

COMPETITION FOR NITROGEN BETWEEN SPRING WHEAT AND SPRING BARLEY IN THE CONDITIONS OF VARIOUS NPK FERTILIZATION

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Abstract. In pot experiment, carried out according to the additive pattern on medium soil fertilized with standard and 50% higher dose of NPK, the effect of competitive interactions between spring wheat and spring barley was estimated on nitrogen accumulation in the above-ground mass, with the distinction of stems, leaves, and spikes. Studies included three series, which were carried out in years 2003-2004 in five periods set by the rhythm of development of barley in pure sowing, namely in phases: emergence (BBCH 10-13), tillering (23), straw shooting (32), earing (55), and ripening (87-89). In a mixture, both cereals accumulated less nitrogen in the above-ground mass than in pure sowing starting from the tillering phase until the end of growth. In wheat, the decrease to a similar degree included straws, leaves and spikes, and in barley during earing it was more clearly marked in straws and leaves, and during ripening in spikes. Doses of mineral fertilization with NPK had no effect on nitrogen accumulation by barley and wheat grown in pure and mixed sowing. Competition for nitrogen between cereals started in the tillering phase and grew until the earing phase, after which it decreased slightly. Almost in the entire period of common growth, barley demonstrated to be a stronger competitor than wheat in nitrogen gaining. On bedding richer in NPK, competitive interactions between barley and wheat were more intensive than on poorer one.

Key words: cereal mixtures, competition ratio, mixed sowing, nitrogen accumulation, relative yield, spring cereals

INTRODUCTION

In mixed sowings, various interactions take place between the species, both positive and negative. They may take place through emitting to the environment diverse biochemical compounds (allelopathy) and competitive or complementary resource using [Howard 2001, Callaway 2002, Fitter 2003, Sobkowicz and Tendziagolska 2005]. Those phenomena usually occur simultaneously and, as a result, are difficult to separate. Intensity and direction of the above processes depend on the selection of species and

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cultivars, morphological and physiological traits, developmental stage, and habitat conditions [Keating and Carberry 1993, Sobkowicz 2003, 2005]. As a result of those interactions, mixture yield and nutrition content is different than in the same species and cultivars in pure sowing [Sobkowicz 2003].

Aims of the experiment were: 1) how interactions between spring wheat and spring barley affect nitrogen accumulation in various parts of both species during the entire growth period; 2) does soil richness in NPK diversify the intensity of competitive interactions for this element?

MATERIAL AND METHODS

Basis of the work was a strict pot experiment carried out in three series and four repetitions in years 2003-2004 at the greenhouse laboratory of the University of Warmia and Mazury in Olsztyn. Subject of the assessment was spring wheat (cultivar Torka) and spring barley (cultivar Rabel), which were grown in a mixture and in pure growth. First series lasted from April 10th to July 7th 2003, the second one from February 26th to May 24th 2004, and the third one from September 18th to December 20th 2004. Experiment was set up according to the additive pattern, according to which the number of plants per mixture was the sum of their density in pure sowing [Sattore and Snaydon 1992, Semere and Froud-Williams 2001, Sobkowicz 2001, Sobkowicz and Tendziagolska 2005].

Factors of the experiment were as follows:

a) NPK fertilisation levels:

- basic dose: 162 kg·ha⁻¹ of pure NPK components, including N – 70 kg, P – 26 kg, and K – 66 kg, which scaled per one pot amounted to (g): N – 0.50, P – 0.20, and K – 0.45,
- dose increased in relation to the standard one by 50% (together 243 kg·ha⁻¹), including: N – 105 kg, P – 39 kg, and K – 99 kg; per one pot, respectively 0.75, 0.30, and 0.68 g, in the work, basic dose is to be defined as 1 NPK, and the increased one as 1.5 NPK;

b) sowing method:

- pure,
- mixed.

Pots were filled with bedding taken from soil layer up to 30 cm. It was medium soil, proper brown, from coarse sand in subsoil with loose dusty sand. It was characterized by organic matter content from 1.22 to 1.91%, slightly acid pH, and high richness in the assimilable forms of phosphorus, potassium, and magnesium. Before pot filling, the soil was sieved and mixed with the appropriate doses of mineral fertilizers. Nitrogen fertilizers were applied in the form of urea (half of the dose), potassium fertilizers in the form of potassium sulphate, and phosphorus fertilizers in the form of potassium. The second part of N dose was applied at the beginning of the straw shooting phase of barley.

