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INTERCROPPING BARLEY AND PEA AT UNIFORM AND ALTERNATE ROW ARRANGEMENT OF THE CEREAL COMPONENT

Piotr Sobkowicz, Ewa Tendziagolska
Department of Agroecosystems and Green Areas Management, Wrocław University of Environmental and Life Sciences, Poland

ABSTRACT

In a field experiment conducted in 2005–2007 on light soil, medium-tall leafy field pea (*Pisum sativum* L.) cultivar Wiato (dry seed type) and tall leafy pea cultivar Fidelia (green forage/dry seed type) were grown in two-species mixtures with spring barley (*Hordeum vulgare* L.). The aim of the research was to assess the effect of partial separation of the components in the intercrop on barley-pea interaction, canopy lodging, biomass yield and grain production. The species were sown in intercrops using separate passes of the seeder in the same direction, with pea seeded first in regular row spacing of 10.8 cm. The partial species separation was achieved through sowing barley in four different row arrangements in the intercrop: uniform row spacing of 10.8 and 21.6 cm, and alternate row spacing of 10.8/32.4 cm and 10.8/43.2 cm. The intercrop with barley seeded in rows spaced 10.8 cm apart and that with alternate row spacing of 10.8/43.2 cm yielded the same grain during the experimental years. Compared to those, the mixture with alternate 10.8/32.4 cm row spacing of barley yielded significantly less grain in 2005 and 2006.

Key words: plant lodging, competition, facilitation, resource complementarity, row spacing.

INTRODUCTION

Research shows that barley-pea intercrops are more biologically effective than sole cropped components [3, 6]. This is attributed to complementary use of nitrogen by the species in the intercrop, when the legume acquires mainly atmospheric N for its growth while the cereal uses soil N. The closeness of roots of the components and competition for soil N in the intercrop promotes also more efficient atmospheric N fixation by legume than in pure stand [3]. In addition it may promote the transfer of biologically fixed N from the legume to the cereal that is a form of facilitation of the cereal by the legume [11].

Field pea having climbing plants needs external support for vertical growth. When sown in pure stand, young plants of pea support themselves effectively but in reproductive stages of growth they have tendency to lodging that increases until full maturity [26]. This may lead to yield reduction due to unfavourable light conditions in the canopy and due to fungal diseases that may spread in the lodged and wet plant stand [27]. Pea is frequently intercropped with cereals that perform the function of supporting crop for the legume. The support is particularly important for conventional leafy pea cultivars that lodge heavily when sole cropped [23]. The role of cereal may be considered as a form of aboveground facilitation, which is met in natural vegetation when vines of one species use stiff stems of other species as a support [5]. These below- and above-ground facilitative interactions in barley-pea mixture are counterbalanced by competition between species for resources. The competition is intense because dense plant stand is required to maximize yield per unit area. According to most research, barley outcompetes pea in mixture [6, 10, 21, 31]. It grows faster than pea during early stages of plant development and is better able to acquire resources from soil than pea [1, 28, 29]. Better early growth of barley in mixture with pea may be connected with its ability to form longer roots than in pure stand [19].

It is usually assumed that competition is distant-dependent phenomenon and in order to reduce species dominance in intercrops, spatial separation of components has been used by researchers. In those studies crops were sown in alternate rows, paired (twin) rows or in separate strips [6, 9, 16, 21]. Midmore [20] showed the separation is important when components differ in plant height because it reduces shading of the shorter species and decreases access of dominant species to soil resources.

Little research exists on the effect of changing spatial arrangement of components on the performance of barley-pea intercrop. Chen et al. [6] grew barley-pea mixture with plants of the species mixed in rows or with alternating two rows of barley with two rows of pea or four rows of barley with four rows of pea. They observed that the greater was the separation of components the higher was biomass yield of the legume component, however biomass yield of the intercrop and its yield advantage over pure stands was higher when the species were mixed in rows. Musa et al. [21] did not find any increase in pea yield in mixture with barley when the species were grown in alternate pairs of rows compared to the treatment where they were mixed in rows. They noted however reduction in total biomass and grain yield of the mixture.

While it is expected that altering spatial arrangement of components in barley-pea mixture affects competition between them, little attention has been given to assessing how the change affects the supporting function of barley for pea. It may be assumed that like competition, also this type of interaction is distant-dependent, however almost no data exists on the issue. Musa et al. [21] showed that barley provided better support for pea when plants of the species grew in the same row compared to the treatment in which they were grown in alternate pairs of rows. The authors suggested that closeness of barley enhanced growth of pea resulting in its better competitiveness for light.

Supporting function of barley for pea in intercrop, being a direct facilitative interaction, overlaps with competition between species for resources. The intensity of these "+ –" interactions may change in different way depending on the distance of plants of pea from barley plants in mixture.

