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MICRONUTRIENT CONTENTS IN THE GREEN MASS OF MIXTURES OF BLUE LUPINE WITH SPRING RYE DEPENDING ON PROPORTION OF COMPONENTS AND TIME OF HARVESTING

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ABSTRACT

Background. Mixed crops allow providing feed with a wide range of minerals and a better quality in comparison with crops from pure sowing. The paper presents the results of a study from 2009–2011 aimed at determining the impact of a proportion of components and the time of harvesting mixtures of blue lupine with spring rye on the content of micronutrients in the green mass and their mutual relations. This knowledge allows for the correct selection of species for legume – cereal mixtures for animal feeding.

Material and methods. Two factors were studied in the experiment: I – proportion of components in a mixture: blue lupine – pure sowing 100%, spring rye – pure sowing 100%, blue lupine 75% + spring rye 25%, blue lupine 50% + spring rye 50%, blue lupine 25% + spring rye 75%; II – time of harvesting: flowering stage of blue lupine (BBCH 65), flat green pod stage of blue lupine (BBCH 79). During the harvesting of mixtures, average samples of fresh mass were collected from each plot for chemical analysis. The content of micronutrients (Fe, Mn, Zn, Cu) was determined in the collected plant material.

Results. Significantly the highest contents of iron, manganese and zinc were recorded in the green mass of blue lupine cultivated in pure sowing and in the mixture of blue lupine with spring rye with proportions of components of 75% and 25%, respectively, harvested at the flat green pod stage (BBCH 79) of blue lupine. Significantly higher content of copper was observed in pure sowing of blue lupine and in the mixture of blue lupine and spring rye with proportions of components of 75% and 25%, respectively, harvested at the flowering stage of lupine. Harvesting the mixtures at the flat green pod stage (BBCH 79) of blue lupine allows obtaining a higher content of iron, manganese and zinc in comparison with harvesting at the flowering stage of blue lupine (BBCH 65).

Conclusion. Cultivation of a mixture of blue lupine with spring rye with a proportion of components of 75% and 25%, respectively, and pure sowing of blue lupine, harvested at the flowering stage of blue lupine (BBCH 65), allows obtaining green mass with a higher content of iron, manganese and zinc as compared with pure sowing of spring rye.

Key words: blue lupine, copper, iron, manganese, mixture, spring rye, zinc

INTRODUCTION

The proportion of cereals in the cropping structure in Poland amounts to 70%, therefore it requires cultivation of cereals in monocultures. Efforts should be made to increase biodiversity of crops in order to reduce the negative effects of improper plant rotation (Kostrzewska *et al*., 2009; Księżak, 2010; Kotecki, 2014). An important role here is played by legumes, which in agricultural practice are recommended for growing in

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mixtures with cereals (Noworolnik, 2000). Many authors (Tuna and Orak, 2007; Ahmad *et al*., 2008; Mahapatra, 2011, Pappa *et al*., 2012) showed in their studies an increase in the yield of plants grown in mixtures compared with pure sowing, when one of the components was a legume. According to Kotwica and Rudnicki (2003), growing mixtures of lupine with cereals also increases yielding stability. In the years of water shortage in the soil, the low yield of legumes is compensated by the yield of cereals. According to Szpunar-Krok *et al*. (2009), concentrated feed obtained from legume-cereal mixtures is better balanced in terms of energy and protein, the content of amino acids and minerals, in comparison with pure sowing, thanks to which it is utilized more effectively by animals. In their study, Szpunar-Krok *et al*. (2009) found more advantageous proportions between micronutrients of legume-cereal mixtures compared with single-species sowing, which resulted in a feed better balanced in terms of the nutritional value. According to Pozdišek *et al*. (2011), components of mixtures may interact with each other, resulting in a mixture with a more favourable chemical composition compared with monoculture crops. According to Księżak (2010), lupines give the best yields in light soils. Podleśny *et al*. (2010) point blue lupine as a species with high resistance to anthracnose. All cereal species can be grown in mixtures with legumes, however, due to the possibility of simultaneous sowing, the spring form is used (Kotecki, 2014). The potential cereal component of legume-cereal mixtures may be spring rye, which is characterized by fairly low soil requirements (Kotwica and Rudnicki, 2003; Wasilewski, 2006). There are no more comprehensive publications evaluating the content of micronutrients in the green mass of a mixture of blue lupine with spring rye.

