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CONTENT OF COPPER, IRON, MANGANESE AND ZINC IN TYPICAL LIGHT BROWN SOIL AND SPRING TRITICALE GRAIN DEPENDING ON A FERTILIZATION SYSTEM

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Abstract

The impact of mineral fertilization with or without multi-component fertilizers on the content of microelements in soil and spring triticale grains was investigated in field trials, in 2009-2011. The experiment was carried out on 8 fertilizing treatments with three replications, which included two varieties of spring triticale: Andrus and Milewo. The content of available zinc and manganese was higher on plots cropped with the cultivar Andrus and nitrogen fertilization with urea or with urea and ammonium nitrate. It was also found out that the content of available manganese, zinc and iron in the analyzed soils was within the natural average range. A higher content of manganese and zinc in grains was detected after the application of multi-component fertilizers. Nitrogen fertilization at a dose of 120 $kg \cdot ha^{-1}$ together with Azofoska and Ekolist resulted in an increase in the iron content in cv. Andrus. The regression analysis between the content of the analyzed microelements in soil and in triticale grains revealed a significant increase in the iron, manganese and zinc content in grains together with an increase in the content of these elements in soil under cv. Milewo. With respect to the zinc content in soil and in grain from this variety, the coefficient of determination was the closest to the coefficient of a linear correlation ($R^2 = 0.9105$). It was shown that an increase in the content of microelements in soil was not always accompanied by an increase in the content of these elements in spring triticale grains.

Key words: spring triticale, fertilization, microelements.

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ZAWARTOŚĆ MIEDZI, ŻELAZA MANGANU I CYNKU W TYPOWEJ LEKKIEJ GLEBIE BRUNATNEJ I W ZIARNIE PSZENŻYTA JAREGO W ZALEŻNOŚCI OD SYSTEMU NAWOŻENIA

Abstrakt

W latach 2009-2011 w doświadczeniu polowym badano wpływ nawożenia NPK stosowanego bez nawozów wieloskładnikowych lub łącznie z nimi na zawartość mikroelementów w glebie i ziarnie pszenżyta jarego. Doświadczenie obejmowało 8 obiektów nawozowych w 3 powtórzeniach z uwzględnieniem 2 odmian pszenżyta jarego: Andrus i Milewo. Stwierdzono, że gleba zawierała więcej przyswajalnego cynku i manganu w przypadku nawożenia azotem w formie mocznika lub mocznika i saletry amonowej w uprawie odmiany Andrus. Stwierdzono ponadto, że zasobność badanych gleb w przyswajalny mangan, cynk i żelazo kształtowała się w granicach ich zasobności na poziomie średnim. W ziarnie zaobserwowano przede wszystkim większe nagromadzenie manganu i cynku po zastosowania nawozów wieloskładnikowych. Nawożenie azotem w dawce 120 kg ha^{-1} łącznie z azofoską i ekolistem przyczyniło się również do zwiększenia zawartości żelaza w ziarnie odmiany Andrus. Analiza regresji między zawartością badanych mikroelementów wykazała istotny wzrost zawartości żelaza, manganu i cynku w ziarnie w miarę zwiększania się zasobności gleby w uprawie pszenżyta jarego odmiany Milewo. W przypadku zawartości cynku w glebie i w ziarnie tej odmiany, współczynnik determinacji był najbliższy współczynnikowi korelacji liniowej (R^2 = 0,9105). Wykazano, że wraz ze zwiększeniem się zawartości mikroelementów w glebie nie zawsze następował wzrost zawartości tych składników w ziarnie pszenżyta jarego.

Słowa kluczowe: pszenżyto jare, nawożenie, mikroelementy.

INTRODUCTION

Our interest in the content of microelements in the environment is driven mainly by the wish to attain an appropriate quality of soil and agricultural produce. As a life-sustaining habitat, soil plays the principal role in the growth of plants, but it also influences the development of humans and animals. Any excess or deficit of microelements has a negative impact on the physiological processes in plants (Grzyś 2004, Spiak 2000). Iron, zinc, copper and manganese are regarded to be as essential elements in nutrition (Knapowski et al. 2009). In the body, they activate numerous enzymes responsible for the metabolism of cells (Grzyś 2004, Knapowski et al. 2010).