Cereals were sown in Kick-Brauckmann pots with the diameter of 22 cm and the depth of 28 cm with the density of 19 caryopses per pot (38 in the mixture). On the surface of the pots, caryopses were placed (with the use of templates) in equal distances from one another and put in soil bedding at the depth of 3 cm. At the laboratory, for most of the growth period, temperature between 20-22°C was kept. During full barley

emergence, temperature for the period of 10 days was lowered to 5-6°C. In the third series, due to the fact that it was carried out in the conditions of days growing shorter, artificial additional light was applied; its length and intensity was adapted to the requirements of the cereals.

Research was carried out in five periods set by the developmental rhythm of spring barley in pure sowing fertilized with the basic dose of NPK, that is in phases: emergence (BBCH 10-13), tillering (23), straw shooting (32), earing (55), and ripeness (87-89).

Experiment was made of 120 pots (24 pots for each phase) placed in equal distances from one another. After reaching proper phase by spring barley in pure sowing, from 24 randomly chosen pots all the plants were removed, and the above-ground part was separated from the roots. In the phases of earing and ripeness, the above-ground part was divided into straws, leaves, and spikes. In the plant material dried to air-dry soil, total Kjeldahl nitrogen content was marked. Analyses were carried out at the Chemical-Agricultural Station in Olsztyn. Analyzed samples originated from three series and four repetitions. Data concerning plant biomass and nitrogen concentration was published in earlier works [Treder et al. 2008, 2009]. On the basis of the obtained results and plant dry mass measurements, the yield of nitrogen accumulated in the above-ground parts of both cereals was calculated. This data was used for the calculation of relative nitrogen yield (RY), total yield of relative nitrogen (RYT), and competition ratio (CR) for this biogene of spring wheat in relation to spring barley [Semere and Froud-Williams 2001, Sobkowicz 2001, 2003]:

$$\text{relative yields: } RY_i = Y_{ij}/Y_{ii} \quad RY_j = Y_{ji}/Y_{jj}$$

$$\text{relative yield total: } RYT = RY_i + RY_j$$

$$\text{competition ratio: } CR_{ij} = RY_i / RY_j \quad CR_{ji} = RY_j / RY_i$$

where:

- RY_i – relative yield of species i (spring wheat),
- RY_j – relative yield of species j (spring barley),
- Y_{ii} – yield of species i (wheat) in pure sowing,
- Y_{jj} – yield of species j (barley) in pure sowing,
- Y_{ij} – yield of species i (wheat) in a mixture with species j (barley),
- Y_{ji} – yield of species j (barley) in a mixture with species i (wheat),
- RYT – relative yield total,
- CR_i – competition ratio of spring wheat against spring barley.

In a case when there are no interactions between the species, the yield of each of them is the same as in pure sowing ($RY = 1.0$; $RYT = 2.0$). Values of RYT within the range of 1.0 to 2.0 signify that competition concerns only part of the environmental resources, and the remaining part is used by species complementarily.

Competition ratio (CR) of species i in relation to species j signifies proportional change of mixture composition in relation to the expected content, that is a content in which the share of both species in the yield is equal to the one in the total biomass formed by joining together pure sowings.

Results concerning the mass of the total Kjeldahl nitrogen accumulated in plants were processed statistically with the use of the analysis of variance with the error

probability of $P = 0.05$. For the assessment of inter-object differences, the Tukey's test was used. Analyses were carried out with the use of the Statistica program.

RESULTS AND DISCUSSION

Mass of nitrogen accumulated in the above-ground parts of spring wheat increased up to the earing phase, and afterwards it decreased in the final stage of growth. In relation to the earing phase, it amounted to: in independent growth 21.4%, and in the mixture 12.9% (Table 1).

