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PHOSPHORUS CONTENT IN SPRING BARLEY AND RED CLOVER PLANTS IN PURE AND MIXED SOWING

Magdalena Jastrzębska, Marta K. Kostrzewska, Maria Wanic, Przemysław Makowski, Kinga Treder
University of Warmia and Mazury in Olsztyn

Abstract. During the growth of underplant and cover crop interactions occur, the patterns and mechanisms of which are not totally known, particularly within the changeability of ecological factors. Joint use of environmental resources may modify the uptake of nutrients from the bedding and their accumulation in the particular plant organs. The aim of the study was the determination of the effect of interactions between spring barley and red clover on phosphorus content in their organs against diversified water provision. In a pot experiment (three cycles), the study factors were: (1) plant sowing type (growth of each species in pure and mixed sowing), and (2) plant provision with water (dose that satisfies plant requirements and one lowered by 50%). Mixture was composed according to the additive pattern. Phosphorus content was marked in plant material uptaken at five stages set by the developmental rhythm of barley in pure sowing in the conditions of more favourable water supply. Sowing type had no effect on phosphorus content in spring barley organs but mixed sowing resulted in the accumulation of a higher amount of phosphorus in the roots at the straw-shooting stage, and a lower amount in the shoots and spikes at the end of growth. In red clover, mixed sowing lowered phosphorus content in the roots at cereal maturity stage. Competition on the part of barley inhibited the uptake and accumulation of phosphorus by red clover. Water supply did not diversify phosphorus content in the organs of spring barley and red clover but water deficit almost throughout the entire period of growth limited phosphorus uptake by both species. Competition on the part of barley was for red clover a stronger factor that impeded phosphorus accumulation in plant organs than water deficit. Water stress did not intensify further the negative effect of competition.

Key words: competition, intercrop, phosphorus accumulation, plant developmental stages, plant parts, water deficit

Corresponding author: dr hab. Magdalena Jastrzębska, Department of Agricultural Systems of University of Warmia and Mazury in Olsztyn, pl. Łódzki 3, 10-718 Olsztyn, e-mail: jama@uwm.edu.pl

INTRODUCTION

Cultivation of spring barley with red clover underplant is common in agricultural practice and is particularly valued in ecological and integrated management system [Lithourgidis *et al*. 2011]. During the growth of underplant and cover crop, interactions occur, the patterns and mechanisms of which are not totally known, particularly within the changeability of ecological factors [Zhang *et al*. 2008, Wanic *et al*. 2013]. One of the most significant factors that inhibit plant growth and yield is water deficit [Alam 1999]. Some studies indicate that competition may be less significant in the conditions of water shortage because plant growth is disturbed by water stress more than by competition [Grime 1977]. Other researchers found lack of differences in competition intensity with changeable water access [Xu *et al*. 2013].

Limited water access inhibits the uptake of nutrients and often their level in plants [Baligar *et al*. 2001]. It results from the hitherto existing studies that joint usage of environmental resources by two or more species may modify nutrient uptake from the bedding and their accumulation in the particular plant organs [Treder *et al*. 2009, Wanic and Michalska 2009].

Studies on competition between plants in recent years resulted in many significant findings but so far no models have been established which explain fully how plants compete for water and how this competition may interact with competition for nutrients [Craine and Dybzinski 2013].

From the agricultural point of view, studies on interaction between plants in mixed sowings should not only bring the recognition of the mechanisms of those interactions but also be helpful in the construction of systems that will assure the most effective use possible of habitat resources [Xu *et al*. 2013]. In relation to the effectiveness of the use of nutrients in mixtures, nitrogen is the best well-known, particularly in the case of the growth of cereals with legumes and N_2 fixation. However, studies on phosphorus content are few [Wanic and Michalska 2009, Hinsinger *et al*. 2011]. The present study may be a contribution to the existing information.