The aim of the research was to assess the effect of partial separation of the components in barley-pea intercrop on interactions between them and on biomass, and grain production. It was assumed that the separation would reduce competition between species without decreasing the ability of barley to prevent pea from lodging and in consequence without reducing pea yield.

MATERIALS AND METHODS

A field experiment presented here is the third one conducted in 2005, 2006 and 2007 with barley-pea mixtures at Swojec Agricultural Experimental Station belonging to Wrocław University of Environmental and Life Sciences, located in Wrocław, Poland. The results of the other two experiments together with detailed weather data were presented elsewhere [23].

While total rainfall sums for March–August period differed little in experimental years, ranging from 340 mm (2006) to 352 mm (2007), distribution of rainfall during plant growth varied considerably. In May 2005 precipitation was several times greater than in May 2006 and more than two times greater than in 2007 and from the long-term average for that month (121 mm vs. 16 mm, 50 mm and 53 mm, respectively). In July 2006 there was only 12 mm of rain compared to 109 mm in 2005 and 121 mm in 2007. Also mean air temperature in July 2006 exceeded that of 2005 and 2007 by 3.6 and 4.2ºC.

The experiment was carry out on alluvial loamy sand soil. It contained 0.5 g kg^1 of total N in the 0–20 cm layer and pH of the soil was 5.5–5.6. Preceding crop before the experiment was spring oats. After the harvest of oats shallow post-harvest soil tillage was done and before winter the field was plowed to a depth of 25–27 cm. In spring the field was harrowed with spike-tooth harrow before the sowing of intercrop. Phosphorus and potassium fertilizers were applied in fall in 2004 and 2005, and in spring in 2007. Triple superphosphate and potassium chloride were used at a rate of 17 kg P ha^{-1} and 50 kg K ha^{-1} in 2004, and 22 kg P ha^{-1} and 66 kg K ha^{-1} in 2005 and 2007. Directly after sowing of the intercrop, N was applied at a rate of 40 kg ha^{-1} as 46%-N urea. Each year weeds were controlled on all plots with Basagran 600 SL (bentazon) at a rate of 2 L ha^1. Due to the incidence of aphids on crops in 2005, the experimental area was sprayed with Fastac 100 EC (alpha-cypermethrin) at a rate of 0.15 L ha^{-1}.

In the experiment medium-tall leafy pea (*Pisum sativum* L.) cultivar Wiato of dry seed type and tall leafy pea cultivar Fidelia of green fodder/dry seed type were grown in two-species mixtures with spring barley (*Hordeum vulgare* L.) (cultivar Refren). The experiment was conducted according to randomized complete block design with four replicates. It comprised eleven treatments: pure stand of barley, pure stands of Wiato and Fidelia pea, four intercrops of barley with Wiato and four intercrops of barley with Fidelia. Both cultivars of pea in pure stands and in mixtures with barley were sown with 10.8 cm row spacing. Barley in pure stand was sown in rows spaced 10.8 cm apart while in mixtures with each pea cultivar it was sown in row spacing of 10.8 cm and 21.6 cm, and with alternate row spacing of 10.8/32.4 and 10.8/43.2 cm. Other than 10.8 cm row spacing of barley was achieved by closing appropriate seeding units in the seeding box of the seeder. The mixture with 10.8 cm row spacing of barley represented the most uniform spatial arrangement of components while seeding barley in alternate row spacing of 10.8./43.2 cm represented the least one. The latter seeding method gave the greatest space for those plants of pea that grew between the adjacent rows of barley spaced 43.2 cm apart. These two very different seeding methods are shown in Figure 1.

Fig. 1. View of the two most different arrangements of the components in barley-pea intercrop (with Wiato cultivar of pea): a – barley row spacing of 10.8 cm, b – barley row spacing of 10.8/43.2 cm

Species in mixtures were seeded separately in two parallel passes of the seeder on each plot with pea seeded first. In pure stands recommended seeding densities were used for both crops: 330 viable seeds of barley and 90 seeds of pea per square meter. Proportional substitutive design [12] was used in composing intercrops, with 99 seeds of barley (30% of pure stand) and 63 seeds of pea (70% of pure stand). The constant seeding density of barley in mixtures gave different distance between seeds in a row, depending on row spacing of the cereal.

The plant samples of both species were taken twice from each plot: when pea was at flowering stage and at full maturity of crops. Four 1 m long consecutive rows of plants of pea were dug out from the soil of each plot, except for treatment in which barley was sown in alternate rows of 10.8/43.2 cm. In that treatment five consecutive rows of pea were sampled in order to fully represent different distance of rows with the legume from the rows with barley. For treatment with 10.8 cm row spacing of barley four 1 m long consecutive rows of barley were dig out from the soil while for other seeding methods two rows of barley were sampled. Samples collected at flowering stage of pea were dried in a glasshouse then weighted. Subsamples were taken and dried at 65°C for 48 hours to determine dry matter content in plant material. Samples collected at full maturity were used to determine contribution of each species to grain yield. The data were used to calculate individual grain yields of components in whole-plot grain yields of mixtures harvested by combine harvester.

