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RESPONSE OF SPRING BARLEY TO FOLIAR FERTILIZATION WITH Cu AND Mn

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ABSTRACT

Background. Spring barley grain yield and chemical composition depend on mineral fertilization as well as soil and climatic conditions during plant growth. It is especially important to provide fertilization with microelements that are connected with photosynthesis and respiration rate. The aim of this study was to evaluate the effect of foliar fertilization with manganese and copper on grain yield and its components, chlorophyll content in leaves, selected chlorophyll fluorescence indexes, leaf area index (LAI) and the chemical composition of grain in 3 spring barley fodder cultivars and 1 malting cultivar.
Material and methods. The field experiment was carried out during 2014–2016 at the Experimental Station for Variety Testing in Dukla (49°55' N; 21°68' E), in a split-plot design in 4 repetitions. The study factors were: 4 spring barley cultivars and foliar feeding (control, Cu and Mn).
Results. The foliar fertilizers used in the experiment increased grain yield, ear density, number of grains per ear and 1000 grain weight. The content of chlorophyll in subflag leaves was usually higher in cultivars fertilized with copper compared to manganese, with only the cultivar Suweren having an inverse relationship. Copper application favorably increased the value of the PSII functioning index both compared to the control and to fertilization with manganese. The LAI index was dependent on the cultivar and the foliar feeding. A slight tendency to a higher content of total protein and raw ash on plants fertilized with foliar micronutrients was observed. A larger increase of these contents in comparison to the control was found after the application of copper than of manganese.
Conclusion. Spring barley yield, yield structure components, the relative content of chlorophyll in the leaves, LAI index and chemical composition of grain depended on the weather conditions during the plant growing periods. Foliar feeding with manganese resulted in an increase in grain yield and 1000 grain mass when compared to foliar feeding with copper. Copper fertilization resulted in a greater increase in the relative content of chlorophyll in the leaves and a higher content of total protein and crude ash in the grain compared to manganese fertilization. A greater increase in the LAI index compared to the control was observed in plants fertilized with manganese rather than with copper.

Key words: CCI, foliar fertilization, Fv/Fm, grain chemical composition, grain yield, LAI, PI, spring barley, yield structure components

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INTRODUCTION

An insufficient amount of nutrients in plants causes disturbance of basic physiological processes, weakens the plants growth and development and contributes to lower grain yields. Copper and manganese are necessary as components of the organic compounds involved in the biosynthesis of photosynthetic pigments, especially in the light phase of photosynthesis. They also participate in the synthesis of carbohydrates and lipids. Under the conditions of a deficiency of copper, pollen production and its viability are reduced while a lack of manganese causes a reduction in protein and of nucleic acid biosynthesis (Ruiz, 1998; Henriques, 2003). In recent years we have observed an increase in good-quality grain crops as a result of the combined use of soil fertilization and foliar feeding. Absorption of magnesium, iron, manganese and zinc by barley plants continues until the heading stage, while for nitrogen and copper it is until the flowering stage - Fertilization with micro and macronutrients is especially effective when the plant cannot take up nutrients from the soil in sufficient quantities, e.g. in periods of soil drought such as have been observed in recent years (Czuba, 2000; Michołojć and Szewczuk, 2003). Therefore, research was undertaken to evaluate the response of three spring fodder barley cultivars (Suweren, Saldo and Iron) and one malting cultivar (Olympic) to foliar feeding with ADOB 2.0 Cu and ADOB 2.0 Mn. These are preparations containing manganese and copper, i.e. micronutrients that play an important role in the yield and quality of spring barley grain (Kucharzewski and Dębowski, 2000).

The research hypothesis that was adopted assumes an increase in grain yield and an improvement in its quality from spring barley cultivars after foliar application of manganese and copper.