The aim of the study was the determination of the effect of interactions that occur between spring barley and red clover on phosphorus content in their organs against diversified water supply. Alternative hypothesis was tested that inter-species interactions and water deficit change phosphorus content in plants and its uptake with biomass yield, against zero hypothesis on the lack of effect of those factors on the above parameters.

MATERIAL AND METHODS

Pot experiment was carried out at the greenhouse laboratory of the Biology and Biotechnology Faculty of the University of Warmia and Mazury in Olsztyn. It included three experimental cycles of 102, 97, and 98 days. Subjects of the evaluation were: spring barley (naked-grain cultivar Rastik) and red clover (cultivar Bona).

Experimental factors were:

1) plant sowing types: pure growth of every species (barley in pure sowing PB, clover in pure sowing PC) and in a mixture (barley in a sowing mixture with clover MB, clover in a sowing mixture with barley MC);

2) plant provision with water: dose that satisfies plant requirements (HW) and dose lowered by 50% (LW).

In every growth period, the amount of the delivered water was diversified depending on the developmental stage of the species and the degree of soil humidity. In the subsequent cycles, the plants which were given higher doses obtained in total, respectively, 13400, 12300, and 10900 cm^3 of water per pot, and the plants with the lowered water dose, 50% less.

Plants were sown in Kick-Brauckmann pots (diameter: 22 cm, depth: 25 cm), with the density in one pot with pure sowing of 18 plants of barley and eight plants of clover. The mixture was composed according to the additive pattern [Semere and Froud--Williams 2001], so the total number of plants per pot was the sum of the number of plants of a certain species in pure sowing (18 + 8). Caryopses and seeds were located in the soil in the pots at the depth of 3 cm (barley) and 1.5 cm (clover), while keeping identical reciprocal horizontal distance with the use of templates. The experiment included the total of 120 pots (two levels of plant supply with water × 3 sowing types, separately barley and clover and together in a mixture × 5 developmental stages × 4 repetitions).

Plant bedding consisted of material uptaken from brown leached soil, formed from clay loam according to the Polish Society of Soil Science [PTG 2009], heavy clay soil according to the norm BN-78/9180-11 [PTG 2009], which included: 64.0% fraction with the diameter below 0.02 mm, 12.0% fraction with the diameter of 0.02-0.1 mm, and 24.0% fraction with the diameter of 0.1-1.0 mm). It was characterized by the content of organic substance from 18.4 to 25.2 $g \cdot kg^{-1}$, slightly acid pH (in KCl at the concentration of 1 $mol \cdot dm^{-3}$ from 5.6 to 6.2), high affluence in assimilable phosphorus (92.4-116.1 $mg \cdot kg^{-1}$ soil) and magnesium (88.0-91.1 $mg \cdot kg^{-1}$ soil) and average in potassium (128.7-145.3 $mg \cdot kg^{-1}$ soil). During pot filling with bedding, its affluence was enriched with basic biogenes in the amounts of: P: 0.2 g per one pot (monopotassium phosphate), K: 0.45 (potassium sulphate) equally for all the pots, and N: 0.5 under barley, 0.3 under mixture, and 0.125 g under clover (in the form of urea). Almost throughout the entire duration of the experiment, the temperature in the laboratory was constant and reached 20-22^{o}C. In order to secure proper conditions for the vernalization process for barley plants, at the leaf-development stage, the temperature was lowered to 6-8^{o}C for the period of nine days.

Interactions between the species were studied in five periods set by the developmental rhythm of spring barley in pure sowing, which grew in the conditions of favourable water supply, namely at the stages of: leaf development (BBCH 10-13), tillering (BBCH 25-29), straw-shooting (BBCH 35-37), earing (BBCH 57-59), and ripening (BBCH 87-91). In every subsequent cycle, after given developmental stage was reached, the plants from the particular pots were removed and the soil was washed out on sieves, and then the above-ground parts (shoots) were separated from the roots. After air-drying, shoots and roots were weighed. In the case of barley, from the straw-shooting stage, the shoots were separated into stems and leaves, and from the earing stage also into spikes.

