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FOLIAR APPLICATION OF MICRONUTRIENTS (Cu, Zn and Mn) AND ITS EFFECT ON YIELD AND SELECTED MACRONUTRIENS CONTENT IN WINTER TRITICALE GRAIN

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K e y w o r d s: fertilization, yield components, nutritional value.

A b s t r a c t

The aim of the study was to determine the yield and its components and selected minerals (N, P, K, Ca, Mg, Na) in winter triticale grain as affected by foliar fertilisation with micronutrients, either used individually or in combination. A field experiment was carried out at the Educational and Experimental Station in Tomaszkowo (53°72 N; 20°42 E), Poland.

Regardless of the year, supplementation of NPK fertilisation with Cu resulted in an increase in the N and Na content in triticale grain. Application of Zn and Mn and the micronutrients in combination (Cu + Zn + Mn) resulted in an increase in phosphorus content. The year of the study affected the length of an ear at the plot fertilised with NPK fertiliser as well as the mass of 1.000 grains and Ca content in grain the NPK + Cu option. The weather conditions differentiated the grain yield and the content of N and Na in all the fertilisation options. Micronutrients applied individually and in combination affected the content of potassium in triticale grain. Foliar application of Cu + Zn + Mn stabilised the P content in grain in variable weather conditions. Pearson's correlation coefficient (*r*) showed a positive correlation between the content of N, Na and P in grain and the grain yield and mass of 1.000 grains. The content of K and N in grain was negatively correlated with the grain yield and the mass of 1.000 grains. A positive correlation was observed between the straw yield and the ear length and the potassium and sodium content in triticale grain.

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WPŁYW DOLISTNEGO OPRYSKIWANIA MIKROELEMENTAMI (Cu, Zn i Mn) NA PLONOWANIE I WYBRANE MAKROELEMENTY W ZIARNIE PSZENŻYTA OZIMEGO

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Słowa kluczowe: nawożenie, komponenty plonu, wartość odżywcza.

Abstrakt

Celem pracy było określenie wysokości plonu i jego komponentów oraz wybranych składników mineralnych (N, P, K, Ca, Mg, Na) w ziarnie pszenżyta ozimego pod wpływem dolistnego dokarmiania mikroelementami stosowanymi pojedynczo lub łącznie. Doświadczenie polowe przeprowadzono w Zakładzie Dydaktyczno-Doświadczalnym w Tomaszkowie (53°72 N; 20°42 E), Polska. Niezależnie od lat badań, uzupełnienie podstawowego nawożenia NPK dolistnym dokarmianiem Cu spowodowało wzrost zawartości N i Na w ziarnie pszenżyta. Zastosowanie Zn i Mn oraz mikroelementów łącznie (Cu + Zn + Mn) spowodowało wzrost zawartości fosforu. Lata badań wpłynęły na zmianę długości kłosa w obiekcie nawożonym NPK oraz na MTZ i zawartość Ca w ziarnie w wariancie NPK + Cu. Warunki pogodowe różnicowały plon ziarna oraz zawartość N i Na we wszystkich obiektach nawozowych. Mikroelementy stosowane pojedynczo i łącznie wpłynęły na kształtowanie ilości potasu w ziarnie pszenżyta w latach badań. Zastosowanie dolistne Cu + Zn + Mn oddziaływało na stabilizację zawartości P w ziarnie w zmiennych warunkach pogodowych. Współczynnik korelacji *r* Pearsona wykazał dodatnią zależność pomiędzy zawartością N, Ca i P w ziarnie a plonem ziarna i masą tysiąca ziaren. Zawartość K i Na była ujemnie skorelowana z wielkością plonu ziarna oraz masą tysiąca ziaren. Dodatnio skorelowany były plon słomy i długość kłosa z zawartością K i Na w ziarnie pszenżyta.

Introduction

Obtaining high good quality yield in agricultural production depends largely on appropriate agrotechnical measures, including mineral fertilisation (DEKIĆ et al. 2014). Both macro- and micronutrients applied to soil and foliarly contribute greatly to adequate plant nutrition (ALARU et al. 2009, KNAPOWSKI et al. 2010, STANKOWSKI et al. 2015, WOJTKOWIAK et al. 2015). Copper, zinc and manganese are the most important micronutrients in the cultivation of cereal. They determine the effective use of macronutrients, especially nitrogen and phosphorus, in the production of biomass. As components and activators of enzymes, they participate in many metabolic reactions and play important physiological roles in plants. Copper regulates the transformations of nitrogen compounds and affects the chlorophyll formation process and the formation of cell walls. Manganese regulates the intensity of photosynthesis and participates in the transformation of nitrogen compounds and carbohydrates. Zinc plays a very important role in the synthesis of growth hormones, affecting the transformation of proteins and the synthesis of vitamins B, C, P and it also regulates phosphorus transformation in plants (HÄNSCH and MENDEL 2009).