Table 1. Nitrogen yield in the above-ground parts of spring wheat, $\text{g} \cdot \text{pot}^{-1}$
Tabela 1. Plon azotu w częściach nadziemnych pszenicy jarej, $\text{g} \cdot \text{wazon}^{-1}$

Development stage (BBCH)/plant part Faza rozwojowa (BBCH)/części roślin		1 NPK		1.5 NPK		Mean – Średnia		LSD _{0,05} NIR _{0,05}	
		sowing method – sposób siewu*							
		C	M	C	M	C	M		
10-13		0.23	0.19	0.21	0.25	0.22	0.22	I** ns – ni	II** 0.05
23		2.31	1.92	1.35	1.11	1.83	1.52	I 0.30	II ns – ni
32		2.29	1.70	3.32	1.86	2.78	1.78	I 0.17	II 0.24
55	straws – źdźbła	1.77	0.61	3.16	0.60	2.46	0.61	I 0.34	II ns – ni
	leaves – liście	2.21	1.01	4.23	1.03	3.17	1.03	I 0.41	II ns – ni
	spikes – kłosa	1.44	0.45	1.25	0.29	1.36	0.39	I 0.14	II ns – ni
	total – razem	5.43	2.07	8.64	1.91	7.00	2.02	I 0.68	II ns – ni
87-89	straws – źdźbła	0.83	0.28	1.18	0.25	1.01	0.28	I 0.13	II 0.18
	leaves – liście	0.45	0.19	1.09	0.27	0.74	0.24	I 0.16	II 0.22
	spikes – kłosa	3.17	1.18	4.34	1.29	3.75	1.24	I 0.93	II ns – ni
	total – razem	4.45	1.65	6.61	1.81	5.50	1.76	I 0.73	II ns – ni

* C – pure sowing – siew czysty, M – mixture – siew mieszany

** I – sowing method – sposób siewu, II – interaction (sowing method x fertilization) – współdziałanie (sposób siewu x nawożenie)

ns – ni – non-significant – różnice nieistotne

During emergence, on average for the NPK fertilizer doses, no effect of the sowing method was found on the uptake of this chemical by wheat. A different result was obtained by Ponce [1987], who noted a decrease in nitrogen yield in the above-ground parts of wheat grown in the presence of sterile oat from 340 to 130 mg. Starting from the tillering phase, mixed growth had a negative effect on nitrogen accumulation in the biomass of the analysed cereal. It was the most clearly seen in the period of generative development (earring and ripeness phases). At the same time, Sobkowicz [2000] did not note any significant effect of joint growth of three spring cereal species (barley, oats, and triticale) on total protein yield. In the present study, nitrogen accumulation was lower than in pure sowing in the earing phase by 71.1% and ripeness by 68.0%. To a similar extent, it included straws, leaves, and spikes. The advantage of pure sowing over mixed one marked itself in both fertilization doses. On the bedding poorer in NPK, it lasted throughout the growth period, and on the richer one, from the tillering phase. With the fertilization doses of 1.5 NPK, the differences between mixed and pure sowing were greater, particularly during straw shooting and earing phases (in straws and leaves).

Also the accumulation of nitrogen in the above-ground barely mass decreased under the influence of joint growth with wheat (disregarding emergence in the fertilization doses of 1 NPK; Table 2). Differences between mixed and pure sowing (with the exception of the tillering phase), however, proved to be smaller. On average, for fertilizer combinations they amounted to: tillering 25.2%, straw shooting 5.8%, earing 46.0%, and ripeness 38.5%. It results from the above that in the mixture, like in the case of wheat, the greatest nitrogen yield reduction occurred in the phases of earing and ripeness. Similar relations were noted by Sobkowicz [2009] in his experiment. He showed that joint growth of barley with Persian clover and seradella led to smaller nitrogen accumulation both in spikes and in the remaining above-ground biomass. Presented differences in some periods and plant parts underwent changes under the influence of fertilization doses. With basic NPK fertilization dose during the emergence phase, barley grown in the mixture contained more nitrogen by 47.6% than in pure sowing, with an increased dose less by 18.2%, and in the ripeness phase, this sowing method more strongly limited its accumulation in spikes with richer NPK fertilization doses.