Phosphorus content establishment was carried out at the Chemical-Agricultural Station in Olsztyn according to the established methods. In the case of red clover, observation of phosphorus content in the shoots was possible from barley tillering and in the roots from cereal straw-shooting (before that the mass was too low). Data on the dry matter was printed in a separate publication (in preparation). Phosphorus uptake was determined by multiplying the element content in the particular plant parts by the mass of those organs.

The results were statistically processed with the analysis of variance for a totally randomized design, and differences between treatments were evaluated using the Duncan's test. The established probability of error was P = 0.05. In the tables, mean values for three experimental cycles are presented.

RESULTS

Spring barley demonstrated higher phosphorus content in the shoots than in the roots (Table 1). Particularly high content of this element was noted in young shoots (at leaf development and tillering). Starting from the straw-shooting stage until the end of growth, more phosphorus was accumulated by barley stems than leaves. From earing, the element accumulated mostly in the spikes. Sowing type and water supply had no significant effect on the content of the described component in cereal organs throughout the entire growth.

Table 1. Phosphorus content in spring barley plants, $g \cdot kg^{-1}$ dry matter
Tabela 1. Zawartość fosforu w roślinach jęczmienia jarego, $g \cdot kg^{-1}$ s.m.

Barley developmental stages Fazy rozwojowe jęczmienia	Plant parts Części roślin		PB		MB	
			HW	LW	HW	LW
Leaf development Rozwój liści	roots – korzenie		2.60±0.71	2.35±0.07	2.50±0.28	2.70±0.57
	shoots – pędy		6.48±1.15	6.17±0.99	6.54±0.99	6.02±1.15
Tillering Krzewienie	roots – korzenie		2.20±0.52	2.30±0.40	2.23±0.42	2.37±0.80
	shoots – pędy		5.53±1.40	4.55±0.87	5.25±1.23	4.25±1.34
Straw-shooting Strzelanie w źdźbło	roots – korzenie		2.07±0.75	2.17±0.42	2.53±0.25	2.00±0.46
	shoots pędy	– stems – łodygi	4.30±0.61	4.10±0.75	4.73±0.78	3.93±0.29
		– leaves – liście	3.40±0.53	3.17±0.40	3.50±0.69	3.17±0.41
Earing Kłoszenie	roots – korzenie		2.10±0.20	1.80±0.56	2.10±0.40	2.57±1.46
	shoots pędy	– stems – łodygi	3.67±0.49	3.73±0.31	4.63±1.38	3.60±0.57
		– leaves – liście	2.73±0.40	3.03±0.21	2.53±0.57	2.87±0.21
		– spikes – kłosy	5.00±0.71	5.23±0.55	5.15±0.92	5.07±0.68
Ripeness Dojrzałość	roots – korzenie		2.43±0.95	2.30±0.53	2.10±0.53	2.50±0.60
	shoots pędy	– stems – łodygi	3.07±0.57	3.63±0.72	3.77±1.82	3.03±0.49
		– leaves – liście	2.33±0.93	3.00±0.46	2.67±1.44	2.80±1.37
		– spikes – kłosy	7.00±0.71	6.97±0.12	6.05±0.35	5.83±1.33

PB – barley in pure sowing – jęczmień w siewie czystym
MB – barley in a mixture with clover – jęczmień w mieszance z koniczyną
HW – water dose that satisfies plant requirements – dawka wody zabezpieczająca wymagania roślin
LW – water dose lowered by 50% in relation to HW – dawka wody obniżona o 50% w stosunku do HW

Almost throughout the entire growth period (with the exception of earing), accumulation of phosphorus in barley roots was limited by water deficit (Table 2). Both in absolute numbers and in relative numbers (relation to more favourable water supply expressed in %), the strongest negative effect of this factor was found at the straw-shooting stage.

