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COMPETITION FOR NITROGEN BETWEEN SPRING BARLEY (*Hordeum vulgare* L.) AND PEA (*Pisum sativum* L. *sensu lato*) IN DIVERSIFIED SOIL CONDITIONS

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Abstract. In a pot experiment, carried out in an additive design on light and heavy soils, the effect of interaction between spring barely and pea was evaluated on nitrogen accumulation in different forms of the above-ground matter (stems, leaves, spikes, pods) and roots of both plant species. The experiment included three series, carried out in years 2003-2004 in five periods determined by the developmental stages of spring barley (the BBCH scale): emergence (10-13), tillering (23), stem elongation (32), earing (55), and ripening (87-89). It was demonstrated that the species grown in a mixture accumulated less nitrogen in the above-ground parts and roots than in pure sowing from barley tillering stage to the end of growth. Competition for nitrogen started at the tillering stage, and its intensity increased gradually until the end of the growth period. During tillering, it limited to the greatest extent nitrogen accumulation in the roots of both species, at the straw shooting stage in their above-ground parts, and at the stages of earing and ripening in the roots. With the exception of barley earing stage, pea proved to be a better competitor for nitrogen. Competition was the most intensive on heavy soil.

Key words: barley developmental stages, competition balance index, legume-cereal mixture, nitrogen accumulation, relative yield

INTRODUCTION

Many different interactions take place among plant components in mixed lowland meadows. One type of frequently occurring relations is competition, a negative interaction, which affects survivability, developmental rhythm, and morphological characteristics of plants, and, as a result, yield size and quality [Vandermeer 1992, Connolly *et al*. 2001]. Its intensity depends on the selection of species and cultivar mixtures, developmental stage, habitat conditions, and applied agrotechnics [Lamb *et al*. 2007]. These factors cause the obtained yield, and in particular component share, to be hard to predict, which is the basic shortcoming of this method of plant cultivation

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[Rudnicki and Gałęzewski 2007]. Competition may also affect biogene assimilation and accumulation in different plant parts [Craine 2006, Treder and Wanic 2011]. Taking the above into consideration, a study hypothesis was put forward, which assumed that between spring barely and pea, competitive interaction would take place in relation to nitrogen, and the strength of that interaction would not depend on plant developmental stage or soil conditions. Its verification was carried out on the basis of the experiment whose aim was to assess the effect of the interactions between spring barley and pea grown on light and heavy soils on nitrogen accumulation in different plant parts during their joint growth.

MATERIAL AND METHODS

Study was conducted on the basis of a pot experiment carried out in three series and four repetitions in years 2003-2005 at the greenhouse laboratory of the University of Warmia and Mazury in Olsztyn. The first series took place from March 31st to July 1st, 2003, the second one from February 4th to May 24th, 2004, and the third one from September 16th, 2004 to January 7th, 2005. The subject of the assessment was spring barley (*Hordeum vulgare* L.) and pea (*Pisum sativum* L. *sensu lato*). Plants were sown in a mixture and in pure sowing on light and heavy soils. Light soil was brownish soil, formed from uniform sand of fluvoglacial origin, light loamy silty sand, covering weakly loamy sand, and loose silty sand. In the layer of 0-20 cm it contained 14% floatable parts, 36% silt, and 50% sand. Soil was characterized by slightly acid pH (pH in 1 M KCl from 5.8 to 6.4), organic matter content from 1.14% to 1.34%, high phosphorus content (9.42-10.55 mg·100 g^{-1} soil), and average contents of potassium (8.30-10.29 mg) and magnesium (2.59-2.71 mg). Heavy soil was brown leached soil formed from heavy loam. In the layer of 0-20 cm it contained 64% floatable parts, 12% silt, and 24% sand. It was characterized by slightly acid pH (pH in 1 M KCl from 5.6 to 6.2), organic matter content from 1.84% to 2.52%, high contents of phosphorus (9.24--11.61 mg·100 g^{-1} soil) and magnesium (8.80-9.11 mg), and average potassium content (12.87-14.53 mg). It results from the above characteristics that the soils differed in regard to numerous properties. They were chosen for the experiment on purpose, in order to find out whether soil type would have any effect on the intensity of competitive relations.

