Competition between triticale (*Triticosecale* Witt.) and field beans (*Vicia faba* var. *minor* L.) in additive intercrops

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ABSTRACT

In a microplot experiment conducted in 1999 and 2000 on light soil triticale and field beans were grown as sole crops and in the intercrop system. Two pure stand plant densities were established: 200 and 400 plants/m^2 for triticale and 50 and 100 plants/m^2 for field beans. Four possible intercropping combinations were obtained by adding densities of both crops. Triticale was a better competitor than field beans in all intercrops resulting in competitive balance index significantly greater than zero. The number of pods per plant of field beans was significantly reduced in all intercropping combinations compared to the pure stands, however quality of grain of the legume was unaffected by competition. Intercrop comprising 200 plants/m^2 of triticale and 50 plants/m^2 of field beans was most productive in the experiment but addition 50 more plants/m^2 of the legume decreased significantly grain yield of intercrop by 16.2%. The results also show that effective triticale-field beans intercrop for light soil may be designed as additive one, based on 400 plants/m^2 of triticale.

Keywords: cereal-legume interaction; components of yield; protein yield; competitive balance index

The rationale behind intercropping, as a method of sustainable crop production is that the more diverse system represented by two or more crops grown together should better utilize common limiting resources than the species grown separately. The first problem that can be met when planning efficient cereal-legume intercrop is the choice of the appropriate ratio of component species that produces maximum yield of the intercrop. However the highest yielding ratio of species cannot be known beforehand, in many experiments researchers form the intercrop by adding half of the recommended in pure stand seeding density of each of the component species. The design is termed then "proportional replacement series design" or "proportional substitutive design" (Jolliffe 2000) with 50%/50% proportion of the components. In the design, proportion means the percentage of seeding density derived from pure stand and used to form the intercrop. Using the only one ratio of species in the intercrop is usually the result of limitation in size of any intercrop experiment because an additional factor is often used in such research, for instance different rates of fertilizer. Levels of the factor are then multiplied by pure stand and the intercrop treatments enlarging experimental structure. Such an approach is appropriate, but according to Connolly (1986) the most productive ratio of components in the intercrop can be found only experimentally.

The second problem in the intercropping practice is the proper choice of total density of plants per unit area for an intercrop, namely the lowest total density of plants that produces maximum yield of the intercrop. Plant density of a most productive intercrop may be higher than that imposed by the rule used in proportional substitutive design because it may be assumed that component species are able to better utilize resources when intercropped then when they are grown alone (Spitters 1983). Even if the issues are being considered prior to sowing, the next difficulty in designing the efficient intercrop results from unpredictable outcome of interactions between component species and between the species and the environment (Fukai and Trenbath 1993). The main type

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of interaction between species in any agricultural intercrop is competition (interspecific competition). Environmental conditions may strengthen or weaken competitive abilities of species leading to strong dominance of one component over the other in the intercrop. If cereal severely dominates legume in 50%/50% substitutive intercrop it may not be able to compensate for legume yield loss to maintain high yield of the intercrop (Sobkowicz and Parylak 2002, Sobkowicz and Śniady 2004). This may suggest that under conditions unfavorable for one component species, the second species should be represented by greater number of plants in the intercrop system.

The objective of the study was to determine the effect of intercropping spring triticale with field beans at varying plant density and different ratio of components on their performance and intercrop yield. This article is a part of greater research and results of another experiment in which the effect of nitrogen fertilization on triticale-field beans intercrop was studied were published elsewhere (Sobkowicz and Parylak 2002, Sobkowicz and Śniady 2004).

