Variation in Response of Five Polish Winter Wheat Cultivars to Foliar Copper Application

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Abstract. The aim of the study was to verify whether new, intensive and commonly grown winter wheat cultivars in Poland differ significantly in Cu efficiency. Winter wheat is considered as one of the most sensitive agronomic species to Cu deficiency. Copper fertilization of wheat seems to be a necessity in our country due to common Cu deficiency in Polish soils.

In 2004-2006, three field experiments were conducted in the Experimental Station Osiny in Eastern Poland, where the response of five winter wheat cultivars to foliar copper application was tested. Copper was applied in the form of $CuSO_4 \cdot 5H_2O$ at a rate of 305 g ha^{-1} Cu. Fertilization was performed in spring during the full tillering stage of growth. Analysis of variance was used for statistical calculations. The means were compared using Tukey's test.

It was demonstrated that the five cultivars responded differently to the Cu fertilization, with a medium content of this element in soil. A single Cu spray caused 5-9% increase in grain yield in three out of the five tested cultivars. The other two cultivars did not show any significant yield increase in response to copper application. Besides, all the cultivars accumulated different quantities of copper in plant tissues, such as shoots and grain.

The field trials have proven that winter wheat cultivars are diverse in their nutritional demand for copper. The necessity of winter wheat fertilization with Cu depends not only on the concentration of this nutrient in soil, but also on the tolerance of a given wheat cultivar to copper deficiency.

Key words: winter wheat, cultivars, copper, fertilization requirements

INTRODUCTION

Winter wheat is considered to be one of the most Cu deficit sensitive species (Fageria, 2000; Katyal & Randhawa, 1983). It is also the crop that covers the largest sowing area in Poland. At present, it seems necessary in Poland to fertilize wheat with copper due to the considerable deficiency of this element in soils and crops, as observed in the recent years (Gembarzewski, 2000). An inventory study completed in our country, based on 100,000 samples, has demonstrated that up to 36% of soils in Poland are deficient in Cu (Kucharzewski & Debowski, 2000). In some reports from Australia and Canada, it is claimed that the wheat cultivars grown in these countries are significantly different in their tolerance to copper deficit in soil (Nambiar, 1976; Owuoche et al., 1994; Owuoche et al., 1995; Piening et al., 1989). The purpose of this study has been to find out whether winter wheat cultivars commonly grown in Poland differ in their nutritional demand with respect to copper. It is possible that the decision about copper fertilization of winter wheat should be made depending on what cultivar is to be grown.

MATERIALS AND METHODS

In years 2004-2006, three field experiments were conducted with foliar application of copper to various winter wheat cultivars. The trials were performed at the Experimental Station Osiny near Pulawy (South-East Poland). The soils used for the trials were Haplic Luvisols, acidic or slightly acidic, containing 0.9-1.2% organic matter, well supplied in phosphorus, potassium and magnesium (Table 1).

Table 1. Characteristic of experimental soils

Year	pH KCl	OM	SF I	SF II	P_2O_5	K_2O	Mg	Cu_{HCl}
			%			mg kg^{-1}		
2004	5.2	1.2	18	19	94	143	64	4.7
2005	5.2	1.2	15	24	127	153	40	2.6
2006	6.3	0.9	17	23	128	140	81	2.4

OM-organic matter, SF I-soil fraction<0.02 mm, SF II-soil fraction 0.1-0.02 mm.

The copper concentration in soil extracted with 1 M HCl ranged from 2.4 to 4.7 mg kg^{-1} and was higher in the first year than in the other two years of the experiment. According to the criteria applied in Poland (Gembarzewski & Korzeniowska, 1996), all the three soils were classified as being moderately abundant in copper. Soils moderately rich in copper were purposefully selected for the trials as this factor was expected to cause both positive and, possibly, negative response of some wheat cultivars to copper application. The experiment was set up as a two-factor one with 4 replications, in a split-plot design. Five winter wheat cultivars produced in Polish breeding stations were tested (Table 2).