The experiment was set up as a random design, and competition was studied according to the additive pattern, where the number of plants in the mixture was the sum of species density in pure sowings [Snaydon 1991, Semere and Froud-Williams 2001].

The factors of the experiment were as follows:

– soil category: light and heavy,

– plant sowing method: in a mixture and in pure sowing.

The experiment was carried out in five periods determined by the developmental stages of spring barely grown on light soil in pure sowing, that is at the stages of (according to the BBCH scale): emergence (10-13), tillering (23), stem elongation (32), earing (55), and ripening (87-89).

In total, the experiment consisted of 120 Kick-Brauckmann pots.

Due to soil richness in phosphorus and potassium, in the experiment only nitrogen fertilization was applied at the dose of pure element (g N·pot^{-1}): spring barely 0.500; pea 0.125; mixture 0.300.

Spring barely cultivar used in the experiment was Rabel, and pea cultivar was Grapis. The plants were sown at the density of germinating caryopses or seeds in pots spring barley 18 plants and pea 9 plants, which was equivalent to plant density per 1 m^2 spring barley 350 and pea 100. Barley grains and pea seeds were placed in pots at equal distance using stencils and then inserted into the soil at the depth of 3 cm (barley) and 5 cm (pea).

During growth, water shortages in the pots were replenished daily up to 50% of the maximum water capacity of the soil.

At the time when spring barley reached proper developmental stage, all the plants were removed from the pots and the above-ground part was separated from the roots. The above-ground part was split into stems, leaves, and spikes or pods (from the moment it was possible to single them out). The distinguished parts were dried to air dry matter and total nitrogen content was established. The analyses were carried out at the Chemical-Agricultural Station in Olsztyn. Samples for the analyses originated from three series and four repetitions. Data concerning plant biomass and nitrogen concentration can be found in previous papers [Michalska *et al*. 2008, Wanic and Michalska 2009].

On the basis of the obtained results and plant dry matter measurements, the yield of nitrogen accumulated in the above-ground parts and roots of both plant species was calculated. The data was used for calculating nitrogen relative yield (RY), nitrogen relative yield total (RYT) [Snaydon 1991], and competition balance index (Cb) [Wilson 1988]. The following parameters were calculated:

– relative yield: RYi = Yij/Yii RYj = Yji/Yjj
– relative yield total: RYT = RYi + RYj
– competition balance index: Cb = ln [(Yij/Yji)/(Yii/Yjj)]

where:
RYi – relative yield of species i (barley),
RYj – relative yield of species j (pea),
Yii – yield of species i (barley) in pure sowing,
Yjj – yield of species j (pea) in pure sowing,
Yij – yield of species i (barley) in a mixture with species j (pea),
Yji – yield of species j (pea) in a mixture with species i (barley),
ln – natural logarithm.

Results concerning total nitrogen yield in plants were statistically processed with the analysis of variance for factorial design, at P = 0.05, using the Statistica program. The analysis was conducted separately for every developmental stage and particular plant parts. For the assessment of interplant variation, the Tukey's test was used.

RESULTS

Soil type significantly diversified nitrogen yield in the biomass of spring barley only during emergence. At that time, more of this element could be found in the plants grown on light soil (Table 1). The analysis of the particular plant parts demonstrated that light soil was conducive to nitrogen accumulation in the roots at the stages of tillering and stem elongation, in the spikes during earing, and in the straws and leaves during ripening. Heavy soil was conducive to nitrogen accumulation in the straws during stem elongation, in the leaves during earing, and in the spikes during ripening.