Table 2. Nitrogen yield in the above-ground parts of spring barley, g·pot⁻¹
Tabela 2. Plon azotu w częściach nadziemnych jęczmienia jarego, g·wazon⁻¹

Development stage (BBCH)/plant part Faza rozwojowa (BBCH)/części roślin		1 NPK		1.5 NPK		Mean – Średnia		LSD _{0.05} NIR _{0.05}		
		sowing method – sposób siewu*								
		C	M	C	M	C	M			
10-13		0.21	0.31	0.33	0.27	0.27	0.29	I** ns – ni	II	0.06
23		2.33	1.63	2.73	2.15	2.54	1.90	I	0.33	II ns – ni
32		1.84	2.12	3.77	2.94	2.74	2.58		I i II	ns – ni
55	straws – źdźbła	2.38	0.95	2.65	1.69	2.53	1.30	I	0.30	II ns – ni
	leaves – liście	2.46	1.06	2.41	1.47	2.44	1.27	I	0.24	II ns – ni
	spikes – kłosy	0.41	0.31	0.27	0.24	0.34	0.30		I i II	ns – ni
	total – razem	5.26	2.32	5.33	3.40	5.31	2.87	I	0.54	II ns – ni
87-89	straws – źdźbła	0.67	0.84	1.62	1.09	1.11	0.97	I	0.12	II 0.18
	leaves – liście	0.62	0.41	0.99	0.83	0.81	0.60	I	0.09	II ns – ni
	spikes – kłosy	3.38	1.55	2.98	1.56	3.21	1.59	I	0.31	II ns – ni
	total – razem	4.67	2.80	5.59	3.48	5.14	3.16	I	0.34	II ns – ni

Explanation under Table 1 – objaśnienia pod tabelą 1

Figures 1 and 2 present the effect of competition on nitrogen uptake by the assessed cereals. Relative yield total (RYT) values inform that during emergence, no interactions of that sort took place between the species. With poorer NPK fertilization doses, nitrogen accumulation in the mixture was even higher than the total amount of this component accumulated in both cereals grown independently. In the mixture with 1 NPK, barley accumulated more of it, and with 1.5 NPK – wheat, which is demonstrated by the RY values. Higher amount of the uptaken nitrogen by barley grown in a mixture than in pure sowing resulted both from its higher concentration and more shapely plants, and in wheat only from greater plant dry mass, since percentage nitrogen content was lower than in pure sowing [Treder et al. 2008 i 2009].