MATERIAL AND METHODS

The field experiment was carried out in 2014–2016 at the Experimental Station for Variety Testing in Dukla, the Low Beskids mesoregion (49^{o}55’ N; 21^{o}68’ E), in a split-plot design in 4 repetitions. The following factors were included in the study: Factor I: spring barley cultivars – fodder Suweren, Saldo and Iron and malting Olimpic; Factor II: foliar feeding (control, copper fertilization and manganese fertilization). ADOB 2.0 fertilizers are groups of foliar products intended to eliminate deficiencies of macro- and micronutrients. Micronutrients – have been chelated with the IDHA (Iminodisuccinic acid – $C_8H_{11}O_8N$) biodegradable chelating agent to increase the bioavailability of longer-acting micronutrients. The composition of the fertilizers used is given in Table 1.

Table 1. Characteristics of the foliar fertilizers

Foliar fertilizer composition (weight %)	ADOB Cu IDHA	ADOB Mn IDHA
Manganese	–	9.0
Copper	10	–

Foliar fertilization was applied during the tillering (BBCH 27) and shooting stages (BBCH 38) at a dose of Cu – 1 $dm^3 \cdot ha^{-1}$ and Mn – 2 $dm^3 \cdot ha^{-1}$. The plot area to be harvested was 18 m^2. The crop previous to barley was pea. The area of the experiment included weathering soils with a significant skeletal content, lying on the slope of a hill – in the type of leached brown soils with a granulometric composition of silty clay and heavy silty loams. From the point of view of the agronomic category it can be included in the category of heavy soils. In terms of the fodder value it was soil of the mountain cereal complex, quality class IVb. It was characterized by a slightly acid reaction (pH 5.72) and a low value of hydrolytic acidity (1.12 cmol (+) kg d.m.). The soil sorption complex had a high sorption capacity (24.72 cmol (+) kg d.m.) and was saturated with basic cations at a level of nearly 95%. The organic carbon content was high and amounted to 12.6 $g \cdot kg^{-1}$. The content of mineral nitrogen in the soil was 1.51 $g \cdot kg^{-1}$ d.m. The content of available forms of macronutrients in the soil was in mg per kg of the soil: 17.7 P_2O_5 (medium abundance), 243 K_2O (medium abundance) and 8.2 Mg (medium abundance). The content of micronutrients in the soil was also determined in mg per kg d.m. of the soil: Cu – 24.6 (medium abundance) and Mn –

376.1 (medium abundance) (Gorlach and Mazur, 2001 for abundance classification).

After harvesting the previous crop, standard pre-winter – and post-winter – cultivating measures (skimming, harrowing, fall plowing) were made. In spring, mineral fertilization was applied and a tillage unit composed of a cultivator and a string roller was used. Phosphorus in the amount of 80 kg·ha^{-1} P_2O_5 and potassium in the amount of 100 kg·ha^{-1} K_2O were used before sowing in the form of granulated superphosphate and potassium salt 60%. In the years of the study the spring barley grain was sown between the 1st and 20th of April with a grain drill at a row spacing of 12.5 cm and a seeding rate of 350 grains per 1 m^2. The seed had been treated with the Funaben T seed dressing at a rate of 200 g per 100kg of grain. The barley crop cultivation was in line with the recommendations of Gacek (2016). During the growing season, Chwastoks Turbo was sprayed in an amount of 2 dm^3·ha^{-1}, Falcon 465 in an amount of 0.6 dm^3·ha^{-1} and Bi 58 Nowy 400 EC in an amount of 0.56 dm^3·ha^{-1}.

Ear density per 1 m^2 was calculated before harvesting. During growth, at (BBCH 39) – shooting and (BBCH 51) – earing, the leaf area index was assessed using a LAI – 2000 device from LI-COR Inc. The relative chlorophyll content in CCI subflag leaves was also assessed with a Chlorophyll Content Meter-CL-01 and a chlorophyll fluorescence analysis was carried out with a Packet PEA Fluorimeter (Plant Efficiency Analyser). Both devices were made by Hansatech Instruments Ltd., England. The analysis was performed 10 days after the foliar application of the manganese and copper. Fluorescence analysis was carried out on 20 leaves from the middle of the leaf blade of a fully developed subflag leaf on each test treatment, after 30 minutes of adaptation of the leaf to the dark. The given measurements are average values. Maximum performance index PSII (Fv/Fm) and PSII functioning index (PI) were determined (Lazar, 1999; Kalaji and Łoboda, 2009).