In Poland, the natural concentration of microelements in soil is highly diverse within provinces and regions (Dąbkowska-Naskręt et al. 2006, Lipnicki 2009). The current level of soil abundance indicates a high share of areas with low copper concentrations (Lipnicki 2009). The content of other elements is on a moderate level. Numerous studies have shown that the phytoabsorption in soil and grains is conditioned by many factors, such as soil reaction, abundance of nutrients, absorbable forms of elements, fertilization, species and varieties of plants (Kalembasa et al. 2009, Diatta 2008, Diatta, Grzebisz 2006, Jakubus 2006, Ścigalska et al. 2000). The levels of microelements in plants are indirectly influenced by a dose and method of fertilization with other components, particularly with nitrogen (Diatta, Grzebisz 2006, Sienkiewicz et al. 2009, Wei et al. 2006). Intensive agronomic technologies involved in the cultivation of high-yielding plants, which have high nutritional and fertilizing demands, as well as the target increase in crop yields have led to the depletion of these microelements in soils.

Foliar fertilization is the most popular way to supply microelements in plant production. Simultaneous application of essential elements and microelements produces grain crops with the quality characteristics which enhance their value as food and feeds (Sztuder 2009). Direct feeding of plants by spraying is faster and more effective than absorption of nutrients from soil (Wójcik 2004). This method of plant nourishment is particularly suitable when soils are deficient in microelements and during the phases of intensive growth of plants. It is also necessary to supply microelements in doses appropriate for plants and sustainable for the environment.

The content of microelements in grain is a quality descriptor applied in the context of its value for human and animal consumption. It contributes to the composition of a daily nutritional ration (Knapowski et al. 2009).

In Poland, the rising interest in foliar fertilization with microelements is encouraged by the high percentage of light acid soils with a low and average content of absorbable forms, and by the low concentration of these elements in plants. Cereals are among the plants most sensitive to deficiencies of microelements. However, rational fertilization may replenish the loss of these elements in soil.

The aim of this study was to determine to what degree soil and foliar fertilization with multi-component fertilizers influences the content of zinc, manganese, copper and iron in soil and their content in spring triticale grain.

MATERIAL AND METHODS

In 2009-2011, a field trial was carried out at the Teaching and Research Centre of the UWM in Tomaszkowo. The experiment was set up on typical brown soil with the texture of light clay class III b with the silt subsoil. The soil was acidic, with a low content of organic carbon (C_{org} 7.71 g kg^{-1}), an average content of available zinc, manganese and iron and a low copper content (Table 1).

The experiment was set up in randomized blocks with 3 replications. The size of a single plot was 6.25 m^2, of which 4.0 m^2 were harvested. Spring

Table 1

The content of C_{org}, Cu, Fe, Mn and Zn in the soil before the experiment

pH KCl	$C_{org.}$ (g kg^{-1})	Content of available microelements (mg kg^{-1} in d.m.)							
		Cu		Fe		Mn		Zn	
		actual	wealth	actual	wealth	actual	wealth	actual	wealth
5.0	7.71	2.1	low	1100	mean	182	mean	14.5	mean

triticale was sown in the following densities: cv. Andrus 282.1 kg ha^{-1} and cv. Milewo 237.9 kg ha^{-1}. Both varieties sown in rows spaced 10.5 cm from one another. Winter triticale was the preceding crop in both cases. In all the experimental objects, fertilization with phosphorus and potassium was identical. A dose of 30.2 kg·ha^{-1} of phosphorus (P) in the form of 46% triple superphosphate and 83.1 kg ha^{-1} of potassium (K) in the form of potassium salt were used. Nitrogen fertilization and the supplementation of basic fertilization were applied according to the scheme (Table 2).

Table 2

Scheme of the field experiment

Treatment	Total N fertilization (kg N ha^{-1})	Fertilizer type and application time (kg ha^{-1} dose)		
		before sowing	tillering stage [BBCH 23-29]	stem elongation stage [BBCH 31-32]
1	80	-	urea (40)	urea (40)
2	80	-	urea (20) Azofoska (20)	urea (40)
3	80	-	urea (40)	urea 40*
4	80	-	urea (40)	ammonium nitrate (32) + ekolist* (8)
5	120	ammonium nitrate (40)	urea (40)	urea (40)
6	120	ammonium nitrate (40)	urea (40) zofoska (20)	urea (40)
7	120	ammonium nitrate (40)	urea (40)	urea (40)*
8	120	ammonium nitrate (40)	urea (40)	ammonium nitrate (32) + ekolist*(8)

*foliar fertilization

Two recommended multi-component fertilizers containing basic essential elements and the composition of selected microelements were used in the experiment (Table 3).