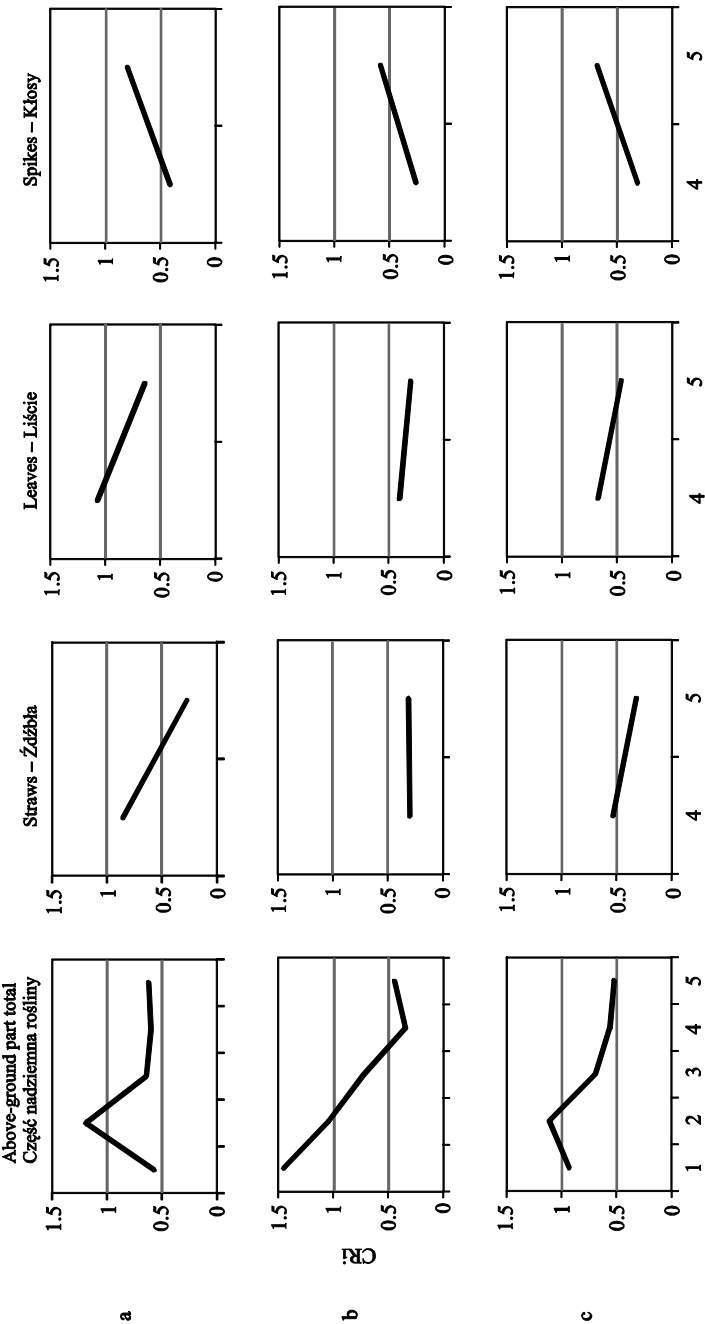


Fig. 1. Competition ratio of spring wheat against spring barley in the particular growth phases (1 – emergence, 2 – tillering, 3 – straw shooting, 4 – earing, 5 – ripeness) with diversified fertilization levels (a – 1 NPK, b – 1.5 NPK, c – mean for the doses) on the basis of total Kjeldahl nitrogen content in the above-ground plant parts and straws, leaves, and spikes

Rys. 1. Wpływ zawartości azotu ogólnego w częściach nadziemnych roślin oraz źdźbeł, liści i kłosów na podstawę zawartości azotu ogólnego w częściach nadziemnych roślin oraz źdźbeł, liści i kłosów

