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Assessing the impact of foliar fertilization with manganese and copper on the yield and chemical composition of spring barley

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Abstract. The study assessed the impact of foliar fertilization with manganese and copper on the yield, yield structure features, SPAD, LAI, and the chemical composition of 4 spring barley cultivars. It has been demonstrated that the cultivars responded to the applied foliar fertilization with manganese and copper with yield increases. In the case of hulled cultivars Hajduczek and Promyk, as well as in the hulless cultivar Gawrosz, higher yield increases, compared to those in the control treatment, were observed after foliar fertilization with manganese than with copper. The cultivar Suweren responded more favourably to foliar fertilization with copper than with manganese. Foliar fertilization with copper resulted in a higher number of ears per 1 m^2 and number of grains per ear and a lower weight of a 1000 grains. The relative chlorophyll content in F-2 leaves was higher in the cultivars fertilized with copper, compared to manganese; the opposite was true only for Suweren. The LAI index depended on the cultivar and the microelement used. The cultivars Hajduczek and Gawrosz demonstrated the most favourable LAI index. The analysis revealed a higher contents of both total protein and crude ash in the chemical composition of grains from micronutrient treated plots vs. the control plots. Larger increases in comparison to the control were observed after the application of copper than manganese.

Keywords: spring barley, copper, manganese, foliar fertilization, grain yield, SPAD, LAI, chemical composition of a grain

INTRODUCTION

The condition required for obtaining high grain yields of good quality is the use of soil fertilization combined with the foliar application of fertilizers, which works almost immediately and allows a high efficiency to be achieved while using a small amount of the element (Michałojć, Szewczuk, 2003). The foliar application of components that are absorbed by plants in relatively small amounts, e.g. microelements, is particularly beneficial. In Poland, foliar application of fertilizers is widely used in the cultivation of cereal crops, including barley. It is effective if it is carried out in the phase of stem formation and during periods of soil drought, when the plant cannot absorb nutrients from the soil in sufficient quantities (Czuba, 2000; Michałojć, Szewczuk 2003). Manganese and copper are microelements that play an important role in the yield formation of spring barley, and their deficit reduces the intensity of photosynthesis and increases the intensity of plant respiration instead. Copper is an important component influencing the synthesis of plant growth hormones (Kabata-Pendias, Pendias, 1993). In the relevant literature, there is little information on the effect of foliar application of manganese and copper on grain yield, SPAD and LAI indices, as well as the chemical composition of new cultivars of spring barley, including the hulless cultivars of this cereal.

Therefore, research was undertaken to assess the response of three hulled cultivars of spring barley: Suweren, Hajduczek, Promyk and one hulless cultivar, Gawrosz, to the foliar application of ADOB 2,0 Cu and ADOB 2,0 Mn agents. These are agents containing manganese and copper, that is, microelements that play an important role in the yield formation of barley whose content in the soil is insufficient in many regions (Kucharzewski, Dębowski, 2000).

A research hypothesis was adopted, which assumes the increase of grain yield and the improvement of its quality in four cultivars of spring barley, after the foliar application of manganese and copper.

MATERIALS AND METHODS

The field experiment was carried out in the years 2014–2016 in the experimental field operated by the Faculty of Biology and Agriculture of the University of Rzeszów in Krasne near Rzeszów, Poland. The experiment was carried

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out in a split-plot design in four replications. The following factors were taken into account in the study: factor I: spring barley cultivar: Suweren, Hajduczek, Promyk and Gawrosz, factor II: foliar fertilization (control, fertilization with Cu (ADOB 2,0 Cu IDHA) and fertilization with Mn (ADOB 2,0 Mn IDHA)). The ADOB 2,0 fertilizers constitute groups of foliarly-applied products intended for supplementing shortages of macro- and micronutrients (Table 1). The micronutrients were chelated with a biodegradable IDHA chelate by the manufacturer to increase the absorption of micronutrients whose effects last longer.

Foliar fertilization was applied in the phase of tillering (BBCH 25) and stem formation (BBCH 35) at 1 dm^3 ha^{-1} for ADOB Cu and 2 dm^3 ha^{-1} for ADOB 2.0 Mn. The area of plots for harvesting totalled 16.5 m^2. The forecrop of barley was mustard cultivated for seeds.