Table 3

Composition of the applied multi-component fertilizers

Type of multi-component fertilizer	N	P	K	Mg	S	Cu	Zn	Mn	Fe	Mo	B
Ekolist (g dm^{-3})	120.0	-	65.0	20	5	5.00	2.50	0.50	1.00	0.02	5.00
Azofoska (%)	13.6	1.83	15.9	2.71	9.2	0.18	0.045	0.27	0.17	0.04	0.045

The agronomic technologies applied to spring triticale were carried out as required.

The meteorological conditions, i.e. rainfalls, presented as the annual averages for the years when the experiment was conducted, differed from the values measured in the previous years (Table 4). The precipitation in April was less than half the average value for the previous years. In May, June and July the average precipitation was higher by 51.4, 28.8 and 46.7%, respectively, than the means from the previous years.

Table 4

Meteorological conditions in the investigadet period

Month / Period	April	May	June	July	August	Average Apr-Aug
Temperature (°C)						
2009-2011	8.9	12.5	16.1	19.4	18.2	15.0
1961-2005	6.9	12.8	15.9	17.8	17.7	14.2
Precipitation (mm)						
2009-2011	15.2	78.6	101.1	110.2	65.6	74.1
1961-2005	35.7	51.9	78.5	75.1	66.1	61.5

The soil sampled after harvest was dried, ground in a china mortar and passed through a sieve with 1mm mesh. The soil reaction (pH) was determined by the potentiometer method in 1 M KCl dm^{-3}. The microelements soluble in 1M HCl dm^{-3} were extracted at a chemical agricultural station, according to the total method, i.e. by shaking a soil sample with hydrochloric acid at the 1:10 ratio for 1 hour (Gembarzewski, Korzeniowska 1996)

The samples of grains were ground in a WŻ-1 laboratory-type mill and then mineralized in a heated mixture of HNO_3 and $HClO_4$ acids in the 3:1 ratio.

After soil extraction and grain mineralization, the content of Cu, Zn, Mn and Fe was determined in the solutions using the flame technique on an atomic absorption spectrometer.

The statistical calculations were performed according to a two-way analysis of variance, which was consistent with the experimental mathematical model, i.e. randomized blocks. Apart from basic statistical parameters, statistically homogenous groups were determined with the Tukey's range test at $\alpha = 0.05$. The relationships between the content of microelements in soil and their content in grains were also investigated. All statistical analyses and calculations were performed with MS Office Excel and Statistica software.

RESULTS AND DISCUSSION

The pH values (in KCl solution of a concentration 1 M) of the tested soil samples collected after the harvest of spring triticale were within the range of 4.75 and 5.04 for cv. Andrus and from 4.79 to 4.96 for cv. Milewo (Table 5). Under the experimental conditions, i.e. with small differences in pH values, the soil reaction did not influence the concentration of microelements, as reported by Diatta (2008) and Wei et al. (2006).

Table 5

Absorbable content of Cu, Fe, Mn and Zn in soil (the average in 2009-2011)

