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The effect of different doses of multi-nutrient fertilisers on macroelement content in two spring triticale cultivars

Wpływ zróżnicowanych dawek nawozów wieloskładnikowych na zawartość makroelementów w dwóch odmianach pszenżyta

Summary. A field experiment was conducted in the years 2017–2019 at Borki-Wyrki, Zbuczyn Gmina (commune). Three experimental factors were examined in the trial: factor one was spring triticale cultivar (Milewo, Dublet), factor two was mineral fertiliser type (Polifoska 6, Polifoska Krzem) and factor three was mineral fertiliser rate (0, 140, 280 and 420 kg ha^{-1}). Phosphorus, potassium, magnesium, calcium and sodium contents in grain varied in study years as affected by weather patterns. The highest phosphorus, magnesium and sodium contents were determined in the grain of spring triticale cv. Dublet whereas the highest potassium and calcium contents in cv. Milewo grain. The applied fertiliser rates increased mineral contents, excluding magnesium and sodium, in the grain of test cultivars. Chemical composition analysis of grain of the spring triticale cultivars demonstrated that there was no significant effect of fertiliser type on grain quality.

Key words: × *Triticosecale* Wittm. ex A. Camus, macroelements, multi-nutrient fertilisers, fertiliser rate

INTRODUCTION

The current world agricultural production includes the use of large quantities of fertilizers in most commercial crops, mainly nitrogen (N), phosphorus (P), and potassium (K). Reduction/optimization of fertilizer input would be an essential step in the agricul-

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tural sector which would allow the crop producers to manage fertilizer use more precisely and to improve productivity and sustainability [Agrahari et al. 2021]. According to numerous soil analyzes carried out in recent years in Poland, significant deficiencies of macroelements have been found. For this reason, it is reasonable to use compound fertilizers that enrich the soil with macroelements. Compound fertilizers are widely used due to their trouble-free application, solubility and comprehensive elemental composition but important is optimal doses treatment. These are competitive to single-ingredient fertilizers, because they make it possible to introduce several ingredients into the soil at the same time [Nogalska et al. 2010].

The concentration of minerals in grain varies greatly, the variation being the result of an influence of many factors including atmospheric conditions during the growing season and harvest, in particular air temperature and atmospheric precipitation, soil type and mineral availability, fertilisation methods and rates, and agrotechnological practices [Jaskulski et al. 2011, Dekić et al. 2014, Klikocka et al. 2015, Brzozowska and Brzozowski 2016, Gill and Omokanye 2016]. In his studies, Stankiewicz [2005] demonstrated that mineral composition variability due to habitat and agrotechnological factors was greater in spring triticale compared with other cereal species. Brzozowska [2006] found that nitrogen, phosphorus, potassium and magnesium contents increased following decreasing atmospheric precipitation and increasing air temperature. Stankowski et al. [2015] reported that in their research nitrogen fertiliser application at 40–80 kg N ha^{-1} did not affect nitrogen, phosphorus, potassium, calcium or magnesium contents in spring triticale grain. A significant increase in spring triticale grain nitrogen was recorded following an application of the highest nitrogen fertiliser rate, that is 120 kg N ha^{-1}. Kozera et al. [2015] confirmed that an increasing nitrogen rate from 80 to 120 kg N ha^{-1} contributed to a decline in magnesium content in spring triticale grain. However, there are many authors [Filipek 2001, Krzywy et al. 2001, Nogalska et al. 2010] whose research has revealed no substantial effect of multi-nutrient fertilisers on cereal grain mineral composition.

The objective of the study was to assess macroelement content in two spring triticale cultivars as affected by fertiliser rates, the fertiliser being Polifoska 6 or Polifoska Krzem. The content of macroelements will be diversified in varieties of spring triticale depending on the doses of fertilizers used.

