Response of spring wheat to different soil and foliar fertilization

Reakcja pszenicy jarej na zróżnicowane nawożenie doglebowe i dolistne

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Abstract

In the years 2013-2015 a field experiment was carried out, whose aim was to determine the response of spring wheat cultivar Arabella to different levels of soil fertilization with NPK and foliar feeding Plonvit Zboża. Higher level of soil fertilization with NPK caused an increase in the LAI (Leaf Area Index), MTA (Mean Tip Angle) and SPAD (Soil Plant Analysis Development) indices in comparison to lower fertilization level. The applied soil fertilization and foliar application did not differentiate the number of plants after emergences and prior to the harvest. The higher dose of NPK caused an increase in the number of ears per 1 m^2, TGW and grain yield in comparison to the lower dose. Two-time and three-time foliar application caused an increase in MTA and SPAD indices, while TGW and grain yield increased three times in comparison to the control. The higher level of NPK fertilization caused an increase in total protein, K, Cu and Mn contents in grain and a decrease in Fe content. Three-time foliar application caused an increase in ash and Mg contents in grain in comparison to the control. An increase in Cu and Zn contents, in comparison to single foliar application and the control, was also observed.

Keywords: foliar feeding, LAI, MTA, NPK levels, nutrients, SPAD, wheat, yield

Streszczenie

W latach 2013-2015 przeprowadzono ścisłe doświadczenie polowe, którego celem było określenie reakcji pszenicy jarej odmiany Arabella na zróżnicowane nawożenie doglebowe NPK i dokarmianie dolistne wieloskładnikowym nawozem Plonvit Zboża. Wyższy poziom nawożenia doglebowego NPK wpłynął na wzrost indeksu LAI, MTA i SPAD w porównaniu do niższego poziomu nawożenia. Nawożenie doglebowe i dolistne nie zróżnicowało liczby roślin po wschodach i przed zbiorem. Wyższa dawka NPK wpłynęła na wzrost liczby kłosów na 1 m^2, MTZ oraz plonu ziarna w porównaniu do dawki niższej. Dwukrotne i trzykrotne nawożenie dolistne zwiększyło indeks MTA i SPAD, a trzykrotne dodatkowo MTZ i plon ziarna w porównaniu do kontroli. Wyższy poziom nawożenia NPK wpłynął na zwiększenie zwartości w ziarnie białka ogólnego, K, Cu i Mn, zaś zmniejszenie Fe. Trzykrotne nawożenie dolistne zwiększyło zawartość w ziarnie popiołu i Mg w porównaniu do kontroli oraz zawartość Cu i Zn w porównaniu do obiektu jednokrotnie nawożonego dolistnie oraz kontrolnego.

Słowa kluczowe: dokarmianie dolistne, LAI, MTA, plon, poziomy NPK, pszenica, składniki mineralne, SPAD

