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SHOOT AND ROOT COMPETITION BETWEEN SPRING TRITICALE AND FIELD BEANS DURING EARLY GROWTH

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Abstract. The experiment was carried out according to additive design to study shoot and root competition between spring triticale and field bean during early stages of plant growth. It was conducted in plastic boxes 76 cm long, 15 cm wide and 15 cm deep, filled with 16 kg of aerial dry alluvial sandy loam soil, containing 15-20% of silt. The soil was classified as good rye agricultural suitability complex. Appropriate arrangement of boxes and aboveground aluminium foil partitions allowed separating four competition treatments: no competition, shoot, root and shoot + root competition. The results of the experiment showed that at the beginning of species interaction in triticale-field bean intercrop system, root competition is more intense than shoot competition. Triticale outcompeted field bean when crops interacted with their roots, but when only shoots competed, field bean tended to be the dominant species. The study presented did not show definitely that cereal is better competitor than legume during early stages of plant growth.

Key words: competition, spring triticale, field bean, intercrop, nitrogen, competition indices

INTRODUCTION

Research into triticale-field bean intercrop demonstrated its suitability to fertile soil conditions [Rudnicki and Kotwica 1999] however other experiments conducted with cereal-field bean intercrops showed some limitations for their growth on light soil [Ceglarek et al. 1997a, b, Ignaczak and Andrzejewska 1997]. In the previous study conducted on sandy loam soil field beans was severely suppressed by triticale in the intercrop [Sobkowicz and Parylak 2002]. Causes of competitive dominance of cereals in intercrops are often inferred from final yields of crops, yet the mechanism remains unknown. According to Sobkowicz [2003], the stable competitive hierarchy between species in cereal mixture establishes at tillering stage and does not change until full

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maturity. Another experiment showed that competition between root systems of crops in mixture is more important than aboveground interaction in creating the hierarchy during early stages of plant growth [Sobkowicz 2001]. This may suggest the competitive success of a crop in terms of grain yield depends greatly on its ability to win competition for soil resources immediately after plant emergence. The importance of root competition has been confirmed also by other researchers [Bozsa and Oliver 1990, Satorre and Snaydon 1992, Semere and Froud-Williams 2001]. Little is known about the meaning of shoot and root interactions between cereals and field beans when intercropped. In research of Martin and Snaydon [1982] barley dominated field beans mainly due to root competition.

There are various factors that may contribute to competitiveness of a species. Some views emphasize morphology of a plant as a determinant of competitive success. For example, researchers argue that the greater is the seed of a plant the higher is its competitive ability. This relationship was found in competitive studies of Exley and Snaydon [1992] for such different species as wheat and *Alopecurus myousuroides* but also in research of Litav and Isti [1974] for two strains of spinach. According to Francis [1989], leaf orientation is yet another main factor determining the success of a species in mixtures. Species with horizontally oriented leaves usually gain advantage over the other species in an intercrop [Keating and Carberry 1993]. Based on these views field beans may be predicted to be a better competitor than triticale during initial stages of plant growth as it possesses both of the attributes. Other scientists show, however, that a faster initial growth rate of one species after plant emergence determines its competitive advantage over slower growing species [Fukai and Trenbath 1993]. The faster growing species is then able to preempt essential growth resources making them unavailable to the other species [Goldberg and Landa 1991]. This was supported by research of Jensen [1996] in which barley was able to uptake soil nitrogen faster than pea in the intercrop. In that study, competitive advantage of barley came also from higher density of its root system than roots of pea. Ofori and Stern [1987] in review article on cereal-legume intercrops also indicate that cereals are better competitors for soil resources than legumes due to their extensive fibrous root system.

The concepts presented suggest that triticale is a species which is more competitive for soil resources than field beans, while the legume may gain advantage in competition for light. The experiment was conducted to verify the notion and comprised two objectives. Since the previous field experiment showed a strong dominance of triticale in the intercrop at maturity [Sobkowicz and Parylak 2002, Sobkowicz and Śniady 2004], the first objective was to explain if competitive advantage of triticale over field beans occurs early after plant emergence. The second objective was to determine the importance of shoot and root interactions between the two crops.