Variety	Object	pH	Cu	Fe	Mn	Zn
			(mg kg^{-1} of d.m.)			
Andrus	1	4.83 ± 0.24^{ab}	2.1 ± 0.18^{a}	1200 ± 156^{ab}	158 ± 18.9^{abc}	12.1 ± 1.81^{ab}
	2	4.88 ± 0,34^{bc}	2.3 ± 0.27^{a}	1300 ± 118^{b}	153 ± 16.8^{ab}	12.2 ± 1.58^{ab}
	3	5.04 ± 0.50^{d}	1.9 ± 0.17^{a}	1100 ± 132^{ab}	177 ± 26.5^{d}	13.8 ± 1.10^{e}
	4	4.87 ± 0.58^{bc}	1.9 ± 0.26^{a}	1300 ± 182^{b}	150 ± 13.5^{a}	12.8 ± 2.17^{bcd}
	5	4.94 ± 0.20^{c}	1.9 ± 0.21^{b}	1200 ± 132^{ab}	161 ± 22.5^{abc}	12.6 ± 1.38^{abc}
	6	4.75 ± 0.28^{a}	2.0 ± 0.12^{a}	1110± 165^{ab}	165 ± 14.8^{bcd}	11.9 ± 2.02^{a}
	7	4.94 ± 0.39^{c}	2.1 ± 0.27^{a}	1150 ± 113^{ab}	169 ± 27.4^{cd}	13.5 ± 1.62^{de}
	8	4.95 ± 0.59^{cd}	2.2 ± 0.24^{a}	1060 ± 94^{a}	167 ± 18.4^{cd}	13.2 ± 1.18^{cde}
Milewo	1	4.91± 0.43^{bc}	1.9 ± 0.19^{a}	1200 ± 144^{a}	151 ± 19.6^{a}	12.2 ± 1.83^{a}
	2	4.82± 0.59^{ab}	2.1 ± 0.18^{a}	1100 ± 143^{a}	162 ± 22.7^{bc}	12.2 ± 1.34^{a}
	3	4.96± 0.34^{c}	2.3 ± 0.25^{a}	1000 ± 140^{a}	158 ± 19.0^{ab}	12.9 ± 0.91^{ab}
	4	4.83± 0.58^{ab}	2.3 ± 0.32^{a}	1200 ±108^{a}	163 ± 22.8^{bc}	12.2 ± 1.58^{a}
	5	4.79± 0.95^{a}	2.2± 0.26^{a}	1200 ± 204^{a}	165 ±14.8^{bcd}	13.5 ± 1.48^{ab}
	6	4.83± 0.19^{ab}	1.9 ± 0.28^{a}	1050 ± 136^{a}	172 ± 10.3^{d}	14.0 ± 1.12^{b}
	7	4.79± 0.48^{ab}	2.1 ± 0.27^{a}	1300 ± 182^{a}	165 ± 21.4^{bcd}	13.5 ± 2.16^{ab}
	8	4.96± 0.35^{c}	2.3 ± 0.41^{a}	1150 ± 138^{a}	168 ± 23.5^{cd}	13.4 ± 1.85^{ab}
Average for varieties						
Andrus		4.90± 0.64^{b}	2. 0± 0.32^{a}	1178 ± 153^{a}	163 ± 21.2^{a}	12.8 ± 2.18^{a}
Milewo		4.86± 0.68^{a}	2.2 ± 0.24^{a}	1150 ± 184^{a}	163 ± 27.7^{a}	13.0 ± 1.68^{a}
Average for fertilization						
1		4.87 ± 0.53^{b}	2.0 ± 0.28^{a}	1200 ± 168^{ab}	154 ± 20.0^{a}	12.2 ± 1.71^{a}
2		4.85 ± 0.72^{b}	2.2 ± 0.24^{a}	1200 ± 204^{ab}	158 ± 17.4^{ab}	12.2 ± 1.59^{a}
3		5.00 ± 0.60^{c}	2.1± 0.27^{a}	1050 ± 126^{a}	168 ± 25.2^{c}	13.4 ± 2.01^{c}
4		4.85 ± 0.63^{b}	2.1 ± 0.31^{a}	1250 ± 175^{b}	157 ± 22.0^{ab}	12.5± 1.50^{ab}
5		4.87± 0.88^{b}	2.1 ± 0.29^{a}	1200 ± 192^{ab}	163 ± 22.4^{bc}	13.1± 2.10^{bc}
6		4.79± 0.62^{b}	2.0 ± 0.26^{a}	1080 ± 151^{ab}	169 ± 28.7^{c}	13.0 ± 2.08^{bc}
7		4.87± 0.73^{b}	2.1 ± 0.36^{a}	1225 ± 196^{b}	167 ± 23.4^{c}	13.5 ± 1.89^{c}
8		4.96± 0.59^{c}	2.3 ± 0.32^{a}	1105 ± 166^{ab}	168 ± 21.6^{c}	13.3 ± 2.13^{bc}

± standard error of the mean (SEM)
a, *b*, *c*, … homogenous groups

It was found that the content of absorbable fractions of zinc, copper, manganese and iron in soil after the harvest of spring triticale was differentiated (Table 5). According to DIATTA and GRZEBISZ (2006), depending on the type of soil, nitrogen fertilizers such as $(NH_4)_2SO_4$, $CO(NH_2)_2$ and $NH_4NO_3 \cdot \cdot CaCO_3$ affect the buffer capacity of soil, hence altering the concentration of some microelements. Rutkowska et al. (2009) reports that nitrogen fertilization reduces the reaction of soil and causes an increase in the content of iron, manganese, zinc and copper. Other authors (Sienkiewicz et al. 2009) claim that manure fertilization significantly influences the accumulation of microelements in soil. In our experiment, a higher content of manganese and zinc was found only under the influence of nitrogen fertilization in the form of urea or urea with ammonium nitrate in the cultivation of cv. Andrus. The content of zinc in the cultivation of cv. Andrus increased as a result of the supplementation with Azofoska.