Streszczenie szczegółowe

Ścisłe doświadczenie polowe z pszenicą jarą odmiany Arabella przeprowadzono w latach 2013-2015 w Stacji Doświadczalnej Uniwersytetu Rzeszowskiego w Krasnem (50°03′N, 22°06′E), południowo-wschodnia Polska. Pierwszym badanym czynnikiem było zróżnicowane nawożenie doglebowe NPK: 80-30-60 kg·ha^{-1} (poziom I) oraz 120-45-90 kg·ha^{-1} (poziom II). Drugim czynnikiem było nawożenie dolistne nawozem Plonvit Zboża, zastosowane jednokrotnie, dwukrotnie lub trzykrotnie w okresie wegetacji pszenicy w porównaniu do obiektu kontrolnego, bez dokarmiania. Siew zaprawionych nasion wykonano: 16 kwietnia 2013 r., 01 kwietnia. 2014 r. oraz 08 kwietnia 2015 r. Ilość wysiewu wyniosła 450 nasion·m^{-2}. Przedplonem był rzepak ozimy. Powierzchnia poletek do siewu wyniosła 12 m^2, zaś do zbioru 10 m^2. Zbiór przeprowadzono w terminie: 19 sierpnia 2013 r., 16 sierpnia 2014 r. i 11 sierpnia 2015 r. Rośliny do pomiarów biometrycznych pobrano z 1 m^2 każdego poletka w fazie dojrzałości pełnej ziarna (BBCH 89). Pomiary indeksów: LAI, MTA i SPAD wykonano w fazie dojrzałości mlecznej (BBCH 75). Plon ziarna przeliczono na powierzchnię 1 ha i sprowadzono do stałej wilgotności 15%. Ilość w ziarnie białka ogólnego, tłuszczu surowego, popiołu i włókna oznaczono metodą NIRS, a zawartość makroelementów i mikroelementów techniką ASA. W wyniku przeprowadzonych badań wykazano, że wyższy poziom nawożenia doglebowego NPK wpłynął na wzrost indeksu LAI, MTA i SPAD w porównaniu do niższego poziomu nawożenia. Zastosowane nawożenie doglebowe i dolistne nie zróżnicowało liczby roślin po wschodach i przed zbiorem. Ubytki roślin w latach badań w okresie wegetacji wyniosły średnio 11.9 szt.·m^{-2}. Wyższa dawka NPK wpłynęła na wzrost liczby kłosów na 1 m^2, MTZ oraz plonu ziarna w porównaniu do dawki niższej. Dwukrotne i trzykrotne nawożenie dolistne zwiększyło indeks MTA i SPAD, a trzykrotne dodatkowo MTZ i plon ziarna w porównaniu do kontroli. Wyższy poziom nawożenia NPK wpłynął na zwiększenie zwartości w ziarnie białka ogólnego, K, Cu i Mn, zaś zmniejszenie Fe. Trzykrotne nawożenie dolistne zwiększyło zawartość w ziarnie popiołu i Mg w porównaniu do kontroli oraz zawartość Cu i Zn w porównaniu do obiektu jednokrotnie nawożonego dolistnie oraz kontrolnego.

Introduction

Mineral fertilization of spring wheat determines the quantity and quality of obtained grain yield. It is particularly essential to balance mineral fertilization with nitrogen, phosphorus and potassium (Arif et al., 2006). Many authors (Seadh et al., 2009;

Khan et al., 2010; Rawashdeh and Sala, 2016) report that the application of microelements is also of great importance in growing this form of wheat. During the wheat growing season nutrients may be applied to soil (Rehman et al., 2010; Nadim et al., 2013; Islam et al., 2014) or on leaves (Seadh et al., 2009; Tahir et al., 2009; Ahmad and Irshad, 2011; Ali et al., 2013; Rawashdeh and Florin, 2015). Mineral fertilization should be performed according to the wheat plant needs, at suitable rates, proportions and times (Ralcewicz et al., 2009). Modern measurement techniques are useful in determination of needs of cultivated crops, including wheat, in respect of top-dressing. They allow for an easy, quick and non-invasive assessment of the plantation condition, including, among others, the indices: Leaf Area Index – LAI (Olsen and Weiner, 2007; Zheng and Moskal, 2009), Mean Tip Angle – MTA (Bobrecka-Jamro et al., 2015) and Soil Plant Analysis Development, SPAD (Hamblin et al., 2014; Barutçular et al., 2015). Analysis of the mentioned indices also allows for predicting a cereal grain yield.

The aim of this study was to assess the response of spring wheat to different soil NPK fertilization levels and foliar fertilizer application. The research hypothesis assumed that the used fertilization variants modified the assessed parameters, indices and the quantity and quality of grain yield of the spring wheat cultivar Arabella.

Material and methods

Over 2013-2015 a strict field experiment was carried out at the Experimental Station of the University of Rzeszow at Krasne (50°03′N, 22°06′E), Poland. This was a two factorial experiment established with four replications, in the split-plot design. The test plant was spring wheat, cultivar Arabella (breeder: Danko Hodowla Roślin Sp. z o.o., Poland). The first studied factor was NPK fertilization levels: 80-30-60 $kg \cdot ha^{-1}$ (level I) and 120-45-90 $kg \cdot ha^{-1}$ (level II).