Increasing attention has been attracted by beneficial effect of fertilisation of cereals with macronutrients in combination with micronutrients. The need for fertilisation with micronutrients arises from the decreasing use of mineral fertilisers and manure, which is a source of mineral nutrients (ADAMIAK et al. 2002). Foliar fertilisation with micronutrients is one of the most important methods of application of fertilisers in agricultural practice with the aim of increasing the concentration of mineral nutrients in grain (MALAKOUTI 2008, KNAPOWSKI et al. 2010, BOORBOORI et al. 2012, WOJTKOWIAK et al. 2015). According to RAWASHDEH and FLORIN (2015), the foliar application of nutrients facilitates their easy and quick absorption by penetrating the stomata or leaf cuticle and entering the cells. The spraying of micronutrients has led to the improving root growth of wheat and increased macro and micronutrient uptake (BAMERI et al. 2012).

The aim of the study was to determine the yield and its components and selected minerals (N, P, K, Ca, Mg, Na) in winter triticale grain as affected by foliar fertilisation with micronutrients, either used individually or in combination.

Materials and Methods

The field experiment was conducted at the Research and Education Centre of the University of Warmia and Mazury in Tomaszkowo (53°72 N; 20°42 E) in the years 2012–2013 on podzolic soil with the granulometric composition typical of medium silty clay (*Klasyfikacja uziarnienia gleb...* 2008). The granulometric composition, pH, content of $C_{org.}$, $N_{og.}$, P, K Cu, Zn, Mn and Fe were determined in soil samples taken before the experiment was set up, according to commonly applied methods. The experiment was set up by the method of random blocks in 3 replications. The major characteristics of the soil were presented in Table 1. The area of the plot for sowing was 6.25 m^2, and for harvesting – 4.0 m^2. Winter triticale of the Dinaro cultivar was sown after winter triticale at 194 kg ha^{-1} in 2011 and 203 kg ha^{-1} in 2012, density of 550 plants per m^2.

The following micronutrient fertilisation options were examined in the experiment:

– “NPK” (control) – Nitrogen was applied to all the plots at the dose of 90.0 kg ha^{-1}; the amount was divided in the following way: applied to soil – 54.0 kg ha^{-1} (urea 46%), during the tillering phase (BBCH 22–23) and foliarly

Table 1

Physical and chemical soil properties before the experiment started (average 2011–2012)

Measured parameters		Corresponding values
Granulometric composition		loam
pH in 1 mol/L KCl		4.95
Total organic C [g kg^{-1} DM]		7.9
Total N [g kg^{-1} DM]		1.01
Available nutrients [mg kg^{-1}]	P	64.1
	K	187
	Mg	75
	Cu	3.2
	Fe	1900
	Zn	7.5
	Mn	202

– 36.0 kg N ha^{-1} (10% solution of urea) during the shooting phase (BBCH 30–31), triple superphosphate (46%) at the dose equivalent to 30,2 kg P ha^{-1}, and potassium salt (56%) at the dose of 83,1 kg K ha^{-1}, as pre-plant application;

– "NPK + Cu" – Mineral fertilisation as in the "NPK" option + foliar application of 0.2 kg Cu ha^{-1} (1% solution of $CuSO_4$);

– "NPK + Zn" – Mineral fertilisation as in the "NPK" option + foliar application of 0.2 kg Zn ha^{-1} (1% solution of $ZnSO_4$);

– "NPK + Mn" – Mineral fertilisation as in the "NPK" option + foliar application of 0.2 kg Mn ha^{-1} (0,5% solution of $MnSO_4$);

– "NPK + Cu, Zn, Mn" – Mineral fertilisation as in the "NPK" option + foliar application of: 0.2 kg Cu ha^{-1}; 0.2 kg Zn ha^{-1}; 0.2 kg Mn ha^{-1}.

Cu, Zn and Mn (individually or in combination) were applied foliarly as aqueous solutions during the shooting phase (BBCH 30–31).