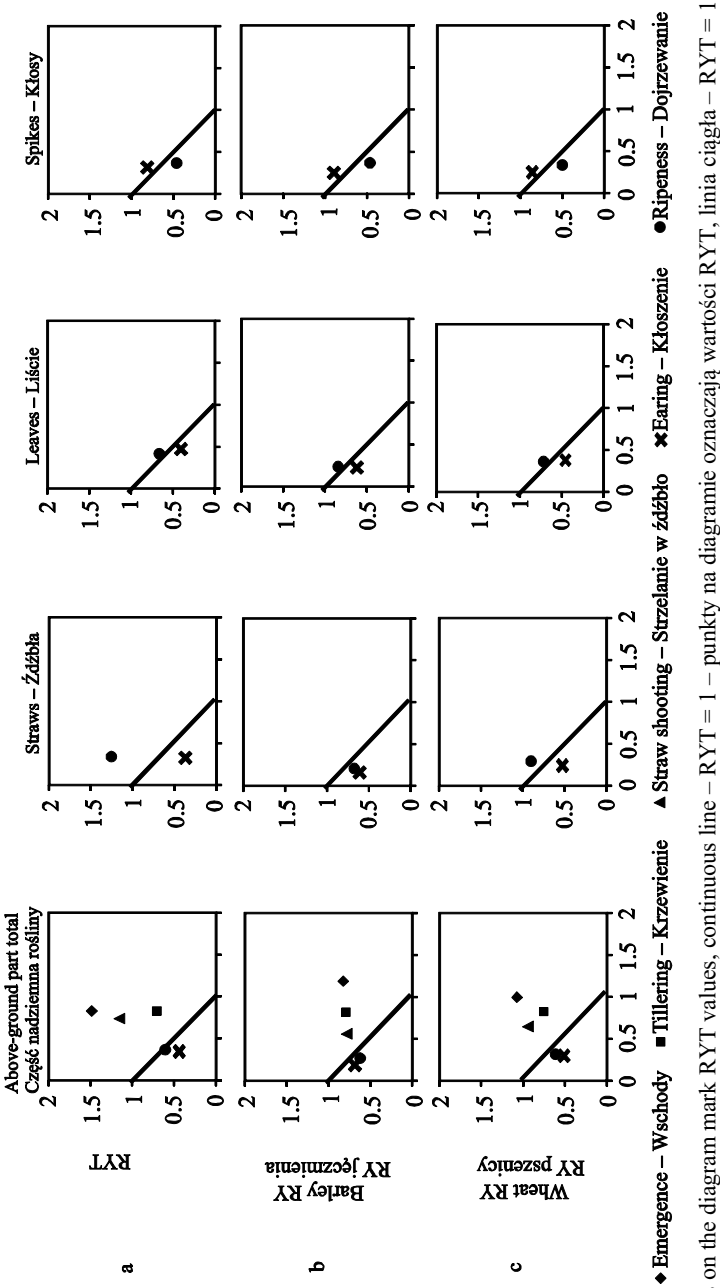


Fig. 2. Values of relative yield total (RYT) and relative yields (RY) of wheat and barley on the basis of total Kjeldahl nitrogen content in the above-ground plant parts in chosen organs (straws, leaves, and spikes) in the particular plant growth phases with various fertilization levels (a – 1 NPK, b – 1.5 NPK, c – mean for the doses)

Rys. 2. Wartości całkowitego plonu względnego (RYT) oraz plonów względnych (RY) pszenicy i jęczmienia na podstawie całkowitej zawartości azotu w nadziemnych częściach roślin wybranych organach (żółtla, liściach i kłosach) w poszczególnych fazach wzrostu roślin przy różnych poziomach nawożenia (a – 1 NPK, b – 1,5 NPK, c – średnio dla dawek)

However, already in the tillering phase with both fertilization doses, the amount of resources was insufficient for both species. Competition started between them, which lasted until the end of the growth period. According to Giambalvo et al. [2010], it resulted from the ability to mutually limit the access to the resources by plants that grow next to each other. With basic NPK fertilization dose, during tillering and straw shooting phases competition concerned respectively 47 and 11% of the factors that affect nitrogen accumulation. During the first period, wheat used them a little bit more effectively, and in the second one, barely did significantly better. During earing, very strong interaction occurred between cereals (total relative nitrogen yield reached value lower than 1). To the greatest extent, it was marked in the mass of nitrogen accumulated in straws, and to the smallest extent in spikes. It resulted from both lowering the percentage content of this biogene and dry mass reduction [Treder et al. 2008, 2009]. Different results were obtained by Sobkowicz and Śniady [2004]. They showed that the mixture of spring barley and faba bean accumulated more nitrogen than did pure sowings of those species. In the present study, in the conditions of strong competitive interactions, barley managed better. In the mixture, nitrogen accumulation in the spikes of this cereal was higher than in wheat spikes, with no significant diversifications in straws and leaves. Strength of negative influence of both cereals lessened towards the end of the growth period. In spite of this fact, they still competed for the entire set of factors responsible for nitrogen assimilation. In this period, barley was more effective in its accumulation. It accumulated in straws 25% more nitrogen than in pure sowing, and the difference between mixed sowing and pure sowing in leaves and spikes was smaller than in wheat (RY). Barley domination over other cereals was documented also by Sobkowicz [2003] in his studies. The author additionally showed that towards the end of the growth period, the strength of cereal mutual competitive interactions weakens, which is convergent with the present study.

With 1.5 NPK fertilization dose, competition between the species grew from the tillering phase to the earing phase, in which it reached the highest intensity (full competition; RYT <1) and it stayed at a similar level until the end of the growth period. Competition during earing to the greatest extent limited nitrogen accumulation in straws and leaves, and during ripeness in straws and spikes. In the conditions of resource shortage, which limited nitrogen accumulation, starting from the straw shooting phase barley accumulated more of it than wheat. It ought to be underscored that during ripeness, competition was stronger in the case of 50% higher NPK fertilization dose.