Table 2. Phosphorus uptake by spring barley plants, mg·pot^{-1}
Tabela 2. Pobranie fosforu przez rośliny jęczmienia jarego, mg·wazon^{-1}

Barley developmental stages Fazy rozwojowe jęczmienia	Plant parts Części roślin	PB		MB		Factor significance Istotność czynników		
		HW	LW	HW	LW	ST	WS	ST × WS
Leaf development Rozwój liści	roots – korzenie	0.91	0.68	0.90	0.70		*	
	shoots – pędy	4.60	3.83	5.56	3.85		*	
Tillering Krzewienie	roots – korzenie	2.71	2.14	3.14	2.70		*	
	shoots – pędy	28.15	11.74	30.35	10.84		*	
Straw-shooting Strzelanie w źdźbło	roots – korzenie	3.27 b	2.32 b	6.43 a	2.28 b	*	*	*
	shoots – pędy	34.07	13.75	34.17	14.33		*	
	stems – łodygi	18.53	6.40	18.21	7.03		*	
	leaves – liście	15.54	7.35	15.96	7.29		*	
Earing Kłoszenie	roots – korzenie	3.65	2.66	3.93	4.24			
	shoots – pędy	80.61	47.69	88.64	44.93		*	
	stems – łodygi	40.59 b	26.07 c	49.31 a	22.14 d		*	*
	leaves – liście	22.77 a	17.48 bc	18.47 b	16.76 c	*	*	
	spikes – kłosy	17.25	4.13	20.86	6.03		*	
Ripeness Dojrzałość	roots – korzenie	2.62	1.73	2.06	1.93		*	
	shoots – pędy	103.28 a	64.30 bc	85.15 b	51.86 c	*	*	
	stems – łodygi	34.08	25.63	33.44	22.09		*	
	leaves – liście	19.29	15.39	19.28	11.23		*	
	spikes – kłosy	49.91 a	23.28 c	32.43 b	18.54 c		*	*

PB, MB, HW, LW – for explanations, see Table 1 – objaśnienia pod tabelą 1
ST – sowing type – rodzaj siewu
WS – water supply – zaopatrzenie w wodę
* factor influence significant at p = 0.05 – wpływ czynnika istotny przy p = 0,05
a, b, c – homogenous groups for ST × WS: values marked with different letters vary significantly at P = 0.05 – grupy jednorodne dla ST × WS: wartości oznaczone różną literą różnią się istotnie przy P = 0,05

Effect of the sowing type on the amount of phosphorus in barley roots was only visible at the straw-shooting stage: in relation to pure sowing, more phosphorus in the roots was then accumulated by spring barley plants grown with clover. At that stage, sowing type interacted with water supply, which manifested itself with higher phosphorus accumulation in the roots of plants MB-HW than in PB-HW, in the face of lack of differences between PB-LW and MB-LW.

In plants PB-HW, PB-LW and MB-LW, the greatest amount of phosphorus accumulated in barley roots was noted at earing, after which its loss occurred with the reduction of root mass. In plants MB-HW, reduction started earlier.

Like in the case of roots, the sowing type did not have as a strong effect on phosphorus accumulation in the shoots as water supply. Water deficit inhibited the accumulation of this element in the shoots throughout the entire growth period. Taking the reduction as absolute numbers, the strongest negative element of this factor was marked at the straw-shooting stage, whereas in relative numbers – at tillering.

Sowing type did not diversify the amount of accumulated phosphorus in the mass of the above-ground barley parts until earing. At earing, mixed sowing significantly limited the amount of phosphorus in the leaves. Simultaneously, an increase in the amount of phosphorus accumulated in the stems of barley MB-HW occurred (effect of factor interaction). Those opposing effects transferred to a lack of differences in the amount of phosphorus accumulated in total in the shoots at that stage. Mixed sowing also limited the accumulation of phosphorus in the shoots in total at ripening. This resulted first of all from a lower amount of this component accumulated in the spikes of plants MB-HW (factor interaction).