The temperature and amount of rainfall was monitored during the field experiment (Table 2). The average monthly air temperature during the triticale vegetation period were similar and they did not deviate from the multi-year average. The total rainfall in September 2011 was higher by 21.8 mm than 2012 year and by 10.6 mm than the multi-year average. The total rainfall in October and November 2011 was lower by 39.0 and 31.1 mm compared to 2012 and by 13.1 and 30.7 mm compared to the multi-year average. The total rainfall more than twice higher than the multi-year average recorded in April 2012. The total rainfall at the beginning of the tillering stage (May) during the years of study was similar. The total rainfall in June 2012 was much higher than the total rainfall in the subsequent year (2013). The rainfall in July 2012 and 2013 was similar, but it was 39% higher than the multi-year average.

Table 2

Weather conditions in 2011–2013 and the multi-year average of 1981–2010

Year	Month												
	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX–VIII
Temperature [°C]													average
2011–2012	14.1	8.3	3.1	2.3	-1.7	-7.5	3.0	7.8	13.4	15.0	19.0	17.7	7.9
2012–2013	13.5	7.4	4.9	-3.5	-4.6	-1.1	-3.5	5.9	14.8	17.5	18.0	17.4	7.2
1981–2010	12.8	8.0	2.9	-0.9	-2.4	-1.7	1.8	7.7	13.5	16.1	18.7	17.9	7.9
Precipitation [mm]													sum
2011–2012	67.5	29.5	14.1	25.8	61.8	27.7	24.1	73.1	51.7	103.2	121.0	45.1	644.6
2012–2013	45.7	68.5	45.2	11.8	44.1	22.6	18.1	28.5	54.5	61.2	121.9	37.6	559.7
1981–2010	56.9	42.6	44.8	38.2	36.4	24.2	32.9	33.3	58.5	80.4	74.2	59.4	581.8

Agrotechnical practices included skimming done as soon as the forecrop had been harvested. Post-harvest remnants were covered by pre-sow ploughing and harrowing before winter triticale was sown. A cultivation and sowing unit was used immediately before sowing in order to mix the mineral fertilisers and to prepare the soil for sowing. Weeds were destroyed using herbicides in 2012 (BBCH 21–29) – Mustang Forte 195 SE (a.i. florasulam 5 g, aminopyralid 10 g, 2.4 D 180 g) in dose of 1.0 dm^{-3} ha^{-1} and Puma Universal 069 WG (a.i. fenoxaprop-P-ethyl 69.0 g) in dose of 1.2 dm^{-3} ha^{-1}. In 2013 – were used (BBCH 21–29) Atlantis 12 OD (a.i. iodosulfuron methyl sodium 2 g; mesosulfuron methyl 10 g) in dose of 0.45 dm^{-3} ha^{-1} + Sekator 125 OD (a.i.: iodosulfuron methyl sodium 25 g, amidosulfuron 100 g) in dose of 0.15 dm^{-3} ha^{-1}. Protection against pests and diseases was not performed.

The grain was harvested during the maturation phase (BBCH 89–92) with a plot harvester. Samples of grain from individual years were analysed in the laboratory; the following were determined: N by the Kjeldahl method, Ca, Mg, K and Na by atomic absorption spectrometry (flame technique) and phosphorus by the vanadium-molybdenum method in material mineralised earlier with H_2SO_4 with H_2O_2 as an oxidiser.

The results were processed with STATISTICA 10.0 software (StatSoft, Tulsa, Oklahoma, USA). The statistical calculations were performed with two-way ANOVA. Apart from the basic parameters, standard deviation and statistically homogeneous groups were determined using Tukey's test at α = 0.05. Coefficients of linear correlation (Pearson's r) were calculated.

Results and Discussion

The yield of winter triticale ranged from 5.53 t ha^{-1} to 8.73 t ha^{-1} and the yield of straw – from 6.00 t ha^{-1} to 7.50 t ha^{-1}. This is more (by 3.50 and 3.34 t ha^{-1}, respectively) than the average yield obtained in agricultural practice in Poland and worldwide (FAO 2014) – Table 3. Fertilisation with NPK with Zn application contributed to an increase (not statistically) by 1.8% of the yield compared to the NPK fertilisers. Other fertilization treatments of micronutrients did not differ significantly from the control of NPK fertilization.