MATERIAL AND METHODS

The microplot experiment was carried out in 1999 and 2000 at the Experimental Station of Agricultural University of Wrocław on sandy loam soil containing 15–20% of silt. Area of one plot was 1 m^2 and the plot comprised five (pure stand) or ten (intercrop) rows of plants one meter long. In pure stand plots rows were spaced 200 mm apart while in plots with the intercrop the species were grown in alternate rows spaced 100 mm apart. The arrangement of rows in the intercrop was similar to that used in agricultural practice because due to difference in grain size two separate passes of a seeder are required to sow triticale-field beans intercrop. Excess of seeds was sown 6.4.1999 and 10.4.2000 by hand in rows and after plant emergence the stand was thinned to required plant density per unit area: 200 plants/m^2 (T) and 400 plants/m^2 (TT) for triticale and 50 plants/m^2 (B) and 100 plants/m^2 (BB) for field beans. The higher plant populations of both species were similar to those recommended in agricultural practice for sole cropping. Four possible intercropping combinations were obtained by adding plant densities of both crops (plants/m^2): 200 + 50 (TB), 200 + 100 (TBB), 400 + 50 (TTB) and 400 + 100 (TTBB). It means 1:1 additive design was used for each intercrop because each species was grown at the same plant density in the intercrop as in the corresponding pure stand. In the experiment cultivar Migo of triticale was used while for field beans cultivar of determinate growth form Optimal was chosen. The experiment was arranged in a randomized complete block design with four replications. Plots were fertilized with 3.5 g N, 2.7 g P and 5.8 g K prior to sowing. Weeds were controlled by hand. The experiment was harvested when both species reached full maturity, 2.8.1999 and 2.8.2000. Three central rows of each species were harvested in pure stands and in the intercrop (0.6 m^2). Plant height was determined based on 25 plants of each crop in each plot while number of ears (pods) per plant was recorded based on the whole plant sample. After threshing the samples, yield of grain and biomass (grain + straw) was noted. Dry matter was determined in whole biomass and in grain based on treatment mean subsamples that were dried in the laboratory drier. The harvest index was calculated as the ratio of grain dry matter yield to the whole biomass dry matter yield. After recording a thousand grain weight (TGW) the number of grain per ear (pod) was calculated. The content of crude protein (N × 6.25) in plant dry matter was determined based on treatment mean samples of each species using standard Kjeldahl method. Protein yields were calculated by multiplying treatment mean protein content in grain or biomass by dry matter yield of grain or biomass from each plot.

Competition was analyzed according to additive design (Snaydon 1991). Relative yield (RY) and relative yield total (RYT) of grain and biomass dry matter and crude protein of each species were calculated:

$$RY_i = Y_{ij}/Y_{ii}, \quad RY_j = Y_{ji}/Y_{jj}, \quad RYT = RY_i + RY_j$$

where: Y_{ii} is the yield of species *i* in pure stand, Y_{ij} is the yield of species *i* intercropped with species *j*, Y_{jj} is the yield of species *j* in pure stand and Y_{ji} is the yield of species *j* intercropped with species *i*.

In the additive design RY is the response of a species that occupies a certain space to the addition of plants of another species to that space. According to Austin et al. (1988) different values of RY have different meanings: RY < 1.0 indicates competition (interference), RY = 1.0 lack of interaction, RY > 1.0 stimulation. Relative yield total is a measure of resource complementarity and indicates to what extent species compete for limiting resources. If the species completely share common limiting resources RYT = 1.0. Relative yield total greater than 1.0 indicate partial resource complementarities between competing species. It means the competing species use partially different growing resources or utilize the same resources but more efficiently due to differences in plant architecture, physiology or growing cycle (Bulson et al. 1997). If there is no competition between species RYT = 2.0.

To measure competitive abilities of the species in terms of biomass yield, competitive balance index was used after Wilson (1988) for 1:1 additive intercrop:

$$C_b = \ln[(Y_{ij}/Y_{ji})/(Y_{ii}/Y_{jj})]$$

The original Wilson equation uses weight per planted plant but for any 1:1 additive intercrop, yield per area can be used in the equation (Wilson 1988, Snaydon 1991). If the species are equal competitors then $C_b = 0$, when species i is a better competitor than species j then $C_b > 0$, if the reverse is true then $C_b < 0$. In the experiment C_b of triticale with relation to field beans was calculated.

Data were subjected to analysis of variance and means were compared using Tukey's honest significant test ($HSD_{0.05}$). Values of RYT were tested for deviation from 1.0 and values of C_b for deviation from zero using paired comparison t-test.

RESULTS

Intercropping triticale at a single (T) or double (TT) plant density with field beans did not affect plant height of the cereal compared to the pure stands but doubling density of triticale plants in pure stand had significant negative influence on their height (Table 1). The latter effect was also observed for such traits as number of ears per plant or number of grains per ear. The highest number of ears per plant was produced by triticale grown in pure stand at a single density and it decreased gradually with addition of plants of the legume. The trait was unaffected in the intercrops in which triticale was grown at double density of plants. Adding 50 plants of field beans to 200 plants of triticale per m^2 (TB) significantly increased thousand grain weight (TGW) of cereal by 5.3% but TGW did not change when double density triticale was intercropped with legume. Harvest index of triticale was unaffected by experimental treatments while biomass protein and grain protein increased in triticale with increasing density of plants of field beans in the intercrop.