Total phosphorus content accumulated in the shoots of plants PB-HW, PB-LW and MB-LW increased during growth, and its highest value was marked at ripeness. Until earing, the growth was a resultant of higher and higher phosphorus accumulation in all the above-ground organs. During the period of earing-ripening, an increase in the amount of total phosphorus in the shoots was noted, although its decrease occurred in the stems and leaves. The loss was compensated for with excess by the amount of phosphorus accumulated in the spikes. In plants MB-HW, the loss of phosphorus in the stems was so high that the increase of its amount in the spikes, and also to a lesser extent in the leaves, did not improve the total balance of this component in the shoots.

Clover demonstrated higher phosphorus content in the roots than in the shoots, whereas the sowing type did not diversify its content in clover shoots during growth (Table 3). Mixed sowing with barley lowered phosphorus content in clover roots at cereal ripeness. Water supply, however, did not affect phosphorus content in clover organs.

Table 3. Phosphorus content in red clover plants, $g \cdot kg^{-1}$ dry matter
Tabela 3. Zawartość fosforu w roślinach koniczyny czerwonej, $g \cdot kg^{-1}$ s.m.

Barley developmental stages Fazy rozwojowe jęczmienia	Plant parts Części roślin	PC		MC	
		HW	LW	HW	LW
Tillering Krzewienie	shoots – pędy	3.97±0.55	4.20±0.98	4.50±0.99	4.20±1.41
Straw-shooting Strzelanie w źdźbło	roots – korzenie	5.13±1.72	4.67±0.60	4.85±0.15	4.90±0.10
	shoots – pędy	3.80±1.75	3.30±0.56	3.33±1.17	3.05±0.64
Earing Kłoszenie	roots – korzenie	4.80±1.51	5.27±0.55	5.10±0.28	5.70±0.71
	shoots – pędy	3.27±0.76	3.77±1.34	3.13±0.64	2.83±0.38
Ripeness Dojrzałość	roots – korzenie	5.10±1.15	4.73±0.45	3.53±0.64	3.68±0.37
		4.90 a		3.61 b	
	shoots – pędy	3.07±0.35	3.00±0.26	3.67±0.96	3.35±0.35

PC – clover in pure sowing – koniczyna w siewie czystym
MC – clover in a mixture with barley – koniczyna w mieszance z jęczmieniem
HW, LW – for explanations, see Table 1 – objaśnienia pod tabelą 1
a, b – homogenous groups: values marked with different letters vary significantly at P = 0.05 – grupy jednorodne: wartości oznaczone różną literą różnią się istotnie przy P = 0,05

What affected phosphorus accumulation in the roots and shoots of red clover almost in all the study periods (with the exception of the roots at ripening) was both the sowing type and water supply, as well as factor interaction (Table 4). At straw-shooting and earing, mixed sowing caused a greater reduction in phosphorus accumulated in roots than water deficit. Stress caused by competition on the part of spring barley was strong enough so introducing another stress factor, namely water deficit, had no effect. At ripening, only sowing type affected phosphorus accumulation in the roots: mixed sowing limited it in comparison with pure sowing.

Table 4. Phosphorus uptake by red clover plants, $mg \cdot pot^{-1}$
Tabela 4. Pobranie fosforu przez rośliny koniczyny czerwonej, $mg \cdot wazon^{-1}$

Barley developmental stages Fazy rozwojowe jęczmienia	Plant parts Części roślin	PC		MC		Factor significance Istotność czynników		
		HW	LW	HW	LW	ST	WS	ST x WS
Tillering Krzewienie	shoots – pędy	3.41 a	0.71 b	0.99 b	0.80 b	*	*	*
Straw-shooting Strzelanie w źdźbło	roots – korzenie	2.87 a	1.77 b	0.97 c	0.88 c	*	*	*
	shoots – pędy	6.27 a	3.53 b	1.70 c	1.31 c	*	*	*
Earing Kłoszenie	roots – korzenie	19.58 a	16.97 b	1.38 c	0.57 c	*	*	*
	shoots – pędy	38.26 a	18.74 b	2.79 c	1.56 c	*	*	*
Ripeness Dojrzałość	roots – korzenie	33.61	30.51	2.22	4.16	*		
	shoots – pędy	63.06 a	39.90 b	6.86 c	7.10 c	*	*	*