It was assumed that the use of mixtures of blue lupine with spring rye and their harvesting at the flowering stage and at the flat green pod stage (BBCH 79) of lupine will allow for determination of differences in the content of micronutrients and selection of combinations that will be characterized by the highest content of micronutrients (Fe, Mn, Zn, Cu).

The aim of the conducted study was to determine the effect of a varied proportion of components and the time of harvesting a mixture of blue lupine with spring rye on the content of selected micronutrients.

MATERIAL AND METHODS

The field study was conducted in 2009–2011 at the Agricultural Experimental Station at Zawady owned by the University of Natural Sciences and Humanities in Siedlce, located at 50°20' N and 22°30' E. The experiment was established in the split-block design, with three replications, on plots with an area of 15 m^2. Two factors were studied in the experiment: I – proportion of components in a mixture: blue lupine (the cultivar Zeus) – pure sowing, spring rye (the cultivar Bojko) – pure sowing, blue lupine 75% + spring rye 25%, blue lupine 50% + spring rye 50%, blue lupine 25% + spring rye 75%; II – time of harvesting: flowering stage of blue lupine (BBCH 65), flat green pod stage of blue lupine (BBCH 79). The detailed list of mixtures and plant densities per 1 m^2 was at follows: blue lupine 175, spring rye 500, blue lupine 128 + spring rye 125, blue lupine 85 + spring rye 250, blue lupine 43 + spring rye 375.

The field experiments were carried out in the Luvisols. The ground was flat, water erosion did not occur. In terms of agricultural suitability, these soils were included in the very good rye complex, quality class IV b. The soil was characterized by neutral reaction, the average abundance of available phosphorus, potassium and magnesium. The content of humus was 1.42%. In all the years of the study, the previous crop for the mixtures were cereals. In the autumn, phosphorus-potassium fertilizers were used at rates dependent on the chemical composition of the soil, i.e. 32.2 $kg \cdot ha^{-1}$ P in the form of triple superphosphate 46% and 99.6 $kg \cdot ha^{-1}$ K in the form of 60% potassium salt. In the spring before seed sowing, nitrogen fertilizers were used in the form of ammonium nitrate 34% at a dose of 30 $kg \cdot ha^{-1}$ N, on all treatments, except for blue lupine in pure sowing. At the shooting stage (BBCH 32), an additional 50 $kg \cdot ha^{-1}$ N was applied under spring rye and 30 $kg \cdot ha^{-1}$ under the mixture of blue lupine with spring rye. Sowing the seeds of blue lupine (the cultivar Zeus) and spring rye (the cultivar Bojko) was performed within the first ten days of April in accordance with the first experimental factor. The harvesting was carried out in accordance with the second experimental factor, i.e. within the last ten days of June and the 1st ten days of July. During the harvesting of mixtures,

average samples of fresh mass were collected from each plot for chemical analysis. The contents of: iron, zinc, manganese and copper were determined in the collected plant material – by atomic absorption spectrometry.

Each of the studied traits was analysed by variance analysis in accordance with the split-block design. For significant sources of variability, a detailed comparison of means was made with the Tukey's test. For statistical calculations, our own algorithms developed in MS Excel 7.0 were used.

