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COMPETITION BETWEEN SPRING WHEAT AND SPRING BARLEY UNDER CONDITIONS OF DIVERSIFIED FERTILISATION PART II. INFLUENCE ON BIOMASS OF PLANTS AND RATE OF ITS ACCUMULATION

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Abstract. In a closed, static jar experiment implemented in three cycles during the years 2003-2004 at a greenhouse laboratory the competitive influence between spring wheat and spring barley was investigated. It was assessed on the basis of dry mass accumulation in aboveground parts (stems, leaves, heads) and roots as well as crop growth rate. The crops were sown in a mix with equal shares of both components and as single crops on medium soil supplied with standard NPK dose and the dose increased by 50% in relation to the standard one. The number of plants of both crops in mixed cultivation was equal to the sum of plants of both crops cultivated as single crops. Analyses were conducted during the stages of seedling development, tillering, stem elongation, inflorescence emergence and ripening. It was shown that barley had a stronger negative influence on wheat than the other way round. In the mixed crop, as compared to single crop cultivation, the dry mass of wheat was progressively reduced from tillering until inflorescence emergence stage, covering to a similar extent the stems, leaves and heads. Wheat, on the other hand, had a negative influence on the increase of aboveground biomass of barley during tillering, inflorescence emergence and ripening. Until inflorescence emergence stage, the differences between sowing methods appeared for the test samples from jars poorer in NPK, while during ripening they were levelled. The scale of root mass in the mix had similar value to that of the aboveground parts, without the differentiating influence of fertilisation doses. In view of the conducted studies, wheat in the presence of barley was characterised by smaller - than in single crop cultivation - day increases in biomass during the interphases of seedling development-tillering and stem elongation-inflorescence emergence. The biomass accumulation rate for barley cultivated in the mix was subject to gradual slowing from the beginning of vegetation (with the exception of the tillering-stem elongation period). In the case of both cereals the process was more pronounced in the case of more abundant NPK fertilization.

Keywords: competition, wheat, barley, phenophases, fertilisation, biomass of plants

INTRODUCTION

In both natural and anthropogenic systems various relations occur between organisms neighbouring each other. Competition – one sided or mutual negative influence on the composition, structure and dynamics of biocenoses - is one of the more important of them (Connolly *et al.* 2001). It represents rivalry between two or more individuals (of the same or different species) for the environmental resources under circumstances when the pool of the resources is insufficient to cover their combined demands. Competition is a highly complex process and its development and consequences are hard to forecast (Sobkowicz 2003). Depending on the structure of partner plants, their build, share in the biocenosis, stage of development and environmental factors, the intensity of the process can be highly different (Goldberg & Landa 1991, Keating and Carberry 1993, Sobkowicz 2003). The effects of those influences are changes in the development rhythm, biomass and fertility of organisms that are subject to such influences (Connolly & Wayne 1996, Satore and Snaydon 1992).

Although during recent years many studies on competitive influences in the case of mixed cultivation of crops have been published, little has been published on the development of that process throughout the entire vegetation period and its influence on the root system.

This study aims at assessment of competition occurring between spring wheat and spring barley from the perspective of its influence on biomass and rate of its accumulation during different stages of joint vegetation.

MATERIALS AND METHODS

The information concerning the experiment, place, conditions and added components, as well as implementation protocol, has been provided in part one of the paper.

Determination of dry mass of plants studied was conducted during 5 development stages, i.e. during seedling development (Zadoks 10-13), tillering (25), stem elongation (37), inflorescence emergence (55) and ripening (87-91); the time was determined on the basis of the development rhythm of barley cultivated as a single crop.

During the identified periods, all the plants were removed from jars (planned for a given stage) and next the aboveground parts were separated from the roots. The aboveground parts, with the development process, were divided into stems, leaves (from stem elongation stage) and heads (from inflorescence emergence stage). The separated parts of plants were dried to air-dry mass and weighted. On the basis of the dry mass of the plants the crop growth rate (CGR) was computed using the following formula (Sobkowicz 2001, 2003):

Crop growth rate: $CGR = dW_c/dt \cdot 1/P$

where:
CGR – crop growth rate
dWc – crop dry weight increase (g of dry mass)
dt – time period during which growth occurred
P – jar surface area (m^2)

The numeric data were presented as average values from three test cycles. The majority of results were processed statistically using the variance analysis. Tukey's test was used for assessment of differences between objects, computing the LSD value for the error probability at $p = 0.05$.