Before harvest 20 representative plants were randomly taken from each plot to determine the yield components, such as ear density per 1 m^2, the number of grains per ear and 1000 grain weight. In the years of the study the barley grain was harvested between the 20th and the 31st of July and the calculations were conducted at 15% humidity. The grain was subjected to laboratory analysis in which the content of total protein, crude fat, crude fiber and crude ash were assessed. Chemical analyzes were performed in the laboratory of the of the Plant Production Unit using a Bruker FT NIR MPA Spectrometer (Billerica, USA).

The obtained study results were statistically analyzed by means of variance analysis. The significance of differences was determined by Tukey's test for significance level $P < 0.05$.

RESULTS

The weather pattern during the barley growing period varied during the years of the study (Table 2). The most optimal conditions were in 2014. High and favorably distributed rainfalls in May, June and July caused good grain filling and barley yields were the largest. Less favorable weather conditions prevailed in 2015 and 2016. Drought in July in 2015 and in May and June in 2016 caused an acceleration of plant maturation and limited grain filling, especially in 2015.

The studied barley cultivars responded differently to foliar feeding with copper and with manganese (Table 3). In the fodder cultivars Soldo and Iron and the malting cultivar Olympic a greater increase in yield, relative to the control, was demonstrated after foliar feeding with manganese as compared to that with copper. The yield increase in the Soldo cultivar was 20.5%, in Iron 15.4%, and in Olympic 6.4%. In contrast, the cultivar Suveren responded better to foliar feeding with copper and obtained the overall highest grain yield. In this cultivar the increase in yield after foliar feeding with copper in relation to the control was 7.2%. Out of the analyzed cultivars (irrespective of fertilization) the Suweren cultivar was characterized by the highest grain yield and the Olympic malting cultivar by the smallest. On average, foliar fertilization with manganese, in relation to the control, caused a significant increase in grain yield in spring barley of 10.8%, which was confirmed by the conducted statistical analysis. After analyzing the yield components, significant interactions were found for ear density per 1 m^2 and 1000 grain weight. In the cultivar Olympic the ear density when manganese and copper were used was higher by 11% and 6.3%, respectively, compared to the control, while the 1000 grain weight – in this cultivar was lower on treatments with foliar fertilization compared to the control. The manganese fertilization resulted in a decrease in the 1000 grain weight by 9.2%, and copper by 10.1%. Of the barley cultivars studied (irrespective of foliar feeding) the lowest number of grains per ear and 1000 grain weight was found in the malting cultivar Olympic. The Soldo culivar had the highest weight of 1000 grains and on average it was 6.9 g higher than that of the Olympic cultivar (Table 3).

In comparison with the control, on average, the spring barley plants obtained a higher ear density per 1 m^2 (about 6.1%) and a higher number of grains per ear (about 7.6%) after fertilization with copper and these were higher than they were with manganese fertilization. However, these plants were characterized by a lower grain yield and 1000 grain weight – after copper application compared to the application of manganese.

The response of cultivars to foliar feeding also depended on the weather pattern in the years of the study. The most favorable weather conditions for spring barley development were in 2014 when the highest grain yield, ear density per 1 m^2 and 1000 grain weight were obtained. The least favorable weather conditions during the growing period of plants prevailed in 2015 and drought at the stage of ear formation and grain filling contributed to a decrease in ear density per 1 m^2 and 1000 grain weight. This was the year the lowest grain yield was obtained (Table 3).

An analysis of the relative chlorophyll content of the leaves showed that all cultivars of barley reacted with an increase in this parameters after the application of foliar fertilizers in comparison to the control. The relative content of chlorophyll in subflag leaves was higher in cultivars fertilized with copper compared to manganese except for the cultivar Suweren where this relationship was inversed. A higher chlorophyll content in the leaves after the application of copper was also shown, regardless of the cultivar. The highest content of chlorophyll was obtained by Soldo and the lowest by Iron. In the analyzed years of the study, spring barley cultivars had the most relative chlorophyll content in leaves in 2016 and the least in 2014 (Table 4).