During emergence on light soil, no effect of the sowing method was found on nitrogen yield in the biomass of spring barley. On the other hand, on heavy soil, its efficiency was found to be significantly lower in a mixture than in pure sowing (by 9.3%), particularly in the leaves of the cereal. Starting from the tillering stage, on both soils, barley in a mixture obtained nitrogen significantly poorer than in pure sowing. This situation persisted until the end of growth. Nitrogen mass in the cereal in a mixture was lower than in pure sowing: at the tillering stage by 36.0%, at the stem elongation stage by 47.6%, at the earing stage by 37.2%, and at the ripening stage by 44.6%. With the exception of the tillering stage, greater differences between mixed and pure sowings occurred on heavy soil. At the stem elongation stage, they resulted from significantly higher nitrogen accumulation in the straws and leaves of barley grown in pure sowing than in a mixture. At the earing stage, it resulted from higher nitrogen accumulation in pure sowing in the leaves and its lower accumulation in a mixture in the straws, spikes, and roots, and at the ripening stage it resulted from lower mass of nitrogen found in the leaves and roots of barely in a mixture. Soil type diversified to a greater extent nitrogen accumulation in pea than in spring barely (Table 2). From barley tillering stage to the end of growth, higher yield of this element was found in plants grown on heavy soil (with the exception of emergence and ripening, where no significant differences were found). During the entire growth period, soil type had no effect on nitrogen yield in pea roots. In the above-ground parts (except pea stems during barley earing), its significantly higher accumulation was found on heavy soil.

In pea plants, during emergence on light soil, analogically to the case of barley, no significantly lower uptake of this biogene was found in a mixture in relation to pure sowing. Only a tendency for its lower accumulation in the above-ground matter was noted. In that period, on heavy soil in a mixture, significantly higher nitrogen accumulation was found in the above-ground pea parts (in relation to growth in pure sowing by over 20%). Sowing method did not diversify, however, the mass of this element in the roots. From barley tillering to the end of growth, pea, with the presence of the cereal, assimilated significantly less nitrogen than in pure sowing. On light soil at the tillering and stem elongation stages, lower accumulation of this macroelement was noted in a mixture by, respectively, 26.2% and 33.8%. It was the most visible in stems, and the least in roots. During barley earing, the differences decreased significantly, appearing (for the entire plant matter) as a tendency. This resulted from the lack of differences between the sowing methods in the mass of nitrogen accumulated in stems and pods. In the roots of pea grown in a mixture, on the other hand, over 50% less of this element was found than in pure sowing. At the end of growth, the advantage of pure sowing over mixed sowing strengthened. In a mixture, pea assimilated 47.4% less nitrogen than in pure sowing, which appeared most strongly in roots (65.8% less) and in pods (59.6% less). On heavy soil, the differences between mixed and pure sowings increased from barely tillering stage to its earing (from 17.6% to 68.4%), and then they decreased (to 38.6%). At the tillering stage, barley to the greatest extent limited nitrogen accumulation in pea roots, at the stem elongation stage in the leaves, at the earing stage in the pods, and at the ripening stage in the leaves and roots.

Table 1. Nitrogen yield in the biomass of spring barley, $g \cdot 10^{-2} \cdot pot^{-1}$
Tabela 1. Plon azotu w biomasie jęczmienia jarego, $g \cdot 10^{-2} \cdot wazon^{-1}$