RESULTS

As indicated by the numbers in Table 1, the sowing method of both cereals did not differentiate their biomass during seedling development. The plants at that time were small, had sufficient space and, as a consequence, did not shade one another and the abundance of the soil in biogenes was absolutely sufficient to cover their demands. As of the tillering phase, however, the negative influence of mixed cultivation started. In wheat it was manifested initially by biomass reduction by 14.6% and that trend increased significantly during consecutive vegetation stages. As compared to single crop cultivation, the aboveground mass of wheat in the mix was lower: during stem elongation by 40.5%, during inflorescence emergence by 65.6%, and during ripening by 62.0%. The magnitude of the above differences changed under the influence of fertilisation applied. In the jars fertilised with the standard dose, as of the first phenophase the trend of smaller biomass increases was observed which, during the consecutive periods, assumed significant values; as compared to the 1.5 NPK, that decrease was: during stem elongation – 33.3%, during inflorescence emergence – 57.9%, and during ripening – 45.7%. Wheat showed a more pronounced reaction to the presence of the partner in the environment more abundant in macro-elements. In that case the negative influence of barley appeared during the tillering stage and assumed the largest magnitude (as much as 72%) during inflorescence emergence. Those deviations during the final period of vegetation, similar to 1 NPK cultivation, were mitigated, but to a lesser degree. It is worth highlighting that although in mixed cultivation supplied with 1.5 NPK the plants had 50% more available nitrogen, phosphorus and potassium, still, with the exception of seedling development and stem elongation phases, they developed biomass lower than in the case of the standard dose fertilisation treatment.

Table 1. Dry mass of aboveground parts of cereals (g jar^{-1})

Development stage	1 NPK		1.5 NPK		Average for sowing method	
	sowing method					
	pure	mixed	pure	mixed	pure	mixed
spring wheat						
Seedling growth	0.46	0.38	0.47	0.58	0.47	0.48
Tillering	5.20	4.55	3.17	2.60	4.19	3.58
Stem elongation	8.70	5.80	11.17	6.01	9.94	5.91
Inflorescence emergence	37.3	15.7	44.0	12.3	40.7	14.0
Ripening	38.1	16.9	43.5	14.0	40.8	15.5
spring barley						
Seedling growth	0.47	0.57	0.66	0.53	0.57	0.55
Tillering	5.35	3.93	6.45	5.02	5.90	4.48
Stem elongation	7.32	6.75	11.98	10.98	9.65	8.87
Inflorescence emergence	32.0	16.6	32.5	19.2	32.3	17.9
Ripening	41.6	25.6	46.2	26.5	43.9	26.1

LSD $_{(p = 0.05)}$

spring wheat: seedling growth: sowing method – insignificant; synergy (NPK fertilisation x sowing method) – insignificant, tillering: sowing method – 0.8; synergy (NPK fertilisation x sowing method) – insignificant, stem elongation: sowing method – insignificant; synergy (NPK fertilisation x sowing method) – insignificant., inflorescence emergence: sowing method – 3.2; synergy (NPK fertilisation x sowing method) – insignificant., ripening: sowing method – 2.7; synergy (NPK fertilisation x sowing method) – 3.8.

spring barley: seedling growth: sowing method – insignificant; synergy (NPK fertilisation x sowing method) – 0.11, tillering: sowing method – insignificant; synergy (NPK fertilisation x sowing method) – insignificant, stem elongation: sowing method – 061; synergy (NPK fertilisation x sowing method) – 1.12**,** inflorescence emergence: sowing method – 4.08; synergy (NPK fertilisation x sowing method) – 7.15, ripening: sowing method – 5.49; synergy (NPK fertilisation x sowing method) – insignificant.

As in the case of wheat, mixed sowing did not differentiate barley biomass significantly during seedlings development stage. The inhibiting influence of the other mix component started, during the tillering stage, being manifested through the decrease in its biomass on both fertilised objects. The process assumed a slightly larger magnitude in the case of lower abundance in macro-elements (decrease by 26.5%), and slightly smaller in the case of the higher NPK-abundance (by 22.2%).

During the period of dynamic growth of plants, as a consequence of faster biomass increase in the mix than in single crop cultivation, the differences between sowing methods decreased (without statistical confirmation) and then, during inflorescence emergence and ripening, they reached the highest values. During inflorescence emergence the advantage of single crop sowing over the mix was: on the 1 NPK object as much as 92.8%, and on 1.5 NPK – 69.3%. During the final stage of vegetation, as compared to inflorescence emergence stage, that difference on the object with standard fertilisation dose decreased largely (to 62.5%), while on the one with increased fertilisation it increased slightly (to 74.3%). Ultimately, the competitive influence of wheat on barley, in the case of both fertilisation combinations, resulted in biomass development at similar levels.