Table 2. Weather conditions during barley growth

Year	Month						
	March	April	May	June	July	August	March–August
Means of air temperature, °C							
2014	6.3	9.2	13.2	14.9	19.3	17.3	13.4
2015	4.1	7.5	11.5	16.4	19.1	20.3	13.1
2016	3.7	9.7	12.9	17.6	18.6	17.2	13.2
2000–2013	3.6	6.7	11.6	16.1	18.8	21.1	12.9
Sum of rainfall, mm H_2O							
2014	61	61	130	78	234	71	635
2015	53	25	121	90	99	11	339
2016	49	73	60	37	167	91	477
2000–2013	56.4	36.8	98.2	89.1	119.7	61.4	461

Table 3. Effect of foliar fertilization on grain yield and grain yield shaping characteristics

Cultivar (I)	Foliar fertilization variants (II)	Grain yield $Mg \cdot ha^{-1}$	Ear density $No. \cdot m^{-2}$	Number of grains per ear No.	1000 grain weight g d.m.
Suweren	control	4.56	595	15.8	46.5
	manganese	4.68	610	17.1	47.3
	copper	4.91	627	17.6	46.4
Soldo	control	3.71	481	15.6	50.9
	manganese	4.47	484	17.2	52.0
	copper	4.30	509	16.5	51.7
Iron	control	4.21	492	15.9	49.3
	manganese	4.86	527	17.1	51.2
	copper	4.42	513	17.3	49.2
Olympic*	control	3.75	523	15.4	47.8
	manganese	3.99	581	16.0	44.7
	copper	3.90	560	16.2	43.4
$HSD_{P<0.05}$ I × II		**0.41**	**36.3**	**ns**	**2.13**
	Mean				
	Suweren	4.71	611	16.8	46.7
	Soldo	4.16	491	16.5	51.6
	Iron	4.50	510	16.8	49.9
	Olympic*	3.88	562	15.9	44.7
	$HSD_{P<0.05}$	**0.63**	**52.6**	**0.7**	**4.5**
	control	4.06	523	15.7	47.5
	manganese	4.50	550	16.8	48.9
	copper	4.38	557	16.9	48.3
	$HSD_{P<0.05}$	**0.14**	**15.6**	**0.25**	**0.41**
	Mean	4.31	544	16.5	48.2
	2014	4.92	586	16.6	50.3
	2015	3.70	503	16.3	46.2
	2016	3.87	542	17.7	49.7
	$HSD_{P<0.05}$	**0.60**	**5.49**	**0.419**	**0.227**

*malting cutivar, ns – not-significant differences

Table 4. Effect of foliar fertilization on chlorophyll content in subflag leaves and leaf area index (LAI)

Cultivar (I)	Foliar fertilization variants (II)	CCI	PI	Fv/F_M	LAI
Suweren	control	42.7	2.72	0.813	4.0
	manganese	44.5	3.29	0.823	4.4
	copper	43.8	3.57	0.828	4.2
Soldo	control	45.1	3.18	0.843	4.7
	manganese	46.3	3.47	0.830	4.9
	copper	47.8	4.08	0.832	5.0
Iron	control	38.4	3.78	0.823	4.4
	manganese	39.7	4.03	0.849	4.7
	copper	42.2	4.98	0.851	3.7
Olympic*	control	41.1	4.01	0.822	3.9
	manganese	42.9	3.87	0.825	4.1
	copper	43.8	4.66	0.839	4.4
$HSD_{P<0.05}$ I × II		1.21	ns	ns	0.4
Mean					
Suweren		43.7	3.20	0.821	4.2
Soldo		46.4	3.58	0.835	4.8
Iron		40.1	4.26	0.841	3.8
Olympic*		42.6	4.18	0.829	4.3
$HSD_{P<0.05}$		1.96	0.98	ns	0.59
control		41.9	3.42	0.825	4.2
manganese		43.4	3.67	0.832	4.5
copper		44.4	4.32	0.837	4.3
$HSD_{P<0.05}$		2.69	0.628	ns	0.18
2014		41.1	3.93	0.828	4.2
2015		44.4	3.68	0.835	4.6
2016		45.5	3.57	0.837	4.4
$HSD_{P<0.05}$		1.98	ns	ns	0.24

