 2020.
Effect of the sowing date and NPK fertilization on the content of macronutrients in winter triticale grain.
J. Elem., 25(2): 757-770. DOI: 10.5601/jelem.2019.24.4.1924

RECEIVED: 16 October 2019
ACCEPTED: 24 February 2020

ORIGINAL PAPER

EFFECT OF THE SOWING DATE AND NPK FERTILIZATION ON THE CONTENT OF MACRONUTRIENTS IN WINTER TRITICALE GRAIN*

Irena Brzozowska, Jan Brzozowski

Department of Agroecosystems
University of Warmia and Mazury in Olsztyn, Poland

Abstract

The content of macronutrients in cereal grains depends on the species- and cultivar-related traits as well as the soil and weather conditions, in addition to the applied agrotechnical treatments. The purpose of this study has been to determine the effect of the date of sowing and NPK fertilization level on the content of macronutrients (N, P, K, Mg, Ca) in the winter triticale cultivar called Twingo. The first experimental factor was the date of sowing (4 dates, set at two-week intervals): I – 15-16 September, II – 29-30 September, III – 14-15 October, and IV – 29-30 October. The second factor consisted of two NPK fertilization variants (in kg ha^{-1}): 1 NPK (280 kg ha^{-1}), including 120 N, 60 P and 100 K, and 1.5 NPK (420 kg ha^{-1}), including 180 N, 90 P and 150 K. The date of sowing of the winter triticale variety Twingo did not have any distinct and year repeatable effects causing significant changes in the content of the analyzed macronutrients in grain. Nevertheless, the highest accumulation of nitrogen and magnesium was determined in the grain of triticale sown on the latest date, at the end of October, while phosphorus and calcium accumulated the most in the grain of triticale sown in mid-September, and potassium was most abundant in the grain of triticale sown in late September. The higher NPK fertilization level had a significant effect, particularly increasing the content of nitrogen in grain, but also stimulating the accumulation of phosphorus and magnesium. The content of potassium did not show any distinctly consistent trend over the years, while the content of calcium in grain did not depend on the NPK level. The content of the analyzed macronutrients in winter triticale grain tended to be significantly different between the research years. The highest concentrations of macronutrients, except phosphorus, were achieved in the last year, when the grain yields were the lowest.

Keywords: winter triticale, macronutrients, sowing date, NPK.

Irena Brzozowska, PhD DSc., Department of Agroecosystems of University of Warmia and Mazury in Olsztyn, pl. Łódzki 3, 10-718 Olsztyn, Poland, e-mail: irena.brzozowska@uwm.edu.pl
* Source of funding: a grant from the Ministry of Science and Higher Education allocated to the University of Warmia and Mazury inOlsztyn Project financially supported by the Minister of Science and Higher Education from the program titled "Regional Initiative of Excellence" for the years 2019-2022, Project No. 010/RID/2018/19, amount of funding 12.000.000 PLN.

INTRODUCTION

Triticale grain is mostly used in farm animal nutrition (Peña 2004, Bruckner et al. 2013, Bona et al. 2014). In Poland, this cereal is particularly popular in regions with highly intensive animal production. In 2017, the total triticale grain harvest in Poland reached 5.32 million tons, which made up 45.4% of European production (11.69 m t) and 34.2% of global production (15.6 m t) – FAOSTAT (2019). According to Myer and Lozano del Rio (2004), triticale grain is characterized by better availability and digestibility of some mineral nutrients than maize grain. This permits lower supplementation of minerals to feeds, which is economically more profitable. Thus, the content of macronutrients in cereal grains is essential, playing an important role when developing feed recipes. Insufficient amounts of macronutrients in grain may have a particularly negative effect on the metabolism of animal organisms (Friedrich, Podlaszewska 2015). The deficit of some elements, including calcium and phosphorus, can contribute to the etiology of some animal diseases, e.g. osteoporosis, which is conducive to fractures of bones in limbs (Egermann et al. 2005). Magnesium participates in the synthesis of many enzymes and in the transformations of proteins, lipids, carbohydrates as well as nucleic acids, or in synthesis of ATP, in addition to which it regulates the intracellular concentration of potassium ions (Kurek et al. 2017). The content of macronutrients in cereal grains depends on species- and cultivar-related traits of crops, as well as on the soil and weather conditions in which they grow, in addition to the performed agrotechnical treatments, including the date of sowing and fertilization (Ducsay, Ložek 2004, Bobrecka-Jamro et al. 2013, Gaj et al. 2013, Dekić et al. 2014, Woźniak 2016). A study completed by Stankiewicz (2005) implicates greater variation in the mineral composition of triticale grain due to environmental conditions and agrotechnical treatments than in grain of other cereals. Many researchers also point to the dependence between the volumes of harvested yields or the chemical composition of grain and the course of weather conditions, especially amounts of rainfall and temperatures during the plant growing season (Erekul, Kohn 2006, Bassu et al. 2011, Jaskulski et al. 2011, Stępień, Wojtkowiak 2016). Our working hypothesis was that the chemical composition of triticale grain is a dynamic trait that depends on natural conditions (habitat) and artificial (anthropogenic) ones, including particularly important agronomic treatments, such as the date of sowing and NPK fertilization regimes. The aim of our study was to determine the impact of the date of sowing and NPK fertilization levels on the content of macronutrients (N, P, K, Mg and Ca) in winter triticale grain.