Developmental stage (BBCH)/plant parts Faza rozwojowa (BBCH)/części roślin		Light soil – Gleba lekka			Heavy soil – Gleba ciężka			Mean – Średnia			$LSD_{0.05}$ – $NIR_{0,05}$		
		Sowing method – Sposób siewu											
		C*	M	mean średnia	C	M	mean średnia	C	M	mean średnia			
Emergence Wschody (10-13)	leaves – liście	5.30	5.20	5.25	4.80	4.40	4.60	5.10	4.80	4.95	** I 0.41	II 0.20	I x II 0.40
	roots – korzenie	0.70	0.80	0.75	0.60	0.50	0.55	0.70	0.70	0.70	I 0.12	II ns – ni	I x II ns – ni
	total – razem	6.00	6.00	6.00	5.40	4.90	5.15	5.80	5.50	5.65	I 0.66	II ns – ni	I x II 0.30
Tillering Krzewienie (23)	leaves – liście	12.10	7.70	9.90	11.60	7.70	9.65	11.90	7.70	9.80	I ns – ni	II 3.70	I x II ns – ni
	roots – korzenie	2.20	1.50	1.85	1.70	0.90	1.30	2.00	1.20	1.60	I 0.54	II 0.60	I x II ns – ni
	total – razem	14.30	9.20	11.75	13.30	8.60	10.95	13.90	8.90	11.40	I ns – ni	II 4.40	I x II ns – ni
Stem elongation Strzelanie w źdźbło (32)	straws – źdźbła	8.00	4.20	6.10	12.1	4.70	8.40	10.10	4.50	7.30	I 1.95	II 3.00	I x II 6.80
	leaves – liście	17.30	12.00	14.65	22.10	10.10	16.10	19.70	11.10	15.40	I ns – ni	II 7.90	I x II 9.30
	roots – korzenie	5.20	2.40	3.80	2.40	1.50	1.95	3.80	2.00	2.90	I 1.79 I	I 1.60	I x II 2.20
	total – razem	30.50	18.60	24.55	36.60	16.30	26.45	33.60	17.60	25.60	I ns – ni	II 11.60	I x II 14.70
Earing Kłoszenie (55)	straws – źdźbła	7.60	8.40	8.00	11.60	6.70	9.15	9.60	7.60	8.60	I 0.99	II ns – ni	I x II 3.90
	leaves – liście	12.10	10.70	11.40	19.80	10.60	15.20	16.00	10.70	13.35	I 2.97	II 3.70	I x II 8.40
	spikes – kłosy	5.90	2.70	4.30	4.80	1.20	3.00	5.40	2.00	3.70	I 1.25	II 2.80	I x II ns – ni
	roots – korzenie	4.40	2.50	3.45	5.50	2.00	3.75	5.00	2.30	3.65	I ns – ni	II 2.10	I x II 3.30
	total – razem	30.00	24.30	27.15	41.70	20.50	31.10	36.00	22.60	29.30	I ns – ni	II 12.10	I x II 13.90
Ripening Dojrzewanie (87-89)	straws – źdźbła	6.20	6.50	6.35	4.30	4.10	4.20	5.30	5.30	5.30	I 2.13	II ns – ni	I x II ns – ni
	leaves – liście	7.80	4.70	6.25	7.00	3.50	5.25	7.40	4.10	5.75	I ns – ni	II 2.70	I x II ns – ni
	spikes – kłosy	22.00	9.40	15.70	30.90	14.50	22.70	26.50	12.00	19.25	I 6.22	II 13.10	I x II ns – ni
	roots – korzenie	2.50	2.20	2.35	2.80	1.30	2.05	2.70	1.80	2.25	I ns – ni	II ns – ni	I x II 1.10
	total – razem	38.50	22.80	30.65	45.00	23.40	34.20	41.90	23.20	32.55	I ns – ni	II 13.80	I x II ns – ni

* C – pure sowing – siew czysty, M – mixed sowing – siew mieszany
** I – soil – gleba, II – sowing method – sposób siewu
ns – ni – non-significant – nieistotne

Table 2. Nitrogen yield in the biomass of pea, $g \cdot 10^{-2} \cdot pot^{-1}$
Tabela 2. Plon azotu w biomasie grochu siewnego, $g \cdot 10^{-2} \cdot wazon^{-1}$