PC – clover in pure sowing – koniczyna w siewie czystym
MC – clover in a mixture with barley – koniczyna w mieszance z jęczmieniem
HW – water dose that satisfies plant requirements – dawka wody zabezpieczająca wymagania roślin
LW – water dose lowered by 50% in relation to HW – dawka wody obniżona o 50% w stosunku do HW
ST – sowing type – rodzaj siewu
WS – water supply – zaopatrzenie w wodę
* factor influence significant at P = 0.05 – wpływ czynnika istotny przy P = 0,05
a, b, c – homogenous groups for ST × WS: values marked with different letters vary significantly at P = 0.05 – grupy jednorodne dla ST × WS: wartości oznaczone różną literą różnią się istotnie przy P = 0,05

From barley tillering to its ripening, both study factors, as well as their interaction, affected phosphorus accumulation in red clover shoots. At tillering, negative effects of mixed sowing and water deficit were comparable, and summing up the effect of both stress factors did not intensify the reduction in the amount of accumulated phosphorus. From cereal straw-shooting to the end of growth, mixed sowing more strongly than water deficit inhibited phosphorus accumulation in clover shoots, and in the case of adding up the stresses, water deficit had no effect. Increase in phosphorus accumulation in clover organs was proportional to an increasing clover biomass.

DISCUSSION

Interactions between plants in natural or anthropogenic competitive units may be of competitive, complementary resource use, or resource uptake facilitation character [Hinsinger *et al*. 2011]. According to some authors, these are different aspects of the same interaction [Aminifar and Ghanbari 2014]. As far as joint use of nutrients is concerned, the greatest amount of information is given on nitrogen. Studies on phosphorus are fewer but there is some information on increased phosphorus uptake by cereals which are accompanied by a legume [Hinsinger *et al*. 2011]. Zhang and Li [2003] signalled that *Vicia faba* L. and *Cicer arietinum* L. made phosphorus uptake easier by, respectively, maize and wheat. In Danish and German studies [Hauggaard-

Nielsen *et al*. 2009] phosphorus accumulation by barley grown with *Pisum sativum* L. was higher by 20% than in pure sowing. Ghosh *et al*. [2009] demonstrated that sorghum grown in a mixture with soybean accumulated more phosphorus in the shoots than in pure sowing, with the exception of the period before plant harvest. Wanic and Michalska [2009] proved that mixed sowing with pea increased phosphorus content in the above-ground barley mass at earing and ripening in all the parts, and small changes were noted in the phosphorus content in the roots.

Facilitation of phosphorus uptake for the partner is attributed to element release from organic compounds through the action of extracellular enzymes [Dakora 2003] or through the release of non-organic phosphorus fixed in the soil as a result of pH lowering by legumes that participated in N_2 fixation [Yan *et al*. 1996]. Other works inform about phosphorus transfer between plants through scraps of mycorrhizal fungi [Yao *et al*. 2003].

In the present study, spring barley sowing jointly with red clover did not change the phosphorus content in its organs in comparison with pure sowing but it affected the accumulation of this element in cereal biomass. It was diversified during growth but at the final stage it proved to be unfavourable. At the straw-shooting stage, spring barley plants grown with clover absorbed more phosphorus to the roots, which may suggest a facilitating aspect on the part of clover. At the subsequent stage, phosphorus was transferred faster to the stems and spikes, and the differences in the amount of the element in the roots between the plants in mixed and pure sowing were insignificant. At the end of growth, under the influence of clover proximity, barley accumulated less total phosphorus in the shoots, especially in the spikes, which probably resulted from competitive interactions.