RESULTS AND DISSCUSION

The content of iron in the green mass of mixtures of blue lupine with spring rye was significantly differentiated by the experimental factors studied and their co-operation (Table 1). The highest iron content was recorded in the green mass of blue lupine and the lowest in spring life grown in pure sowing. Larralde and Martinez (1991) point the legume plant as an important source of iron. The study by Woźniak and Soroka (2016) and Ciećko *et al*. (2004) indicate that leguminous plants have a higher iron content compared with cereals. In the conducted study, increasing the proportion of blue lupine in the mixture significantly increased iron content. The highest iron content was determined in the mixture of blue lupine with spring rye with a proportion of components of 75 + 25%, significantly higher as compared with the iron content recorded in mixtures with proportions of components 50 + 50% and 25 + 75%. Also, the study carried out by Goliński *et al*. (2007) showed a higher value of iron in a legume in pure sowing as compared with a mixture of grasses with a legume with a proportion of component of 65 + 35%. However, the study carried out by Szpunar-Krok *et al*. (2009) did not reveal any significant differences in the iron content between pure sowing of a legume and its mixtures with cereals. In the present author's study, the time of harvesting blue lupine significantly differentiated the iron content in the mixture. The mixture harvested at the flat green pod stage (BBCH 79) was characterized by a significantly higher iron content. Błaziak (2006) observed in her study a reduction in the iron content in aboveground parts of barley with the delay of harvest time from the shooting stage to the heading stage, while the reverse relationship was observed in the case of oats.

Table 1. Iron content in mixtures of blue lupine with spring rye (means from 2009–2011), mg·kg^{-1} d.m.

Proportion of components in the mixture	Time of harvesting		Means
	flowering stage of blue lupine BBCH 65	flat green pod stage of lupine BBCH 79	
Blue lupine – pure sowing	198	242	220
Spring rye – pure sowing	134	187	161
Blue lupine 75% + spring rye 25%	187	234	211
Blue lupine 50% + spring rye 50%	170	219	195
Blue lupine 25% + spring rye 75%	156	207	182
Means	169	218	–
$HSD_{0.05}$ for:			
proportion of components in the mixture			6.2
time of harvesting			3.1
interaction			9.4

In the study conducted, an interaction was determined which showed that the highest content of iron was found in blue lupine from pure sowing harvested at the flat green pod stage (BBCH 79) and the mixture of blue lupine with spring rye with the proportion of components of 75 + 25% harvested at the same developmental stage.

Statistical analysis showed a significant variation in manganese content in mixtures of blue lupine with spring rye by the experimental factors studied and their interaction (Table 2). The highest content of manganese was recorded in the green mass of blue lupine, while the lowest in spring rye grown in pure sowing. The study carried out by Szpunar-Krok *et al*. (2009) on oat and faba bean showed that the leguminous plant contained significantly less manganese in seeds compared with the cereal. Also, Trąba and Wolański (2003) in their study showed greater abundance of manganese in sward which included grasses and legume plants in comparison with pure sowing of legumes. Whereas Jarecki and Bobrecka-Jamro (2015) obtained a similar content of manganese in soybeans in comparison with the content of this micronutrient in the wheat grain obtained by Woźniak and Soroka (2016). In the present author's study, an increase in the proportion of blue lupine in the mixture caused a significant increase in the content of manganese in the mixture. Significantly the highest manganese content was obtained with the proportion of components of 75% of blue lupine and 25% of spring rye, respectively. Goliński *et al*. (2007) observed an increase in the content of manganese in the mixture of a leguminous plant and grasses with a proportion of components of 35 + 65% in relation to the legume plant grown in pure sowing. The date of harvesting significantly differentiated the manganese content in the mixtures, a significantly higher content was obtained in the mixtures of blue lupine and spring rye harvested at the flat green pod stage of blue lupine (BBCH 79). The study carried out by Błaziak (2006) showed a significant increase in manganese content in the aboveground parts of oats along with a delay of harvest from the heading stage to the panicle extension stage (BBCH 55). Statistical analysis indicated an interaction showing that the highest content of manganese was found in blue lupine in pure sowing and a mixture of blue lupine with spring rye with a proportion of components of 75 + 25% components harvested at the flat green pod stage of blue lupine (BBCH 79), while the lowest in spring rye grown in pure sowing harvested at the flowering stage of blue lupine (BBCH 65).