MATERIAL AND METHODS

In order to achieve the assumed research objectives, a field study with spring triticale was conducted in the years 2017–2019. The experiment was established at Borki-Wyrki, a locality in Zbuczyn Gmina, Siedlce Poviat. The soil of the experiment was a podzol type whose granulometric composition was that of a medium loam soil (BN-78/9180-11). According to WRB FAO [World reference base for soil resources 2014], the soil represents Albic Podzols (Ochric), and in terms of granulometry, it is a sandy clay loam according to the international USDA classification. The soil had a high phosphorus content, and average potassium and magnesium contents, acid soil reaction. The experiment was a split-split-plot arrangement of plots with three replicates.

The gross plot area was 18 m^2, and the area for harvest 15 m^2. Three experimental factors were included: the first factor was spring triticale cultivar – Milewo, Dublet, the second factor was mineral fertiliser type – Polifoska 6, Polifoska Krzem, and the third factor was mineral fertiliser rate – 0, 140, 280, 420 kg ha^{-1}. Oats were the preceding crop in each study year. Phosphorus and potassium fertilisers were applied in the spring following the methodological assumptions. Nitrogen fertilisation was supplemented by the first rate of 40 kg ha^{-1} applied preplant, and the second rate of 40 kg ha^{-1} applied post-plant, each time in the form of ammonium nitrate (34%) at the first node stage (BBCH 31). Cultivation practices included herbicide and insecticide applications. The total content of macroelements P, K, Mg, Ca, Na was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) on a Perkin Elmer Optima 8300 spectrometer. Before sample analysis, to check precision and accuracy a number of quality checks have been carried out. Some of these tests include instrument tuning, calibration, performance checks, instrument detection limits (IDL), method detection limits (MDL), quality control (QC) samples and linear dynamic range (LDR). The analytical wavelengths and instrument detection limits were as follow: P 213.617, 0,090 mg L^{-1}; K 766.490, 0,030 mg L^{-1}; Mg 285.213, 0,002 mg L^{-1}; Ca 317.933, 0,010 mg L^{-1}; Na 589.592, 0,010 mg L^{-1}. The instrument was set up with the operating conditions: RF power – 1500W, plasma argon flow rate – 8 L min^{-1}, auxiliary argon flow rate – 0.2 L min^{-1}, nebuliser argon flow rate – 0.7 L min^{-1}, sample flow rate – 1 mL min^{-1}, integration time – 10 s. The lack of significant differences between the concentrations determined that would have been caused by different physical properties of the sample and the standard solutions was tested using the internal standard method (Y 371.029 nm). The tests carried out with a positive result confirmed the very good precision and accuracy of the ICP-OES analysis.

The research results were statistically analysed using the split-split-plot variance analysis which was performed for each study year separately and as a three-year synthesis. The confidence half-intervals for comparing means were calculated using Tukey's test at the significance level of $p = 0.05$. Weather conditions are presented based on data obtained from the Meteorological Station located at Zawady Experimental Farm which belongs to Siedlce University of Natural Sciences and Humanities. The distribution of temperature and precipitation in the study years varied. In the growing season of 2017, atmospheric precipitation was fairly plentiful in April compared with long-term means. The month of May was characterised by lower rainfall whereas July and August were very warm and dry. The weather conditions in the growing season of 2018 differed from the conditions of the previous growing season. In April, the atmospheric precipitation sum was similar to long-term sums, and average daily air temperatures were higher compared with long-term means. May and June were both dry and warm, which did not contribute to normal plant vegetation. Very warm and extremely dry were the months of July and August. The weather conditions at the beginning of the 2019 growing season were unfavourable for plants sown in spring due to drought with the atmospheric precipitation sum in April being lower than the long-term mean. The drought was followed by intense rainfall in May when the precipitation sum exceeded the long-term mean. The month of June was warm, the average air temperature being similar to the long-term average temperature, and its atmospheric precipitation sum was lower than the long-term mean. July and August were also warm and dry.