Diversification of the total aboveground mass of cereals under the influence of analysed factors was the effect of changes in its individual components, i.e. stems, leaves and heads. The data in Table 2 indicate that the negative influence of barley on the mass of wheat stems started already during their formation and the other way round during inflorescence emergence. Adequately to the total aboveground mass, stronger negative reaction was recorded in wheat and weaker in barley. In the mix, as compared to single crop cultivation, the averages for fertiliser doses show that wheat developed the mass of stems lower by 58.0% during stem elongation phase, by 66.2% during inflorescence emergence, and by 65.0% during ripening. During the stem elongation phase, mixed sowing was more limiting for the increase in dry mass of stems on the object fertilised with the lower NPK dose. During inflorescence emergence the differences between sowing methods for both fertilisation doses were levelling. On the other hand, during ripening, in the case of the object supplied with 1 NPK, as compared to the preceding period, it increased (from 57.5 to 62.7%), which resulted from the loss of stems mass in single crop cultivation and inhibition of its accumulation in the mix. In the combination with 1.5 NPK the opposite situation was recorded. The differences appearing during inflorescence emergence increased at the end of vegetation, determining the ultimate biomass of stems in the mixed cultivation at as much as 72.6% less than in single crop cultivation (significant differences). Comparison of mixed sowing supplied with the standard dose with that supplied with the NPK dose increased by 50% showed the tendency of wheat to create more abundant stems on the object less abundant with biogenes.

Table 2. Dry mass of stems (g jar^{-1})

Development stage	1 NPK		1.5 NPK		Average for sowing method	
	sowing method					
	pure	mixed	pure	mixed	pure	mixed
			spring wheat			
Stem elongation	3.38	1.04	4.90	2.43	4.14	1.74
Inflorescence emergence	20.4	7.6	20.9	6.4	20.7	7.0
Ripening	18.1	7.7	17.9	4.9	18.0	6.3
			spring barley			
Stem elongation	1.34	1.32	4.26	4.37	2.80	2.85
Inflorescence emergence	18.9	9.2	19.6	11.2	19.3	10.2
Ripening	16.4	12.4	21.9	12.7	19.2	12.6

$LSD_{(p = 0.05)}$

spring wheat: stem elongation: sowing method – 2.11; synergy (NPK fertilisation x sowing method) – 2.36, inflorescence emergence: sowing method – 2.9; synergy– insignificant, ripening: sowing method – 2.3; synergy (NPK fertilisation x sowing method) – 3.3.
spring barley: stem elongation: sowing method – insignificant.; synergy (NPK fertilisation x sowing method) – insignificant., inflorescence emergence: sowing method – 2.5; synergy (NPK fertilisation x sowing method) – insignificant, ripening: sowing method – 6.1; synergy (NPK fertilisation x sowing method) – 3.7.

Cultivation of plants in the mix, as compared to single crop cultivation, resulted also in much smaller barley stems during the phases of inflorescence development and ripening; their average mass, depending on fertilisation level, was lower by 47.2% and 34.4%, respectively. In the habitat less abundant with biogenes, wheat showed the largest limiting influence on increase in barley stems biomass during inflorescence emergence (by 51.3%), and that influence decreased clearly, to 24.4% of that influence during ripening. In the explanation it should be considered that in single crop sowing barley completed vegetation earlier and in the mix the increase of biomass of plants continued. On the object supplied with 1.5 NPK, in the mix, during inflorescence emergence and ripening, dry mass of stems was lower than in single crop cultivation by over 40%. The above indicates that higher abundance of the soil did not compensate for the negative influence of wheat on increase in barley stems biomass. During ripening the opposite situation was recorded because the reduction of dry mass on that object in the mix was almost twice higher than in the case of the lower fertilisation. As a consequence of the above, changes in the dry mass of stems in both fertilisation variants reached similar levels.