In the intercrops the lodging of plants was assessed visually for each plot according to Stapper and Fischer [25] method:

$$\text{lodging score (points)} = (p \times \alpha) / 90,$$

where p is the percentage of area of a plot that lodged, α is the angle of deviation of plant canopy from the vertical. This method gives scores within the range of 0–100 points, where zero means no plant lodging while 100 points means complete plant lodging. In intercrops, the lodging was assessed as the mean lodging of plants of both intercropped components. The assessments were done twice each year, during formation of pods on pea plants and at full maturity of mixtures.

For aboveground plant dry matter yields of mixtures collected at flowering stage of pea and for grain yields the land equivalent ratio (LER) [18] was calculated to determine the yield advantage of barley-pea intercrop over pure stands:

$$LER = RY_{barley} + RY_{pea}$$

$$RY_{barley} = Y_{barley\text{-}mix} / Y_{barley\text{-}pure}$$

$$RY_{pea} = Y_{pea\text{-}mix} / Y_{pea\text{-}pure}$$

where:
RY_{barley} is the relative yield of barley,
RY_{pea} – the relative yield of pea,
$Y_{barley\text{-}mix}$ – the yield of barley intercropped with pea,
$Y_{barley\text{-}pure}$ – the yield of barley sole crop,
$Y_{pea\text{-}mix}$ – the yield of pea intercropped with barley,
$Y_{pea\text{-}pure}$ – the yield of pea sole crop.

LER shows the combined area of land needed in pure stands to produce the same quantity of biomass or grain of each species as unit of land of the intercrop. LER > 1.0 means gain from intercropping.

Because the aim of the research was to compare the performance of barley-Wiato and barley-Fidelia intercrops, and the interactions of the components at different row arrangement of the intercropped cereal, the experiment was considered as two-factorial experiment with row spacing of barley in the intercrop as one factor and pea cultivar as the second factor. Thus the analysis of variance was performed for two-factor randomized complete block design according to Gomez and Gomez [8], for individual years, and the means were compared with LSD test at $P = 0.05$. Scores from lodging assessment were square root from (x + 0.5) transformed before analysis to homogenize the variance. Data from pure stands of the species was submitted to separate analysis of variance for one-factor randomized complete block design and these results are presented in Table 1.

Table 1. Performance of species in pure stands

Species/cultivar	Aboveground plant dry matter yield			Grain yield		
	2005	2006	2007	2005	2006	2007
	[g m^{-2}]			[t ha^{-1}]		
Barley	899a	374b	513a	4.43a	2.53a	3.15a
Pea cultivar Wiato	651b	704a	496a	1.88b	0.76b	1.04b
Pea cultivar Fidelia	578b	677a	409a	1.32c	0.92b	1.37b

Within columns, means followed by the same letter do not differ significantly according to LSD (0.05) test.

RESULTS

At flowering stage of pea barley grown alone produced significantly greater aboveground plant dry matter yield than both pea cultivars in 2005, while reverse was true in 2006 (Tab. 1). No significant difference was noted between dry matter yields of pure stands in 2007. Grain yield of barley grown alone was on the average 2.7–3.0 times higher than grain yield of pure stand pea. In 2005, Wiato yielded 42.4% more grain than Fidelia while no significant difference in grain yield between the cultivars was observed in 2006 and 2007.

At flowering stage of pea in 2005, barley-pea mixture with the cereal sown in alternate rows spaced 10.8/43.2 cm apart produced significantly higher aboveground plant dry matter yield than mixture in which barley was sown in regular row spacing of 21.6 cm (Tab. 2). Interaction between row arrangement of barley and pea cultivar in 2006 shows that mixture of tall cultivar Fidelia and barley sown in equidistant row spacing of 10.8 cm was significantly more productive than other mixtures with the cultivar. Among barley-Wiato intercrops that one with barley sown in rows spaced 21.6 cm apart produced significantly higher aboveground plant dry matter yield than both mixtures with alternate row spacing of the cereal. Irrespective of pea cultivars in

2006 and 2007 the most productive intercrop was that with the cereal sown in 10.8 cm rows. When averaged over row spacing of intercropped cereal, no difference was noted between barley-Wiato and barley-Fidelia mixture in 2005 and 2007 in aboveground plant dry matter production, while in 2006 barley-Wiato mixture yielded significantly more dry matter than barley-Fidelia intercrop.