MATERIAL AND METHODS

In 2014-2016, a field experiment involving the winter triticale variety Twingo was carried out at the Research Station in Tomaszkowo (53°42′ N; 20°26′ E), affiliated with the University of Warmia and Mazury in Olsztyn. The cultivar Twingo was added to the national Register of Agricultural Crop Cultivars in 2012. It is recommended for cultivation in all Poland. This is a winter hardy cultivar, which is suitable for delayed sowing and intensive cultivation technology (Danko… 2012). Triticale was grown after winter triticale. Soil tillage was performed as recommended. The experiment was set up in a design of random sub-blocks with three replicates, on proper brown soil underlain by sandy clay loam (Polish Soil Classification 2011), which according to the WRB taxonomy (IUSS Working Group WRB 2015) belonged to Haplic Cambisols. The soil was characterized by a moderate content of humus (1.48-1.71%), moderate abundance of available nutrients, including phosphorus (47-66 mg kg^{-1} of soil), potassium (117-139 mg kg^{-1} of soil), magnesium (48-63 mg kg^{-1} of soil), and a slightly acidic pH (from 6.1 to 6.5). The surface area of a single plot was 16 m^2. The first factor in the experiment was the date of sowing (4 dates, at two-week intervals), I – 15-16 September, II – 29-30 September, III – 14-15 October, and IV – 29-30 October. The sowing density was 400 seeds m^{-2}, at a weight of 1000 seeds of approximately 47.0 - 50.0 g. The second factor consisted of two NPK fertilization levels (kg ha^{-1}): 1 NPK (280 kg ha^{-1}), including 120 N, 60 P and 100 K, and 1.5 NPK (420 kg ha^{-1}), including 180 N, 90 P and 150 K. The fertilization of triticale with phosphorus and potassium was carried out before sowing, and the doses applied are presented in the elemental form. Nitrogen fertilizers were applied on 3 dates (Table 1).

Grain samples for analyses of the concentrations of macronutrients (N, P, K, Mg, Ca) were collected during harvest, carried out with a combine harvester. All analyses were made at the Agricultural Chemical Station in Olsztyn, using the following methods: potentiometric titration after digestion in sulphuric acid to assess the content of nitrogen, spectrophotometric method on a spectrocolorimeter Specol 11 to determine phosphorus, flame

Table 1

Regimes of winter triticale nitrogen fertilization (kg ha^{-1})

Dates of nitrogen application	Type of fertilizer	1 NPK	1.5 NPK
After resumed vegetative growth (BBCH 12-21)	ammonium nitrate 34%	60	90
Stem elongation (BBCH 32-33)	urea 46%	40	60
Inflorescence emergence (BBCH 52-53)	urea 46%	20	30

atomic absorption spectrometry on a AAS1 apparatus to measure the content of magnesium, and flame photometry on a Flavo 4 apparatus to determine the concentrations of potassium and calcium. All chemical assays were accredited. The accreditation certificate (AB 277) was issued by the Polish Accreditation Centre, which confirmed that the laboratory satisfies the requirements of the Polish standard PN-EN ISO/IEC 17025:2005.

Statistical analyses

The research results were submitted to statistical analysis, using analysis of variance for two-factorial experiments (date of sowing, NPK fertilization level) in each year of the experiment, and three-factorial experiments (years, date of sowing, nitrogen fertilization level) for the data achieved during the three years of the field trials set up in split-plot random sub-blocks. Significance of differences was verified with the Duncan's test, at the probability of error set at $p = 0.05$. Simple correlation and multiple regression analyses were applied to assess the effect of the experimental factors on the content of macronutrients in winter triticale grain. All calculations were supported by Statistica software (StatSoft, Inc., 2010).