The biomass of leaves of both cereals increased until inflorescence emergence phase, and at the end of vegetation it was reduced (Tab. 3). That was caused by drying, dying and next falling off of leaf blades. Larger losses occurred in wheat and smaller in barley. Mixed sowing had a negative influence on wheat leaves biomass production reducing it significantly, as compared to single crop cultivation by 28.1% during stem elongation phase, by 65.1% during inflorescence emergence, and by 57.4% during ripening. The magnitude of those differences changed clearly under the influence of applied fertilisation level. On the object fertilised with the lower NPK dose the plants cultivated as single crop were characterised by rich foliage. During stem elongation the differences between single crop and mixed cultivation were relatively small (10.5%), but already during inflorescence emergence they reached 49.5%, to decrease during the final stage to 40.4% (without exceeding the threshold of significance). On soil more abundant in macro-elements, the presence of barley had an even more negative effect than in the less abundant environment on the biomass of wheat leaves. It was significantly lower than in single crop cultivation during stem elongation - by 42.9%, during inflorescence emergence by 74.5, and during ripening by 68.7%.

Joint cultivation of cereals (similar to the case of stems) had a less inhibitory effect on increase of barley leaves mass. During stem elongation phase that appeared as a trend (12.1%), and during inflorescence emergence and ripening it resulted in a significant reduction reaching, as compared to single crop cultivation, 37.7 and 42.4%, respectively. Although during stem elongation and inflorescence emergence the interaction of fertilisation doses with sowing method did not show any significant relations, highly evident trends in that respect were manifested. In the case of both fertilisation objects, mixed sowing reduced the mass of leaves significantly. Wheat, competing with barley for place and shading it, caused that in the case of mixed crop the assimilation system of that cereal was weaker developed than in the case of single crop cultivation: on the object with 1 NPK at stem elongation phase by 9.2%, and during inflorescence formation phase by 46.8%, while in the case of 1.5 NPK fertilisation the results were 14.4 and 29.1%, respectively. During inflorescence emergence more abundant fertilisation limited the negative influence of the cereal partner. The strength of its influence on biomass of barley leaves during ripening on the object with standard fertilisation dose decreased (by 7.2%), while on that with higher fertilization it increased (by 14.4%). This resulted in a situation where ultimately the biomass of leaves on the above objects was at levels significantly lower than in the case of single crop cultivation - by 39.2 and 44.0%, respectively.

Table 3. Dry mass of leaves (g jar^{-1})

Development stage	1 NPK		1.5 NPK		Average for sowing method	
	sowing method					
	pure	mixed	pure	mixed	pure	mixed
spring wheat						
Stem elongation	5.32	4.76	6.27	3.58	5.80	4.17
Inflorescence emergence	11.3	5.7	18.4	4.7	14.9	5.2
Ripening	5.2	3.1	8.3	2.6	6.8	2.9
spring barley						
Stem elongation	5.98	5.43	7.72	6.61	6.85	6.02
Inflorescence emergence	11.1	5.9	11.7	8.3	11.4	7.1
Ripening	7.4	4.5	10.9	6.1	9.2	5.3

LSD $_{(p = 0.05)}$

spring wheat: stem elongation**:** sowing method – 1.45; synergy (NPK fertilisation x sowing method) – 0.54, inflorescence emergence: sowing method – 1.1; synergy (NPK fertilisation x sowing method) – 5.8, ripening: sowing method – 2.6; synergy (NPK fertilistion x sowing method) – 3.7.
spring barley: stem elongation**:** sowing method – 0.63; synergy (NPK fertilisation x sowing method) – 0.54, inflorescence emergence: sowing method – 1.4; synergy (NPK fertilisation x sowing method) – insignificant, ripening: sowing method – 1.9; synergy (NPK fertilisation x sowing method) – 2.8.

Common vegetation of the two cereals also limited accumulation of dry mass in their heads (Tab. 4). In the case of wheat in mixed sowing their mass was significantly lower than in the case of single crop cultivation during inflorescence emergence - by 65.4%, and during ripening by 60.2%, while in the case of barley the decrease was by 25.0% (trend) and by 50.6% (significant difference), respectively; that process had a similar intensity in both fertilisation experiments.

Table 4. Dry mass of heads (g jar^{-1})

Development stage	1 NPK		1.5 NPK		Average for sowing method	
	sowing method					
	pure	mixed	pure	mixed	pure	mixed
	spring wheat					
Inflorescence emergence	5.6	2.4	4.7	1.2	5.2	1.8
Ripening	14.8	6.2	17.3	6.6	16.1	6.4
	spring barley					
Inflorescence emergence	2.0	1.5	1.2	0.8	1.6	1.2
Ripening	17.7	8.8	13.5	6.6	15.6	7.7

LSD $_{(p = 0.05)}$

spring wheat: inflorescence emergence: sowing method – 1.6; synergy (NPK fertilisation x sowing method) – insignificant, ripening: sowing method – 1.4; synergy (NPK fertilisation x sowing method) – insignificant.
spring barley: inflorescence emergence: sowing method – insignificant; synergy (NPK fertilisation x sowing method) – insignificant, ripening: sowing method – 3.2; synergy (NPK fertilisation x sowing method) – insignificant.