MATERIAL AND METHODS

The experiment was conducted at the Experimental Station of Agricultural University of Wrocław according to the method used by different authors [Schreiber 1967, Satorre and Snaydon 1992, Sobkowicz 2001] (Fig. 1). White plastic boxes 76 cm long, 15 cm wide and 15 cm deep, were filled with 16 kg of aerial dry soil taken from plough layer of one of the fields belonging to the Station. It was alluvial sandy loam soil containing 15-20% of silt classified as good rye agricultural suitability complex. Excess of seeds of spring triticale (cv. Migo) and field beans (cv. Optimal) was sown in rows and after plant emergence triticale was thinned to 40 plants per row while field beans - to 10 plants per row. An appropriate arrangement of the boxes and aboveground aluminium foil partitions allowed separating four competition treatments: no competition, shoot competition, root competition and shoot + root competition (see Figure 1). Two levels of aboveground partitions were used. To avoid shading of small plants after emergence, the first level was 25 cm high, and when the highest plants reached top of the partitions, the next level was installed, increasing the total height of the partitions up to 45 cm.

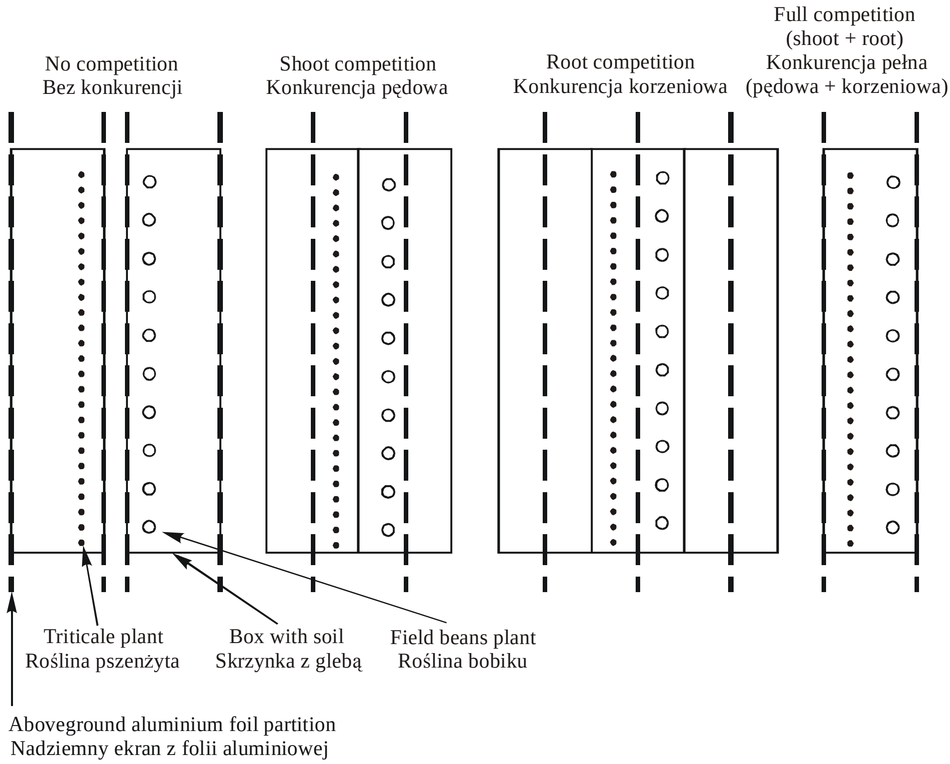


Fig. 1. Experimental treatments
Rys. 1. Obiekty doświadczalne

The experiment was conducted according to randomized complete block design with four replicates. Soil in boxes was watered each day to maintain about 60-70% field capacity of soil. Weeds were controlled by hand. No additional treatments were applied in the experiment until harvest. At the end of the series plants of triticale reached jointing stage, with first node detectable, while plants of field beans had 5-6 leaves. The experiment ended when the highest plants reaching the top of the second partition level. This allowed for conducting two series of the experiment in one year. The first two were carried out from 14.04.2000 to 19.05.2000 (series 1) and from 29.05.2000 to 03.07.2000 (series 2) and the next two from 05.04.2002 to 31.05.2002 (series 3) and from 10.06.2002 to 18.07.2002 (series 4). After each series boxes were refilled with a new soil. After each harvest of aboveground biomass, the height of plants was determined based on 10 plants of each crop. Plant samples were dried at 70°C in laboratory drier until constant weight. The nitrogen content in plant dry matter was determined based on treatment mean subsamples of each species using standard Kjeldahl method. The nitrogen output was calculated by multiplying treatment mean nitrogen content by plant dry matter yield from each box.