The experiment was carried out on a brown soil created from loess, rated as a good wheat complex, IIIa quality class. The content of mineral nitrogen in the soil totalled 0.80 mg 100 g DM (low content). The content of macroelements in the soil (mg/100 g DM) totalled: 10.3 P_2O_5 (low content), 19.1 K_2O (average content) and 3.87 Mg (low content). The content of micronutrients in the soil was expressed in mg/1000 g DM: Cu – 4.3 (low content) and Mn – 176.7 (average content) (Gorlach, Mazur, 2001). The soil pH was slightly acidic (pH 5.62). After harvesting the forecrop, after-harvest and pre-winter measures (skimming, harrowing and pre-winter ploughing) were carried out. In the spring, mineral fertilizers were sown and a cultivation unit consisting of a cultivator and a string roller was used. Phosphorus in the amount of 70 kg ha^{-1} P_2O_5 and potassium in the amount of 90 kg ha^{-1} K_2O were supplied to the soil before sowing, in the form of granulated superphosphate and 60% potassium salt. In the study years, spring barley grains were sown in the first and second decade of April (8/4/2014: 6/4/2015: 14/04/2016) using a grain drill in a row spacing of 12.5 cm and at a sowing density of 350 grains per 1 m^2. The seeds were dressed with Funaben T in the amount of 200 g per 100 kg of grains. The cultivation practices were in line with the recommendations for spring barley (Research Centre for Cultivar Testing). During the vegetation period, the plants were sprayed with the following agents: Chwastox Turbo in the amount of 2 l ha^{-1}, Falcon 465 in the amount of 0.6 l ha^{-1} and Bi 58 Nowy 400 EC in the amount of 0.5 l ha^{-1}.

Before harvesting the plants, the number of ears per 1 m^2 was determined. The LAI index was evaluated twice during vegetation, i.e. in the stem formation phase (BBCH 35) and in the earing phase (BBCH 58), using the LAI-2000 device by LI-COR Inc. The relative chlorophyll content in F-2 leaves was also assessed using the SPAD-502 Plus Chlorophyll Meter (Konica Minolta) 7 days after the application of manganese and copper. 20 F-2 leaves were analysed from each subject of the experiment. Before the harvest, 20 representative plants were randomly selected from each plot in order to determine yield components such as: the number of ears per 1 m^2, the number of grains in the ear and the weight of a 1000 grains. Each year, the harvest of barley was carried out in the third decade of July. Grain yield was determined from on average from a plot, calculated at 15% moisture. In order to determine grain humidity and perform chemical analyses, approx. 2 kg of grains were collected from each plot. Chemical analyses of the grain were carried out in the laboratory of the Department of Crop Production the Faculty of Biology and Agriculture of the University of Rzeszów. They included the assessment of total protein, crude fat, crude fibre and crude ash content in accordance with the Polish designation norms.

The results were analysed statistically using analysis of variance. The significance of differences was determined using Tukey's test at a significance level of α = 0.05.

Table 1. Chemical composition of foliar fertilizers in % weight.

Fertilizer	$N\text{-}NO_3$	Mn	Cu
ABOB Cu IDHA	2.00	-	4.4
ABOB Mn IDHA	-	9.0	-

RESULTS

The pattern of weather conditions during barley vegetation period varied across study years (Table 2). Optimal conditions prevailed in 2014. High and favourably distributed rainfall in June and in the beginning of July resulted in good grain plumpness and barley yields were the highest. Less favourable weather conditions prevailed in 2015 and 2016. The drought in June in 2015 and May in 2016, caused accelerated plant maturation and weaker grain plumpness, especially in 2015.

The cultivars responded differently to the applied foliar fertilization with copper and manganese (Table 3). In the hulled cultivars Hajduczek and Promyk, as well as the hulless cultivar Gawrosz, a greater yield increase compared to the control was found after foliar fertilization with manganese than with copper. The cultivar Suweren responded better to foliar fertilization with copper and was characterized by the highest grain yield. Among the yield components, significant interactions were demonstrated for the weight of a 1000 grains. In the cultivar Promyk, fertilization with copper, in comparison to fertilization with manganese, caused an decrease in this feature amounting to 1.9 g. In the cultivar Gawrosz, both manganese and copper, in comparison to the control, caused an increase in the weight of a 1000 grains, by 4.9% and 6.6% respectively.

In comparison to the control, spring barley plants obtained a larger number of ears per 1 m^2 and a larger num-

Table 2. Weather conditions during vegetation period of study years.

