J. Elementol. 2008, 13(3): 291-300

CONTENTS AND RATIOS OF MINERAL COMPONENTS IN WINTER BARLEY BIOMASS CULTIVATED UNDER CONDITIONS OF DIFFERENT NITROGEN FERTILISATION

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Abstract

In 1999-2002, a strict two-factor field experiment was conducted at the University of Technology and Agriculture in Bydgoszcz to evaluate the effect of different nitrogen doses on the content and mutual ratios of macro-elements in green mass of winter barley in relation to barley growth stage. The experiment was established at the Research Station in Wierzchucinek near Bydgoszcz. The plant material consisted of samples of winter barley biomass taken at five stages of maturity: tillering, shooting (stem elongation), heading, initial grain filling and soft dough phases. The following nitrogen doses in $kg \cdot ha^{-1}$ were applied as ammonium nitrate: 0, 60, 120, 180. The results showed that the content of N, P, K, Ca, Mg and Na in winter barley vegetative mass decreased in the consecutive phenological phases, from tillering to soft dough. The largest decrease in the consecutive growth stages was detected for nitrogen and magnesium. With respect to nitrogen, phosphorus, calcium and sodium, their decrease in winter barley biomass during the growing season was generally higher in objects fertilised with nitrogen than in objects with no nitrogen fertilisation. In general, nitrogen had a positive effect on the content of the assayed macroelements in winter barley vegetative mass in all the growth phases. The ratio of the total content of nitrogen cations was observed to have attained the highest values in the later plant growth phases in the objects with no nitrogen or those fertilised with 60 kg N ha^{-1}.

Key words: winter barley, maturity stages, nitrogen, fertilization, macroelements.

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ZAWARTOŚĆ I PROPORCJE SKŁADNIKÓW MINERALNYCH W BIOMASIE JĘCZMIENIA OZIMEGO UPRAWIANEGO W WARUNKACH ZRÓŻNICOWANEGO NAWOŻENIA AZOTEM

Abstrakt

Materiał badawczy stanowiła biomasa jęczmienia ozimego, pochodząca z czteroletniego doświadczenia polowego, zbierana w następujących fazach wegetacji jęczmienia ozimego: krzewienie, strzelanie w źdźbło, kłoszenie, początek zawiązywania ziarna, dojrzałość mleczno-woskowa ziarna. W doświadczeniu zastosowano azot w formie saletry amonowej w dawkach (kg $N \cdot ha^{-1}$): 0, 60, 120, 180. Wykazano, że zawartość N, P, K, Ca, Mg i Na w masie wegetatywnej jęczmienia ozimego zmniejszała się w kolejnych fazach rozwoju roślin, począwszy od krzewienia aż do dojrzałości mleczno-woskowej ziarna. Największy spadek zawartości w kolejnych stadiach wegetacji dotyczył azotu i magnezu. W przypadku azotu, fosforu, wapnia i sodu zmniejszanie się zawartości w biomasie jęczmienia ozimego podczas jego wegetacji było z reguły większe na obiektach nawożonych azotem, w porównaniu z obiektami bez azotu. Wykazano na ogół dodatni wpływ nawożenia azotem na zawartość badanych makroskładników w masie wegetatywnej jęczmienia ozimego we wszystkich jego fazach rozwojowych. Stwierdzono, że iloraz sumy zawartości kationów do azotu osiągał najwyższe wartości w późnych fazach rozwoju roślin na obiektach bez azotu lub nawożonych dawką 60 kg N ha^{-1}.

Słowa kluczowe: jęczmień ozimy, fazy dojrzałości, azot, nawożenie, makroelementy.

INTRODUCTION

Maintaining proper contents of macro- and microelements in cultivated plants is essential for their correct growth as well as the amount and quality of the yield. The content of mineral components in a plant, which is a measure of its nutritional condition, depends mainly on a species but environmental factors, agronomic practice as well as the plant's growth phase are important. Although physiological roles of basic nutrients in plants are well recognised, mutual ionic ratios of macro-components in biomass of plants cultivated under conditions of diverse mineral fertilisation are less known.