Meteorological conditions

The research period (2014 - 2016) was distinguished by highly changeable weather conditions (Table 2). During the first two seasons (2013/2014 and 2014/2015), the weather in autumn was beneficial to the development of plants in terms of the soil moisture content during the seed sowing. Winters were warmer than the multi-annual average. In the third year of the experiment, severe rainfall deficits and lower air temperatures occurred in October, in comparison with the multi-year average data. As a result, the plants emerged later and fewer. Moreover, rainfalls were excessive in July, having a negative influence on plant yields, a consequence also indicated by Rymuza et al. (2012).

RESULTS AND DISCUSSION

In the experiment reported in this paper, the yields of winter triticale, as three-year average, reached 6.85 t ha^{-1} (Table 3). There were significant differences between the years. The highest yielding was achieved by triticale grown in the second year (8.24 t ha^{-1} on average), while the lowest yield was produced in the third year (4.71 t ha^{-1} on average). The third date of sowing was the most beneficial in terms of the yield obtained (7.03 t ha^{-1} on average), and the differences were significant in comparison with the average yields obtained from triticale sown on the first and the fourth date (6.69 t ha^{-1} and 6.72 t ha^{-1}, respectively). The level of NPK fertilization

Table 2

Air temperatures and rainfall in the plant growing period of winter triticale in 2013-2016 according to the Meteorological Station in Tomaszkowo

Month	Air temperature (°C)				Rainfall (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	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 (April-July)	13.4	14.1	12.9	14.1	243.2	146.8	179.3	285.4

higher by 50% resulted in a significant increase in the triticale grain yield (from 6.74 to 6.95 t ha^{-1}).

The different dates of sowing tested in this experiment had an equivocal effect on the content of macronutrients in the consecutive years of the field trials (Table 4). This could be attributed to the different weather conditions in the three plant growing seasons. As for nitrogen, the highest three-year average concentration of this element was noted in grain of triticale sown on the last date (21.5 mg kg^{-1}), and the differences relative to the previous dates of sowing were significant. Out of the three research seasons, the highest nitrogen content in triticale grain (on average 25.6 mg kg^{-1}) was determined in 2016, a year with the markedly lowest yields (4.71 t ha^{-1}). Regarding phosphorus, its highest three-year average content was determined in grain of triticale sown on the first date (3.43 mg kg^{-1}), and again the differences were significant in comparison with all the later dates, with significant differences determined between them as well (3.28-3.33 mg kg^{-1}). In 2016, significantly the highest content of phosphorus occurred in grain harvested from triticale sown on the first two dates of sowing (2.98 and

Table 3

The yielding of winter triticale 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	7.55	7.64	4.88	6.69
II	7.85	8.12	4.83	6.93
III	7.94	8.47	4.68	7.03
IV	7.02	8.73	4.42	6.72
$NIR_{(0.05)}$ – $LSD_{(0.05)}$	0.40	0.56	n.s.	0.27
Level of NPK fertilization				
1 NPK	7.40	8.11	4.71	6.74
1.5 NPK	7.78	8.36	4.70	6.95
$LSD_{(0.05)}$	0.18	n.s.	n.s.	0.12
Mean for years	7.59	8.24	4.71	6.85
$LSD_{(0.05)}$ for years - 0.50				

n.s. – not significant,
* I – 15-16 September, II – 29-30 September, III – 14-15 October, IV – 29-30 October
1 NPK (280 kg ha^{-1}), including 120 N, 60 P and 100 K,
1.5 NPK (420 kg ha^{-1}), including 180 N, 90 P and 150 K.

2.96 mg kg^{-1}), in contrast to the last two dates (2.74-2.75 mg kg^{-1}). With respect to potassium, its highest concentration was detected in triticale grain from the second date of sowing (8.29 mg kg^{-1} on average from the three years) and from the fourth date (8.25 mg kg^{-1} on average), while significantly less of this element accumulated in grain of triticale sown on the first (7.96 mg kg^{-1}) and third date (8.15 mg kg^{-1}). The concentration of magnesium in triticale grain was significantly dependent on the date of sowing in the first and third year of the research. The highest concentration of this element in the first year was found in grain of triticale sown on the last date (1.90 mg kg^{-1}), while in the third year it accumulated the most in grain of triticale sown on the second (2.04 mg kg^{-1}) and fourth (2.01 mg kg^{-1}) dates. The three-year average concentration of calcium in grain varied from 0.61 mg kg^{-1} for the 3rd and 4th dates of sowing to 0.65 mg kg^{-1} for the 1st and 2nd dates, but no significant differences were determined.