RESULTS

Table 1 shows significance of variation sources in the synthesis of 3 experimental factors across 3 study years for 5 macroelements.

Table 1. Significance of variation sources in the synthesis of 3 experimental factors across 3 study years for 5 macroelements

Source of variation	Traits (g·kg^{-1} d.m.)				
	Phosphorus content	Potassium content	Magnesium content	Calcium content	Sodium content
Years (Y)	*	*	*	*	*
Culivars (C)	*	*	*	*	*
Fertiliser types (T)	n.s.	n.s.	n.s.	n.s.	n.s.
Fertiliser rates (R)	*	*	n.s.	*	*
T × C	n.s.	n.s.	n.s.	n.s.	n.s.
R × C	*	n.s.	*	n.s.	n.s.
R × T	n.s.	n.s.	n.s.	n.s.	n.s.
Y × C	*	*	*	*	n.s.
Y × T	n.s.	n.s.	n.s.	n.s.	n.s.
Y × R	n.s.	*	*	n.s.	n.s.
C × T × R	n.s.	n.s.	n.s.	n.s.	n.s.
Y × C × T × R	n.s.	n.s.	n.s.	n.s.	n.s.

* significant, n.s. – non-significant

Variance analysis of means calculated across study years demonstrated a significant effect of cultivar and fertiliser rate on phosphorus content in spring triticale grain. Also, there was confirmed an interaction of fertiliser rate and cultivar (Tab. 2 and 3). Cv. Dublet had a higher phosphorus content in its grain compared with cv. Milewo. Fertiliser rate significantly influenced phosphorus content in spring triticale grain. A significant difference was confirmed between plots amended with 280 or 420 kg ha^{-1} and either unamended plots or units fertilised with the lowest rate, that is 140 kg ha^{-1}. An interaction between fertiliser rate and cultivar was confirmed indicating that after fertiliser applications of 140 and 280 kg ha^{-1} phosphorus content in spring triticale grain was higher for cv. Dublet compared with Milewo. However, when the rate was further increased to 420 kg ha^{-1}, the spring triticale grain content of phosphorus was higher for cv. Milewo. Growing season conditions significantly affected phosphorus content in spring triticale grain. The highest values of this characteristic were recorded for the grain of spring triticale harvested in 2019, them being significantly lower in 2017 and the lowest in 2018 (Tab. 4) There was confirmed an interaction years × cultivars which indicated that under the growing conditions of 2019 cv. Dublet accumulated significantly more phosphorus in grain, there being no such interaction confirmed for the previous years (Tab. 1).

Table 2. Effect of fertiliser rates on macroelements (g kg^{-1} d.m.), average values across 3 years

Traits	Fertiliser rates ($kg \cdot ha^{-1}$)				$LSD_{0.05}$
	0	140	280	420	
Phosphorus content	2.95	2.98	3.06	3.11	0.13
Potassium content	4.61	4.76	4.91	5.03	0.21
Magnesium content	1.07	1.07	1.07	1.07	n.s.
Calcium content	0.28	0.31	0.34	0.36	0.06
Sodium content	0.034	0.029	0.029	0.030	0.005

n.s. – non-significant

Table 3. Effect of cultivars types on macroelements ($g \cdot kg^{-1}$ d.m.), average values across 3 years

Traits	Cultivars		$LSD_{0.05}$
	Milewo	Dublet	
Phosphorus content	2.95	3.08	0.06
Potassium content	4.90	4.75	0.10
Magnesium content	1.02	1.12	0.02
Calcium content	0.34	0.30	0.03
Sodium content	0.028	0.033	0.002

Table 4. Effect of years on macroelements (g kg^{-1} d.m.), average values across 3 years

Traits	Years			$LSD_{0.05}$
	2017	2018	2019	
Phosphorus content	2.91	2.55	3.56	0.14
Potassium content	4.87	4.36	5.28	0.16
Magnesium content	1.11	1.01	1.09	0.03
Calcium content	0.26	0.39	0.31	0.05
Sodium content	0.034	0.030	0.027	0.004