Winter barley is a cereal plant that may produce a high crop of green mass abundant in protein and mineral salts. With the growth in animal farming, green fodder has become a basic component in ruminants' nutrition. Nitrogen fertilisation is one of the most important factors that shapes the quality of winter barley fodder (Spaldon, Hlavenkova 1990, Kandera 1991, Renzo et al. 1991, Hefnavy, Sayed 1992, Oscarsson et al. 1998, Barczak 1999). This is not only a results of the growth in the protein content but also a consequence of the changes in the content of microelements in the vegetative mass of crop plants (Czarnowska 1975, Brogowski, Czarnowska 1987, Jurkowska et al. 1990, Kobbia et al. 1992, Mottaleb et al. 1992, Czapla 2000, Krzbietke, Sienkiewicz 2004, Kołodziej et al. 2005).

The aim of this research has been to assess the effect of differentiated nitrogen doses on the content and mutual proportion of macro-components in green mass of winter barley, depending on its growth phase.

MATERIAL AND METHODS

In 1999-2002, a strict two-factor field experiment with three replications, designed according to the method of randomised sub-blocks, was conducted at the University of Technology and Agriculture in Bydgoszcz. The experiment was established at the Research Station in Wierzchucinek near Bydgoszcz, on a typical fallow soil belonging to a very good rye complex. The soil, classified as 3b soil in the Polish soil classification system, was slightly acidic in reaction (pH in 1 $mol \cdot dm^{-3}$ KCl – 5.7) and moderately abundant in available forms of nitrogen, phosphorus and magnesium. The soil contained 1.5 g $humus \cdot kg^{-1}$.

The first factor of the experiment included vegetation phases of winter barley (n=5):

- tillering (phase A),
- stem elongation (phase B),
- heading (phase C),
- initial grain-filling (phase D),
- soft dough stage (phase E).

The other factor was made by nitrogen doses (n=4), in kg $N \cdot ha^{-1}$: 0, 60, 120 and 180. Nitrogen fertilisers were sown as 34% ammonium nitrate once in the springtime, when barley vegetation started. Fertilisation with phosphorus and potassium as 60% potash salt (100 kg $K \cdot ha^{-1}$) and magnesium superphosphate (25 kg $P \cdot ha^{-1}$) was applied in the autumn, before sowing. Aerial parts of winter barley plants were used for the assays. Green mass produced by barley in the five growth phases was sampled in order to perform determinations. Samples were taken from randomly chosen 1 m^2 areas over individual 15 m^2 plots. In each year of the experiment, barley was preceded by oats as a forecrop. Cultivar Paweł winter barley, bred at the Plant Breeding Station in Polanowice, was tested.

The plant material was wet mineralised and subjected to the following determinations: total nitrogen by Kjeldahl's method, phosphorus – colorimetrically, using a DR 400 colorimeter, calcium, potassium and sodium – in a flame photometer Flavo 4, and magnesium – using an AAS spectrometer.

The results are reported in milligram equivalents (meq) per kg of winter barley aerial plant dry mass and analysed statistically to assess differences between the means, using Tukey's test at p = 0.05.

RESULTS AND DISCUSSION

Nitrogen was a prevailing macroelement among the components determined in the green mass of the test winter barley, with its content reaching 1,488 meq·kg^{-1} (Table 1). Phosphorus, potassium, calcium and magnesium appeared in considerably lower concentrations – their average content in meq·kg^{-1} was respectively: 129, 422, 120 and 192. Sodium was present in the lowest concentration (17 meq·kg^{-1}). The content in the elements in winter barley biomass was arranged in a decreasing series N>K>Mg>Ca=P>Na, being identical in all the growth phases, regardless of nitrogen fertilisation.