Table 3

Grain, straw yield and yield components of winter triticale

Year	Fertilisation treatments				
	NPK	NPK + Cu	NPK + Zn	NPK + Mn	NPK + Cu + Zn + Mn
Grain yield [t ha^{-1}]					
2012	5.82^{b} ± 0.08	5.63^{b} ± 0.26	5.93^{b} ± 0.45	6.02^{b} ± 0.49	5.53^{b} ± 0.33
2013	8.52^{a} ± 0.46	8.73^{a} ± 0.29	8.67^{a} ± 0.61	8.45^{a} ± 0.63	8.18^{a} ± 0.33
Ave.	7.17A^{B} ± 1.51	7.18A^{B} ± 1.72	7.30^{A} ±1.57	7.23^{A} ± 1.42	6.86^{AB} ± 1.48
Straw yield [t ha^{-1}]					
2012	7.00^{a} ± 0.50	6.92^{a} ± 0.38	7.17^{a} ± 1.38	7.50^{a} ± 0.25	6.92^{a} ± 0.80
2013	6.00^{a} ± 0.66	6.50^{a} ± 0.25	6.58^{a} ± 0.52	6.25^{a} ± 0.50	6.42^{a} ± 0.14
Ave.	6.50^{A} ± 0.76	6.71^{A} ± 0.37	6.87^{A} ± 0.98	6.88^{A} ± 0.77	6.67^{A} ± 0.58
Ear length [mm]					
2012	99.0^{a} ± 6.73	90.9^{ab} ± 2.38	91.4^{ab} ± 3.45	87.8^{ab} ± 4.69	93.5^{ab} ± 1.99
2013	81.8^{b} ± 1.08	87.4^{ab} ± 5.61	82.5^{b} ± 1.58	86.3^{ab} ± 8.62	81.9^{b} ± 3.25
Ave.	90.4^{A} ± 10.4	89.2^{A} ± 4.30	87.0^{AB} ± 5.43	87.1^{AB} ± 6.26	87.7^{AB} ± 6.83
Number of grains per ear					
2012	45.4^{a} ± 5.97	43.9^{a} ± 3.32	41.1^{a} ± 2.11	41.6^{a} ± 1.51	41.0^{a} ± 1.53
2013	39.2^{a} ± 0.42	43.5^{a} ± 4.60	39.1^{a} ± 2.22	41.5^{a} ± 5.70	38.9^{a} ± 4.24
Ave.	42.3^{AB} ± 5.11	43.7^{A} ± 3.60	40.1^{B} ± 2.21	41.6^{B} ± 3.73	39.9^{B} ± 3.07
Mass of grains per ear [g]					
2012	1.38^{a} ± 0.14	1.29^{ab} ± 0.24	1.17^{a} ± 0.08	1.25^{a} ± 0.01	1.23^{a} ± 0.12
2013	1.21^{a} ± 0.09	1.38^{a} ± 0.12	1.21^{a} ± 0.09	1.26^{a} ± 0.31	1.15^{a} ± 0.06
Ave.	1.30^{A} ± 0.14	1.33^{A} ± 0.18	1.19^{A} ± 0.08	1.25^{A} ± 0.20	1.19^{A} ± 0.09
Mass of 1.000 grains [g]					
2012	31.5^{bc} ± 1.56	31.0^{c} ± 0.91	31.2^{bc} ± 0.80	32.3^{abc} ± 1.05	31.1^{bc} ± 0.95
2013	33.3^{abc} ± 0.92	34.3^{a} ± 0.39	33.5^{abc} ± 0.20	32.7^{abc} ± 0.09	33.6^{ab} ± 0.92
Ave.	32.4^{A} ± 1.53	32.7^{A} ± 1.90	32.3^{A} ± 1.34	32.5^{A} ± 0.71^{A}	*32.4*^{A} ± 1.61

Ave.: average, ± standard deviation

a,b ... *A,B* ... Averages in rows followed by the same letter are insignificant (α < 0.05)

According to WOJTKOWIAK et al. (2015), foliar application of $CO(NH_2)_2$in combination with a multi-component fertiliser (Ecolist), which contains both macro-nutrients and a set of micro-nutrients, contributed to an increase in the yield of spring triticale cultivated in the same conditions. They attribute great importance to the micronutrients present in multi-component fertilisers, which take part in fixing nitrogen, thereby contributing to achieving the maximum grain yield.