Developmental stage (BBCH)/plant parts Faza rozwojowa (BBCH)/części roślin		Light soil – Gleba lekka			Heavy soil – Gleba ciężka			Mean – Średnia			$LSD_{0.05}$ – $NIR_{0,05}$		
		Sowing method – Sposób siewu											
		C*	M	mean średnia	C	M	mean średnia	C	M	mean średnia			
Emergence Wschody (10-13)	stems – łodygi	6.00	5.60	5.80	5.40	6.60	6.00	5.70	6.10	5.90	** I ns – ni	II ns – ni	I x II 0.80
	roots – korzenie	1.70	1.80	1.75	1.20	1.00	1.10	1.50	1.40	1.45	I ns – ni	II ns – ni	I x II ns – ni
	total – razem	7.70	7.40	7.55	6.60	7.60	7.10	7.20	7.50	7.35	I ns – ni	II ns – ni	I x II 0.70
Tillering Krzewienie (23)	stems – łodygi	5.90	3.80	4.85	6.30	5.50	5.90	6.10	4.70	5.40	I 0.96	II 0.70	I x II ns – ni
	leaves – liście	6.30	5.20	5.75	8.60	7.20	7.90	7.50	6.20	6.85	I 1.13	II 1.10	I x II ns – ni
	roots – korzenie	2.70	2.00	2.35	2.10	1.30	1.70	2.40	1.70	2.05	I ns – ni	II 0.50	I x II ns – ni
	total – razem	14.90	11.00	12.95	17.00	14.00	15.50	16.00	12.60	14.30	I 1.97	II 2.80	I x II ns – ni
Stem elongation Strzelanie w źdźbło (32)	stems – łodygi	8.40	5.00	6.70	9.90	7.60	8.75	9.20	6.30	7.75	I 1.64	II 2.50	I x II 2.70
	leaves – liście	8.30	5.30	6.65	13.00	7.60	10.30	10.70	6.50	8.60	I 3.48	II 7.90	I x II 9.30
	roots – korzenie	3.40	3.00	3.20	2.70	2.50	2.60	3.10	2.80	2.95	I 1.79 I	I 2.90	I x II ns – ni
	total – razem	20.10	13.30	16.70	25.60	17.70	21.65	23.00	15.60	19.30	I 3.99	II 5.80	I x II ns – ni
Earing Kłoszenie (55)	stems – łodygi	10.70	11.30	11.00	18.90	8.20	13.55	14.80	9.80	12.30	I ns – ni	II ns – ni	I x II 8.70
	leaves – liście	8.90	6.80	7.85	15.30	7.90	11.60	12.10	7.40	9.75	I 2.87	II 3.90	I x II 6.40
	pods – strąki	11.00	10.40	10.70	34.70	5.40	20.50	22.90	7.90	15.40	I 5.33	II 10.0	I x II 17.7
	roots – korzenie	5.50	2.60	4.05	5.10	1.90	3.50	5.30	2.30	3.80	I ns – ni	II 1.40	I x II ns – ni
	total – razem	36.10	31.10	33.55	74.0	23.40	48.70	55.10	27.40	41.25	I 13.5	II 10.6	I x II 25.9
Ripening Dojrzewanie (87-89)	stems – łodygi	8.80	9.20	9.00	6.90	6.10	6.50	7.90	7.70	7.80	I ns – ni	II ns – ni	I x II ns – ni
	leaves – liście	2.70	2.20	2.45	4.80	1.70	3.15	3.80	2.00	2.90	I ns – ni	II ns – ni	I x II 2.60
	pods – strąki	38.10	15.40	26.75	55.0	33.90	44.45	46.60	24.70	35.65	I 10.4	II 17.7	I x II ns – ni
	roots – korzenie	3.80	1.30	2.55	3.70	1.50	2.60	3.80	1.40	2.60	I ns – ni	II 17.7	I x II ns – ni
	total – razem	53.40	28.10	40.75	70.40	43.20	56.80	62.10	35.80	48.45	I ns – ni	II 20.6	I x II ns – ni