Uptake of phosphorus by a plant is to a higher degree conditioned by the size of the created biomass and does not have to correlate with its content. In addition to the present study, this is also confirmed by the observations by Høgh-Jensen *et al*. [2001]. According to the authors, *Lolium perenne* L. grown in a mixture with *Trifolium repens* L. demonstrated higher phosphorus content per unit of dry matter of shoots but lower total yield of this element, which resulted from a lower mass in comparison with pure sowing.

The observed in the present study variability of the effects of interspecies interactions during growth is also confirmed by the studies by Treder *et al*. [2009] on competition between spring barley and spring wheat. In the quoted studies, barley grown in a mixture in relation to pure sowing demonstrated higher phosphorus content in the shoots at emergence, and lower in the blades at earing. The values for the other stages and organs were comparable for both sowing types. On the other hand, wheat grown in a mixture, in comparison with pure sowing, had lower phosphorus content from emergence to straw-shooting, and greater at ripening.

Complexity of interspecies interaction mechanisms in relation to phosphorus uptake is emphasized by the research results by Aminpanah [2012] on the competition between rice and cockspur grass (*Echinochloa crus-galli* (L.) P. Beauv). Each of the two studied rice cultivars reacted differently to growing competition on the part of the weed with the increase in its density: one of them with an increase in phosphorus content and accumulation in the grain, and the second one with a decrease in those parameters. Phosphorus content and accumulation in the straw and leaves of those cultivars demonstrated even higher diversification of responses to competition.

In the present study, mixed sowing with barley did not change phosphorus content in clover shoots during growth but it limited its content in the roots at cereal ripeness. Throughout almost the entire period of joint growth, competition on the part of barley inhibited the uptake of this element and its storage in both the under- and above-ground parts. Clover is recognized as a species that poorly competes with grass, including cereals grown in main yield [Känkänen and Eriksson 2007]. By comparison, in the studies by Høgh-Jensen *et al*. [2001], *Trifolium repens* L. grown in a mixture with *Lolium perenne* L. demonstrated lower phosphorus content in leaf blades and stems in comparison with pure sowing. Also the yield of this element in its organs was lower in comparison with pure sowing. Studies by Yao *et al.* [2003] ascertain that transfer of phosphorus occurs between red clover and perennial ryegrass through scraps of mycorrhizal fungi. Although the quoted authors found a two-way transfer, they also indicated that the rate of transfer towards ryegrass was faster. In the studies by Ghosh *et al.* [2009], also another legume, soybean, grown in a mixture with sorghum absorbed less phosphorus than in pure sowing, with the exception of the period between 60th and 80th day after sowing. Opposing results were obtained by Hauggaard-Nielsen *et al.* [2009]: pea (*Pisum sativum* L.) in a mixture with barley accumulated more phosphorus than in pure sowing. On the other hand, Wanic and Michalska [2009] demonstrated that phosphorus content in pea plants was similar regardless of pure sowing or growth in a mixture with barley.

Poor water availability limits nutrient uptake, including phosphorus [Suriyagoda *et al.* 2014] and may also decrease the level of mineral components in plants [Baligar *et al.* 2001]. In the studies by Ali *et al.* [2008], water stress lowered phosphorus content in the shoots and roots of maize. In the present study, water supply did not diversify phosphorus content in the organs of spring barley and red clover but its deficit almost throughout the entire growth period limited phosphorus uptake by those species. Similarly in the studies by Slamka and Krček [2011], drought had no effect on phosphorus content in barley plants but lowered its uptake by 20-35% in comparison with optimum water supply. Castillo *et al.* [2013] found that legumes from *Lotus* spp. at poorer water access accumulated less phosphorus in the shoots in comparison with full supply but no differences in phosphorus content in the shoots was noted.