The highest increase in the zinc content (by 14.7%) was reported after the fertilization of cv. Milewo with the higher dose of nitrogen (120 kg ha^{-1}) and with Azofoska. A significant increase in the manganese content (by 11%) was observed in the cultivation of cv. Milewo fertilized with Azofoska, regardless of the nitrogen dose.

It was also found that the content of manganese, zinc and iron in the tested soil samples ranged within their natural average concentrations, while the content of copper was on a low level regardless of the type of fertilization.

Kastori et al. (2006), Szabó and Fodor (2006) showed that the accumulation of microelements, particularly zinc and manganese, in triticale or winter wheat grains and in sunflower or maize seeds largely depended on soil abundance. In our experiment, the content of the analyzed elements in spring triticale grains was differentiated and, similarly to reports by other authors (Wójcik 2004, Sienkiewicz et al. 2009, Sztuder 2009, Ścigalska et al. 2000, 2011), depended on the type of fertilization.

The average content of copper in grain ranged between 2.26 mg·kg^{-1} and 2.80 mg·kg^{-1} for cv. Andrus and from 2.44 mg kg^{-1} to 3.27 mg kg^{-1} for cv. Milewo (Table 6). A higher content of copper was observed under the influence of foliar and soil nitrogen fertilization at a dose of 80 kg ha^{-1}. The application of Azofoska resulted in cv. Andrus grain having 12.4% more copper than grain from triticale fertilized with urea at a dose of 80 kg ha^{-1}.

Nitrogen fertilization at a dose of 120 kg ha^{-1} together with Ekolist and Azofoska supplied during the BBCH 31-32 phase stimulated the iron accumulation in grains from cv. Andrus (up to 27.8 mg kg^{-1} and 28.0 mg kg^{-1}). In cv. Milewo, the highest content of iron was reported only under the impact of nitrogen fertilization at a dose of 120 kg ha^{-1}.

In the cultivation of triticale fertilized with the higher dose of nitrogen (120 kg ha^{-1}), the beneficial effect of Azofoska supplied during the BBCH 23-29 phase on the content of manganese was observed for the cultivar Andrus. This type of fertilization affected the content of zinc in cv. Andrus variety grains and manganese and zinc in cv. Milewo grains. This experiment has indicated that foliar fertilization with liquid preparations is one of the most cost-efficient agrotechnical procedures (Sztuder 2009).

In the studies carried out by Kastori et al. (2006) on the cultivation of

Table 6

Content of Cu, Fe, Mn and Zn in triticale grains (the average in 2009-2011)