Year	Month						
	III	IV	V	VI	VII	VIII	III–VIII
			Mean air temperature [°C]				
2014	6.7	10.1	14.1	16.3	20.1	18.1	14.2
2015	4.7	8.6	13.0	17.6	19.9	21.4	14.2
2016	4.7	10.0	13.9	18.7	19.3	18.0	14.1
2014–2016	5.4	9.6	13.7	17.5	19.8	19.2	14.2
2003–2013	3.3	9.7	13.6	18.1	19.8	19.1	13.9
			Sum of rainfall [mm]				
2014	37.8	29.9	92.2	48.1	57.1	46.8	312.1
2015	38.0	25.7	85.1	8.9	52.4	6.1	216.2
2016	21.9	51.1	19.9	41.1	31.6	35.1	200.8
2014–2016	32.6	35.6	65.7	32.7	47.0	29.3	243.0
2003–2013	45.4	33.8	88.2	106.5	113.7	51.4	438.9
			Days with rainfall >0.5 mm				
2014	12	18	15	10	14	21	5
2015	12	13	15	6	11	3	3
2016	8	15	15	19	11	9	4
2014–2016	10.7	15.3	15	11.7	12	11	4

Table 3. Yield and yield components of spring barley in dependent of manganese and copper fertilization.

Cultivar (I)	Foliar fertilization microelements (II)	Grain yield [Mg ha^{-1}]	Ear density before harvest [no. m^{-2}]	Number of grains per ear [no.]	1000 grains weight [g d.m.]
Suweren	control	4.34	567	15.1	44.2
	Adob Mn	4.45	581	16.3	45.1
	Adob Cu	4.68	597	16.8	44.1
Hajduczek	control	3.53	458	14.9	48.5
	Adob Mn	4.26	461	16.4	49.5
	Adob Cu	4.10	485	15.7	49.3
Promyk	control	4.01	468	15.2	47.0
	Adob Mn	4.63	502	16.3	48.8
	Adob Cu	4.21	488	16.5	46.9
Gawrosz#	control	3.57	498	14.7	41.0
	Adob Mn	3.80	553	15.3	43.0
	Adob Cu	3.72	533	15.4	43.7
$HSD_{\alpha=0.05}$ I×II		0.231	n.s.	n.s.	1.82
		Mean			
Suweren		4.49	582	16.0	44.5
Hajduczek		3.96	468	15.7	49.1
Promyk		4.28	486	16.0	47.5
Gawrosz#		3.70	535	15.1	42.6
$HSD_{\alpha=0.05}$		0.60	49.6	0.63	1.42
control		3.86	498	15.0	45.2
Adob Mn		4.29	524	16.0	46.6
Adob Cu		4.18	531	16.1	46.0
$HSD_{\alpha=0.05}$		0.42	3.94	0.44	0.54
2014		4.69	558	15.8	47.9
2015		3.52	479	15.6	44.0
2016		3.69	516	16.9	47.3
$HSD_{\alpha=0.05}$		0.57	5.23	0.399	0.22

naked-grain cultivar

n.s. – non significant difference

Table 4. Relative chlorophyll content in underflag leaves and leaf area index of spring barley cultivars in dependent of manganese and copper fertilization.

Cultivar (I)	Foliar fertilization microelements (II)	SPAD	LAI [m^2 m^{-2}]
Suweren	control	39.50	3.70
	Adob Mn	41.20	4.10
	Adob Cu	40.60	3.89
Hajduczek	control	41.80	4.31
	Adob Mn	42.90	4.56
	Adob Cu	44.30	4.61
Promyk	control	35.60	4.10
	Adob Mn	36.80	4.31
	Adob Cu	39.10	3.46
Gawrosz#	control	38.10	3.61
	Adob Mn	39.70	3.81
	Adob Cu	40.60	4.10
$HSD_{\alpha=0.05}$ I×II		0.89	0.31
Means			
Suweren		40.43	3.9
Hajduczek		43.00	4.5
Promyk		37.17	3.6
Gawrosz#		39.47	4.0
$HSD_{\alpha=0.05}$		2.36	1.27
kontrola		38.75	3.93
Adob Mn		40.15	4.20
Adob Cu		41.51	4.02
$HSD_{\alpha=0.05}$		2.78	0.201
2014		42.2	3.89
2015		39.2	3.26
2016		41.10	4.10
$HSD_{\alpha=0.05}$		1.98	0.71

naked-grain cultivar

ber of grains per ear when fertilized with copper than with manganese. They were characterized by a lower grain yield. Although it was not confirmed statistically, it demonstrated an downward trend.