The design used in the experiment is referred to as 1 : 1 additive design because each species was represented by the same number of plants in no competition treatment as in each competition treatment [Snaydon 1991]. For mixtures of agricultural crops substitutive (replacement series) design or proportional substitutive design is usually employed. Those designs are valid when the comparison between yields of pure stand and mixture is the main aim of research. In early stages of competition substitutive design gives results the interpretation of which may be ambiguous [Snaydon 1991, Sobkowicz 2001].

Interactions between crops in the experiment were measured using three indices: relative yield (RY), intensity of competition (INT) and competition balance index (C_b). The relative yield measures the response of a species to competition from another species:

$$RY_t = Y_{tb}/Y_t, \qquad RY_b = Y_{bt}/Y_b$$

where:

- Y_t – the yield per box of plant dry matter of triticale grown alone,
- Y_{tb} – the yield per box of plant dry matter of triticale in competition with field beans,
- Y_b – the yield per box of plant dry matter of field beans grown alone,
- Y_{bt} – the yield per box of plant dry matter of field beans in competition with triticale.

In the same way also relative nitrogen output per box was calculated in the experiment. For any species $RY < 1.0$ means competition while $RY > 1.0$ denotes facilitation (positive interaction between species). The intensity of interspecific competition between crops was calculated according to the following modified equation derived from Keddy [2001]:

$$INT = 1 - RY_t + 1 - RY_b$$

At sowing $INT = 0$ while after plant emergence, the more plants of each species are affected by competition during growth, the higher is the value of INT. To measure competitive abilities of the crops, competitive balance index was used following Wilson [1988]:

$$C_b = \ln[(Y_{tb}/Y_{bt}) / (Y_t/Y_b)]$$

If species are equal competitors, then $C_b = 0$, when triticale is a better competitor than field beans then $C_b > 0$, if the reverse is true, then $C_b < 0$. Original Keddy's and Wilson's equations use weight per plant but for any 1 : 1 additive design yield per area (here, per box) can be used in both equations as when calculating the yield per plant for each species, the number of plants cancels out in the equations. The competition intensity and C_b were computed based on plant dry matter yields only.

The data were subjected to analysis of variance. Comparison of means was made using Tukey honestly significant difference test. The results from all the replications of all the series were used to test if the series-mean relative yield of a species differs significantly from 1 or if the competition intensity and competition balance index differed significantly from 0. For this purpose, a paired comparison t-test was used.

RESULTS AND DISCUSSION

In the experiment, except for the root competition treatment, triticale and field beans plants were about the same high (Table 1). As compared to the treatment without competition, the root interaction between species reduced significantly the height of field beans plants by 8.4 cm, 8.8 cm and 10.1 cm in series 1, 2 and 4, respectively, but did not affect the height of triticale plants. The effect of shoot competition on plant height was opposite than that of root competition and in series 1 plants of both species were significantly higher when their shoots interacted than when they were grown alone.

Table 1. Plant height, cm
Tabela 1. Wysokość roślin, cm

Competition Konkurencja	Triticale – Pszenżyto					Field beans – Bobik				
	Serie – Seria				Mean Średnia	Serie – Seria				Mean Średnia
	1	2	3	4		1	2	3	4	
No competition Bez konkurencji	34.9	46.8	35.4	34.3	37.9	35.4	35.7	31.9	39.2	35.6
Shoot Pędowa	39.7	45.9	35.9	36.1	39.4	41.9	39.6	34.3	39.6	38.9
Root Korzeniowa	32.9	41.1	35.3	35.6	36.2	27.0	26.9	26.8	29.1	27.5
Full Pełna	35.8	43.9	35.9	35.1	37.7	33.8	35.5	34.1	33.3	34.2
$LSD_{0.05}$ – $NIR_{0,05}$	4.6	ns – ni	ns – ni	ns – ni	2.1	4.3	5.5	ns – ni	6.3	2.9