The other studied factor was times of foliar application of the fertilizer Plonvit Zboża (by the company Intermag Sp. z o.o., Poland). The foliar fertilizer was applied once, two times or three times during the plant growing season, in relation to the control, without fertilization (Table 1).

Foliar fertilization was performed with a manual sprayer and the amount of working liquid was 300 $dm^3 \cdot ha^{-1}$. Isolation strips between the plots amounted to 1.5 m. Chemical composition of the foliar fertilizer Plonvit Zboża (Plonvit Z) included in $g \cdot dm^{-3}$: 195 N, 26 MgO, 59 SO_3, 0.18 B, 11.7 Cu, 10.4 Fe, 14.3 Mn, 0.065 Mo and 13 Zn. Sowing dressed seeds was performed on: 16 April 2013, 01 April 2014 and 08 April 2015. The sowing rate was 450 $seeds \cdot m^{-2}$. Agricultural techniques were performed according to the recommendations for spring wheat cultivation. The previous crop was winter oilseed rape. The area of plots for sowing was 12 m^2 and for harvest 10 m^2. Nitrogen fertilization (ammonium nitrate) on level I was divided into two doses, and on level II, into three doses (Table 1).

Table 1. Fertilization diagram

Fertilizers, dose	Application time, dose		
NPK ($kg \cdot ha^{-1}$)	Before sowing	BBCH 21	BBCH 31
80 – 30 – 60	50 N – 30 P – 60 K	30 N	–
120 – 45 – 90	60 N – 45 P – 90 K	40 N	20 N
Plonvit Z ($dm^{-3} \cdot ha^{-1}$)	BBCH 27	BBCH 39	BBCH 71
Control	–	–	–
1.5	1.5	–	–
3	1.5	1.5	–
4.5	1.5	1.5	1.5

Fertilization with phosphorus (granulated triple superphosphate) and potassium (potash salt) was applied prior to sowing. Wheat plants were protected with the use of: herbicide, Chwastox Extra 300 SL (3.5 $dm^3 \cdot ha^{-1}$), insecticide, Sumi – Alpha 050 EC (0.25 $dm^3 \cdot ha^{-1}$), fungicide, Juwel TT 483 SE (1.5 $dm^3 \cdot ha^{-1}$) and growth regulator, Cerone 480 SL (0.75 $dm^3 \cdot ha^{-1}$).

The soil of the experimental area has the texture of clay loam. According to the classification by the IUSS Working Group WRB, this soil was classified as gleic fluvisol (Food and Agriculture Organization of the United Nations, 2014).

The soil pH was slightly acidic. It was characterized by a high content of available phosphorus, medium content of potassium, high or very high content of magnesium and low content of sulphur. The content of microelements was generally medium (Table 2).

The weather conditions were given according to the data of the Meteorological Station of the University of Rzeszow. High rainfalls were recorded in June 2013 and in July 2014 in comparison to the long-term data. The lowest total precipitation in the period from April to August was recorded in 2015. Air temperatures also differed from the long-term mean. High temperatures were recorded in July 2014 and in August 2015 in comparison to the long-term data (Table 3).

Table 2. Physicochemical soil properties

Parameter	Unit	2013	2014	2015
Soil reaction	pH in KCl 1 mol·dm^3	5.86	6.23	5.96
Humus	%	2.89	2.75	2.71
N_{min}	kg·ha^{-1}	60.2	42.3	56.3
	Content of available nutrients in soil			
P_2O_5		182	194	185
K_2O		195	185	190
Mg		86	98	75
$S\text{-}SO_4$		0.52	0.48	0.55
Fe	mg·kg^{-1}	1,216.3	2,605.5	1,762.5
Mn		195	334.2	215.3
Zn		9.7	16.8	14.2
B		1.23	1.86	1.56
Cu		4.8	8.4	5.63

Table 3. Average monthly temperature (ºC) and total precipitation (mm)

Month	Precipitation				Temperature			
	2013	2014	2015	Long-term	2013	2014	2015	Long-term
IV	33.9	29.9	25.7	48.27	9.39	10.1	8.6	8.89
V	87.5	92.2	85.1	78.06	9.84	14.1	13	13.74
VI	143.4	48.1	8.9	85.83	18.48	16.3	17.6	17.2
VII	19.2	112.4	52.4	90.55	19.33	20.1	19.9	19.14
VIII	11	46.8	6.1	62.67	19.58	18.1	21.4	18.35