With 1 NPK fertilization dose, almost during the entire growth period barley proved to be a stronger competitor for nitrogen gaining than wheat. The only phase in which the strength of interactions was almost equal (with a slight superiority of wheat) was tillering. In the remaining periods, barely accumulated nitrogen about 40% more effectively than wheat. Its competitive advantage in the earing phase was most clearly shown in spikes, and in the ripeness phase in straws. Competition for nitrogen had a different course in the environment richer in biogenes. During emergence, it was accumulated significantly better by wheat, during tillering the strength of mutual interactions was more equal, and from the moment of straw shooting, barley dominated. Its advantage over wheat was the highest during the earing phase in straws and spikes, and it lessened somewhat towards the end of the growth period in spikes. With 1.5 NPK fertilization dose, barley with a greater strength affected wheat than with 1 NPK from the straw shooting phase to the end of the growth period. Sattore and Snaydon [1992], are of different opinion, and according to them on bedding richer in nitrogen, competition for this biogene is smaller than on poorer one.

CONCLUSIONS

1. In the mixture of spring wheat and spring barley, in the above-ground mass they accumulated less total Kjeldahl nitrogen than in pure sowing from the tillering phase to the end of the growth period. The greatest differences between sowing methods were noted in the period of generative growth (earring, ripeness).

2. Mixed sowing to a greater extent limited nitrogen accumulation in spring wheat than in spring barley.

3. In spring wheat grown in a mixture, the lowering of accumulated nitrogen mass to the same extent included straws, leaves, and spikes, whereas in spring barley during earing it was marked in straws and leaves, and during ripeness it was most clearly seen in spikes.

4. Competition for nitrogen between cereals started during the tillering phase of barley. The strength of this process grew up to the earing phase, and then it lowered slightly.

5. Doses of mineral fertilization with NPK had no effect on nitrogen accumulation by barley and wheat grown in pure and mixed sowing.

6. With 1 NPK fertilization dose, spring barley proved to be a stronger competitor than wheat for nitrogen gaining throughout the growth period, and with 1.5 NPK fertilization dose from the straw shooting phase.

7. Almost during the entire growth period with richer NPK fertilization dose, competitive effect of barley on wheat was stronger than with the poorer one.

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KONKURENCJA O AZOT MIĘDZY PSZENICĄ JARĄ A JĘCZMIENIEM JARYM W WARUNKACH ZRÓŻNICOWANEGO NAWOŻENIA NPK

Streszczenie. W doświadczeniu wazonowym, realizowanym według schematu addytywnego na podłożu gleby średniej nawożonej standardową i podwyższoną o 50% dawką NPK, oceniano wpływ oddziaływań konkurencyjnych między pszenicą jarą a jęczmieniem jarym na akumulację azotu w masie nadziemnej, z wyróżnieniem łodyg, liści i kłosów. Badania obejmowały trzy serie, które zrealizowane zostały w latach 2003-2004 w pięciu okresach, wyznaczonych przez rytm rozwojowy jęczmienia w siewie czystym, tj. w fazach: wschody (BBCH 10-13), krzewienie (23), strzelanie w źdźbło (32), kłoszenie (55) i dojrzewanie (87-89). Wykazano, że w mieszanke oba zboża gromadziły w masie nadziemnej mniej azotu niż w siewie czystym począwszy od fazy krzewienia do końca wegetacji. U pszenicy zmniejszenie to w podobnym stopniu objęło źdźbła, liście i kłosy, a u jęczmienia w fazie kłoszenia wyraźniej zaznaczyło się w źdźbłach i liściach, zaś w fazie dojrzewania w kłosach. Dawki nawożenia mineralnego NPK nie miały wpływu na akumulację azotu przez jęczmień i pszenicę uprawiane w siewie czystym i mieszanym. Konkurencja o azot między zbożami rozpoczęła się w fazie krzewienia i narastała do fazy kłoszenia, po czym uległa niewielkiemu zmniejszeniu. Prawie w całym okresie wspólnej wegetacji w pozyskiwaniu azotu jęczmień okazał się silniejszym konkurentem od pszenicy. Na obiekcie zasobniejszym w NPK oddziaływanie konkurencyjne jęczmienia na pszenicę było intensywniejsze niż na uboższym.

Słowa kluczowe: kumulacja azotu, mieszanki zbóż, plon względny, siew mieszany, współczynnik konkurencji, zboża jare

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