ns – ni – non-significant difference – różnica nieistotna

When triticale and field beans interacted fully no significant changes in plant height were noticed in both crops. Averaged over four series, plants of triticale from shoot competition treatment were significantly higher than those from root competition treatment. Across series the influence of competition was greater for legume species as shoot competition increased the height of plants while root competition decreased it significantly, as compared with the plants from no competition treatment. Similar findings have been reported in the previous experiment in which competition for soil resources decreased the height of barley and oats plants while competition for light increased [Sobkowicz 2001]. Bozsa and Oliver [1990] observed shorter plants of soybeans due to root competition with plants of *Xanthium strumarium*. Semere and Froud-Williams [2001] noticed a reduced height of plants of maize and pea competing belowground.

Plants of field beans accumulated more nitrogen than plants of triticale in series 1, 3 and 4 of the experiment, however in series 2 a high concentration of nitrogen was observed in plants of triticale (Table 2). The difference in N concentration in plants between both species indicates that legume fixed N from the air during the period of plant growth. There was a tendency to increase the content of nitrogen in triticale biomass when crops interacted fully, however, in the first series of the experiment it was the shoot competition which increased N content in plants of triticale most. As compared to N content in plants of field beans grown alone, the competition for soil resources reduced the concentration of nitrogen in plants in the second series of the experiment. In the other series changes in N content in plants were rather small. Martin and Snaydon [1982] observed an increased concentration of N in plants of barley due to root competition with field beans and little effect of this kind of competition on N in legume plants.

Table 2. Nitrogen content in plant dry matter, %
Tabela 2. Zawartość azotu w suchej masie roślin, %

Competition Konkurencja	Triticale – Pszenżyto					Field beans – Bobik				
	Serie – Seria				Mean Średnia	Serie – Seria				Mean Średnia
	1	2	3	4		1	2	3	4	
No competition Bez konkurencji	2.1	4.3	1.6	1.8	2.5	3.8	4.4	4.5	4.4	4.3
Shoot Pędowa	2.7	4.4	1.7	2.0	2.7	3.5	4.2	4.4	4.5	4.2
Root Korzeniowa	2.0	4.3	1.8	2.1	2.6	3.9	3.7	4.5	4.6	4.2
Full Pełna	2.4	4.5	1.9	2.2	2.8	3.8	3.9	4.4	4.3	4.1

Triticale was similarly affected by competition treatments in the experiment because most differences in relative yields calculated for plant dry matter and for plant nitrogen were non-significant (Table 3). Only in the first series was the relative nitrogen yield of triticale in root competition treatment lower than the relative nitrogen yield in shoot competition treatment. The latter was even higher than 1.0 showing there was some facilitative effect of field beans on the cereal. In each series a higher nitrogen relative yield than the plant dry matter relative yield was noted for triticale in full competition treatment, an equivalent treatment to field conditions. An increased protein relative yield compared to the plant dry matter relative yield was noted also in field study conducted with the intercrop [Sobkowicz and Śniady 2004]. In any legume-nonlegume intercrop system N from the air fixed by legume species becomes another source of the nutrient that probably promotes more N content in non-legume species. The competition for soil resources was more severe for legume species than the shoot competition. Except for series 3, dry matter and nitrogen relative yields of the legume calculated for root competition were significantly lower than those calculated for shoot competition. The same was true when the results were averaged over series. When the whole plant of field beans competed with the whole triticale plant, the effect of competition on the legume was the same when only roots competed. Averaged data over series shows both crops were unaffected by aboveground interaction since their RYs for plant dry matter and plant nitrogen were not significantly different from 1. Any of the competition treatments did not reduce N uptake by triticale, while root and full competition decreased N accumulation in legume. All that implies triticale was a better competitor for soil N.