explanations under Table 1 – objaśnienia pod tabelą 1

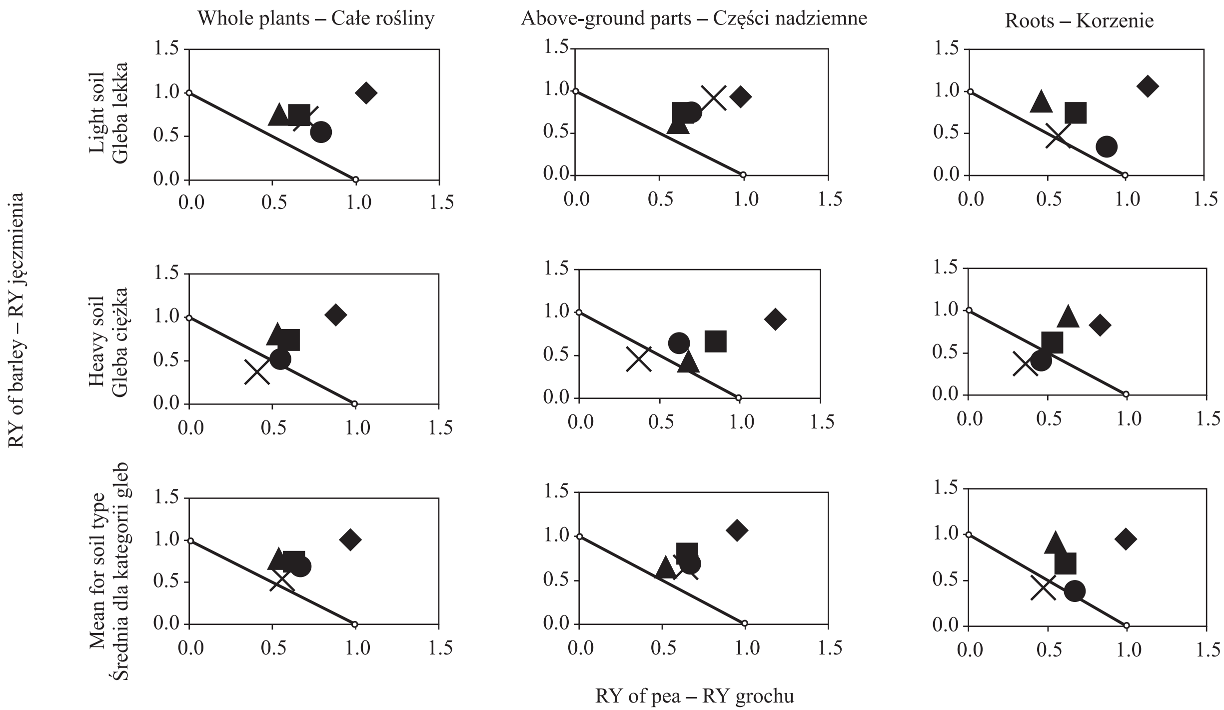
Analysis of the relative yields of total plants demonstrated that, on average, for the soil conditions during emergence almost entire nitrogen supply was used complementarily by both species (Figure 1). Nitrogen accumulation in the above-ground parts of pea in a mixture was even higher than in its pure sowing. However, already at the barley tillering stage, nitrogen supply was becoming insufficient for both species. Therefore, competition started to take place between them, which lasted until the end of growth. Its strength intensified up to barley earing stage, and towards the end of growth it underwent slight weakening. During tillering, the plants competed for 63% of nitrogen, at the stem elongation stage for 68%, during earing for 91%, and during ripening for 80%. From emergence to stem elongation, pea assimilated nitrogen more effectively, and later both species uptaked nitrogen to a similar degree. During tillering, competition more strongly limited nitrogen accumulation in the roots than in the above-ground parts, especially in pea. At the stem elongation stage, this was more evident in the above-ground plant parts than in the roots.

The above relations changed under the effect of soil conditions. On light soil, during emergence, mutually positive effect was found of the species on nitrogen accumulation in barley roots (Figure 1a). In the following period, negative relations occurred between the species (stronger ones on the part of pea), which increased up to the stem elongation stage. During tillering, plants competed for 60% of nitrogen, and at the stem elongation stage for 71%. During barley earing, competition underwent clear reduction (it concerned 61% of nitrogen) and slightly increased towards the end of growth (by 66% of the supply of the element).

On heavy soil, from the beginning of growth, incomplete nitrogen use took place by both species in a mixture, which was reflected in lower by 10% accumulation of this biogene in their matter (Figure 1b). At the tillering and stem elongation stages, the plants competed for 67% of the nitrogen supply, and during earing for its entire supply. This action decreased at the end of growth and concerned 93% of the uptaken nitrogen. During emergence, pea limited nitrogen accumulation in full barley plants, and barley positively affected its accumulation in the above-ground pea parts and negatively in roots. At the tillering stage, competition was more visible in the roots than in the above--ground parts of both species.

On average for the soil category, except tillering stage, pea proved to be a stronger competitor than barley in gaining nitrogen (Table 3), and its domination over cereal, up to the stem elongation stage, increased successively. During emergence and tillering, it affected to a greater extent nitrogen accumulation in the above-ground barley parts, and during stem elongation in its roots. At the tillering stage, barley started to dominate pea. At the end of growth, interrelations between the above-ground parts of both plants equalized. However, barley roots started to dominate pea roots.

Degree of relations between the plants in nitrogen uptake was modified by soil conditions. On light soil, during emergence, small competitive advantage of barley was noted, and during barley tillering, stem elongation, and earing, pea started to dominate. Towards the end of growth, barley started to dominate pea. This happened as a result of more effective nitrogen uptake by barley roots. On heavy soil, form emergence to stem elongation, pea dominated barley in obtaining nitrogen. At the earing stage, the situation was opposite, and during ripening, pea again proved to be a stronger competitor.