Variety	Object	(mg kg^{-1} of d.m.)			
		Cu	Fe	Mn	Zn
Andrus	1	2.26 ± 0.23^{a}	24.1 ± 2.17^{e}	32.2 ± 3.54^{b}	30.6 ± 2.45^{d}
	2	2.80 ± 0.39^{f}	21.1 ± 2.95^{c}	34.5 ± 2.41^{c}	28.9 ± 3.46^{a}
	3	2.72 ± 0.29^{e}	21.8 ± 1.74^{d}	31.2 ± 2.81^{ab}	29.1 ±3.49^{a}
	4	2.50 ± 0.20^{c}	19.3 ± 1.93^{a}	30.0 ± 2.70^{a}	29.1 ± 2.32^{a}
	5	2.44 ± 0.34^{b}	20.5 ± 2.66^{b}	31.6 ± 4.11^{b}	29.7 ± 4.45^{b}
	6	2.50 ± 0.22^{c}	27.8 ± 2.50^{g}	35.3 ± 5.29^{c}	32.3 ± 3.55^{e}
	7	2.49 ± 0.17^{c}	25.8 ± 3.09^{f}	31.3 ±3.76^{ab}	30.3 ± 2.70^{c}
	8	2.56 ± 0.33^{d}	28.0 ±1.63^{g}	34.6 ± 3.81^{c}	30.4 ± 3.34^{cd}
Milewo	1	3.14 ±0.40^{e}	25.8 ± 2.06^{e}	29.9 ± 3.59^{b}	30.8 ± 2.16^{a}
	2	2.80 ± 0.31^{c}	24.6 ± 3.44^{b}	29.7 ± 2.97^{b}	30.6 ± 3.67^{a}
	3	3.27 ± 0.26^{f}	24.5 ± 1.48^{b}	27.8 ± 3.61^{a}	31.3 ± 2.50^{b}
	4	2.84 ± 0.42^{d}	25.0 ± 3.50^{c}	27.6 ± 3.04^{a}	30.6 ± 2.75^{a}
	5	2.44 ± 0.22^{a}	26.8 ± 3.75^{f}	30.5 ± 1.83^{d}	35.5 ± 4.26^{d}
	6	2.55 ± 0.17^{b}	23.9 ± 1.91^{a}	32.6 ± 32.6^{e}	38.6 ± 3.86^{e}
	7	2.45 ± 0.34^{a}	27.5 ± 1.65^{g}	30.3 ± 3.33^{cd}	34.7 ±1.39^{c}
	8	2.79 ± 0.33^{c}	25.3 ± 3.04^{d}	30.2 ± 2.72^{c}	34.8 ± 3.82^{c}
Average for varieties					
Andrus		2.53 ± 0.43^{a}	23.6 ± 3.30^{a}	32.6 ± 3.90^{a}	30.1 ± 5.11^{a}
Milewo		2.64 ± 0.39^{b}	23.8 ± 3.09^{b}	32.3 ± 5.49^{b}	33.4 ± 5.01^{b}
Average for fertilization					
1		2.70 ± 0.38^{e}	25.0 ± 3.74^{e}	31.1 ± 5.28^{c}	30.7 ± 4.30^{c}
2		2.80 ± 0.33^{f}	22.9 ±2.97^{b}	32.1 ± 3.53^{d}	29.8 ± 4.46^{a}
3		3.00 ± 0.48^{g}	23.2± 3.24^{c}	29.5 ± 4.72^{b}	30.2 ± 5.13^{b}
4		2.67 ± 0.29^{d}	22.2 ± 3.10^{a}	28.8 ± 4.90^{a}	29.9 ± 5.37^{a}
5		2.44 ± 0.41^{a}	23.7 ± 3.78^{d}	31.1 ± 4.04^{c}	32.6 ± 4.24^{d}
6		2.53 ± 0.33^{c}	25.9 ± 2.58^{f}	34.0 ± 4.07^{e}	35.5 ± 5.32^{e}
7		2.47 ± 0.37^{b}	26.7 ± 3.73^{g}	30.8 ± 4.62^{c}	32.5 ± 4.87^{d}
8		2.68 ± 0.30^{d}	26.7 ± 3.99^{g}	32.4 ± 4.54^{d}	32.6 ± 5.54^{d}

± standard error of the mean (SEM)
a, *b*, *c*, … homogenous groups

triticale on Chermozem soil and fertilization with foliar supply of microelements, a significant correlation between the dose of fertilizer and the content of elements in grains was observed.

An increase in the content of microelements in soil was not always accompanied by an increase in the content of these elements in spring triticale grains. Analysis of regression confirmed these relations (Figures 1 - 8). Our