According to the results of the statistical analysis, the year of study has a significant effect on the yield in all the fertilisation options under study, where the yield increased by 40.4% (NPK + Mn) to 55.1% (NPK + Cu) in 2013. Such differences may have been caused by the total rainfall and its distribution, as confirmed by studies of KALBARCZYK (2010), BRZOZOWSKA and BRZOZOWSKI (2011), ESTRADA-CAMPUZANO et al. (2012) and BRZOZOWSKA et al. (2016). Excessive rainfall, especially during the period of intensive growth and development of triticale in 2012 (73 mm in April, including 32 mm in the second 10-day period of April, 42.6 mm in the second 10-day period of May and 103 mm in June, including 50.9 mm in the third 10-day period) resulted in an increase in the vegetative mass (straw yield) and a decrease in the grain yield.

The application of NPK fertilisers enriched with micro-nutrients applied foliarly in this study did not have a significant effect on the structural features of the triticale yield. According to BAMERI et al. (2012), the negative response to foliar application of (Zn + Fe + Mn) on wheat growth may be attributed to micronutrient uptake problems and antagonistic effect among Fe, Zn and Mn in their combination. The years of study affected some elements of the yield structure. The longest ear was achieved in the first year of study (2012), when mineral fertilisation (NPK) alone was applied. The mass of 1.000 grains increased by 10.6% following application of NPK + Cu in 2013 (compared to 2012). According to JASKULSKI and PIASECKA (2007), the yield of winter triticale depends much more on variable habitat conditions than on the forecrop. According to SPYCHAJ-FABISIAK et al. (2005) and ALARU et al. (2009), a high yield of triticale grain and protein content can be achieved as a result of nitrogen application at 90–120 kg ha^{-1}.

JANUŠAUSKAIT (2014) claims that variable weather conditions affect the effectiveness of nitrogen fertilisation, thereby diversifying the number of ears (from 72.6% to 83.5%), kernels per ear (from 46.6% to 94%.) and mass of 1.000 grains (from 84.5% to 92.7%). The findings of a study conducted by ZEIDAN et al. (2010) indicate that spraying plants with Fe, Mn and Zn results in increased yield of grain, straw, TKW, number of kernels per ear and protein content in grain. Foliar application of micronutrients (Fe=1%, Mn=2%, Zn=2%, Cu=1%, B=1%) at different growth stages of wheat increased plant height, grains per spike, mass of 1.000 grains, biological yield, harvest index, straw and grain yield (KHAN et al. 2010).

Table 4

Content of macronutrients in the grain of winter triticale [g kg^{-1} DM]

Year	Fertilisation treatments				
	NPK	NPK + Cu	NPK + Zn	NPK + Mn	NPK + Cu + Zn + Mn
N					
2012	18.09^{c} ± 0.17	17.16^{d} ± 0.02	17.97^{c} ± 0.27	17.97^{c} ± 0.36	17.86^{c} ± 0.10
2013	20.06^{a} ± 0.36	19.65^{ab} ± 0.17	19.36^{b} ± 0.20	19.88^{ab} ± 0.10	19.83^{ab} ± 0.17
Ave.	19.07^{A} ± 1.11	18.41^{C} ± 1.38	18.67^{BC} ± 0.79	18.93^{AB} ± 1.07	18.84^{AB} ± 1.08
P					
2012	1.70^{d} ± 0.06	1.62^{d} ± 0.040	1.61^{d} ± 0.02	2.30^{c} ± 0.04	2.40^{c} ± 0.06
2013	2.70^{b} ± 0.05	2.70^{b} ± 0.030	3.30^{a} ± 0.10	2.70^{b} ± 0.05	2.30^{c} ± 0.03
Ave.	2.20^{C} ± 0.54	2.16^{C} ± 0.59	2.45^{A} ± 0.93	2.50^{A} ± 0.22	2.35^{B} ± 0.07
K					
2012	4.25^{a} ± 0.06	1.46^{f} ± 0.03	1.29^{g} ± 0.05	1.32^{g} ± 0.03	1.27^{g} ± 0.09
2013	4.16^{ab} ± 0.09	4.08^{bc} ± 0.06	4.00^{c} ± 0.03	3.21^{e} ± 0.03	3.84^{d} ± 0.039
Ave.	4.21^{A} ± 0.08	2.77^{B} ± 0.14	2.64^{C} ± 0.15	2.27^{E} ± 0.10	2.55^{D} ± 0.14
Mg					
2012	0.90^{a} ± 0.01	0.90^{a} ± 0.20	0.97^{a} ± 0.16	1.10^{a} ± 0.10	0.67^{a} ± 0.49
2013	1.07^{a} ± 0.21	0.93^{a} ± 0.06	1.03^{a} ± 0.46	1.10^{a} ± 0.20	1.17^{a} ± 0.15
Ave.	1.00^{a} ± 0.17	0.92^{a} ± 0.13	1.00^{a} ± 0.03	1.10^{a} ± 0.14	0.92^{a} ± 0.04
Ca					
2012	2.26^{b} ± 0.14	2.14^{b} ± 0.21	2.28^{b} ± 0.11	2.29^{b} ± 0.20	2.38^{b} ± 0.32
2013	2.66^{ab} ± 0.26	3.16^{a} ± 0.27	2.47*b* ± 0.19	2.47^{b} ± 0.15	2.42^{b} ± 0.19
Ave.	2.46^{a} ± 0.29	2.65^{a} ± 0.60	2.38^{a} ± 0.17	2.38^{a} ± 0.19	2.40^{a} ± 0.24
Na					
2012	0.768^{b} ± 0.007	0.984^{a} ± 0.001	0.656^{c} ± 0.015	0.625^{c} ± 0.015	0.522^{d} ± 0.002
2013	0.404^{e} ± 0.002	0.238^{f} ± 0.000*	0.178^{g} ± 0.001	0.194^{g} ± 0.001	0.194^{g} ± 0.002
Ave.	0.586^{B} ± 0.006	0.611^{A} ± 0.002	0.417^{C} ± 0.092	0.409^{C} ±0.092	0.358^{D} ± 0.026