In the consecutive phenological phases, irrespectively of the nitrogen rates, a significant decrease in the content of all the macroelements except phosphorus occurred in the winter barley vegetative mass. A decrease in the content of these elements which appeared in the growing plants grow was a result of a considerable biomass increase, resulting in the so called „dilution effect" (Jurkowska et al. 1990, Brogowski, Czarnowska 1987, Gereudas, Sattelmacher 2000). The biggest differences in the content of the macroelements in winter barley biomass between phase A (tillering) and phase E (soft dough) was found for nitrogen and magnesium: 67.5% and 62.2% respectively as four-year means. Sodium was the element whose content declined the least as barley plants grew. In thesoft dough stage, the mean concentration of this element in winter barley biomass was 75.0% of its content in the tillering phase. The analogous ratios for potassium, calcium and magnesium of winter barley biomass in phases E and A were, respectively, 37.0, 36.9 and 62.2%. According to Brogowski et al. (1989), the elements whose contents decrease proportionally to the increase in the growing plants' biomass are absorbed mainly in the early growing season and, to a much smaller degree, in the later growth stages. It is worth noticing that, in general, a decrease in nitrogen, phosphorus, calcium and sodium during the growth of winter barley was significant on these plots where nitrogen fertilisation was applied. This relationship was probably created by what is known as a dilution effect, which appears when winter barley biomass grows larger owing to a better nitrogen supply, a powerful yield forming factor (Spaldon, Hlavenkova 1990, Hejnak et al. 2001, Gereudas, Sattelmacher 2000). A slightly higher decrease in the magnesium content in the objects not fertilized with nitrogen was more difficult to explain.

The results of our research find confirmation in the results achieved by Brogowski and Czarnowska (1987) for winter wheat, Brogowski et al. (1989) for spring barley, Jurkowska et al. (1990) for oats, Brogowski et al. (1993) for winter rye and by Kruczek (1996) for maize. Some of the authors (e.g. Brogowski et al. 1993), noticed a progressing decrease in the content of calcium, potassium and sodium in aerial parts of plants, but only from the phase of heading and not starting in the tillering stage, as it has been shown in this research.

Table 1

Content of macroelements in biomass of winter barley in different phenological phases (four-year means)

Macro-elements	Doses kg N·ha^{-1}	Phenological phases					Mean	$LSD_{0.05}$
		A	B	C	D	E		
N	0	1582	1195	947	781	673	1036	I fac. – 40.4
	60	2531	1648	1252	905	738	1415	II fac. – 34.2
	120	3004	1968	1532	1005	831	1668	IxII – 76.5
	180	3105	2079	1670	1225	1079	1832	IIxI – 68.4
	x	2556	1723	1350	979	830	1488	
P	0	159	142	132	118	77	126	Ifac. – n.s.
	60	172	149	139	102	83	129	IIfac. – n.s.
	120	182	151	153	89	76	130	IxII – n.s.
	180	176	155	140	108	82	132	IIxI – n.s.
	x	172	149	141	99	80	129	
K^+	0	435	433	385	301	287	368	Ifac. – 15.5
	60	514	507	445	339	307	422	IIfac. – 15.4
	120	531	537	453	339	321	436	IxII – 34.4
	180	534	552	468	372	353	456	IIxI – 30.7
	x	503	507	438	348	317	422	
Ca^{2+}	0	111	100	89	84	75	92	Ifac. –14.3
	60	156	130	113	99	85	117	IIfac. – 12.4
	120	130	164	138	105	98	136	IxII – 27.6
	180	155	151	135	130	119	138	IIxI – 24.7
	x	149	136	119	104	94	120	
Mg^{2+}	0	262	238	201	129	88	184	Ifac. – 15.6
	60	262	233	201	148	107	190	IIfac. – n.s
	120	275	233	204	136	104	190	IxII – n.s.
	180	271	242	229	164	103	202	IIxI – n.s.
	x	267	237	209	144	101	192	
Na^+	0	18	16	16	14	15	16	Ifac. – 0.7
	60	19	18	15	16	15	17	IIfac. – n.s
	120	21	17	16	15	15	17	IxII – n.s.
	180	22	17	17	15	16	17	IIxI – n.s.
	x	20	17	16	15	15	17	

I fac. – phenological stages (A – tillering, B – shooting (stem elongation), C – heading, D – initial grain filling E – soft dough maturity), II fac.–- nitrogen

Table 2

Content of macroelements in biomass of winter barley in different phenological phases of (four-year means) (meq·kg^{-1})