Developmental stages of barley according to BBCH – Fazy rozwojowe jęczmienia według BBCH: ◆1 – 13, ■23, ▲32, ×55, ●87-89

points in the diagram mark the RYT values, the line – RYT = 1 – punkty na diagramie oznaczają wartości RYT, linia ciągła – RYT = 1

Fig. 1. Values of relative yields (RY) and relative yield total (RYT) of spring barley and pea calculated on the basis of total nitrogen content in the whole plants, above-ground parts, and leaves

Rys. 1. Wartości plonów względnych (RY) oraz całkowitego plonu względnego (RYT) jęczmienia jarego i grochu siewnego obliczone na podstawie całkowitej zawartości azotu w całych roślinach, częściach nadziemnych i korzeniach

Table 3. Competition balance index (Cb)
Tabela 3. Wskaźnik równowagi konkurencyjnej (Cb)

Barley developmental stage (BBCH)/plant parts Faza rozwojowa jęczmienia (BBCH)/części roślin		Light soil Gleba lekka	Heavy soil Gleba ciężka	Mean Średnia
Emergence Wschody (10-13)	above-ground part – część nadziemna	0.05	-0.29	-0.13
	roots – korzenie	0.08	0.00	-0.09
	whole plant – cała roślina	0.04	-0.24	-0.11
Tillering Krzewienie (23)	above-ground part – część nadziemna	-0.15	-0.25	-0.21
	roots – korzenie	-0.08	-0.16	-0.17
	whole plant – cała roślina	-0.13	-0.24	-0.20
Stem elongation Strzelanie w źdźbło (32)	above-ground part – część nadziemna	0.04	-0.43	-0.21
	roots – korzenie	-0.65	-0.39	-0.59
	whole plant – cała roślina	-0.08	-0.44	-0.26
Earing Kłoszenie (55)	above-ground part – część nadziemna	-0.09	0.49	0.25
	roots – korzenie	0.18	-0.22	0.06
	whole plant – cała roślina	-0.06	0.44	0.22
Ripening Dojrzewanie (87-89)	above-ground part – część nadziemna	0.06	-0.18	-0.08
	roots – korzenie	0.94	0.14	0.54
	whole plant – cała roślina	0.12	-0.16	-0.04

DISCUSSION

The study proved that spring barely and pea grown in a mixture accumulated in their matter less nitrogen than in pure sowing. In spring barley, up to the earing stage, it resulted from the formation of both lower biomass and concentration of nitrogen in it, whereas during further growth from lower dry matter, as percentage nitrogen content was higher in it. On the other hand, in pea it resulted mostly from lower dry matter yield of this plant [Michalska *et al*. 2008, Wanic and Michalska 2009]. This is partly confirmed in the studies by Danso *et al*. [1987], who demonstrated that faba bean grown in a mixture with barley uptaked less nitrogen with yield than in pure sowing. Nevertheless, concentration of this biogene in the biomass was higher. Bedoussac and Justes [2010] are of a different opinion, as well as Podgórska-Lesiak *et al*. [2011], who showed that cereal components with legumes uptaked more nitrogen with yield than their pure sowings. Also Kübler *et al*. [2010] showed that growth of cereals with legumes contributes to increasing nitrogen content in their grains. On the other hand, Sobkowicz and Podgórska-Lesiak [2009] did not find, at the end of growth, any clear changes in protein content in the grain and biomass of spring barley under the effect of the sowing method. However, it results form other studies by Sobkowicz [2009] that competitive interactions of Persian clover and seradella on spring barley caused an increase in nitrogen uptake with grain yield of this cereal.