Intercropping caused a reduction in most yield components of field beans (Table 2). Plant height of field beans at single and at double plant density decreased along with increasing plant density of triticale in the intercrop. When cereal was present at a double plant density in the intercrops (TTB and TTBB) legume plants were 88 mm and 123 mm shorter than those in the respective pure stands. Among all plant traits of field beans the number of pods per plant was most severely reduced due to intercropping with triticale. Compared to pure stand of single density field beans, when the legume was grown with single and double density triticale a significant 61.0% and 76.3% reduction in number of pods per plant was noticed respectively. For double density field beans the reductions were 57.6% and 63.6%. The more plants of triticale were added to plants of field beans the

Table 1. Performance of triticale in pure stand and in intercrop (mean 1999–2000)

Cropping system	Plant height (mm)	Ears per plant	TGW (g)	Grains per ear	Harvest index	Biomass protein (% d.m.)	Grain protein (% d.m.)
T	842	1.8	41.7	37	0.48	6.7	11.1
TB	868	1.5	43.9	40	0.49	7.2	12.0
TBB	839	1.3	43.3	35	0.49	7.7	12.5
TT	772	1.2	41.8	28	0.47	6.7	11.3
TTB	796	1.2	41.3	27	0.47	7.0	11.7
TTBB	811	1.2	42.6	27	0.49	7.5	12.2
$HSD_{0.05}$	61	0.2	2.2	5	NS	–	–

d.m. – dry matter; NS – not significant difference

Table 2. Performance of field beans in pure stand and in intercrop (mean 1999–2000)

Cropping system	Plant height (mm)	Pods per plant	TGW (g)	Grains per pod	Harvest index	Biomass protein (% d.m.)	Grain protein (% d.m.)
B	553	5.9	351	2.6	0.43	15.1	27.9
TB	523	2.3	357	2.5	0.37	14.0	28.1
TTB	465	1.4	378	2.1	0.31	13.8	28.3
BB	594	3.3	372	2.7	0.42	15.0	28.0
TBB	539	1.4	365	2.2	0.30	13.1	28.4
TTBB	471	1.2	382	1.9	0.27	12.7	28.8
$HSD_{0.05}$	49	0.7	NS	0.5	0.04	–	–

more were reduced: the number of grains per pod and harvest index of the legume. Thousand-grain weight (TGW) of field beans was not affected in the experiment. An increasing number of plants of cereal in the intercrop reduced concentration of protein in biomass of legume. Reverse trend was noticed for grain protein, however those changes were less pronounced.

Yield potential of triticale was significantly higher then the yield potential of field beans (Table 3). Single density triticale yielded 90.7% more grain and 72.4% more biomass than single density field beans while double density triticale yielded 61.5% and 42.6% more grain and biomass than double density field beans. Intercrop comprised 200 plants/m^2 of triticale and 50 plants/m^2 of field beans (TB) was most productive but addition 50 more plants/m^2 of the legume to the intercrop (TBB) decreased significantly grain yield of the intercrop by 16.2%. Grain yield of other intercrops did not differ significantly from the yield of TB intercrop. Only intercrop comprised 200 plants/m^2 of cereal and 50 plants/m^2 of legume (TB) produced 16.9% more grain than single density triticale in pure stand. Other intercrops did not perform significantly better than pure stands of the cereal. All intercrops yielded significantly more grain than field beans grown in both pure stands. A similar yielding pattern was observed for biomass, however there were no significant differences among intercrop yields, and TB and TTBB intercrops out-yielded single density pure stand triticale. Protein yields did not differ among intercrops but most intercrops yielded more grain and biomass protein than triticale in pure stands except for grain protein yield of TTB intercrop that did not differ from the yield of double density triticale (TT).

In three out of four intercrops triticale yielded almost its full grain yield from corresponding pure stands as it was shown by high values of relative

Table 3. Yields of pure stands and intercrops (mean 1999–2000)

Cropping system	Grain	Biomass	Grain protein	Biomass protein
	(g d.m./m^2)		(g/m^2)	
T	433	895	48	60
TT	449	951	51	63
B	227	519	63	78
BB	278	667	78	100
TB	506	1092	75	96
TBB	424	990	68	93
TTB	463	1042	62	84
TTBB	482	1070	69	92
$HSD_{0.05}$	73	151	14	16

Table 4. Competition indices for grain and biomass (mean 1999–2000)