One of the conditions for winter cereals to develop properly in autumn, and to winter well and grow in spring is to sow them on the optimal date. In north-eastern Poland, winter triticale is recommended to be sown in a period between 5th and 20th September. However, it is very difficult to adhere to these optimal dates, largely due to the weather conditions. In north-eastern Poland, where long-term studies have demonstrated that over 80% of the total acreage cropped with winter wheat is sown after the

Table 4

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

Specification*		Year of research			Mean
		2014	2015	2016	
Nitrogen (N)	I	18.6	19.4	25.3	21.0
	II	18.4	18.7	24.9	20.7
	III	18.6	18.2	26.3	21.0
	IV	19.1	19.4	25.9	21.5
	$LSD_{(0.05)}$	n.s.	n.s.	0.9	0.5
	mean for years	18.7	18.9	25.6	21.1
	$LSD_{(0.05)}$ for years – 0.3				
Phosphorus (P)	I	3.53	3.78	2.98	3.43
	II	3.51	3.44	2.96	3.30
	III	3.53	3.56	2.74	3.28
	IV	3.63	3.62	2.75	3.33
	$LSD_{(0.05)}$	0.08	0.06	0.06	0.04
	mean for years	3.55	3.60	2.86	3.34
	$LSD_{(0.05)}$ for years – 0.06				
Potassium (K)	I	7.94	8.46	7.48	7.96
	II	8.04	7.71	9.13	8.29
	III	7.66	7.63	9.16	8.15
	IV	8.32	7.47	8.95	8.25
	$LSD_{(0.05)}$	0.08	0.11	0.07	0.05
	mean for years	7.99	7.82	8.68	8.16
	$LSD_{(0.05)}$ for years – 0.14				
Magnesium (Mg)	I	1.85	1.92	1.79	1.85
	II	1.83	1.83	2.04	1.90
	III	1.74	1.87	1.96	1.86
	IV	1.90	1.87	2.01	1.93
	$LSD_{(0.05)}$	0.07	n.s.	0.05	n.s.
	mean for years	1.83	1.87	1.95	1.89
	$LSD_{(0.05)}$ for years – 0.07				
Calcium (Ca)	I	0.54	0.65	0.79	0.66
	II	0.69	0.59	0.67	0.65
	III	0.48	0.64	0.71	0.61
	IV	0.46	0.61	0.75	0.61
	$LSD_{(0.05)}$	n.s.	n.s.	n.s.	n.s.
	mean for years	0.54	0.62	0.73	0.63
	$LSD_{(0.05)}$ for years – 0.05				

n.s. – not significant
* explanations under Table 3

recommended agrotechnical date, thus causing significant yield losses, estimated at 2.5 - 4.5% (Oleksiak, 2014). In practice, the situation of growing winter triticale is similar or even worse, as triticale seems more sensitive to delayed sowing than winter wheat (Jaśkiewicz 2009). If for any reason sowing was not carried out on the optimal date, various measures could be taken to prevent the expected losses, for instance NPK fertilization should be adequately adjusted. In general, it can be claimed that the content of macronutrients in grain is lower in years which favour the yielding of triticale, and vice versa, the accumulation of higher amounts of these elements is typical of years with lower yields. In a study conducted in India, the sowing of wheat delayed by two weeks resulted in an increase of the nitrogen content of grain by 6.7% and a decrease in the concentrations of P and K by 11.0 and 4.3%, respectively (Kumar 2012). In an American study, winter triticale sown in mid-October in 2002 contained significantly more nitrogen (18.5 g kg^{-1} d.m.) than grain of this cereal sown earlier, in late September (17.5 g kg^{-1} d.m.) (Schwarte et al. 2005).