Table 2. Characteristic of wheat cultivars

Cultivar	Group of wheat	Plant Breeder Company
Kobra	B	Seeds of Kobierzyce Ltd
Zyta	A	Plant Breeding Strzelce Ltd
Sakwa	B	Plant Breeding Strzelce Ltd
Jawa	C	Plant Breeding Strzelce Ltd
Korweta	A	Danko Plant Breeders Ltd

A – quality wheat (very good baking quality), B – bread wheat (good baking quality), C – fodder wheat (weak baking quality).

Copper was applied as $CuSO_4 \cdot 5H_2O$ at the tillering stage of growth at the rate of 305 Cu g·ha^{-1}. All the experimental treatments received identical basic fertilization N – 130, P_2O_5 – 60, K_2O –70 kg·ha^{-1}. In all the years, chemical control against weeds (Maraton 375 SC) and fungi (Amistar 250 SC+Bavistin 500 WG and

Artea 330 EC) was carried out. The surface of each plot was 30 m^2, with 25 m^2 to be harvested.

All the years when the experiments were conducted were characterized by a lower average rainfall compared to the long-term one (Table 3).

Table 3. Monthly sums of precipitation in Osiny (mm)

Year	Month										Total
	X	XI	XII	I	II	III	IV	V	VI	VII	
2003-2004	49.3	20.1	30.1	20.7	43.6	34.1	38.9	19.0	52.1	93.0	400.9
2004-2005	30.8	54.5	12.7	37.8	17.7	27.8	16.3	66.9	31.6	106.5	402.6
2005-2006	3.6	27.4	64.7	12.1	19.3	40.3	27.1	58.0	19.2	20.7	292.4
1956-2000	42.0	39.0	36.0	25.0	25.0	27.0	41.0	54.0	75.0	82.0	446.0

The 2005-2006 growing season proved to be particularly dry, when, after a dry autumn and winter, April had very little rain while June and July were almost rainless. The average annual temperatures in 2003-2004 and 2005-2006 were close to the long-term average and the differences did not exceed 3% (Table 4). The 2004-2005 season was demonstrably warmer than the long-term temperature and the other two experimental seasons.

Table 4. Mean monthly air temperatures in Osiny (^{o}C)

Year	Month										Mean
	X	XI	XII	I	II	III	IV	V	VI	VII	
2003-2004	5.4	5.0	0.7	-5.0	-0.3	3.3	8.6	12.5	16.5	18.5	6.5
2004-2005	10.1	3.6	1.9	0.5	-3.7	0.2	9.0	13.9	16.4	20.2	7.2
2005-2006	8.6	3.1	0.6	-8.0	-3.8	-0.7	9.2	13.9	17.7	22.5	6.3
1956-2000	8.4	3.1	-0.8	-3.0	-2.2	1.7	7.8	13.4	16.7	18.2	6.3

Soil samples were taken for chemical analyses before the establishment of trials. In addition, aerial parts of wheat plants at the early elongation stage and grain samples were collected from each trial.

Organic carbon in soil was determined by Tiurin method (acc. to Polish standard No. PN-91/Z-15005), pH was established potentiometrically in 1 mol $KCl\cdot dm^{-3}$, P and K were determined using Enger-Riehm method (Polish standards No. PN-R-04023:1996 and PN-R-04022:1996 adequately), and Mg by Schachtschabel method (Polish standard No. PN-R-04020:1994). Copper was first extracted in 1 mol $HCl\,dm^{-3}$ (Gembarzewski & Korzeniowska, 1990) and then determined using AAS method.

Having wet digested (H_2SO_4+H_2O_2) the plant samples, N and P were determined using flow analysis (CFA) and spectrometric detection, K was assayed by flame emission spectrophotometry and Mg by AAS method. Copper in shoots and grain was determined by the AAS method following dry digestion.

Program AWAR (Filipiak & Wilkos, 1995), made by Department of Applied Informatics, Institute of Soil Science and Plant Cultivation in Pulawy, was used to perform the analysis of variance. First, the two-way ANOVA for split-plot was conducted for each year separately. Next, an across-years ANOVA was used. Means were compared using the Tukey test.