Macro-elements	Doses kg N·ha^{-1}	Phenological phases					Mean	$LSD_{0.05}$
		A	B	C	D	E		
Σcat.	0	826	787	691	528	465	659	Ifac. – 38.8
	60	951	888	774	602	514	746	IIfac. – 36.6
	120	1000	951	811	595	538	779	IxII – 75.3
	180	982	962	849	681	591	817	IIxI – 73.0
	x	939	897	781	602	527	751	
Σcat./N	0	5.2	6.6	7.3	6.8	6.9	6.6	Ifac. – 0.54
	60	3.8	5.4	6.2	6.7	7.0	5.8	IIfac. – 0.48
	120	3.3	4.8	5.3	5.9	6.5	5.2	IxII – 1.07
	180	3.2	4.6	5.1	5.6	5.5	4.8	IIxI – 0.96
	x	3.9	5.3	6.0	6.2	6.5	5.6	
$Ca^{2+}+Mg^{2+}$ /$K^{+}+Na^{+}$	0	8.2	7.5	7.2	6.8	5.4	7.0	Ifac. – 0.11
	60	7.8	6.9	6.8	7.0	6.0	6.9	IIfac. – 0.09
	120	8.1	7.2	7.3	6.8	6.0	7.1	IxII – 0.21
	180	7.7	6.9	7.5	7.6	6.0	7.1	IIxI – 0.19
	x	8.0	7.1	7.2	7.1	5.9	7.0	
Ca^{2+}/P	0	7.0	7.0	6.7	7.1	9.7	7.5	Ifac. – n.i./n.s.
	60	9.1	8.7	8.1	9.7	10.2	9.2	IIfac. – 0.47
	120	9.5	10.9	9.0	11.8	12.9	10.8	IxII – 0.68
	180	8.8	9.7	9.6	12.0	14.5	10.9	IIxI – 0.72
	x	8.6	9.1	8.4	10.2	11.8	9.6	

Likewise in other plant species (Czarnowska 1975, Brogowski, Czarnowska 1987, Jurkowska et al. 1990, Renzo et al. 1991, Mottaleb et al. 1992, Kruczek 1996, Gerendas, Sattelmacher 2000), this study has demonstrated that higher doses of nitrogen generally increased the content of macroelements in winter barley biomass in all the plant growth stages assayed. Nitrogen fertilization had the strongest effect on the content of nitrogen and calcium – the four-year mean increase in the content of these elements resulting from an application of 180 kg N·ha^{-1} and was 76.8 and 54.4% respectively. At the same time, a relatively small effect of nitrogen doses on the content of phosphorus and sodium was shown.

For nitrogen and phosphorus, the effect of increasing doses of nitrogen was the strongest during the tillering phase. In the next growth stages, the variations in the content of these elements in the green mass of winter barleywere much smaller. For univalent cations, changes in their contents under the effect of intensifying nitrogen fertilization depended on the plant

Table 3

Correlation coefficients between macroelements

	P	K	Ca	Mg	Na	Σcat.	Σcat./N	Ca+Mg /K+Na
N	0.847*	0.878*	0.810*	0.841*	0.930*	0.905*	-0.960*	0.687*
P		0.900*	0.690*	0.971*	0.766*	0.934*	-0.744*	0.824*
K			0.870*	0.921*	0.760*	0.991*	-0.821*	0.657*
Ca				0.713*	0.635*	0.859*	-0.857*	0.569*
Mg					0.784*	0.957*	-0.748*	0.853*
Na						0.799*	-0.867*	0.636*
Scat.							-0.846*	0.749*
Σcat./N								0.641*