In the experiment presented in this article, the higher NPK fertilization dose applied to winter triticale had an equivocal effect on the content of the analysed macronutrients in grain. The three-year average data show that it caused an increase in the content of nitrogen (from 20.7 to 22.2 mg kg^{-1}), phosphorus (from 3.31 to 3.36 mg kg^{-1}) and magnesium (from 1.85 to 1.91 mg kg^{-1}), where the nitrogen content was higher every year while the content of phosphorus and magnesium increased in the first and third year only (Table 5). In turn, the concentrations of potassium and calcium, as three-year average results, did not show any significant differences. In the case of calcium, this held true in every year of the experiment. As regards potassium, the higher NPK fertilization level caused a significant increase in the grain content of this element in the second (from 7.77 to 7.87 mg kg^{-1}) and third year (from 8.63 to 8.73 mg kg^{-1}), whereas in the first year it caused a significant decrease in the concentration of this element in triticale grain (from 8.13 to 7.85 mg kg^{-1}). In an experiment conducted by Lewandowski and Kauter (2003), an increase in the dose of nitrogen from 70 to 140 kg ha^{-1} caused a significant increase in yields of winter triticale as well as a higher grain content of nitrogen, while not differentiating the grain concentrations of potassium and calcium. The research results reported from Serbia by Dekić et al. (2014) showed that among the three tested variants of fertilization with nitrogen combined with either P or K, or nitrogen in combination with P and K, the highest grain yields were produced by the winter triticale variety Favorit fertilized with the three macronutrients N, P K in doses: 80 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, or supplied NPK in the variant: 80 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, where the respective yields reached 4.0 and 3.9 t ha^{-1}. Knapowski et al. (2010) report that an increase in nitrogen fertilization from 80 to 120 kg ha^{-1} led to a significant increase in the content of nitrogen, potassium and calcium in spring triticale grain, by 5.8, 5.8 and 17.4%, respectively. In turn, Bielski (2015)

Table 5

Content of macroelements of winter triticale grain depending on the level of NPK fertilization ($g\ kg^{-1}$ d.m.)

Specification*		Year of research			Mean
		2014	2015	2016	
Nitrogen (N)	1 NPK	18.3	18.4	24.5	20.7
	1.5 NPK	19.9	19.3	26.7	22.2
	$LSD_{(0.05)}$	1.1	0.6	0.8	0.6
	mean for years	18.7	18.9	25.6	21.5
	$LSD_{(0.05)}$ for years – 0.3				
Phosphorus (P)	1 NPK	3.50	3.64	2.79	3.31
	1.5 NPK	3.60	3.56	2.92	3.36
	$LSD_{(0.05)}$	0.06	0.08	0.07	0.04
	mean for years	3.55	3.60	2.86	3.34
	$LSD_{(0.05)}$ for years – 0.04				
Potassium (K)	1 NPK	8.13	7.77	8.63	8.18
	1.5 NPK	7.85	7.87	8.73	8.15
	$LSD_{(0.05)}$	0.09	0.05	0.07	r.n.
	mean for years	7.99	7.82	8.68	8.17
	$LSD_{(0.05)}$ for years – 0.04				
Magnesium (Mg)	1 NPK	1.79	1.87	1.90	1.85
	1.5 NPK	1.86	1.87	2.00	1.91
	$LSD_{(0.05)}$	0.04	n.s.	0.05	0.04
	mean for years	1.83	1.87	1.95	1.88
	$LSD_{(0.05)}$ for years – 0.02				
Calcium (Ca)	1 NPK	0.56	0.65	0.73	0.65
	1.5 NPK	0.52	0.59	0.73	0.61
	$LSD_{(0.05)}$	n.s.	n.s.	n.s.	n.s.
	Mean for years	0.54	0.62	0.73	0.63
	$LSD_{(0.05)}$ for years – 0.05				

n.s. – not significant,
* explanations under Table 3

demonstrated that a rise in the nitrogen fertilizer dose from 30 to 150 kg ha $^{-1}$ had a significant impact, increasing the content of N (from 15.1 to 18.8 g kg^{-1} d.m.) and Ca (from 0.512 to 0.636 g kg^{-1} d.m.), but did not differentiated the concentrations of P, K and Mg in triticale grain. In a study carried out by GAJ (2012), the yield-forming responde of winter triticale in the set experi-mental conditions proved that the crop is more sensitive to the deficit of potassium than phosphorus. Ten-year long absence of K and P fertilization reduced the yield of triticale by 12.8% and 4.6%, respectively. Tababtabaei and Ranjbar (2012) showed that the highest yield of triticale (6.1 t ha^{-1}) grown in Iran was harvested when 160 kg ha^{-1} of nitrogen and 90 kg ha^{-1} of potassium were applied. Gibczyńska et al. (2016) found out that the grain of all varieties of triticale cultivated in an organic system contained more phosphorus and magnesium than in conventional cultivation. The compared systems of cultivation did not differentiate the content of calcium and potassium in grain of 4 winter triticale cultivars: Benetto, Cultivo, Grenado and Moderato. No relationship between the total content of phosphorus, calcium or magnesium and the triticale cultivar grown was noted. The quantity of potassium in triticale grain was differentiated by a cultivar tested as an experimental factor. Some authors underline that a significant role is played not only by concentrations of particular macronutrients but also by their proper mutual proportions, which become of key importance in an assessment of the consumption and fodder values of grain (Gaj et al. 2013). Mutual interactions between bioelements have a considerable influence on their availability in the digestive tract and on the cellular absorption of nutrients by animals. According to Łabądź et al. (2017), both a deficit and an excess of any element induces changes in the content of other nutrients.