RESULTS AND DISCUSSION

The wheat yields in 2004 and 2005 were similar (Table 5). The lower yields in 2006 were caused by the shortage of rainfall, mainly in June and July (cf. Table 3). The weather conditions in the three years significantly affected the general level of wheat yields, although they did not alter the direction of the crop's response to copper application. This enabled us to perform an across 3 years ANOVA (Table 6).

In each year, cultivar Kobra responded to Cu application with a statistically significant increase in grain yield ranged 8.5-10.8% (Table 5). Cultivar Sakwa responded only in 2004 (5.8%) and cv. Zyta in 2006 (9.0%). In none of the years, copper fertilization evoked a significant response of cv. Jawa or cv. Korweta.

The highest increase in yield was obtained in 2006 and the smallest one – in 2004, which is attributable to the content and availability of Cu in soil. The soil in which the trials were established in 2006 had the smallest concentration of this element and the highest pH. It has long been known that Cu is less available when the soil pH is high (Harry & Graham, 1981; Kabata-Pendias & Pendias, 2001).

Table 5. Grain yield (t ha^{-1})

Cultivar – *factor II*	Cu application – *factor I*								
	0	Cu	increase[1] %	0	Cu	increase[1] %	0	Cu	increase[1] %
	2004			2005			2006		
Kobra	9.70	10.53	8.5*	8.24	8.88	7.8*	4.93	5.46	10.8*
Zyta	9.89	10.16	2.7	8.73	9.52	9.0*	4.32	4.44	2.8
Sakwa	10.78	11.41	5.8*	9.87	10.03	1.5	5.32	5.77	8.6
Jawa	10.27	10.35	0.7	9.53	9.79	2.8	4.21	4.13	-1.9
Korweta	9.91	9.81	-1.0	8.68	8.41	-3.1	4.28	4.37	2.2
Tukey LSD (α <0.05):	*II/I factor - 0.412* *I/II factor - 0.611*			*II/I factor - 0.473* *I/II factor - 0.710*			*II/I factor - 0.516* *I/II factor - 0.558*		

[1]) Increase as a result of Cu application, *) Statistically significant

The three-year grain yield means (Table 6) demonstrated that the highest significant yield increase following an application of Cu was obtained for cv. Kobra (8.7%) followed by cv. Zyta (5.1%) and cv. Sakwa (4.7%). The cultivars Jawa and Korweta did not respond with a higher yield to Cu fertilization. In a study based on 115 field trials, Karamanos et al. (2003) obtained average yield increases of 9.9% on soils with low and 46.7% on soils with very low Cu concentration (<0,4 mg·kg^{-1} Cu in DTPA).

Table 6. Average grain yield over 3 tested years (t ha^{-1})

Cultivar – *factor II*	Cu application – *factor I*						Increase %
	0			+Cu			
Kobra	7.62	*A*	*a*	8.29	*B*	*b*	8.7*
Zyta	7.65	*A*	*a*	8.04	*B*	*b*	5.1*
Sakwa	8.66	*A*	*c*	9.06	*B*	*c*	4.7*
Korweta	7.62	*A*	*a*	7.53	*A*	*a*	-1.2
Jawa	8.00	*A*	*b*	8.09	*A*	*b*	1.1
Tukey LSD (α <0.05): II/I factor - 0.255, I/II factor – 0.342							

Yields marked with the same capital letters within the same line and with the same small letters within columns did not differ according to Tukey's test. *) Significant increase as a result of Cu application.

The tested wheat cultivars differed significantly from one another in weight of 1,000 seeds. Copper application did not influence grain size of any tested cultivars (Table 7). The weight of 1,000 seeds from the control and Cu treatments was similar, including that of the cultivars responding positively to copper fertilization. This means that copper nutrition led to a higher number of grains in an ear rather than bigger grain size. The finding supports a well-known, positive influence of copper on the process of grain formation in wheat (Dell, 1981; Owuoche et al., 1994).