Cropping system	Grain dry matter			Biomass dry matter			
	RY triticale	RY field beans	RYT	RY triticale	RY field beans	RYT	C_b triticale
TB	0.96	0.40	1.36**	0.95	0.47	1.42**	0.69**
TBB	0.76	0.34	1.10	0.75	0.47	1.22**	0.47**
TTB	0.93	0.21	1.14**	0.93	0.30	1.23**	1.13**
TTBB	0.93	0.24	1.17*	0.89	0.34	1.23**	0.96**
$HSD_{0.05}$	0.14	0.10	0.16	0.15	0.10	0.16	0.39

**RYT significantly different from 1.0 (P = 0.01), C_b significantly different from 0.0 (P = 0.01)
*RYT significantly different from 1.0 (P = 0.05), C_b significantly different from 0.0 (P = 0.05)

yields (Table 4). The exception was intercrop comprised 200 plants/m^2 of triticale and 100 plants/m^2 of field beans (TBB) in which cereal yielded 24% less than in pure stand and the relative yield differed significantly from RYs of triticale in other intercrops. The field beans were a weaker competitor than triticale in terms of grain production because its RYs ranged from only 0.21 to 0.40. The lowest values of legume RYs were obtained in the intercrops with double density triticale. Nevertheless there was a significant gain from intercropping of both species in terms of grain yield because three intercrops gave RYT significantly greater than 1.0 and only RYT for TBB intercrop did not differ from 1.0. Relative yield total of grain in the intercrop that comprised single plant densities of both species (TB) was significantly higher than other RYTs in the experiment.

Relative biomass dry matter yields of triticale were similar to those observed for grain yield, while biomass RYs of field beans were greater than those recorded for grain. This resulted in higher biomass RYTs of all intercrops compared to RYTs of grain. Relative yield total of biomass in TB intercrop was significantly higher than in other intercrops. A competitive balance index confirms competitive advantage of triticale over field beans because all C_b values were significantly higher than zero. The advantage was greater in the intercrops with double plant density of triticale. On the other hand relative competitive abilities of both species did not change significantly due to increasing total plant density of the intercrop because C_b recorded for TTBB intercrop did not differ significantly from that noted for TB intercrop.

Protein relative yields of triticale calculated for grain and biomass were higher than RYs recorded for dry matter (Table 5). The same comparison made for field beans showed that RYs of grain protein equaled RYs of grain dry matter while RYs of biomass protein were lower than RYs of biomass dry matter. Nevertheless relative yield totals for grain and biomass protein were slightly higher than respective RYTs for grain and biomass dry matter indicating gain in N acquisition by intercrops. The lowest values of triticale RYs for

Table 5. Relative protein yields (mean 1999–2000)

Cropping system	Grain protein			Biomass protein		
	RY triticale	RY field beans	RYT	RY triticale	RY field beans	RYT
TB	1.03	0.40	1.43**	1.01	0.44	1.45**
TBB	0.85	0.34	1.19**	0.85	0.41	1.26**
TTB	0.96	0.21	1.17**	0.98	0.28	1.26**
TTBB	1.01	0.23	1.24**	1.00	0.29	1.29**
$HSD_{0.05}$	0.15	0.10	0.17	0.16	0.10	0.16

**RYT significantly different from 1.0 (P = 0.01); *RYT significantly different from 1.0 (P = 0.05) grain and biomass protein were noticed in TBB intercrop. Relative protein yields of field beans grown in intercrops with single density triticale were higher than those recorded for the legume grown with double density triticale.

DISCUSSION

The competitive abilities of the legume weakened by unproductive environment of light soil allowed triticale to produce almost its full pure stand grain and biomass yield in three intercrops supporting their high yield. The result was similar for both experimental years (data for years are not presented) indicating soil conditions were more important in establishing competitive hierarchy than were variations in weather conditions. Cereals are perceived as stronger competitors than legumes mainly due to higher grow rate and denser root system as pointed out Ofori and Stern (1987) in their review. In spite of significant suppression of field beans the quality of grain of the legume was almost unchanged in terms of thousand-grain weight and grain protein content. In 1999 there was even a tendency to increase TGW of the legume due to intercropping. Thus competition between triticale and field beans was probably most intense before grain filling. The primary contributing component to decrease grain yield of field beans was the number of pods per plant. The result is in agreement with that of Rauber et al. (2000) in which reduced number of pods per plant was the main cause of low yield of pea intercropped with oats.