The response of barley to foliar fertilization also depended on the pattern of weather conditions during study years. The weather conditions in 2014 were optimal for the development of barley, when the highest grain yield, number of ears per 1 m^2 and weight of a 1000 grains were obtained. The least favourable weather conditions during the plants' vegetation period prevailed in 2015, when the lack of rainfall during the heading and filling of grains contributed to the reduction in the number of ears per 1 m^2 and the weight of 1000 grains (Table 3).

The relative chlorophyll content (Table 4) in sub-phagus leaves was higher in the cultivars fertilized with copper in comparison to manganese, except for Suweren. The higher relative chlorophyll content in the leaves after the application of copper was also demonstrated regardless of the cultivar. The biggest one was obtained by Hajduczek and the smallest one – by Promyk. Over the three-year study period, the highest relative chlorophyll content in the leaves of spring barley cultivars was observed in 2014, and the lowest in 2015 (Table 4).

The LAI index depended on the variety and type of foliar fertilization. The most favourable one was obtained by Hajduczek, when the smallest Promyk. Suweren cultivar showed an increase of this index by 10.8% compared to the control after the foliar application of manganese. In the case of Promyk, foliar fertilization with copper caused a significant decrease in LAI compared to fertilization with manganese and with the control, by 19.7% and 15.6% respectively. The hulless Gawrosz responded with an increase in LAI amounting to 13.6% compared to the control after the application of copper. A greater increase in this index, by 6.9% compared to the control, was observed in plants fertilized foliarly with manganese, rather than with copper (2.3%). The highest LAI index was shown by plants in 2016, and the lowest in 2015 (Table 4).

An analysis of the chemical composition of spring barley grain showed (Table 5) a higher content of total protein and crude ash in plants fertilized foliarly with micronutrients. A significantly higher increase in comparison to the control occurred after the application of copper, rather than manganese. Foliar fertilization with copper resulted in 0,4% increase of protein content in grain in comparison to manganese fertilization. The chemical composition of the grain also depended on the cultivar. The higher contents of protein, fibre and ash than in the hulless Gawrosz were characteristic of the hulled cultivars of barley, and the Suweren cultivar had the most favourable composition. A diversity of the chemical composition over study years was demonstrated. The highest content of protein, fibre and ash, as well as the lowest content of fat in the grain was accumulated by plants in 2016 (Table 5).

Table 5. Organic components and ash of spring barley grain in dependent of manganese and copper fertilization.

Cultivars (I)	Foliar fertilazation microelements (II)	Crude protein	Crude fat	Crude fiber	Crude ash
		[g kg^{-1} d.m.]			
Suweren	control	150.5	24.7	25	19
	Adob Mn	162.8	25.6	26	19
	Adob Cu	167.9	26.3	27	18
Hajduczek	control	149.0	24.5	37	15
	Adob Mn	164.0	24.3	39	17
	Adob Cu	157.3	26.3	44	20
Promyk	control	151.8	26.6	25	17
	Adob Mn	162.5	24.8	27	18
	Adob Cu	164.5	26.0	28	17
Gawrosz[#]	control	146.9	25.3	16	14
	Adob Mn	152.5	26.2	15	15
	Adob Cu	154.3	26.0	16	15
$HSD_{\alpha=0.05}$ IxII		n.s.	n.s.	7.8	2.3
Means					
Suweren		160.4	25.5	26	19
Hajduczek		156.8	25.0	40	17
Promyk		159.6	24.8	27	17
Gawrosz		151.2	25.8	15	15
$HSD_{\alpha=0.05}$		0.63	n.s.	7.5	0.9
control		149.5	25.3	26	16
Adob Mn		160.4	25.2	27	17
Adob Cu		161.0	26.1	29	18
$HSD_{\alpha=0.05}$		0.44	n.s.	n.s.	1.2
2014		158.4	24.3	22.0	16
2015		155.2	26.7	32.0	17
2016		168.5	23.2	34.0	18
$HSD_{\alpha=0.05}$		4.4	2.1	2.25	0.2