The study included measurements of the indices: LAI, Leaf Area Index, MTA, Mean Tip Angle, SPAD, Soil Plant Analysis Development (from 0 to 99.9), yield structure and the quantity and quality of grain yield. Measurements with the LI-COR LAI gauge – 2000 (USA) were performed at the stage of milk maturity (BBCH 75). Chlorophyll meter SPAD – 502P (Konica Minolta, Japan) was used at the same developmental stage on 30 flag leaves in the morning hours. Plants for biometric measurements were collected from 1 m^2 of each plot at the stage of full grain maturity (BBCH 89). The grain yield obtained from the plots was calculated per 1 ha, considering 14% humidity, and then corrected with lacking ears collected for biometric measurements. Contents of total protein, raw fat, ash and fibre in grain were determined with the NIRS method in near infrared on the apparatus Spectrometer FT-NIR MPA by Bruker (Germany). Phosphorus was determined with an absorption spectrophotometer within the UV-VIS range. Potassium, magnesium and microelements were determined after mineralization in nitric acid with the AAS technique on the apparatus Hitachi Z-2000 (Japan).

The obtained results were statistically evaluated by the method of analysis of variance (ANOVA). Differences between mean values were evaluated by Tukey's (LSD) test at the level of significance P=0.05. The computations were done using the Statistica 8.0 programme (StatSoft, Tulsa, USA).

Results and discussion

Higher NPK fertilization level affected an increase in the LAI index in comparison to the lower fertilization level. The obtained significant difference amounted to 0.29 $m^2 \cdot m^{-2}$. Foliar fertilization did not differentiate the LAI index. Rehman et al. (2010) also confirmed a significant effect of mineral NPK fertilization on the LAI index in wheat plants. They obtained the highest measurements of LAI (2.5) after the NPK application of 80-60-30 $kg \cdot ha^{-1}$, whereas the lowest on the control treatment (2.19). Nadim et al. (2013) indicated that foliar application of boron increased the LAI index in comparison to foliar application of zinc.The present study found a significant increase in the MTA index in plants fertilized with the higher NPK dose in comparison to the lower dose. After two-time and three-time application of the foliar fertilizer, higher measurements of the MTA index were obtained in comparison to the control. Shibayama and Watanabe (2008) and Bobrecka-Jamro et al. (2015) did not prove the effect of an increased mineral fertilization on the MTA index in wheat plants. The plants fertilized with the higher NPK doses were characterized by the highest values of the SPAD index. Two-time and three-time foliar fertilization also increased the SPAD index in comparison to the control (Table 4). In the previous study Islam et al. (2014) confirmed that high mineral fertilization of wheat results in an increase in the SPAD index, whereas organic manures exert smaller effects on this index.

Table 4. Measurements indices LAI, MTA and SPAD (mean in years)

Index	Foliar fertilization (B)	Soil NPK fertilization (A)		Mean for B
		I level	II level	
LAI ($m^2 \cdot m^{-2}$)	Control	4.13	4.41	4.27
	Once	4.25	4.51	4.38
	Twice	4.23	4.56	4.4
	Three times	4.26	4.54	4.4
	Mean for A	4.22	4.51	4.36
	LSD A – 0.28, B – ns, AxB – ns			
MTA (°)	Control	56.3	61.4	58.9
	Once	59.5	60.9	60.2
	Twice	60.6	63.5	62.1
	Three times	62.4	62.6	62.5
	Mean for A	59.7	62.1	60.9
	LSD A – 2.28, B – 3.14, AxB – ns			
SPAD	Control	48.5	57.2	52.9
	Once	50.2	58.8	54.5
	Twice	52.8	61.6	57.2
	Three times	53.4	61.5	57.5
	Mean for A	51.2	59.8	55.5
	LDS A – 8.05, B – 4.19, AxB – ns			

ns – non-significant differences

Differentiated soil and foliar fertilization did not have a significant effect on the number of plants after emergences and prior to harvest (Table 5). On average in the years of the study, plant losses from the stage of emergences (BBCH 11) to harvest (BBCH 89) amounted to 11.9 pieces$\cdot$m^{-2}. Also Haliniarz et al. (2013) did not indicate the effect of higher NPK doses on the wheat plant density prior to harvest.