Means across study years revealed a significant impact of cultivars and fertiliser rates on potassium content in spring triticale grain (Tab. 3 and 2). Cv. Milewo had a higher grain content of potassium. A significant difference was confirmed between unfertilised control and the fertiliser rate of 280 or 420 kg ha^{-1}. Growing season conditions significantly affected potassium content in spring triticale grain. The most favourable conditions for potassium accumulation in grain were in 2019 followed by 2017. The lowest potassium content in spring triticale grain was confirmed in 2018 (Tab. 4) The interaction between years and cultivars indicated that the test cultivars responded in a different manner to weather conditions in successive growing seasons. The years × fertiliser rates interaction indicated that potassium content in grain changed due to diverse fertilisation regimes and, at the same time, weather conditions in the study years (Tab. 1)

Variance analysis of means across study years demonstrated a significant effect of cultivars on magnesium content in spring triticale grain (Tab. 3). Cv. Dublet was characterised by a significantly higher magnesium content in grain compared with cv. Milewo. Growing season conditions significantly affected the concentration of magnesium in spring triticale grain. The highest magnesium content in grain was recorded in 2017 and 2019, the difference being significantly higher compared with 2018 (Tab. 4) There was confirmed an interaction of years and cultivars which indicated that the cultivars differed in their response to the weather conditions in the study years. Cv. Milewo had the highest magnesium content in grain harvested in 2017 growing season and cv. Dublet in 2019. For the latter cultivar, there was confirmed no significant difference in magnesium content in the grain of spring triticale harvested in 2017 and 2019. A statistically confirmed interaction between years and fertiliser rates indicated a diverse effect of fertiliser rates applied in the growing seasons. In 2017 and 2018, the highest magnesium content in spring triticale grain was associated with the rate of, respectively, 140 and 280 kg ha^{-1}, it being the highest in the unfertilised control unit in 2019 (Tab. 1).

Variance analysis of mean results across years revealed a significant influence of cultivars and fertiliser rates on calcium content in spring triticale grain (Tab. 3 and 2). Spring triticale cv. Milewo contained significantly more calcium in its grain compared with cv. Dublet. A significant difference between unfertilised control and units amended with the fertiliser rate of either 280 or 420 kg ha^{-1}. Growing season conditions significantly influenced calcium content in spring triticale grain. The highest calcium content in spring triticale grain was found in the growing season of 2018, it being the lowest in 2017 (Tab. 4). A statistically confirmed interaction of years and cultivars indicated that the cultivars responded in a different manner, in terms of calcium content, to the weather conditions in the study years. The highest calcium content in the grain of both cv. Milewo and Dublet was determined in 2018 growing season, followed by 2019 and 2017 (Tab. 1).

Means calculated across three years demonstrated a significant effect of cultivar and fertiliser rate on sodium content in spring triticale grain (Tab. 3 and 2). Spring triticale cv. Dublet contained more sodium in grain. The highest sodium content in spring triticale grain was recorded in the control unit which had remained unfertilised. Growing season conditions significantly influenced the concentration of sodium in spring triticale grain. In 2017, a significantly higher sodium content in grain was recorded compared with 2018 and 2019 when the weather conditions were less favourable due to low atmospheric precipitation (Tab. 4). Sodium content showed significant year × cultivar interaction effects indicating that in 2017–2018 significantly higher values were recorded for spring triticale grain, compared with 2019 when no such difference was noted (Tab. 1).

Chemical composition analysis of grain of the spring triticale cultivars demonstrated that there was no significant effect of fertiliser type on grain quality (Tab. 5).