The content of zinc in the mixtures of blue lupine with spring rye was significantly differentiated by the analyzed experimental factors and their interaction (Table 3). Significantly, the highest content of zinc was obtained in the green mass of narrow-leafed lupine grown in pure sowing, while the lowest in pure sowing of spring rye. In own studies, increasing the share of narrow-leafed lupine in the mix significantly increased the concentration of zinc. Also, in research carried out by Szpunar-Krok *et al*. (2009) it was found that leguminous plant has significantly higher zinc content than cereals. Significantly the highest content of zinc was obtained in the green mass of blue lupine grown in pure sowing, while the lowest in pure sowing of spring rye. In the present author's study, increasing the proportion of blue lupine in a mixture significantly increased the concentration of zinc. Also, in the study carried out by Szpunar-Krok *et al*. (2009), it was found that a leguminous plant had a significantly higher zinc content than cereals. The study carried out by Goliński *et al*. (2007) showed a significantly higher zinc content in a leguminous plant grown in pure sowing compared with a mixture with grasses with a proportion of components of 35 + 65%, while Trąba and Wolański (2003) did not show any significant differences in zinc content in grass mixtures with leguminous plants in comparison with pure sowing of legumes. In the conducted study, the time of harvesting had a significant effect on the content of zinc in the green mass of the mixtures. Mixtures harvested at the flat green pod of blue lupine (BBCH 79) were characterized by a significantly higher content of zinc. An interaction was indicated which showed that the highest concentration of zinc was found in blue lupine cultivated in pure sowing and harvested at the flat green pod stage (BBCH 79), and the lowest in spring rye cultivated in pure sowing harvested at the flowering stage of blue lupine (BBCH 65).

Table 2. Content of manganese in mixtures of blue lupine with spring rye (means from 2009–2011), mg·kg^{-1} sm.

Proportion of components in the mixture	Time of harvesting		Means
	flowering stage of blue lupine BBCH 65	flat green pod stage of lupine BBCH 79	
Blue lupine – pure sowing	76.8	86.2	81.5
Spring rye – pure sowing	67.7	78.9	73.3
Blue lupine 75% + spring rye 25%	74.9	85.0	80.0
Blue lupine 50% + spring rye 50%	72.8	83.2	78.0
Blue lupine 25% + spring rye 75%	70.7	81.4	76.1
Means	72.6	82.9	–
$HSD_{0.05}$ for:			
proportion of components in the mixture			1.12
time of harvesting			0.40
interaction			1.63

Table 3. Content of zinc in mixtures of blue lupine with spring rye (means from 2009–2011), mg·kg^{-1} d.m.

Proportion of components in the mixture	Time of harvesting		Means
	flowering stage of blue lupine BBCH 65	flat green pod stage of lupine BBCH 79	
Blue lupine – pure sowing	43.5	49.9	46.7
Spring rye – pure sowing	30.6	36.8	33.7
Blue lupine 75% + spring rye 25%	40.8	47.2	44.0
Blue lupine 50% + spring rye 50%	37.8	44.1	41.0
Blue lupine 25% + spring rye 75%	34.5	40.9	37.7
Means	37.4	43.8	–
$HSD_{0.05}$ for:			
Proportion of components in the mixture			0.83
time of harvesting			0.31
interaction			1.12