In the present experiment, the number of ears per 1 m^2 was on average 430.8 pieces$\cdot$m^{-2}. Application of a higher level of NPK fertilization resulted in a significant increase in the parameter in question, on average by 14.1 pieces$\cdot$m^{-2} in comparison to the lower dose. Foliar fertilization did not have a significant effect on the number of ears per 1 m^2.

Bobrecka-Jamro et al. (2015) confirmed that a higher NPK dose significantly increases the number of ears per 1 m^2.

Seadh et al. (2009) report that the application of a high nitrogen dose and a multi component foliar fertilizer has the most favourable effect on the number of ears per $1m^2$. The study by Tahir et al. (2009) did not indicate the effect of foliar application of boron on the ear density. Arif et al. (2006), in turn, after the application of three-time foliar spraying, obtained a significant increase in the number of ears per 1 m^{-2}.

Table 5. Number of plants and ears in pcs.·m^{-2} (mean in years)

Parameter	Foliar fertilization (B)	Soil NPK fertilization (A)		Mean for B
		I level	II level	
Number of plants after emergence	Control	375	386.4	380.7
	Once	386.5	387.4	387
	Twice	388.6	388.8	388.7
	Three times	386.2	388.9	387.6
	Mean for A	384.1	387.9	386
	LSD A – ns, B – ns, AxB – ns			
Number of plants before harvest	Control	361.4	374.6	368
	Once	374.8	376.7	375.8
	Twice	376.6	377.9	377.3
	Three times	374.4	376.1	375.3
	Mean for A	371.8	376.3	374.1
	LSD A – ns, B – ns, AxB – ns			
Number of ears	Control	411.3	440.7	426
	Once	415.3	442.9	429.1
	Twice	435.9	435.5	435.7
	Three times	432.6	432.4	432.5
	Mean for A	423.8	437.9	430.8
	LSD A – 12.63, B – ns, AxB – ns			

ns – non-significant differences

The number of grains per ear did not significantly depend on soil or foliar fertilization (Table 6). On average 33.9 grains were formed on the spring wheat ear. Arif et al. (2006) obtained a significant increase in the number of grains per wheat ear under the influence of three-time foliar fertilization in comparison to a single spraying. Many authors (Tahir et al., 2009; Khan et al., 2010; Ahmad and Irshad 2011; Rawashdeh and Sala 2016) indicated that foliar fertilization of wheat plants affects an increase in the number of grains per ear. This, however, is dependent on the number of performed sprayings.

Table 6. Yield components and grain yield (mean in years)

Parameter	Foliar fertilization (B)	Soil NPK fertilization (A)		Mean for B
		I level	II level	
The number of grains per ear	Control	31.2	32.3	31.8
	Once	33.6	34.5	34.1
	Twice	34	35.6	34.8
	Three times	34.2	35.4	34.8
	Mean for A	33.3	34.5	33.9
	LSD A – ns, B – ns, AxB – ns			
Thousand grain weight (g)	Control	37.3	40	38.7
	Once	37.8	40.8	39.3
	Twice	39.6	42.1	40.9
	Three times	40.7	43.5	42.1
	Mean for A	38.9	41.6	40.2
	LSD A – 2.45, B – 3.23, AxB – ns			
Grain yield ($Mg \cdot ha^{-1}$)	Control	4.29	5.22	4.76
	Once	4.77	5.72	5.25
	Twice	5.35	6.01	5.68
	Three times	5.49	6.14	5.82
	Mean for A	4.98	5.77	5.37
	LSD A – 0.68, B – 1.01, AxB – ns			

ns – non-significant differences

The higher NPK dose resulted in a significant increase in the thousand grain weight in comparison to the lower dose. The obtained average difference amounted to 2.7 g. Three-time foliar fertilization increased TGW in comparison to the control.