growth stage, but this relationship was statistically proven to a smaller degree. The total content of cations in the vegetative mass of winter barley (Ca^{2+}+Mg^{2+}+K^{+}+Na^{+}) gradually decreased from the tillering to soft dough phases, which was a consequence of such a direction of changes in the concentrations of individual cations during the vegetative season. The average value for four years of the total sum of cations in the biomass collected in the soft dough phase was 57.7% of their content in the tillering phase. In the literature some authors mention the phenomenon of "ion competition" (DIJKSHORN 1972, cit. by BROGOWSKI et al. 1993), which relies on the fact that the total content of basic cations in a given growth phase of a plant is constant, but the values of the components of this sum can vary. This regularity is analogous to the phenomenon of isomorphism in minerals, which comprises a possibility of replacing ions in their crystal lattices. This phenomenon in plants can be observed under deficiency of one of the cations, e.g. under potassium deficiency, when the plant takes up more sodium or calcium. Our field experiment was carried on soil of moderate potassium and magnesium abundance at pH_{KCl} = 5.7, therefore there is no reason to suppose that a phenomenon of ion compensation took place. An increase in the total content of ions resulting from nitrogen fertilisation was observed. The dose of 180 kg $N \cdot ha^{-1}$ resulted in the highest increase in the total ions in the winter barley biomass collected during the soft dough maturity phase (the difference was 27.1% with reference to the plants from the control). The lowest increase occurred in plants in the heading phase (the difference was 13.0%).

It was proven that an average ratio of the content of divalent cations (Ca^{2+}+Mg^{2+}) to the content of univalent cations (K^{+}+Na^{+}) was 0.72. The value of this ratio less than one is characteristic for monocotyledonous plants (BROGOWSKI et al. 1993) and is probably connected with the type of root system of these plants (MATTSON 1975). Monocotyledonous plants, such as winter barley, have a root system with a limited replacement capacity. Therefore, this species takes up more K^{+} and Na^{+} than Ca^{2+} and Mg^{2+}. Quantitative proportions of uni- and divalent cations in a plant can be modified by soil sorption capacity. According to MATTSON (1975), the higher sorption capacity of soil with the same sorption capacity of roots, the greater the amounts of univalent cations taken up by a plant and vice versa.

The highest values of the quotient of the content Ca^{2+}+Mg^{2+} and K^{+}+Na^{+} were characteristic for the green mass of winter barley in the tillering and heading phases in the objects with no nitrogen fertilization. The values of this quotient tended to decrease in the consecutive phases of the winter barley growth, which means that divalent ions were reduced during vegetation to a higher degree than univalent ones. The above relationships are only partly confirmed in the research on winter wheat (BROGOWSKI and CZARNOWSKA 1987), spring barley and winter rye (BROGOWSKI et al. 1989, 1993), where a constant ratio of divalent to univalent ions in particular plant growth phases was proven.

The increase in the nitrogen dose generally reduced not only the value of the above ratio but also that of the ratio of total cations to nitrogen as well. The highest effect of nitrogen fertilisation on shaping the ratio of total cations to nitrogen was found in plants in the tillering phase, which was a consequence of the highest increase in the nitrogen content in this plant growth stage, under the effect of nitrogen fertilisation.

The largest variation in values of the calcium to phosphorus ratio was demonstrated, in the later growth stages of winter barley, i.e. initial grain-filling and soft dough stages, particularly under conditions of intensive nitrogen fertilisation. Similar results were reported by JURKOWSKA et al. (1990).

The correlation analysis showed that the content of the individual macroelements in winter barley biomass are strongly correlated. Noticeable is a highly significant correlation of the nitrogen content versus the other elements, and also the values of the calculated ionic ratios.

CONCLUSIONS

1. The content of N, P, K, Ca, Mg and Na in the vegetative mass of winter barley decreased in the consecutive phenological phases, from tillering to soft dough stages. The highest decrease was detected for nitrogen and magnesium.

2. During the vegetation period of winter barley, a decrease in the content of nitrogen, phosphorus, calcium and sodium in barley biomass was generally higher in objects fertilised with nitrogen than in the objects with no nitrogen fertilisation.

3. Nitrogen fertilisation generally produced a positive effect on the content of the analysed macroelements in the vegetative mass of winter barley in all its growth phases. The highest increase in the nitrogen and calcium content was observed under the influence of nitrogen fertilization.

4. The ratio of total cations to nitrogen for winter barley biomass in the consecutive plant growth phases tended to decrease.

5. The highest values of the content ratio of divalent (Ca^{2+}+Mg^{2+}) to univalent ones (K^{+}+Na^{+}) cations in winter barley green mass were observed in the tillering phase.

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