Under the influence of the experiment factors introduced, changes also occurred in the dry mass of roots of both cereals (Tab. 5). In single crop cultivation it increased as of the beginning of vegetation until inflorescence emergence phase, and then it decreased during ripening. On the other hand, in the mix on the object with standard fertilisation the mass of roots increased until the end of vegetation, while on the one with the increased fertilisation its reduction took place.
Mixed sowing, similar to the situation with the aboveground parts, had a negative influence on the roots mass of cereals (with the exception of tillering stage). During the entire period of joint vegetation it was smaller than the total value computed for barley and wheat. The negative mutual influence of cereals progressed (with minor deviations) with a similar intensity on both fertilised objects, appearing already during seedling development as reduction of roots mass by 18.2%. It was probably not yet the consequence of competition, because the roots at that time were small and did not interlace, but of the influence of factors of another character (maybe the influence of excretions). During the following period – tillering, an absolutely different situation was recorded; on the object with stan-

dard fertilisation the mass of roots of the mix was higher than the sum for barley and wheat cultivated as single crops, while in the case of 1.5 NPK fertilisation it reached a similar magnitude. However, already during stem elongation phase the competition between the cereals resulted in development of roots in their mass lower by 23.8% than in the case of single crop cultivation of the two cereals summed up. That influence was the most clearly marked during inflorescence emergence in the reduction of root mass, reaching on the object with standard fertilization 57.2%, and on that with increased fertilisation – 40.7%; during the final stage of vegetation the above deficiency was decreased to the level of 24.9 and 34.5%, respectively.

Table 5. Dry mass of roots of spring wheat, spring barley and their mix (g jar^{-1})

Development stage	1 NPK			1.5 NPK			Average for sowing method		
	sowing method								
	pure		mixed*	pure		mixed	pure		mixed
	P*	J*		P	J		P	J	
Seedling growth	0.29	0.29	0.48	0.32	0.40	0.60	0.31	0.35	0.54
Tillering	1.01	1.03	2.46	0.82	1.32	2.08	0.92	1.18	2.27
Stem elonga-tion	1.12	1.54	2.00	0.99	1.13	1.66	1.06	1.34	1.83
Inflorescence emergence	13.26	6.68	8.54	11.43	4.59	9.50	12.35	5.64	9.02
Ripening	11.37	4.00	11.54	9.19	4.53	8.98	10.28	4.27	10.26

* – average for mixed sowing, P - wheat, J – barley

The data in Table 6 indicate that spring wheat, in its aboveground part, reached a faster biomass accumulation rate during the interphase of stem elongation-inflorescence emergence and spring barley during the interphase of stem elongation-ripening. In the case of both crops the slowest growth was recorded during the period between sowing and seedling development. Wheat in the mix, on both fertilisation objects, significantly slowed down the process of dry mass accumulation during the period between seedling development and tillering. The difference, as compared to single crop cultivation, was: in combination with 1 NPK – 41.7%, and with 1.5 NPK – 28.6%. On the object more abundant in biogenes, a slower (by as much as 56.6%) growth rate was also recorded during the period between tillering and stem elongation. The situation was different on the object supplied with standard NPK dose, where the mixed sowing accelerated wheat growth by almost 2-fold as compared to single crop cultivation. On the other

Table 6. Day growth of cereals (g jar^{-1})

Development stage	1 NPK		1.5 NPK		Average for sowing method	
	sowing method					
	pure	mixed	pure	mixed	pure	mixed
spring wheat						
Sowing – seedling growth	0.05	0.04	0.05	0.06	0.05	0.05
Seedling growth – tillering	0.24	0.14	0.14	0.10	0.19	0.12
Tillering – stem elongation	0.23	0.53	0.53	0.23	0.38	0.38
Stem elongation – inflorescence emergence	1.02	1.17	1.17	0.22	1.10	0.70
Inflorescence emergence - ripening	0.05	-0.03	-0.03	0.11	0.01	0.04
spring barley						
Sowing – seedling growth	0.07	0.06	0.07	0.05	0.07	0.06
Seedling growth – tillering	0.24	0.17	0.29	0.22	0.27	0.20
Tillering – stem elongation	0.13	0.19	0.37	0.40	0.25	0.30
Stem elongation – inflorescence emergence	0.88	0.35	0.73	0.29	0.81	0.32
Inflorescence emergence - ripening	0.60	0.56	0.86	0.46	0.73	0.51