Statistical analysis showed a significant variation in copper content in mixtures of blue lupine with spring rye by the experiment factors and their interaction (Table 4). A higher copper content, but not significantly, was recorded in the plants of blue lupine and in the mixture of blue lupine and spring rye with a proportion of component of 75 + 25%. There was also no significant difference between the content of copper in the mixtures of blue lupine and spring rye, with proportions of components of 75 + 25% and 50 + 50%, respectively. The lowest content of this mineral element was found in the green mass of spring rye cultivated in pure sowing. Jarecki and Bobrecka-Jarmo (2015) obtained almost twice the concentration of copper in soybeans in comparison with the values obtained by Woźniak and Soroka (2016) in wheat grain. A similar relationship was obtained by Trąba and Wolański (2003), who obtained about twice the copper content in the dry matter of grass-legume mixtures in relation to the cultivation of a legume in pure sowing. Szpunar-Krok *et al*. (2009) observed a higher, but not statistically proven, content of copper in faba bean seeds than in oat grain. In the present author's study, a significantly higher copper content was found in the green mass of mixtures of blue lupine with spring rye harvested during the flowering phase of blue lupine (BBCH 65). Statistical analysis indicated an interaction showing that the highest content of copper was found in blue lupine grown in pure sowing harvested at the flowering stage (BBCH 65), and a mixture of blue lupine with spring rye with a proportion of components of 75 + 25% harvested at an earlier development stage. In addition, no significant differences were found between the mixture of blue lupine and spring rye with a proportion of components of 75 + 25%, respectively, harvested at the flat green pod stage of lupine (BBCH 79) and the mixture with the equal proportion of components harvested during the flowering stage of blue lupine (BBCH 65). The lowest copper content was recorded in spring rye grown in pure sowing irrespective of the harvesting date.

Table 4. Content of copper in mixtures of blue lupine with spring rye (means from 2009–2011), $mg \cdot kg^{-1}$ d.m.

Proportion of components in the mixture	Time of harvesting		Means
	flowering stage of blue lupine BBCH 65	flat green pod stage of lupine BBCH 79	
Blue lupine – pure sowing	5.17	4.98	5.08
Spring rye – pure sowing	4.59	4.37	4.48
Blue lupine 75% + spring rye 25%	5.08	4.88	4.98
Blue lupine 50% + spring rye 50%	4.96	4.74	4.85
Blue lupine 25% + spring rye 75%	4.79	4.57	4.68
Means	4.92	4.71	–
$HSD_{0.05}$ for:			
proportion of components in the mixture			0.211
time of harvesting			0.090
interaction			0.283

For nutritional reasons, not only the content of micronutrients is important, but also their mutual relations. According to Adriano (2001) and Falkowski *et al*. (2000), the optimal Fe/Mn ratio in feed should be 1.5 - 2.5: 1. In the present author's study, the optimal ratio was obtained in mixtures of blue lupine and spring rye with a proportion of components of 25 + 75% and 50 + 50%, and in spring rye in pure sowing (Table 5). According to Falkowski et al. (2000), the optimal content of manganese in feed is 50 mg·kg^{-1} d.m., copper 10 mg·kg^{-1} d.m., whereas zinc 50 mg·kg^{-1} d.m. On this basis, one can determine the optimal ratio of these micronutrients relative to each other; Mn/Cu = 5 : 1, Mn/Zn =1 : 1. In the conducted study, the ratio of manganese to copper significantly exceeded the determined optimal ratio, mainly due to lower copper contents with reference to those given by Falkowski *et al*. (2000). On this basis, the Mn/Zn ratio also exceeded the one determined based on the optimal micronutrient contents in feed. A much higher Mn/Zn ratio was obtained in the pure sowing of spring rye compared with the pure sowing of blue lupine, hence the increase in the proportion of spring rye in a mixture with lupine resulted in extension of the proportion.