Haliniarz et al. (2013) did not indicate an increase in TGW under the influence of a higher NPK dose. Arif et al. (2006) and Rawashdeh and Sala (2016) confirmed that foliar fertilization increases TGW in wheat, but on condition of performing several sprayings during the growing season. Nadim et al. (2013) did not indicate the effect of microelements applied to soil or on leaves on TGW.

The application of the higher NPK dose resulted in a significant increase in grain yield by 0.79 $Mg \cdot ha^{-1}$ in comparison to the lower dose.

It was also proved that three-time foliar fertilization significantly increased grain yield in relation to the control (Table 6).

This is confirmed by the studies by Rehman et al. (2010) and Islam et al. (2014), who obtained the highest wheat yield after the soil application of high doses of mineral fertilizers. Ralcewicz et al. (2009) indicated an increase in spring wheat grain yield after foliar application of nitrogen and magnesium.

Also Arif et al. (2006) and Rawashdeh and Sala (2016) proved that foliar fertilization of wheat affects a significant increase in grain yield. Seadh et al. (2009) report that the wheat grain yield is the most favourably affected by fertilization with a high dose of nitrogen combined with multi-component foliar fertilization.

The use of the higher NPK dose resulted in a significant increase in total protein content in the grain. In the study by El-Habbal et al. (2010) it was confirmed that total protein content in wheat grain increases along with an increase in nitrogen doses. Gomaa et al. (2015) report that soil fertilization changes the chemical composition of wheat grain to a greater extent than foliar fertilization.

Three-time foliar fertilization increased ash content in the grain in comparison to the control (Table 7). Zeidan et al. (2010) and Mekkei and El Haggan Eman (2014) proved that foliar application increases the content of total protein in wheat grain. Gomaa et al. (2015) obtained an increase in fat content in the wheat grain under the influence of foliar application (Zn + Fe).

Seadh et al. (2009), in turn, indicated that total protein content in wheat grain was the most favourably affected by a high dose of nitrogen and multi-component foliar fertilization.

Table 7. Content of the components in the seeds of spring wheat in % D.M. (mean in years)

Component	Foliar fertilization (B)	Soil NPK fertilization (A)		Mean for B
		I level	II level	
Total protein	Control	14.2	14.9	14.6
	Once	14.4	15.1	14.8
	Twice	14.6	15.4	15
	Three times	14.4	15.2	14.8
	Mean for A	14.4	15.2	14.8
	LSD A – 0.72, B – ns, AxB – ns			
Crude fat	Control	1.93	1.86	1.9
	Once	1.91	1.82	1.87
	Twice	1.89	1.84	1.87
	Three times	1.84	1.79	1.82
	Mean for A	1.89	1.83	1.86
	LSD A – ns, B – ns, AxB – ns			
Crude ash	Control	1.87	1.85	1.86
	Once	1.92	1.89	1.91
	Twice	1.94	1.94	1.94
	Three times	1.96	1.95	1.96
	Mean for A	1.92	1.91	1.92
	LSD A – ns, B – 0.09, AxB – ns			
Crude fibre	Control	1.45	1.42	1.44
	Once	1.42	1.42	1.42
	Twice	1.4	1.39	1.4
	Three times	1.39	1.36	1.38
	Mean for A	1.42	1.4	1.41
	LSD A – ns, B – ns, AxB – ns			

ns – non-significant differences

The application of the higher NPK dose resulted in a significant increase in potassium content in the grain, whereas three-time foliar application increased magnesium content in comparison to the control (Table 8).Wilczewski et al. (2013) report that the contents of phosphorus and magnesium in the grain of spring wheat fertilized with nitrogen at doses 120 or 160 kg·ha^{-1} was significantly higher than those obtained after the use of lower doses. Nevertheless, they did not confirm the effect of nitrogen fertilization on potassium concentration in spring wheat grain.