[#] naked-grain cultivar
n.s. – non significant differences

DISCUSSION

The purpose of foliar fertilization of cultivable plants is to quickly provide plants with ingredients, mainly microelements, whose content in the soil is too low, or whose absorption is made difficult by biotic or abiotic stress factors (Szewczuk, Michałojć, 2003; Tobiasz-Salach, Bobrecka-Jamro, 2003). Factors that hinder the access to the nutrients from the soil may include: inappropriate soil reaction, unfavourable pattern of weather conditions during the growing period, or limited access to the organic substances in the soil (Czuba, 2000). Numerous studies, especially those involving malted barley, indicate that the pattern of weather conditions during the growing period has a significant impact on the grain yield and its composition (Kozłowska, Liszewski, 2012; Barczak et al., 2005). This correlation was also demonstrated in studies involving spring barley intended for fodder (Liszewski, 2008). Over the study years, grain yield and its elements were dependent on the pattern of weather conditions during the growing period. Kozłowska and Liszewski (2012) indicate that the cultivars used and fertilization with microelements do not significantly affect the yield of malted barley. These views were not confirmed in our studies, involving cultivars of fodder spring barley. In fact, the influence of the cultivar and fertilization with microelements on grain yield and its components has been demonstrated over the three-year study period, and this correlation was more manifest after the application of manganese than of copper. Similar results were obtained by Barczak et al. (2005), Błażewicz et al. (2015) and Ruszkowska and Wojcieska-Wyskupajtys (1996). The statistical analysis also showed a more beneficial effect of manganese on the yield and 1000-grain weight, as well as copper on number of ears per 1 m^2 and number of grains per ear. These results are consistent with the studies by Barczak et al. (2005), who report the positive effect of manganese applied independently (without the addition of other microelements) on the yield and yielding elements of spring barley.

Mineral components, that is, the macro- and microelements present in the soil, have a great influence on the state of plant nutrition. There is a close, positive correlation between the state of plant nutrition with macro- and microelements, and the relative and actual chlorophyll content in leaves, as well as the LAI index (Appenroth et al., 2000; Kalaji et al., 2004). In the case of a deficit in elements, especially nitrogen, plants have a small assimilation area, are characterized by a lack of firmness, which affects the size and quality of the yield. Excessive doses of fertilizers (especially macroelements) cause the undue lushness of plants and accelerate the ageing of leaves and leaf sheaths of lower layers. In our own studies, the relative chlorophyll content in leaves and the leaf area index depended on the cultivar and application of foliar fertilization. Over the three-year study period, foliar fertilization increased the value of the SPAD and the LAI index in comparison to the control. A greater increase in the SPAD value in comparison to that in the control was noted after the application of copper, while LAI values increased after the application of manganese. The influence of weather conditions on these features was also shown. The most favourable weather prevailed in 2016 and the least favourable in 2015.

In the relevant literature, there is much information about the role of microelements in the transformation of nitrogen compounds, and especially in protein synthesis (Czuba, 2000; Grzywnowicz-Gazda, 1983). Copper participates in many enzymatic reactions and, as the conveyor of electrons, it has a versatile effect on the physiological processes in plants and its deficiency disturbs the process of photosynthesis. Manganese influences the reduction of nitrates and the hydrolysis of peptides and amides. Barczak and Kozera (2003), as well as Liszewski and Błażewicz (2015) report that the application of micronutrients in the cultivation of spring barley contributes to the increase of protein in the grain. These dependencies were confirmed in our own studies. Barley fertilized with copper accumulated more protein, fat, fibre and ash in the grain compared to the control. The increase of protein content was also demonstrated after the application of manganese, though it was smaller.

CONCLUSIONS

1. The size of grain yield and yield elements of spring barley varied across study years and depended on the selected cultivar and foliar nutrition applied.
2. Foliar fertilization with manganese resulted in a higher increase in the yield of Hajduczek, Promyk and Gawrosz cultivars compared to copper. Suweren responded better to copper fertilization compared to the response of manganese.
3. Copper fertilization caused a greater increase in the relative chlorophyll content in leaves compared to manganese in the studied cultivars of barley (except for Suweren, which responded better to manganese fertilization compared to copper).
4. A greater increase in the LAI index compared to the control was observed in plants fertilized with manganese, rather than copper.
5. In the treatments fertilized foliarly with micronutrients, there was a higher content of total protein and crude ash in the grain, and a larger increase in comparison to the control was found after the application of copper than manganese.

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