The mineral composition of triticale grain in the analyzed experiment significantly varied between the years of the trials (Tables 4, 5). The grain harvested in 2016 (with the lowest yield, 4.71 t ha^{-1} on average (Table 3), was characterized by the significantly highest change in the content of nitrogen (25.6 g kg^{-1}), potassium (8.68 g kg^{-1} d.m.), magnesium (1.95 g kg^{-1}) and calcium (0.73 g kg^{-1} d.m.), in comparison with the grain obtained in 2014 and 2015 (average yields of 7.59 and 8.24 t ha^{-1}). Similar dependences in a research project where triticale was grown in three sites in Switzerland were reported by Feil and Fossati (1995), who found that the content of mineral elements in grain, except Mg, was much lower in years with more abundant yields, suggesting that there is a tendency towards a lower nutritive value of triticale grain when yields are higher. The content of proteins and minerals in the experiment conducted by the cited authors was positively correlated. The researchers therefore suggested that triticale with a higher content of protein most likely tended to accumulate higher concentrations of minerals. In our experiment, greater accumulation of elements was most probably stimulated by the plentiful rainfalls in July 2016, higher by 73% than the multi-annual mean value, in which our results resemble data reported by Bielski (2015), who determined the highest concentrations of P, K and Ca in grain in the year with the highest precipitation in July. Some authors draw attention to the relationship between the volume of harvested grain yields and the chemical composition of grain versus the course of meteorological conditions, particularly the amount and distribution of rainfalls as well as the distribution of temperatures during the plant growing period, which causes certain differences in the content of mineral elements in grain between research years (Ducsay, Ložek 2004, Gondek, Gondek 2010). The research done by these authors suggests that the weather conditions in individual plant growing seasons had a much stronger effect on yielding and the content of macronutrients in triticale grain than agrotechnical factors did. Some researchers also highlight the fact that the impact of environmental and agrotechnical circumstances on the level of mineral elements in grains is also largely dependent on a genotype of triticale (Jaskulska et al. 2018).

In our study, significant negative correlations between yield and the content of macronutrients in grain were determined, with the exception of phosphorus, where the correlation was positive (Table 6). The strongest correlations, but contrary ones, were identified between yield versus the grain content of nitrogen and phosphorus, at r = -0.88* and 0.83*, respectively. In turn, positive significant correlations between pairs of elements appeared between nitrogen and potassium, magnesium and calcium, and between potassium and magnesium, while negative significant correlations were determined between phosphorus and potassium (r = -0.56*) as well as calcium (r = -0.55) and magnesium (r = -0.37*).

Table 6

Coefficients of linear correlation between the macroelements and the grain yield of the winter triticale; means from the years 2014-2016

Macroelements (g kg^{-1} d.m.)	Yield (t ha^{-1})	N	P	K	Mg
N	-0.88*	1			
P	0.83*	-0.81*	1		
K	-0.67*	0.61*	-0.56*	1	
Mg	-0.44*	0.53*	-0.37*	0.64*	1
Ca	-0.57*	0.58*	-0.55*	0.25	0.21

Significance of the correlation coefficient r: * – p = 0.05

CONCLUSIONS

1. The date of sowing of the winter triticale cultivar Twingo did not have a distinct and year repeatable effect causing significant changes in the concentrations of the analyzed nutrients in grain.

2. The higher level of NPK fertilization had a significant effect on the grain content of minerals, contributing especially to a much higher content of nitrogen, but also greater accumulation of phosphorus and magnesium. The content of potassium followed a less unambiguous pattern in the years of the experiment, while the grain concentration of calcium did not depend on NPK fertilization levels.

3. The content of the analyzed macronutrients in the grain of winter triticale tended to be significantly varied between the years of the experiment. Their highest concentration, except phosphorus, was determined in the last year, when the grain yields were the lowest.