Table 3. Relative yields of plant dry matter and nitrogen
Tabela 3. Plony względne suchej masy roślin i azotu

Competition Konkurencja	Series 1 Seria 1		Series 2 Seria 2		Series 3 Seria 3		Series 4 Seria 4		Mean Średnia	
	RY_t	RY_b	RY_t	RY_b	RY_t	RY_b	RY_t	RY_b	RY_t	RY_b
Plant dry matter – Sucha masa roślin										
Shoot Pędowa	0.90	1.00	0.77	1.06	0.98	0.95	1.04	0.96	0.92	1.00
Root Korzeniowa	0.90	0.68	0.87	0.75	0.96	0.80	0.90	0.61	0.91**	0.71**
Full Pełna	0.84	0.68	0.74	0.83	1.04	0.89	0.92	0.71	0.89**	0.78**
$LSD_{0.05}$ $NIR_{0,05}$	ns – ni	0.09	ns – ni	0.21	ns – ni	ns – ni	ns – ni	0.19	ns – ni	0.09
Plant nitrogen – Azot w roślinie										
Shoot Pędowa	1.18	0.94	0.80	1.00	1.06	0.95	1.15	0.98	1.05	0.96
Root Korzeniowa	0.86	0.71	0.87	0.62	1.13	0.80	1.02	0.63	0.97	0.69**
Full Pełna	0.98	0.68	0.78	0.73	1.23	0.88	1.11	0.69	1.03	0.75**
$LSD_{0.05}$ $NIR_{0,05}$	0.21	0.09	ns – ni	0.20	ns – ni	ns – ni	ns – ni	0.19	ns – ni	0.08

** RY significantly different from 1 (a = 0.01); T-test was used for series-mean relative yields only – RY istotnie różny od 1 (a = 0,01); test t zastosowano tylko dla średnich obliczonych ze wszystkich serii plonów względnych
ns – ni – non-significant difference – różnica nieistotna

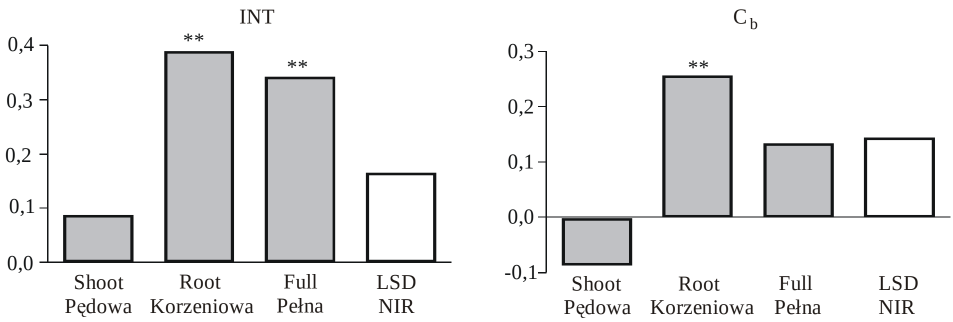
In the first series of the experiment the intensity of competition was greatest when species interacted with roots or with roots and shoots than when they interacted only with shoots (Table 4). The tendency was similar in the second and forth series, however the analysis of variance did not show significant differences. Averaged over series the intensity of competition for light and aboveground space was close to zero, while significantly more intense competition was noted when species competed belowground or fully (Figure 2). A greater intensity of root competition suggests this kind of interaction occurs earlier after plant emergence than the shoot competition [Vandermeer 1989]. According to Ballare et al. [1991], the interaction between plant shoots may be profitable in terms of canopy productivity due to the accumulation of biomass into elongating stems. This may have occurred in the present experiment as plants of triticale and field beans were higher when competed aboveground. The effect, however, did not contribute to a greater dry matter yield of any species in the treatment. The increase in the plant length was probably associated with the reduction in stem diameter or leaf weight.