LSD $_{(p = 0.05)}$

spring wheat

sowing – seedling growth: sowing method – insignificant; synergy (sowing method x NPK fertilisation) – insignificant, seedling growth – tillering: sowing method – 0.06; synergy (sowing method x NPK fertilisation) – insignificant, tillering – stem elongation: sowing method – insignificant; synergy (sowing method x NPK fertilisation) – 0.26, stem elongation – inflorescence emergence: sowing method – insignificant; synergy (sowing method x NPK fertilisation) – insignificant, inflorescence emergence – ripening: sowing method – insignificant; synergy (sowing method x NPK fertilisation) – insignificant.

spring barley

sowing – seedling growth: sowing method – insignificant; synergy (sowing method x NPK fertilisation) – insignificant, seedling growth – tillering: sowing method – 0.05; synergy (sowing method x NPK fertilisation) – insignificant, tillering – stem elongation: sowing method – insignificant; synergy (sowing method x NPK fertilisation) – insignificant, stem elongation – inflorescence emergence: sowing method – 0.35; synergy (sowing method x NPK fertilisation) – 0.44, inflorescence emergence – ripening: sowing method – 0.22; synergy (sowing method x NPK fertilisation)– 0.28.

hand, in the case of barley, “partnership” with wheat slowed the biomass accumulation rate during almost the entire vegetation period. That was most clearly visible between seedling development and tillering (26.0%), between stem elongation and inflorescence emergence (60.5%), and between inflorescence emergence and ripening (30.1%). Only between tillering and stem elongation barley cultivated with wheat showed the tendency for crop growth rate higher than in single crop cultivation (by 20.0%). The magnitude of differences between sowing methods of that cereal changed under the influence of fertilistion applied. In the mix on the object with the standard dose a slower biomass increase rate was found during almost the entire vegetation (except for the period between tillering and stem elongation). It was best visible between stem elongation and inflorescence emergence, resulting in significant decreases in daily growth (by 60.2%). Also in the combination with the increased dose, plants cultivated without the competitor were characterised by larger increases of aboveground mass from seedling development until tillering and between stem elongation and ripening. Mixed cultivation, as compared to single crop cultivation, resulted in the highest (significant) limitation of vegetative parts growth between stem elongation and inflorescence emergence (by 60.3%). and between inflorescence emergence and ripening (by 46.5%).

DISCUSSION

The presented documentation shows that cultivation of both cereals in the mix resulted in a decrease, as compared to single crop cultivation, of the aboveground mass from the tillering stage until the end of vegetation. Similar reaction of wheat and barley was observed by Satore and Snaydon (1992). Also Sobkowicz (2001, 2003) showed that the phytomass of barley, oats and triticale in single crop cultivation was larger than in the mix. Our own studies showed that under the influence of competition a larger reduction in aboveground dry mass occurred on the object more abundant in NPK. Similar consequences of the above-mentioned more favourable environmental conditions were also recorded in their experiments by Jokinen (1991) and Sobkowicz (2003), while Satore and Snaydon (1992) did not prove the influence of diversified nitrogen doses on plant dry mass reduction magnitude.

The factors of the experiment not only differentiated the total weight of aboveground biomass but also its structure. Both species reacted to mixed sowing with reduction of the dry mass of stems. Better adjustment of barley than wheat to cultivation in the mix appeared in the form of lower losses in the mass of its stems. Different results were obtained by Sobkowicz (2003) who showed that at the time of milk ripeness barley plants sown in a mix with oats produced stems with mass greater than in single crop cultivation. During week 12 of vegetation that relation also applied to the joint cultivation with triticale and a mix of three components (barley + oats + triticale). According to the presented results the mass of wheat and barley leaves (irrespective of fertilisation level) was similar during inflorescence emergence phase, but during ripening barley was characterised by more lush foliage. In the mix that cereal developed larger phytomass than wheat and in single crop cultivation a higher value of that characteristic at inflorescence emergence phase was found in wheat and during ripening in barley. That indicates inhibition of mass accumulation in wheat leaves after inflorescence emergence, maybe to the advantage of heads which at that stage were more handsome than those of barley. Lambers & Poorter (1992) report that accumulation of biomass in leaves at the expense of other organs represents the reaction of plants to decreased intensity of solar radiation, which could occur in the case of barley that was characterised by more lush foliage during generative development than wheat. Both species developed more lush foliage in the case of single crop cultivation, and in the mix wheat showed a clearer negative reaction to that sowing method. In the experiment by Sobkowicz (2003), barley did not change the dynamics of dry mass accumulation in individual organs (including the leaves) under the influence of mixed sowing. The author recorded, however, a larger dry mass of leaves in the case of oats cultivated in a mix with barley as well as in a mix with barley and triticale during vegetation week 6; triticale reacted in a similar way to sowing with barley.