Ave.: average, ± standard deviation

a,b ... *A,B* ... Averages in rows followed by the same letter are insignificant ($\alpha < 0.05$)

0.000* – value bellow 0.000

According to MAKARSKA et al. (2010), the level of minerals depends on the genotypes of parent forms. STANKOWSKI et al. (2015) pointed to the high stability of macro-nutrient content in grain of triticale caused by nitrogen fertilisation. According to NOGALSKA et al. (2012), single- and multi-component fertilisers affected the mineral composition of grain and straw of spring triticale in a similar manner. Mineral fertilisers, applied in combination with micronutrients or micronutrient fertilisers, increase the yield, but they also increase the mineral content in triticale grain (MALAKOUTI 2008, KHAN et al.

2010, KNAPOWSKI et al. 2010). According to WOJTKOWIAK et al. (2014) habitat conditions in the years of study diversified the macro-nutrient content.

This study revealed a diverse effect of mineral fertilisation (NPK) without, and in combination with, micronutrients on the content of selected macronutrients in grains of winter triticale of the Dinaro cultivar (Table 4). BAMERI et al. (2012) reported that root growth in wheat was improved by spraying micronutrients, which led to an increase in the uptake of macro and micronutrients. BOORBOORI et al. (2012) found that the content of proteins and components of barley yield increased following foliar spraying with micronutrients. Supplementation of fertilisation with micronutrients applied individually or in combination reduced the content of nitrogen in grain. This may have been caused by a low level of potassium in grain of the cultivar in question, which can be a sign of nitrogen metabolism disorders (MAATHUIS 2009). In effect, this results in reduction of the amount of protein produced by the plant regardless of micronutrient fertilisation. A significant increase in the content of N was caused by supplementation with Cu and Zn (by 3.5% and 2.1%, respectively). A higher content of N in kernels harvested in 2013 was determined at all the plots. A statistical analysis confirmed that the nitrogen content in grain increased from 7.7% (after additional spraying with zinc) to 10.6% (at a plot fertilised with Mn) in the second year of the study. In a study conducted by WARECHOWSKA (2004a, 2004b) and WARECHOWSKA et al. (2004), foliar application of Mn, Zn and Cu significantly increased the content of protein proper in grain of spring triticale of the Maja cultivar compared with plants which were fertilised with nitrogen alone. In presented study additional foliar application of micronutrients (Zn, Mn and Cu + Zn + Mn) resulted in an increase in the content of phosphorus (by 11.4%, 13.6% and 6.8%, respectively). The phosphorus content was found to be higher in all the plots in 2013 (by 43.2% on average). The content of potassium in triticale grain ranged from 1.27 to 4.25 g kg^{-1}. Additional spraying with micronutrients considerably reduced potassium content in triticale grain. No external signs of a deficit of the element were observed during the vegetation period. Supplementation of the basic NPK fertilisation with micronutrients resulted in a multi-fold increase in potassium content in grain in the second year of the study (2013) compared to the first year (2012). A considerable decrease in potassium content may be attributed to several processes associated with an antagonistic relationships, both in soil and in the plant itself. This especially applies to the interaction of K with Ca, Mg, Na ions (MAATHUIS 2009), as well as micronutrients, such as Zn and Cu (MALVI 2011). Additional fertilisation with micronutrients did not change significantly the content of Ca and Mg in triticale grain. The content of Ca increased by 47.7% in 2013 following supplementation with Cu. A study conducted by WOJTKOWIAK and DOMSKA (2009) also showed that additional application of copper, zinc and manganese fertilisers did not cause any significant difference in the accumulation of phosphorus and calcium and, in most cases, potassium in grain of triticale of the Gabo cultivar. The additional application of Cu resulted in an increase in Na content in triticale grain by 4.3%. Supplementation of fertilisation with micronutrients (Zn, Mn and Cu + Zn + Mn) in the other plots reduced the content of Na. Grain obtained in the first year of the study (2012) contained much higher levels of sodium. MOOSAVI and RONAGHI (2011) reported that the high applications of essential nutrients like Fe and Mn decreased absorption of other nutrients by roots or transportation from roots to plant shoot.