According to Grime [1977], competition may be less significant in the conditions of water shortage because plant growth is disturbed more by water stress than by competition. Present study in relation to phosphorus uptake confirms this thesis only in the case of the accumulation of the discussed element in barley spikes during ripening. Earlier, at the straw-shooting stage, facilitation of phosphorus accumulation in barley roots was noted in sowing with clover but only in the conditions of proper moisture. At earing, competition with red clover intensifies the reduction of phosphorus amount in barley leaves caused by water deficit. Claway and Walker [1997] indicate that balance between competition and facilitation in physical stress gradient may change with the developmental stage of both interaction species. In the case of red clover, in the present studies, competition on the part of barley was a stronger stress factor, which inhibited phosphorus accumulation in its organs. Against strong competition, additional appearance of water stress usually had no significance. On the other hand, interaction of factors in the present study did not affect the phosphorus content in the organs of either barley or clover.

CONCLUSIONS

Sowing type had no effect on phosphorus content in the organs of spring barley. Mixed sowing lowered phosphorus content in red clover roots during barley ripeness. Water supply did not diversify phosphorus content in the organs of spring barley and red clover. Mixed sowing contributed to the accumulation by spring barley of higher amount phosphorus in the roots at the straw-shooting stage and lower in the shoots, especially in the spikes towards the end of growth. Competition on the part of barley inhibited the uptake and storage of phosphorus by red clover. Water deficit almost throughout the entire growth period limited phosphorus uptake by spring barley and red clover. Competition on the part of barley was a stronger factor for red clover that made phosphorus storage in the organs difficult than water deficit. Water stress did not intensify the negative effect of competition.

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ZAWARTOŚĆ FOSFORU W ROŚLINACH JĘCZMIENIA JAREGO I KONICZYNY CZERWONEJ W SIEWIE CZYSTYM I MIESZANYM

Streszczenie. Podczas wegetacji wsiewki i rośliny ochronnej zachodzą interakcje, których wzorce i mechanizmy nie są do końca rozpoznane, zwłaszcza w zakresie zmienności czynników ekologicznych. Wspólne korzystanie z puli zasobów środowiska może modyfikować pobieranie składników pokarmowych z podłoża i ich gromadzenie w poszczególnych organach roślin. Celem badań było określenie wpływu interakcji zachodzących między jęczmieniem jarym a koniczyną czerwoną na zawartość fosforu w ich organach na tle zróżnicowanego zaopatrzenia w wodę. W eksperymencie wazonowym (3 cykle) czynnikami badawczymi były: (1) rodzaj siewu roślin (uprawa każdego z gatunków w siewie czystym i w mieszance), (2) zaopatrzenie roślin w wodę (dawka zabezpieczająca wymagania i obniżona o 50%). Mieszankę skomponowano według schematu addytywnego. Zawartość fosforu oznaczano w materiale roślinnym pobieranym w 5 fazach wyznaczonych przez rytm rozwojowy jęczmienia w siewie czystym w warunkach korzystniejszego zaopatrzenia w wodę. Rodzaj siewu nie miał wpływu na zawartość fosforu w organach jęczmienia jarego, ale siew mieszany skutkował nagromadzeniem większej ilości fosforu w korzeniach w fazie strzelania w źdźbło, a mniejszej w pędach i kłosach pod koniec wegetacji. U koniczyny czerwonej siew mieszany obniżył zawartość fosforu w korzeniach w stadium dojrzałości zboża. Konkurencja ze strony jęczmienia hamowała pobieranie i magazynowanie fosforu przez koniczynę czerwoną. Zaopatrzenie w wodę nie różnicowało wprawdzie zawartości fosforu w organach jęczmienia jarego i koniczyny czerwonej, ale deficyt wody niemal przez cały okres wegetacji ograniczał pobranie fosforu przez obydwa gatunki. Konkurencja ze strony jęczmienia była dla koniczyny czerwonej silniejszym czynnikiem utrudniającym magazynowanie fosforu w organach roślin niż deficyt wody. Stres wodny nie pogłębiał już negatywnego wpływu konkurencji.

Słowa kluczowe: akumulacja fosforu, części roślin, deficyt wody, fazy rozwojowe roślin, konkurencja, międzyplon

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