Table 5. Effect of fertiliser types on macroelements (g kg^{-1} d.m.), average values across 3 years

Traits	Fertiliser types		$LSD_{0.05}$
	Polifoska 6	Polifoska Krzem	
Phosphorus content	3.02	3.01	n.s.
Potassium content	4.81	4.87	n.s.
Magnesium content	1.07	1.07	n.s.
Calcium content	0.32	0.33	n.s.
Sodium content	0.031	0.030	n.s.

n.s. – non-significant

DISCUSSION

Phosphorus, potassium, magnesium, calcium and sodium contents in spring triticale grain from 2017 to 2019 varied due to atmospheric conditions, cultivars and fertiliser rates. The highest phosphorus and potassium contents were determined in the grain of spring triticale grown in 2019 when prevailing high air temperatures were accompanied by low precipitation, which concurs with findings of the work by Brzozowska [2006]. Phosphorus and potassium contents in spring triticale grain in 2019 were, respectively, 3.56 and 5.24 g kg^{-1} d.m. The grain contents of these elements were similar to values reported by Wojtkowiak [2014] who examined cv. Milewo. Significant differences were found between the test cultivars. Compared with Milewo, the concentration of phosphorus in the grain of spring triticale cv. Dublet was by 4% higher. Spring triticale fertilisation with the rates of 280 and 420 kg ha^{-1} of multi-nutrient fertiliser contributed to a significant increase in spring triticale grain phosphorus compared with control, which agrees with results reported by Dekić et al. [2014] who found a significant influence of fertiliser rate on the cereal grain content of phosphorus. Cv. Milewo grain contained by 3% more potassium than cv. Dublet. The highest magnesium content in spring triticale grain, 1.11 g kg^{-1} d.m., was determined in 2017 growing season, and it was lower compared with values reported by Wojtkowiak [2014]. According to Kozłowska [2007], the magnesium supply which plants receive depends on the presence in the soil of its available forms. Spring triticale cv. Dublet had a magnesium content in grain which was by 9% higher compared with cv. Milewo. Research by Stępień and Wojtkowiak [2013] and Wojtkowiak [2014] has confirmed that triticale grain quality is dependent upon genetic properties of a given cultivar, but also on environmental and agrotechnological factors. Also in the study by Brzozowska and Brzozowski [2016], atmospheric conditions affected phosphorus, potassium and magnesium contents. In 2017, an increasing fertiliser rate was followed by raising magnesium content, which agrees with findings reported by Koc et al. [1997]. The highest calcium content in spring triticale grain was determined in 2018 and 2019 when low sums of atmospheric precipitation were accompanied by high air temperatures. The average calcium content in spring triticale grain, 0.33 g kg^{-1} d.m., was higher than values found by Knapowski et al. [2010]. Spring triticale cv. Milewo contained by 13% more calcium in its grain than cv. Dublet. The highest sodium content in grain was determined for spring triticale grown in 2017 when atmospheric precipitation was higher than in 2018 or 2019. Górecki and Grzesiuk [2002] claimed that a substantial amount of sodium enters soil with atmospheric precipitation, hence a higher content in grain in years with higher precipitation received throughout the growing season. Cv. Dublet contained by 13% more sodium in grain compared with cv. Milewo. The highest concentration of sodium in spring triticale grain was determined for unfertilised control, which agrees with results reported by Łysoń and Biel [2016] who obtained higher sodium contents in unfertilised units.

CONCLUSIONS

1. Mineral content, including the following macroelements: phosphorus, potassium, magnesium, calcium and sodium, changed in study years due to weather conditions.
2. The highest phosphorus, magnesium and sodium contents were determined in the grain of spring triticale cv. Dublet whereas the highest potassium and calcium contents were characteristic of cv. Milewo.
3. The applied multi-nutrient fertiliser rates contributed to increased concentrations of minerals, excluding magnesium and sodium, in the grain of test cultivars.
4. Analysis of chemical composition of the grain of test cultivars revealed that fertiliser type insignificantly affected grain quality.

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