*malting cultivar, ns – not-significant differences, CCI – relative chlorophyll content, PI – Performance Index, Fv/Fm – Maximum quantum efficiency of Photosystem II, LAI – leaf area index

The work also analyzed the response of the photosynthetic apparatus to foliar feeding with manganese and copper. It was shown that the application of copper favorably increased the value of the PSII functioning index compared to the control and to fertilization with manganese. The highest PSII value was obtained by Iron and the lowest by Suweren. However, no effect of foliar feeding on the value of an indicator of the maximum photochemical efficiency of PSII (Fv/Fm) was observed in the study (Table 4).

The most favorable LAI index was obtained by plants of the cultivars Soldo and Olympic, and the least favorable by Iron. It increased in Soldo and the malting Olympic by 6% and 11.8%, respectively, compared to the control, after the application of copper. In the cultivar Iron, however, copper fertilization caused a decrease in this index compared to fertilization with manganese and to the control by 21.3% and 15.9%, respectively. A greater increase in LAI compared to the control was observed in plants fertilized with manganese than with copper. The highest LAI index was obtained by plants in 2015 and the lowest in 2014.

Analysis of the chemical composition of spring barley grain (Table 5) showed a higher content of total protein and crude ash in plants after micronutrient foliar fertilization. A larger total protein and crude ash increase compared to the control occurred after the application of copper than manganese. Barley fodder cultivars had a higher content of protein, fiber and ash than the malting cultivar. The cultivar Suweren had the most favourable composition. Copper fertilization resulted in an increase in fiber and ash content in spring barley grain compared to the control and to manganese fertilization.

An increase in fiber content by 6.5% and ash content by 2.4% was observed with copper fertiliziation in relation to manganese fertilization. A diversity in the chemical composition of grain in the years of the study could be observed. The plants accumulated most protein, fiber and ash in grain in 2016 (Table 5).

Table 5. Effect of foliar fertilization on the content of organic components and raw ash in spring barley grain [$g \cdot kg^{-1}$ d.m.]

Cultivar (I)	Foliar fertilization variants (II)	Crude protein	Crude fat	Crude fiber	Crude ash
1	2	3	4	5	6
Suweren	control	177.6	29.1	29.0	222
	manganese	192.0	30.2	31.3	21.9
	copper	198.1	31.0	32.4	21.4
Soldo	control	175.8	28.9	43.7	17.6
	manganese	193.5	28.6	46.6	20.2
	copper	185.6	31.0	51.9	24.1
Iron	control	179.1	31.4	29.6	19.8
	manganese	191.8	29.2	31.7	21.0
	copper	194.1	30.6	33.1	20.5
Olympic*	control	173.3	29.8	18.6	17.1
	manganese	180.0	30.9	17.7	18.1
	copper	182.0	30.7	18.4	17.3
$HSD_{P<0.05}$ I × II		**ns**	**ns**	**0.88**	**0.53**

Table 5 continue

1	3	4	5	6
	Mean			
Suweren	189.2	30.1	30.9	21.8
Soldo	185.0	29.5	47.4	20.6
Iron	188.3	30.4	31.4	20.4
Olympic*	178.4	30.5	18.3	17.5
$HSD_{P<0.05}$	**0.98**	**ns**	**8.6**	**2.1**
control	176.4	29.8	30.2	19.2
manganese	189.3	29.7	31.8	20.3
copper	189.9	30.8	34.0	20.8
$HSD_{P<0.05}$	**0.35**	**ns**	**0.85**	**0.92**
2014	186.9	28.7	26.4	19.0
2015	183.1	31.5	37.5	20.2
2016	198.8	30.1	40.4	20.7
$HSD_{P<0.05}$	**5.20**	**0.43**	**2.70**	**0.23**