Table 8. Content of macroelements in the seeds of spring wheat in g·kg^{-1} D.M. (mean in years)

Component	Foliar fertilization (B)	Soil NPK fertilization (A)		Mean for B
		I level	II level	
P	Control	4.41	4.48	4.45
	Once	4.39	4.45	4.42
	Twice	4.44	4.2	4.32
	Three times	4.27	4.49	4.38
	Mean for A	4.38	4.41	4.39
	LSD A – ns, B – ns, AxB – ns			
K	Control	4.21	5.21	4.71
	Once	4.2	5.19	4.7
	Twice	4.18	4.75	4.47
	Three times	4.15	4.62	4.39
	Mean for A	4.19	4.94	4.56
	LSD A – 0.68, B – ns, AxB – ns			
Mg	Control	1.35	1.21	1.28
	Once	1.38	1.26	1.32
	Twice	1.42	1.45	1.44
	Three times	1.44	1.54	1.49
	Mean for A	1.4	1.37	1.38
	LSD A – ns, B – 0.19, AxB – ns			

ns – non-significant differences

Table 9. Content of microelements in the seeds of spring wheat in mg·kg^{-1} D.M. (mean in years)

Component	Foliar fertilization (B)	Soil NPK fertilization (A)		Mean for B
		I level	II level	
Fe	Control	50.2	41.4	45.8
	Once	50.1	41.8	46
	Twice	52.3	42.2	47.3
	Three times	51.8	42	47
	Mean for A	51.1	41.9	46.5
	LSD A - 8.23, B - ns, AxB - ns			
Cu	Control	3.52	4.11	3.82
	Once	3.51	4.06	3.79
	Twice	3.7	4.71	4.21
	Three times	4.08	4.53	4.31
	Mean for A	3.7	4.35	4.03
	LSD A – 0.57, B – 0.42, AxB – ns			
Mn	Control	39.3	45.6	42.5
	Once	39.6	45.5	42.6
	Twice	40.2	47.2	43.7
	Three times	40	48	44
	Mean for A	39.8	46.6	43.2
	LSD A – 5.9, B – ns, AxB – ns			
Zn	Control	35.6	34.3	35
	Once	35.8	35.5	35.7
	Twice	35.7	38.9	37.3
	Three times	36	40.1	38.1
	Mean for A	35.8	37.2	36.5
	LSD A – ns, B – 2.25, AxB – ns			

ns – non-significant differences

Seadh et al. (2009) report that fertilization with a higher nitrogen dose and the use of multi-component foliar fertilization has the most favourable effect on the contents of phosphorus and potassium in wheat grain.

Zeidan et al. (2010) did not obtain a significant effect of foliar application on the contents of phosphorus and potassium in wheat grain.

Higher level of NPK fertilization affected an increase in the contents of copper and manganese and a decrease in the content of iron in the grain.

The obtained results were significant in comparison to the lower fertilization level. Three-time foliar fertilization increased the contents of copper and zinc in grain in comparison to the treatment fertilized with a single dose and with the control treatment (Table 9).

Wróbel (2009) indicated that foliar fertilization of wheat with boron increases the content of this element in the grain. Ali et al. (2013) proved that foliar fertilization with boron and zinc increases the content of both components in the flag leaf and wheat grain. Gomaa et al. (2015) reports that combined foliar fertilization of wheat with iron and zinc significantly increases the contents of these elements in the grain.

Zeidan et al. (2010) also proved that foliar fertilization with microelements has an effect on their changing content in wheat grain.

Conclusions

1. Higher level of NPK fertilization affected an increase in the LAI, MTA and SPAD indices in comparison to the lower fertilization level. Two-time and three-time foliar fertilization increased the MTA and SPAD indices in comparison to the control.
2. The use of the higher NPK dose resulted in an increase in the number of ears per an area unit, TGW and grain yield in comparison to the lower dose. Three-time foliar fertilization increased TGW and grain yield in comparison to the control.
3. Higher NPK fertilization increased the contents of total protein, potassium, copper and manganese in the grain and decreased the content of iron. Three-time foliar fertilization increased the content of ash and magnesium in grain in comparison to the control. Additionally, three-time foliar fertilization increased the contents of copper and zinc in grain in comparison to the treatment fertilized once and with the control.

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