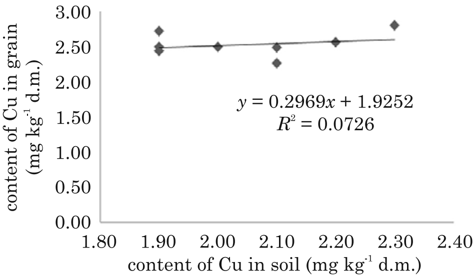


Fig. 1. The relationship between Cu content in cv. Andrus grains and in soil

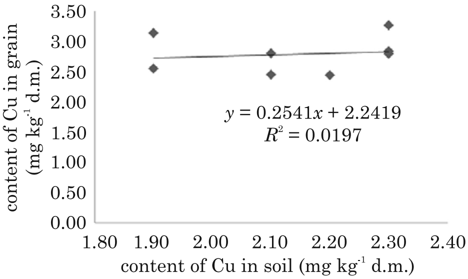
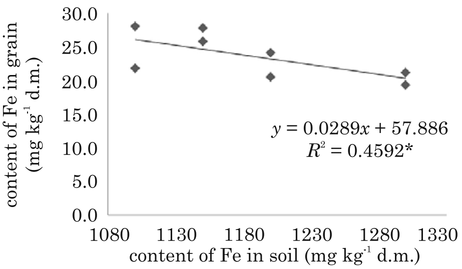
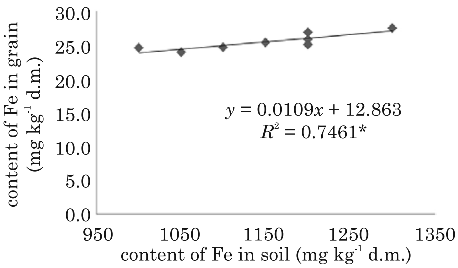


Fig. 2. The relationship between Cu content in cv. Milewo grains and in soil

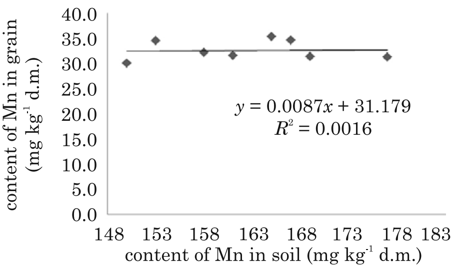


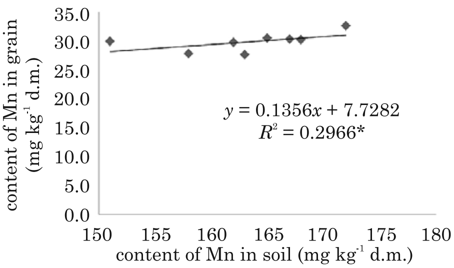


* coefficient of determination (R^2) significant at $p = 0.05$

Fig. 3. The relationship between Fe content in cv. Andrus grains and in soil

Fig. 4. The relationship between Fe content in cv. Milewo grains and in soil





* coefficient of determination (R^2) significant at $p = 0.05$

Fig. 5. The relationship between Mn content in cv. Andrus grains and in soil

Fig. 6. The relationship between Mn content in cv. Milewo grains and in soil

analysis of the relationships between the content of microelements in soil and in triticale grains revealed a significant increase in the content of iron, manganese and zinc in grains together with their increase in the soil in the plots croped with the cultivar Milewo. Regarding the zinc content in soil and in grain from cv. Milewo, the coefficient of determination was the closest to the coefficient of linear correlation ($R^2 = 0.9105$). It was also found that the content of iron in grain from cv. Andrus decreased along with an increase in the content of this element in soil ($R^2 = 0.4592$).

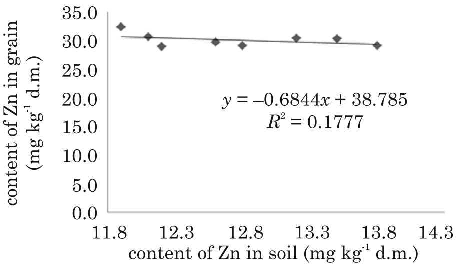
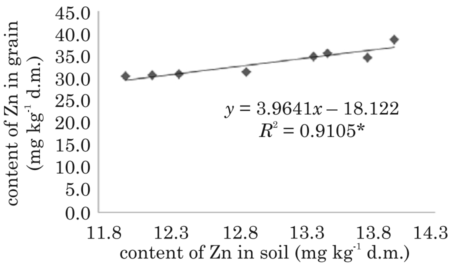


Fig. 7. The relationship between Zn content in cv. Andrus grains and in soil



* coefficient of determination (R^2) significant at $p = 0.05$

Fig. 8. The relationship between Zn content in cv. Milewo grains and in soil

CONCLUSIONS

1. Fertilization resulted in a significant increase in the content of available forms of manganese and zinc in soil, particularly after the application of higher doses of nitrogen with Ekolist and Azofoska.

2. In most cases, a dose of 120 kg N ha^{-1} supplemented with multi-component fertilizers, i.e. Azofoska and Ekolist increased the content of iron and manganese in spring triticale grains.

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