Table 7. Weight of 1000 seeds – average over 3 tested years (g)

Cultivar – *factor II*	Cu application – *factor I*		Mean
	0	+Cu	
Kobra	44.0	44.3	44.2 *b*
Zyta	43.4	43.8	43.6 *ab*
Sakwa	46.5	46.5	46.5 *c*
Jawa	39.0	38.8	38.9 *a*
Korweta	43.0	42.4	42.7 *a*
Mean	43.2 *A*	43.2 *A*	
Tukey LSD (α <0.05): Factor I – n.s., factor II – 0.989., IxII – n.s.			

Yields marked with the same capital letters within the same line and with the same small letters within columns did not differ according to Tukey's test.

The five wheat cultivars showed a tendency toward differentiated accumulation of copper in shoots and accumulated significantly different amounts of this element in grain (Table 8). Average over all cultivars showed that an application of Cu led to a considerable increase in the content of this element in shoots but did not cause a change in the content of Cu in grain. The cultivar-related differences in copper accumulation in plant tissues have also been demonstrated by Owuoche et al. (1995).

The aggregate analysis of yields and Cu content in plant tissues showed that cv. Kobra was characterized by the highest Cu demand. In each year of the experiment, it responded with a significant yield increase to Cu application, and the three-year yield increase mean was the highest among the five tested wheat cultivars. At the same time, this cultivar had a lower Cu content in grain and shoots than the other cultivars.

The cultivars Zyta and Sakwa also responded positively to Cu, although the yield increases were neither as high nor as regular as the ones observed for cv. Kobra. The cultivar Zyta contained similar amounts of Cu in tissues to those found in cv. Kobra, whereas the level of this element in tissues of cv. Sakwa was comparable to the ones determined in the cultivars not responding to Cu, i.e. cv. Jawa and Korweta.

Table 8. Copper concentration in wheat shoots and grain–average over 3 years (mg kg^{-1})

Cultivar – *factor II*	Cu application – *factor I*					
	shoots			grain		
	0	+Cu	Mean	0	+Cu	Mean
Kobra	3.2	3.8	3.5 a	2.5	2.5	2.5 ab
Zyta	3.3	4.0	3.7 a	2.4	2.3	2.4 a
Sakwa	3.1	4.4	3.8 a	2.8	3.0	2.9 c
Jawa	3.3	4.8	4.1 a	2.8	2.7	2.8 bc
Korweta	3.4	4.4	3.9 a	2.9	2.9	2.9 c
Mean	3.3 A	4.3 B		2.7 A	2.7 A	
Tukey LSD (α <0.05)	*Factor I – 0.612, factor II – n.s., IxII – n.s.*			*Factor I – n.s., factor II – 0.362, IxII – n.s.*		

Yields marked with the same capital letters within the same line and with the same small letters within columns did not differ according to Tukey's test.

The cultivars Jawa and Korweta had the lowest Cu demand. These cultivars accumulated more Cu in tissues than the other cultivars. Although copper application led to a significantly higher accumulation of Cu in shoots, this was not accompanied by a significant increase in grain yield. This finding confirms that cv. Jawa and Korweta could utilize the copper found in soil much more efficiently than the other tested wheat cultivars.

The differences in copper demand between the tested wheat cultivars, resulting from different efficiency in copper utilization, have also been demonstrated by Owuoche et al. (1994, 1995) and Piening et al. (1989).

CONCLUSIONS

1. The five tested winter wheat cultivars differed significantly in their nutritional demand for copper. At the same concentration of Cu in soil, three out of the five wheat cultivars responded to foliar copper application with 5-9% grain yield increase while the other two cultivars did not respond to the treatments.

2. Copper application caused an increase of this element in shoots but not in grain of all five wheat cultivars.

3. The tested wheat cultivars differed significantly in the content of copper in grain.

4. Copper fertilization did not influence the size of wheat grains in any of the tested cultivars. It is most probable that copper nutrition led to a higher number of grains in an ear rather than their larger size.

5. Due to existing differences in the demand for copper between individual winter wheat cultivars, a decision whether wheat fields should be fertilized with this element needs to be made based not only on the abundance of Cu in soil, but also on the wheat cultivar to be grown.

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