In the analyzed experiment, competition for nitrogen increased until the end of barley tillering, after which its slight decrease occurred, which is reflected in the values of relative yield total (RYT). Sobkowicz [2006] demonstrated also that competition between triticale and faba bean occurred most intensively in the period that preceded grain filling by cereal. Almost in the entire growth period, pea demonstrated to be a stronger competitor than barley in obtaining nitrogen, and its domination over cereal increased with time. The only period in which barley gained domination over pea was the earing stage (but only on heavy soil). Ofori *et al*. [1987] and Sobkowicz [2009] are of a different opinion and view cereals as a stronger competitor than the legume, mainly due to their higher growth pace. Also Danso *et al*. [1987] demonstrated that barley is more competitive in obtaining nitrogen than the legume. Sobkowicz [2006] suggests that strong competition on the part of triticale is the reason for nitrogen accumulation decrease in faba bean. According to the author, the cereal assimilated probably the majority of nitrogen found in the soil and, at the same time, it prevented the legume from obtaining nitrogen from the atmosphere. Jensen [1996] and Hauggaard-Nielsen *et al*. [2001] suggest that in the soil, nitrogen displacement from legume roots to cereal roots may take place. Fujita *et al*. [1992] and Ledgard and Stelle [1992] showed that grasses use nitrogen emitted by legume roots or released during nodule decay. To some extent, this may be supported by the results obtained earlier by Wanic and Michalska [2009] and in the analyzed experiment. They demonstrated that during earing and ripening, concentration of this element in the biomass of barley grown with pea was higher than in pure sowing. At the end of growth, also domination of barley roots in nitrogen uptake increased.

In the present research, competition for nitrogen was stronger on heavy than on light soil. This is in agreement with Grime's [1979] opinion, according to which higher intensity of negative interspecies relations occurs in more fertile habitats. Also Sobkowicz [2009] noted an increase in competitive relations on soil more abundantly fertilized with nitrogen.

CONCLUSIONS

1. Spring barley and pea grown in a mixture, from barley tillering to the end of growth, accumulated less nitrogen than each of the species grown in pure sowing.
2. In the case of spring barley, greater differences in the mass of accumulated nitrogen between pure and mixed sowings occurred on heavy soil. In relation to pea, the differences between the sowing methods caused by soil conditions depended on the developmental stage.
3. Competition for nitrogen between both species started at barley tillering stage and its intensity increased until the earing stage.
4. At the tillering stage, competition limited to a greater extent nitrogen accumulation in barley and pea roots than in the above-ground parts, at the stem elongation stage in their above-ground parts, and at the end of growth in the roots.
5. Almost during the entire growth period, pea demonstrated to be a stronger competitor in obtaining nitrogen than barley. Only at the earing stage, barley dominated pea.
6. Competition for nitrogen was more intense on heavy than on light soil.

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KONKURENCJA O AZOT MIĘDZY JĘCZMIENIEM JARYM (*Hordeum vulgare* L.) I GROCHEM SIEWNYM (*Pisum sativum* L. *sensu lato*) W ZRÓŻNICOWANYCH WARUNKACH GLEBOWYCH

Streszczenie. W doświadczeniu wazonowym, realizowanym według schematu addytywnego na podłożach gleby lekkiej i ciężkiej, oceniano wpływ oddziaływań pomiędzy jęczmieniem jarym i grochem siewnym na akumulację azotu w różnych częściach masy nadziemnej (łodygach, liściach, kłosach, strąkach) i korzeniach obu roślin. Badania obejmowały trzy serie, zrealizowane w latach 2003-2004 w pięciu okresach wyznaczonych przez fazy rozwojowe jęczmienia jarego (BBCH): wschody (10-13), krzewienie (23), strzelanie w źdźbło (32), kłoszenie (55) i dojrzewanie (87-89). Wykazano, że uprawiane w mieszance gatunki gromadziły w masie nadziemnej i korzeniach mniej azotu niż w siewie czystym od fazy krzewienia jęczmienia do końca wegetacji. Konkurencja o azot rozpoczęła się w fazie krzewienia jęczmienia, a jej intensywność sukcesywnie narastała do końca wegetacji. W fazie krzewienia najbardziej ograniczała ona gromadzenie azotu w korzeniach obu gatunków, w fazie strzelania w źdźbło w ich częściach nadziemnych, a w fazach kłoszenia i dojrzewania – w korzeniach. Z wyjątkiem fazy kłoszenia jęczmienia, w pozyskiwaniu azotu groch okazał się silniejszym konkurentem. Konkurencja była intensywniejsza na glebie ciężkiej.

Słowa kluczowe: fazy rozwojowe jęczmienia, gromadzenie azotu, mieszanka strączkowo-zbożowa, plon względny, wskaźnik równowagi konkurencyjnej

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