Table 5. Mass relations of microelements in mixtures of blue lupine with spring rye

Proportion of components in the mixture	Fe/Mn	Mn/Cu	Mn/Zn
Blue lupine – pure sowing	0.06	16.04	1.75
Spring rye – pure sowing	0.06	16.36	2.18
Blue lupine 75% + spring rye 25%	0.06	16.06	1.82
Blue lupine 50% + spring rye 50%	0.06	16.08	1.90
Blue lupine 25% + spring rye 75%	0.06	16.26	2.02

CONCLUSIONS

1. The highest content of micronutrients (Fe, Mn, Zn, Cu) was found in blue lupine grown in pure sowing and in the mixture of blue lupine with spring rye with a proportion of component of 75 + 25%.
2. Harvesting a mixture of blue lupine with spring rye when the legume reaches the stage BBCH 65 allows for obtaining a higher content of copper in green mass and harvesting at the stage BBCH 79 – a higher content of iron, manganese and zinc.
3. A mixture of blue lupine and spring rye with a proportion of components of 75 + 25% and blue lupine grown in pure sowing harvested at the flat green pod stage of blue lupine (BBCH 79) allows for obtaining the highest concentration of iron, manganese and zinc.

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ZAWARTOŚĆ MIKROELEMENTÓW W ZIELONEJ MASIE MIESZANKI ŁUBINU WĄSKOLITNEGO Z ŻYTEM JARYM W ZALEŻNOŚCI OD UDZIAŁU KOMPONENTÓW I TERMINU ZBIORU

Streszczenie

Zasiewy mieszane pozwalają dostarczyć paszę o szerokim zestawie składników mineralnych i lepszą jakościowo niż siewy czyste. W pracy przedstawiono wyniki badań z lat 2009–2011, które miały na celu określenie wpływu udziału komponentów i terminu zbioru mieszanek łubinu wąskolistnego z żytem jarym na zawartość mikroelementów w zielonej masie oraz ich wzajemnych relacji. Wiedza ta pozwala na prawidłowy dobór gatunków do mieszanek bobowato-zbożowych do żywienia zwierząt. W doświadczeniu badano dwa czynniki: I – udział komponentów w mieszance: łubin wąskolistny – siew czysty 100%, żyto jare – siew czysty 100%, łubin wąskolistny 75% + żyto jare 25%, łubin wąskolistny 50% + żyto jare 50%, łubin wąskolistny 25% + żyto jare 75%; II – termin zbioru: faza kwitnienia łubinu wąskolistnego (BBCH 65), faza płaskiego zielonego strąka łubinu wąskolistnego (BBCH 79). Podczas zbioru mieszanek

z każdego poletka pobrano średnie próby świeżej masy w celu wykonania analiz chemicznych. W pobranym materiale roślinnym oznaczono zawartość mikroelementów (Fe, Mn, Zn, Cu). Istotnie najwyższe zawartości żelaza, manganu i cynku odnotowano w zielonej masie łubinu wąskolistnego uprawianego w siewie czystym oraz w mieszance łubinu wąskolistnego z żytem jarym o udziale komponentów odpowiednio 75% i 25%, zbieranych w fazie płaskiego zielonego strąka (BBCH 79) łubinu wąskolistnego. Istotnie wyższą zawartość miedzi stwierdzono w siewie czystym łubinu wąskolistnego i mieszance łubinu wąskolistnego z żytem jarym o udziale komponentów odpowiednio 75% i 25%, zbieranych w fazie kwitnienia łubinu. Zbiór mieszanek w fazie płaskiego zielonego strąka (BBCH 79) łubinu wąskolistnego pozwala osiągnąć wyższą zawartość żelaza, manganu i cynku w porównaniu ze zbiorem w fazie kwitnienia łubinu wąskolistnego (BBCH 65). Uprawa mieszanki łubinu wąskolistnego z żytem jarym o udziale komponentów odpowiednio 75% i 25% oraz siewu czystego łubinu wąskolistnego, zbieranych w fazie kwitnienia łubinu wąskolistnego (BBCH 65), pozwala uzyskać zieloną masę o wyższej zawartości żelaza, manganu i cynku w porównaniu z siewem czystym żyta jarego.

Słowa kluczowe: cynk, łubin wąskolistny, mangan, miedź, mieszanka, żelazo, żyto jare