In the presented studies, on the less abundant object, wheat heads during formation were more handsome than on the more abundant object, while those of barley were more handsome on that object during ripening. Both cereals reacted to cultivation in the mix by reduction of heads. In the earlier referenced experiment by Sobkowicz (2003), barley did not show any changes in production of dry mass of heads under influence of joint cultivation with oats and triticale, while oats and triticale (with the exception of mix with oats) decreased it significantly.

In our studies the roots of both cereals increased their mass until the end of inflorescence emergence phase, and then their reduction took place. This is consistent with the results by Malicki (1997) who showed that growth of the root system continues during generative development and then decreases as a result of dying out. During the ultimate period of vegetation, more abundant mass of roots was characteristic for wheat, while that of barley was much less abundant, which matches the data presented by Pałys (1980/81). In the subject experiment competition resulted in similar scale of reduction of the cereals root mass and the mass of aboveground parts. Wilson (1988), as well as Semere and Froud-Wiliams (2001), however, showed that competition was stronger between roots of cereals than between their aboveground parts. The process significantly reduced the biomass of underground parts during the period from stem elongation to ripening, reaching the highest magnitude during inflorescence emergence. This is consistent with the data presented by Semere and Froud-Wiliams (2001) who showed that the most intensive root competition occurred during the period of Zadoks phases from 30 to 70. Our own studies showed that in the mix the reduction of cereals root mass reached similar magnitude on objects with both fertilisation doses. Lamb *et al.* (2006), however, assessing competition between fescue, wormwood and quinoa, found that the strength of influence between their roots increased with the increase of nitrogen dose.

In the analysed experiment, daily aboveground mass increases during the early period of growth were similar for both analysed species. The plants at that time were small and had access to all necessary growth factors so they used them according to their own needs. This is consistent with the results of studies by Sobkowicz (2001) which inform that during early development stages competition between barley and oats progressed with low intensity. In our own studies, barley was characterised by faster than wheat rate of dry mass accumulation during the interphase of seedling development-tillering, which indicates its more dynamic growth during that period. This is confirmed by studies by Sobkowicz (2003) who observed the most intensive dry mass increases for that cereal during the first 3 weeks after seedling development. According to Harris & Wilson (1970), Lambers & Poorter (1992) as well as Save *et al*. (2004), species with high growth rate utilise growth factors better during the early stages and quickly take possession of available space, which at the later period results in their advantage during later stages of competition. The domination of barley over oats which, similarly to wheat, is characterized by a slower rate of growth than the competitor, was observed during that period by Jokinen (1991), Michalski & Waligóra (1993) and Taylor (1978). Then, as of the tillering until inflorescence emergence, wheat was characterized by evidently higher dry mass increases, with the exception of objects more abundant with nutrients where the value of that characteristic for both species reached similar levels. The plants of dominated species started strong rivalry for limited environment resources to compensate for the losses incurred during the preceding period. It should also be noticed that barley individuals entering the phase of intensive stem elongation and then inflorescence emergence did not accumulate such a large mass of leaves, which occurred in case of wheat which started its generative development a couple of days later. This result does not agree with domination of barley over oats and triticale as well as their mixes in accumulation of biomass from the phase of stem elongation, as reported by Sobkowicz (2003). In our studies, after inflorescence emergence again larger biomass increases were recorded for barley, while wheat plants were characterised by negative values of that characteristic, which indicated commencement of the process of drying and falling off of the leaves. A similar reaction of barley was observed by Sobkowicz (2003) after week 12 from seedling development.

Spring barley was characterised by faster growth rate as single crop than in the mix with wheat during the entire vegetation period, with the exception of the interphase of tillering-stem elongation. Wheat reacted similarly to the neighbourhood of barley. Only during the final stage of vegetation on objects with the higher fertilisation level that cereal accumulated higher mass per day. In the experiment by Sobkowicz (2003), the mixes with barley were characterised by faster growth rate than the mix of oats and triticale, which indicates a favourable influence of barley on productivity of those crops and which was not confirmed by our studies.