* malting cutivar, ns – not-significant differences

DISCUSSION

Foliar fertilization of crop plants is a quick method of providing plants with components, mainly micronutrients, whose content is too low in the soil or their uptake is difficult due to biotic or abiotic stress (Szewczuk and Michołojć, 2003; Tobiasz-Salach and Bobrecka-Jamro, 2003). Factors that impede the access of minerals from the soil may be inadequate soil reaction, adverse weather conditions during the growing season, or limited access of soil organic substances (Czuba, 2000). Numerous studies, especially with malting barley, show that the weather conditions during the growing period have a decisive impact on grain yield and its components (Barczak *et al*., 2005; Kozłowska and Liszewski, 2012). This relationship has also been demonstrated in studies with spring barley intended for feed (Liszewski, 2008). In the years of this study, grain yield and its components were dependent on the weather during the growing season. Kozłowska and Liszewski (2012) indicate that the varietal factor and micronutrient fertilization do not significantly affect malting barley yield. These views were not confirmed in the present study. The effect of the cultivar and micronutrient fertilization on grain yield and its components was demonstrated in each year of the study, and this relationship was more pronounced after applying manganese as compared to copper. Similar results were obtained by Barczak *et al*. (2005), Błażewicz *et al*. (2015) and Ruszkowska and Wojcieska-Wyskupajtys (1996). Statistical analysis showed the more favorable effect of manganese on 1000 grain weight-, and of copper on ear density and the number of grains per ear. These results are consistent with the study by Barczak *et al.* (2005), who report the positive effect of manganese applied alone (without the addition of other micronutrients) on the yield and yield components of spring barley.

Mineral substances occurring in the soil environment have a great impact on the nutritional status of plants. There is a close, positive correlation between the nutritional status of plants in macro- and micronutrients and the relative content of chlorophyll in their leaves, PI, Fv/Fm parameters and the LAI index (Appenroth *et al*., 2000; Kalaji *et al*., 2004; 2009). With a shortage of mineral elements plants are smaller in area and they lack firmness, which is reflected in the size and quality of the yield. Too high doses of fertilizers (especially macronutrients) cause excessive exuberance of plants and accelerate the aging of leaves and leaf sheaths of the lower floors of stalks. The Fv/Fm value is a reliable indicator of photosynthetic activity. Under stress-free conditions the Fv/Fm value can reach 0.83 for most plants. On the other hand low Fv/Fo values under high temperature conditions indicate a reduced efficiency of water photolysis reaction in PSII (Murkowski, 2002). In the present study the relative content of chlorophyll in the leaves (CCI), the PSII functioning index and the leaf area index (LAI) depended on the cultivar and the foliar feeding application. In each year of the study foliar fertilization increased the CCI value and LAI index when compared to the control. A greater increase in the CCI and PI values relative to the control was noted after the application of copper, and in the LAI values after the application of manganese. A better condition of the photosynthetic apparatus, measured by the PI index, was observed after the application of copper than of manganese. The influence of the weather conditions on these characteristics was also proved. Although the weather conditions for barley development were best in 2014, in 2014 lower LAI and CCI values were observed compared to 2015 and 2016.

There are many reports in the literature about the role of micronutrients in the transformation of nitrogen compounds, especially in protein synthesis (Czuba, 2000; Grzywnowicz-Gazda, 2006). Copper participates in many enzymatic reactions and as an electron transporter comprehensively affects physiological processes in plants, and any deficiency interferes with the process of photosynthesis and cellular respiration. Manganese affects the reduction of nitrates and the hydrolysis of peptides and amides. Barczak and Kozera (2003) and Liszewski and Błażewicz (2015) report that the use of micronutrients in spring barley cultivation contributes to an increase in the protein content in its grain and have a beneficial effect on its quality. These relationships were confirmed in the present study. Barley accumulated more protein, fat, fiber and ash in the grain after fertilization with copper compared to the control. Such an increase was also observed after applying manganese, but it was smaller.