Table 4. Competition indices
Tabela 4. Wskaźniki konkurencji

Competition Konkurencja	INT				C_b			
	Serie – Seria				Serie – Seria			
	1	2	3	4	1	2	3	4
Shoot – Pędowa	0.10	0.17	0.07	0.00	-0.11	-0.32	0.03	0.08
Root – Korzeniowa	0.42	0.38	0.24	0.49	0.29	0.15	0.18	0.39
Full – Pełna	0.48	0.43	0.07	0.37	0.21	-0.11	0.16	0.26
$LSD_{0.05}$ – $NIR_{0,05}$	0.24	ns – ni	ns – ni	ns – ni	0.21	0.29	ns – ni	ns – ni

ns – ni – non-significant difference – różnica nieistotna

Triticale was a better competitor for soil resources than field beans as it was shown by competitive balance index in series 1 and 2, while legume was a dominant species when the crops competed aboveground (Table 4). The competitive advantage of triticale over field beans was also visible in the first series when the species interacted with their aboveground and belowground parts of plant simultaneously. Averaged results show the cereal outcompeted field beans only when root interacted while competitive abilities of the cereal and legume were nearly the same when only shoots competed (Fig. 2).



** INT or C_b significantly different from zero (a = 0.01) – INT lub C_b istotnie różny od zera (a = 0,01)

Fig. 2. Competition indices (mean for all series)
Rys. 2. Wskaźniki konkurencji (średnia ze wszystkich serii)

In circumstances similar to field conditions, when species interacted fully, mean competitive ability of the cereal was also insignificantly higher than the legume but this does not reflect an overall tendency in the experiment as in the second series the value of C_b was less than zero, showing competitive advantage of the legume. The results imply that the competitive advantage of triticale over field beans in the intercrop occurs later in the growing season since the previous study conducted under field conditions on the same type of soil showed a severe competitive advantage of triticale over field beans at full maturity of crops [Sobkowicz and Parylak 2002]. This suggests that competition for soil resources promotes advantage of triticale later during the growing season.

The notion that a species with larger seeds or larger plants has greater competitive abilities was not confirmed in the present experiment. A single grain of the legume used for seeding was on average 13 times heavier than a single grain of cereal (412 g vs.

31.4 g), however, the dry matter weight of plant of the legume in competition treatments was only about four times greater than the weight of the cereal plant (0.87 g vs. 0.21 g). It means that triticale used growing resources per unit biomass more efficiently than field bean [Connolly et al. 2001].

CONCLUSIONS

The results of the present experiment show that at the beginning of species interaction in triticale-field beans intercrop, root competition is more intense than shoot competition. Triticale outcompetes field bean when species interact with their roots, yet when only shoots compete field beans tends to be the dominant species. Therefore the study does not show unequivocally that cereal is a better competitor than legume during early stages of plant growth.

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PĘDOWA I KORZENIOWA KONKURENCJA MIĘDZY PSZENŻYTEM JARYM A BOBIKIEM WE WCZESNEJ FAZIE WZROSTU

Streszczenie. Doświadczenie przeprowadzono w celu zbadania konkurencji między częściami nadziemnymi a podziemnymi roślin pszenżyta jarego i bobiku we wczesnym okresie wegetacji. Założono je w plastikowych skrzynkach o długości 76, szerokości 15 i głębokości 15 cm, wypełnionych glebą lekką, którą stanowiła mada rzeczna właściwa lekka, zawierająca 15-20% części spławialnych, należąca do kompleksu żytniego dobrego. Odpowiednie ustawienie skrzynek oraz zastosowanie nadziemnych ekranów z folii aluminiowej pozwoliło na wydzielenie czterech obiektów: bez konkurencji, z konkurencją pędową, korzeniową oraz pędową i korzeniową łącznie. Jak wykazały badania, na początku oddziaływań międzygatunkowych w mieszance pszenżyta z bobikiem konkurencja między systemami korzeniowymi była bardziej intensywna niż między pędami. Pszenżyto było bardziej konkurencyjne od bobiku, gdy gatunki konkurowały korzeniami, natomiast gdy konkurowały pędami, obserwowano tendencję do dominacji bobiku. Badania nie wykazały jednoznacznie, że pszenżyto ma większe zdolności konkurencyjne niż bobik we wczesnej fazie wzrostu.

Słowa kluczowe: konkurencja, pszenżyto jare, bobik, mieszanka, azot, wskaźniki konkurencji