REFERENCES

Bassu S., Asseng S., Richards R. 2011. *Yield benefits of triticale traits for wheat under current and future climates.* Field Crops Res. 124: 14-24. DOI: 10.1016/j.fcr.2011.05.020.

Bielski S. 2015. *Effect of nitrogen and fungicide protection on macroelement content of winter triticale grain.* Ann. UMCS, Sec. E Agricultura, 70(4): 1-11. (in Polish)

Bobrecka-Jamro D., Kruczek G., Romaniak M., Jarecki W., Buczek J. 2013. *Effect of the dose and method of top-dressing with nitrogen on the yield and quality of winter wheat grain.* Acta Sci. Pol., Agricultura 12(4): 19-30.

Bona L., Acs E., Lantos C., Tomoskozi S., Lango B. 2014. *Human utilization of triticale: Technological and nutritional aspects.* Commun. Agric. Appl. Biol. Sci., 79(4):139-152.

Bruckner P. L., Cash S. D., Lee R. D. 2013. *Nitrogen effects on triticale grain yield, amino acid composition, and feed nutritional quality for swine.* J. Prod. Agric., 11(2): 180-184. DOI:10.2134/jpa1998.0180

Danko Plant Breeding in Chorynia. 2012. *Winter triticale. Varieties. Twingo.* http://danko.pl. (access 27. 11.2019 r.)

Dekić V., Milovanović M., Popović V., Jelić M., Perišić V. 2014. *Effects of fertilization on yield and grain quality in winter triticale.* Rom. Agric. Res., 31: 1-9.

Ducsay L., Ložek O. 2004. *Effect of topdressing with nitrogen on the yield and quality of winter wheat grain.* Plant Soil Environ., 50(7): 309-314.

Egermann M., Goldhahn J., Schneider E. 2005. *Animal models for fracture treatment in osteoporosis.* Osteoporos Int., 16: 29-38. DOI: 10.1007/s00198-005-1859-7.

Erekul O., Kohn W. 2006. *Effect of weather and soil conditions on yield components and bread -making quality of winter wheat (Triticum aestivum* L.*) and winter triticale (Triticosecale* Wittm.*) varieties in north-east Germany.* J. Agron. Crop Sci., 192(6): 452-46. DOI: 10.1111/j.1439-037X.2006.00234.x

FAOSTAT. 2019. *Production-Crops. Food & Agriculture Organization of the United Nations.* http://www.fao.org/faostat/en/#home (access 09.04.2019)

Feil B., Fossati D. 1995. *Mineral composition of triticale grains as related to grain yield and grain protein.* Crop Sci., 35(5): 1426-1431. DOI: 10.2135/cropsci1995.0011183X003500050028x

Friedrich M., Podlaszewska G. 2015. *Assessing effects of supplementing fodder with selected mineral components on their metabolism and distribution in body – model research.* Zyw-Nauk-Technol-Ja, 1(98): 207-219. (in Polish)

Gaj R. 2012. *The effect of different phosphorus and potassium fertilization on plant nutrition in critical stage and yield of winter triticale.* J. Cent. Eur. Agric., 13(4): 704-716. DOI: 10.5513/JCEA01/13.4.1116

Gaj R., Górski D., Przybył J. 2013. *Effect of differentiated phosphorus and potassium fertilization on winter wheat yield and quality.* J. Elem., 18(1): 55-67, DOI: 10.5601/jelem.2013.18.1.04

Gibczyńska M., Dawidowski A., Sobolewska M., Jaroszewska A., Lewandowska L. 2016. *Analysis of influence farming systems on chemical composition of four variety of triticale winter (x triticosecale* Wittm. Ex a. Camus*) grain.* Folia Pomer. Univ. Technol. Stetin., Agric., Aliment., Pisc., Zootech. 326, (38)2: 37-46. DOI: 10.21005/AAPZ2016.38.2.03

Gondek K., Gondek A. 2010. *The influence of mineral fertilization on the yield and content of selected macro and microelements in spring wheat.* J. Res. Appl. Agric. Eng., 55(1): 30-36. (in Polish)

IUSS Working Group WRB. 2015. *World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. Update 2015.* World Soil Resources Report 106, Food and Agriculture Organization of the United Nations, Rome, 188 pp.