The experiment shows that when the environmental conditions are unfavorable for field beans, a large number of plants of the legume may decrease yield of the intercrop. This was the case in the TBB intercrop in which triticale was grown at a single plant density i.e. at about half the density recommended for agricultural practice while field beans was intercropped at full pure stand plant density. As a consequence yield of triticale decreased in the intercrop, but the legume was unable to take advantage of the situation to yield more grain or biomass. In other words competitive abilities of triticale decreased only little in the intercrop and the cereal was still a dominant species. The second year of the experiment contributed mainly to such an outcome. In 2000, field beans was able to produce in the treatment only 25% grain yield of its corresponding pure stand (RY = 0.25) that gave RYT equal to 1.0. In other intercrops low grain or biomass yield of field beans was an addition to almost full pure stand yield of triticale resulting in the yield advantage (RYT > 1.0) when averaged over years. However there were also year differences of RYT in the intercrop in which species were grown at their maximum plant densities (TTBB). In 1999 significant yield advantage was noted (RYT = 1.30) while in 2000 the RYT was only 1.03 because field beans in the system produced only 10% of the sole crop yield (RY = 0.10). Different findings have been reported by Haymes and Lee (1999) who observed yield benefit when field beans was sown in the intercrop at 100% and wheat at 50% of recommended pure stand density or the species were sown in the intercrop at 100% of their recommended pure stand densities. Bulson et al. (1997) noted the highest yield advantage of wheat-field beans intercrop when both components were sown at 75% of recommended pure stand density. Unlike the experiment reported here both studies were conducted in more productive soil conditions that were suitable for both crops. Triticale-field beans intercrop containing 50% of recommended planting densities of both species (TB) produced the highest RYT in the experiment. It is important however the result cannot be unambiguously interpreted as the highest yield advantage. If plant densities of species are too low to ensure maximum yield in pure stands for a given environmental conditions, adding the plant densities to form intercrop increases yield per unit area. Hence RYT in such intercrop will be always greater than 1.0. The situation may have occurred for TB intercrop. Hence one part of RYT value that was higher than 1.0 in TB intercrop may have been the result of only adding plant densities of both species and another part due to real complementarity phenomenon.

Triticale performed relatively better in terms of protein yield than in terms of grain and biomass yield and this was noticed for both years of the experiment. This is the evidence for a net gain from nitrogen fixation in field beans. In any additive intercrop, the addition of plants of legume species to the plants of non-legume species must increase competition between them for soil and fertilizer sources of nitrogen compared to pure stands. Hence the increase in protein content in plants of triticale was a result of acquiring a part of fixed nitrogen added to the intercrop system. Facilitation e.g. positive interaction between plants (Vandermeer 1989) was thus the third phenomenon apart from competition and resource complementarity that operated in the legume-cereal system. The facilitative effect of field beans on triticale through nitrogen supply balanced its competitive effect on the cereal and resulted in RY of triticale approaching 1.0 for grain and biomass yield. Nitrogen may have been transferred from roots of legume to the roots of triticale, however the existence of such transfer is still insufficiently supported by research (Jensen 1996, Hauggaard-Nielsen et al. 2001). Triticale may have used nitrogen also from decaying and mineralizing roots of field beans at the end of growth period as it was suggested by Stern (1993) for any legume-nonlegume inercrop. Bulson et al. (1997) also observed increase in N content in wheat grain due to intercropping with field beans in additive intercrop. They suggested however the increase was a result of lower nitrogen dilution in plants of wheat due to reduced grain and biomass yield in the intercrop compared to pure stand. This was not probably the case in the experiment reported here because in three intercrops triticale produced almost their full pure stand biomass dry matter yield.

Strong competition from triticale caused a decrease in protein content in plants of the legume when averaged over years. It means triticale captured probably most of soil and fertilizer N in the intercrop and interfered also in some way in nitrogen fixation in the legume. However in the second year the decrease in plant protein was not observed for the intercrops in which field beans was grown at a single plant density. The result is only partially in agreement with those of Danso et al. (1987). They reported barley was more successful at extracting soil N in intercrop with field beans, but this caused an increase in N fixation in the legume species.

Results of the experiment show that: (1) triticale is a better competitor than field beans regardless of ratio of component species and total plant density of the intercrop, (2) an effective triticale-field beans intercrop suitable for light soil may be designed as additive one, based on full recommended for pure stand seeding density of cereal, (3) intercropping field beans at 100% and triticale at 50% of their recommended pure stand plant densities decreases intercrop yield.

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