CONCLUSIONS

1. Spring wheat presented stronger than barley negative reaction to joint cultivation. Its biomass under those conditions was subject to progressive reduction from tillering until inflorescence emergence, and then that process was slightly slowed down. The decrease of the aboveground mass of wheat was more pronounced on the object more abundantly supplied with NPK and it applied to a similar degree to the stems, leaves and heads.
2. Mixed sowing significantly limited accumulation of aboveground biomass of spring barley during tillering, inflorescence emergence and ripening. That was more pronounced in stems and heads, and less in leaves. Until inflorescence emergence phase, larger differences between sowing methods developed on the object less abundant in macro-elements, while during ripening they equalised as concerns the leaves and heads; for the stems they were more pronounced in the more abundant combination.
3. Joint cultivation of cereals, as compared to single crop cultivation, resulted in development of roots possessing smaller mass by the cereals; the scale of that reduction was similar to the reduction of aboveground parts; those relations were similar for both fertilisation levels.
4. Wheat sown in the mix was characterised by smaller daily increases of biomass than wheat cultivated as a single crop between seedling development and tillering, as well as between stem elongation and inflorescence emergence. For this sowing method, in the case of barley progressing decrease in the biomass accumulation rate developed with the passage of time (with the exception of the interphase of tillering-stem elongation). In the case of both cereals that process was more pronounced on the objects supplied with NPK more abundantly.

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KONKURENCJA POMIĘDZY PSZENICĄ JARĄ A JĘCZMIENIEM JARYM W WARUNKACH ZRÓŻNICOWANEGO NAWOŻENIA CZ. II. WPŁYW NA BIOMASĘ ROŚLIN I TEMPO JEJ AKUMULACJI

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Streszczenie. W ścisłym, statycznym doświadczeniu wazonowym zrealizowanym w trzech cyklach w latach 2003-2004 w laboratorium szklarniowym śledzono oddziaływania konkurencyjne pomiędzy pszenicą jarą i jęczmieniem jarym. Oceniano je na podstawie akumulacji suchej masy w częściach nadziemnych (w źdźbłach, liściach, kłosach) oraz korzeniach oraz tempa wzrostu łanu. Rośliny wysiewano w mieszance (o jednakowym udziale obu komponentów) oraz w uprawie jednogatunkowej, na podłożu gleby średniej zasilanej standardową i podwyższoną w stosunku do niej o 50% dawką NPK. Liczba obu gatunków w uprawie łącznej stanowiła sumę ich obsady z siewów jednogatunkowych. Analizy wykonywano w fazach: wschodów, krzewienia, strzelania w źdźbło, kłoszenia i dojrzewania. Wykazano, że jęczmień wywierał silniejszy ujemny wpływ na pszenicę aniżeli odwrotnie. W mieszance, w stosunku do uprawy jednogatunkowej, sucha masa pszenicy ulegała postępującej redukcji od fazy krzewienia do kłoszenia, obejmując w zbliżonym stopniu źdźbła, liście i kłosy. Pszenica z kolei ujemnie oddziaływała na przyrost nadziemnej biomasy jęczmienia w fazach krzewienia, kłoszenia i dojrzewania. Do fazy kłoszenia większe różnice pomiędzy sposobami siewu wystąpiły na obiekcie uboższym w NPK, a podczas dojrzewania uległy one wyrównaniu. Skala redukcji masy korzeniowej w mieszance osiągnęła podobną wielkość jak w częściach nadziemnych, bez różnicującego w tym względzie wpływu dawek nawozowych. W świetle przeprowadzonych badań pszenica w obecności jęczmienia charakteryzowała się mniejszymi niż w uprawie samodzielnej dobowymi przyrostami biomasy w międzyfazach: wschody-krzewienie oraz strzelanie w źdźbło - kłoszenie. Tempo akumulacji biomasy jęczmienia uprawianego w mieszance ulegało stopniowemu spowolnieniu od początku wegetacji (z wyjątkiem okresu: krzewienie – strzelanie w źdźbło). U obydwu zbóż proces ten silniej zaznaczył się na obiekcie obficiej zasilanym NPK.

Słowa kluczowe: konkurencja, pszenica, jęczmień, fenofazy, nawożenie, biomasa roślin