Jaskulski D., Jaskulska I., Woźniak M., Osiński G. 2011. *Assessment of variability of cereal grain quality as a component of fodder mixtures*. Acta Sci. Pol., Agric., 10(4): 87-95. (in Polish)

Jaskulska I., Jaskulski D., Gałęzewski L., Knapowski T., Kozera W., Wacławowicz R. 2018. *Mineral composition and baking value of the winter wheat grain under varied environmental and agronomic conditions*. J. Chem., Article ID 5013825, 7 pages, https://DOI.org/10.1155/2018/5013825

Jaśkiewicz B. 2009. *The influence of sowing density and nitrogen application method on yielding and morphological characters of winter triticale* cv. *Woltario*. Biul. IHAR, 252: 169-177. (in Polish)

Knapowski T., Kozera W., Majcherczak E., Barczak B. 2010. *Effect of nitrogen and zinc fertilisation on chemical composition and protein yield of spring triticale grain.* Fragm. Agron., 27(4): 45-55. (in Polish)

Kumar V. 2012. *Effect of dates of sowing on growth and yield of wheat (Triticum aestivum* L.*) varieties*. Department of Agronomy Institute of Agricultural Sciences Banaras Hindu University Varanasi – 221 005, ss. 114. http://krishikosh.egranth.ac.in/bitstream/1/90892/1//Vikesh%202012.pdf, (access 09.04.2019)

Kurek Ł., Lutnicki K., Olech M. 2017. *Influence of subclinical magnesium deficiency in the antenatal period on mineral and energy management during early lactation.* Med. Wet., 73(7): 434-438. (in Polish) DOI: 10.21521/mw.5737

Lewandowski I., Kauter D. 2003. *The influence of nitrogen fertilizer on the yield and combustion quality of whole grain drops for solid fuel use.* Ind. Crop. Prod., 17: 103-117. DOI: 10.1016/S0926-6690(02)00090-0

Łabądź D., Skolarczyk J., Pekar J., Nieradko-Iwanicka B. 2017. *Analysis of the influence of selected elements on the functioning of the bone tissue.* J. Educ. Health Sport., 7(4): 202-209. DOI: http://dx.doi.org/10.5281/zenodo.400815

Myer R., Lozano del Río A. J. 2004. *Triticale as animal feed. Triticale improvement and production.* Food and Agriculture Organization of the United Nations. Roma (FAO). Plant Prod. Protect. Paper, 179: 49-58.

Oleksiak T. 2014. *Effect of sowing date on winter wheat yields in Poland.* J. Cent. Eur. Agric., 15(4): 83-99. DOI: 10.5513/JCEA01/15.4.1513

Peńa R. J. 2004. *Food uses of triticale. Triticale improvement and production.* Food and Agriculture Organization of the United Nations. FAO Plant Prod. Protect. Paper, 179: 37-48.

Polish Soil Classification, 2011. Rocz. Glebozn. – Soil Sci. Ann., 62(3): 1-193 (in Polish with in English abstract)

Rymuza K., Marciniuk-Kluska A, Bombik A. 2012. *Yielding of winter cereals in relation to thermal and precipitation conditions on oroduction fields in the Zawady Experimental Farm.* Woda-Środowisko-Obszary Wiejskie – Water-Environment-Rural Areas, 12, 2(38): 207-220. (in Polish)

Schwarte A. J., Gibson L. R., Karlen D. L., Liebman M., Jannink J. L. 2005. *Planting date effects on winter triticale dry matter and nitrogen accumulation.* Agron. J., 97(5): 1333-1341. DOI: 10.2134/agronj2005.0010

Stankiewicz C. 2005. *Effect of the sowing density and herbicides on the composition of amino acids and biological value of spring triticale protein.* Acta Sci. Pol., Agric., 4(1): 127-139. (in Polish)

StatSoft, Inc. 2010. Statistica (data analysis software system), version 9.1. www.statsoft.com

Stępień A., Wojtkowiak K. 2016. *Effect of foliar application of Cu, Zn, and Mn on yield and quality indicators of winter wheat grain.* Chil. J. Agr. Res., 76(2): 220-227. DOI: 10.4067//S0718-58392016000200012

Tababtabaei S. A., Ranjbar G. H. 2012. *Effect of different levels of nitrogen and potassium on grain yield and protein of triticale*. Int. Res. J. Appl. Basic. Sci., 3(2): 390-393. Available online at http://www._irjabs.com (access 09.04.2019)

Woźniak A. 2016. *Yield and chemical composition of spring triticale grain depending on cropping and tillage systems*. Int. J. Plant Prod., 10(1): 45-52. http://ijpp.gau.ac.ir//article_2552_651e17c32fd86d5ee937297a854d8f97.pdf, (access 09.04.2019)