CONCLUSIONS

1. Spring barley grain yield and yield structure components depended on the weather conditions during the plant growing period, the cultivar and the foliar feeding applied.
2. Foliar feeding with manganese compared to copper resulted in a greater increase in grain yield in the cultivars Soldo and Iron. The cultivar Suweren responded better to feeding with copper compared to manganese.
3. Copper fertilization in 3 of the barley cultivars resulted in a greater increase in relative chlorophyll content in the leaves and PSII functioning index compared to manganese fertilization. Only the cultivar Suweren responded better to feeding with manganese than with copper.
4. A greater increase in the LAI index relative to the control was observed in plants fed with manganese rather than with copper.
5. Barley plants fertilized with foliar micronutrients were characterized by a higher content of total protein and crude ash in grain, and, in comparison to the control, a greater increase was found after the application of copper than of manganese.

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REAKCJA JĘCZMIENIA JAREGO NA DOLISTNE DOKARMIANIE ROŚLIN

Streszczenie

Plon ziarna jęczmienia jarego i skład chemiczny są zależne od nawożenia mineralnego i warunków glebowo-klimatycznych w czasie wegetacji roślin. Szczególnie ważne jest nawożenie mikroelementami, które decyduje o fotosyntezie czy oddychaniu. Celem badań była ocena wpływu nawożenia dolistnego manganem i miedzią na plon ziarna i jego elementy, zawartość chlorofilu w liściach, wybrane wskaźniki fluorescencji chlorofilu, wskaźnik pokrycia liściowego łanu i skład chemiczny ziarna 3 odmian jęczmienia jarego paszowego i 1 odmiany browarnej. Doświadczenie polowe przeprowadzono w latach 2014–2016 na terenie Stacji Doświadczalnej Oceny Odmian w Dukli, mazoregion Beskid Niski (49°55’ N; 21°68’ E), metodą split-plot w 4 powtórzeniach. Badanymi czynnikami były odmiany jęczmienia jarego (Suveren, Soldo, Iron, Olympic) i dokarmianie dolistne (kontrola, Cu i Mn). Zastosowane w doświadczeniu nawozy dolistne wpłynęły na zwiększenie plonu ziarna, obsady kłosów, liczby ziaren z kłosa i masy 1000 ziaren. Zawartość chlorofilu w liściach podflagowych była wyższa u odmian nawożonych miedzią niż manganem, jedynie u odmiany Suweren zależność ta była odwrotna. Zastosowanie miedzi spowodowało wzrost wartości wskaźnika funkcjonowania PSII w porównaniu z kontrolą i nawożeniem manganem. Wskaźnik

LAI zależał od odmiany i dokarmiania dolistnego. Zauważono większą zawartość białka surowego, włókna i popiołu na obiektach nawożonych dolistnie mikroelementami. Większy wzrost, w stosunku do kontroli, stwierdzono po aplikacji miedzi niż manganu. Plonowanie jęczmienia jarego, elementów struktury plonu, względna zawartość chlorofilu w liściach, wskaźnik LAI oraz skład chemiczny ziarna zależały od przebiegu warunków pogodowych w okresie wegetacji roślin. Dolistne dokarmianie manganem spowodowało wzrost plonu ziarna i masy 1000 ziaren w porównaniu z aplikacją miedzi. Nawożenie miedzią spowodowało większy wzrost względnej zawartości chlorofilu w liściach, większą zawartość białka ogólnego i popiołu surowego w ziarnie w porównaniu z nawożeniem manganem. Z kolei większy wzrost wskaźnika LAI w stosunku do kontroli obserwowano u roślin dokarmianych manganem niż miedzią.

Słowa kluczowe: CCI, cechy struktury plonu, Fv/Fm, jęczmień jary, LAI, nawożenie dolistne, PI, plon ziarna, skład chemiczny ziarna