The results of a statistical analysis expressed by Pearson's correlation coefficient (r) showed a positive correlation between the content of N, Na and P in grain and grain yield and mass of 1.000 grains (Table 5). Particularly noteworthy is the strong correlation between the content of N and P and the grain yield (r = 0.895 and r = 0.804, respectively) and mass of 1.000 grains (r = 0.735, r = 0.661, respectively). It was found in a study conducted by BRZOZOWSKA et al. (2016) that there was a significant negative correlation between the content of phosphorus and nitrogen in grain and grain yield of winter triticale, which confirms the findings of BOY and FOSSATI (1995). The high yield of grain obtained in their study was connected with low concentrations of minerals, such as N, P, K, Mg, Fe, Mn, Zn and Cu, and a high concentration of Ca. This shows that production oriented towards obtaining high yield may lead to a decrease in the nutritional value of triticale grain. Unlike in the case of N, Ca and P, the content of K and N in grain in this study was negatively correlated with the grain yield (r = -0.606, r = -0.866, respectively) and the thousand kernel weight (r = -0.373, r = -0.728, respectively). A positive correlation was observed between the straw yield and the ear length and the potassium content (r = 0.513, r = 0.405, respectively) and sodium content (r = 0.461, r = 0.432) in triticale grain.

Table 5

Correlations between content of macronutrients and grain, straw yield and yield components (average 2012–2013)

Specifications	N	P	K	Mg	Ca	Na
Grain yield	0.895	0.804	–0.606	n.s.	0.520	–0.866
Straw yield	–0.546	–0.395	0.513	–0.369	–0.433	0.461
Ear length	–0.371	–0.454	0.405	n.s	–0.367	0.432
Number of grains per ear	n.s.	n.s.	n.s	n.s.	n.s	n.s.
Mass of grains per ear	n.s.	n.s.	n.s	n.s.	n.s	n.s.
Mass of 1.000 grains	0.735	0.661	–0.373	n.s.	0.513	–0.728

Conclusion

1. NPK fertilization with the addition of Zn significantly increased the grain yield of winter triticale. The other micronutrients did not affect the increase in grain yield.

2. Regardless of the year of study, supplementation of NPK fertilisation with Cu resulted in an increase in the N and Na content in triticale grain. Application of Zn and Mn and the micronutrients in combination (Cu + Zn + Mn) resulted in an increase in phosphorus content. Micronutrients applied individually and in combination affected the content of potassium in triticale grain. Foliar application of Cu + Zn + Mn stabilised the phosphorus content in grain in variable weather conditions.

3. The year of the study affected the length of an ear at the plot fertilised with NPK fertiliser as well as the mass of 1.000 grains and Ca content in grain the NPK + Cu option. The weather conditions differentiated the grain yield and the content of N and Na in all the fertilisation options.

4. Pearson's correlation coefficient (r) showed a positive correlation between the content of N, Na and P in grain and the grain yield and mass of 1,000 grains The content of K and N in grain was negatively correlated with the grain yield and the thousand kernel weight. A positive correlation was observed between the straw yield and the ear length and the potassium and sodium content in triticale grain.

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