Table 2. Aboveground plant dry matter yield of barley-pea mixtures at flowering stage of pea

Treatment		2005	2006			2007
			mixture with pea cultivar		mean	
			Wiato	Fidelia		
		[g m^{-2}]				
Barley row spacing in mixture	10.8 cm	766ab	572ab	701a	637a	695a
	21.6 cm	662b	692a	429b	561ab	538b
	10.8/32.4 cm	735ab	541b	431b	486b	539b
	10.8/43.2 cm	867a	517b	469b	493b	556b
Mixture with pea cultivar	Wiato	775a	–		581a	592a
	Fidelia	740a			507b	572a

Within columns, treatment means followed by the same letter do not differ significantly according to LSD (0.05) test.

Results show that in most cases barley was the dominant species in mixtures ($RY_{barley} > 0.3$ and $RY_{pea} < 0.7$) at flowering stage of pea in all the experimental years (Fig. 2, Tab. 3). However significant row spacing of barley ´ pea cultivar interactions in 2005 and 2006 demonstrate that the response of pea cultivars to competition from the cereal sown in varying row arrangement in mixtures differed (Fig. 2). Relative aboveground plant dry matter yield of Fidelia intercropped with barley sown in alternate rows of 10.8/43.2 cm was significantly higher than those of the cultivar in other mixtures in 2005. In 2006, the response of the cultivar to most contrasting row arrangements of barley in mixture (10.8 vs 10.8/43.2 cm) was similar and RY_{pea} in those intercrops significantly exceeded RY_{pea} of the cultivar in mixture with barley sown in rows spaced 21.6 cm apart.

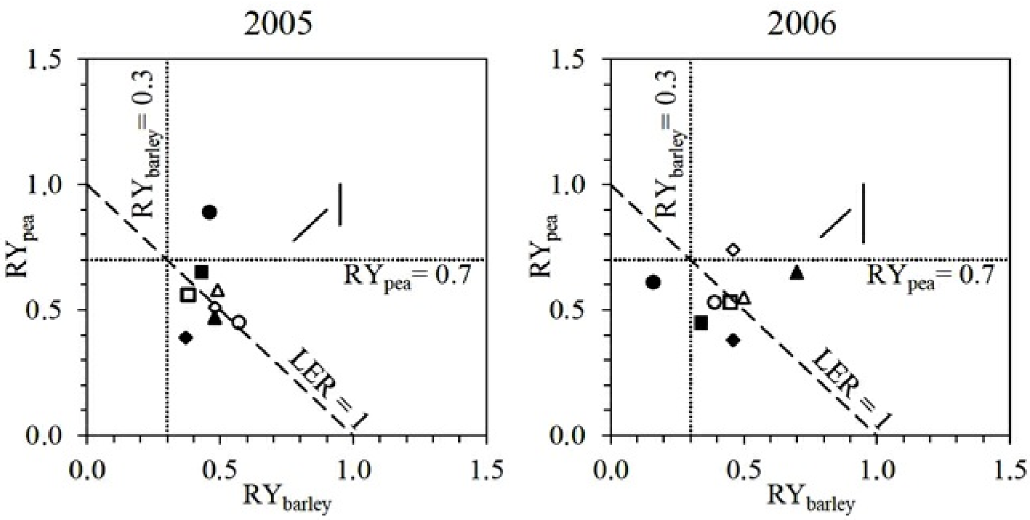

Fig. 2. Interaction between row spacing of barley and pea cultivar for relative yield of pea (RY_{pea}) and the land equivalent ratio (LER) calculated on the basis of aboveground plant dry matter yields at flowering stage of pea in 2005 and 2006. Symbols represent row spacing of barley in mixture: 10.8 cm (triangles), 21.6 cm (diamonds), 10.8/32.4 cm (squares), 10.8/43.2 cm (circles). Open symbols barley-Wiato mixture, closed symbols barley-Fidelia mixture. Solid vertical and diagonal bars represent the LSD(0.05) for the RY_{pea} and LER comparison respectively. No significant difference was detected for relative yield of barley (RY_{barley}) in 2005 and 2006

Table 3. Relative yield of species (RY_{barley}, and RY_{pea}) and the land equivalent ratio (LER) calculated based on aboveground plant dry matter yields at flowering stage of pea

Barley row spacing in mixture	2005			2006			2007		
	RY_{barley}	RY_{pea}	LER	RY_{barley}	RY_{pea}	LER	RY_{barley}	RY_{pea}	LER
10.8 cm	0.49a	0.53bc	1.02ab	0.60a	0.60a	1.20a	0.97a	0.44a	1.41a
21.6 cm	0.43a	0.45c	0.88b	0.46ab	0.56a	1.02b	0.65b	0.45a	1.10b
10.8/32.4 cm	0.41a	0.60ab	1.01ab	0.40bc	0.49a	0.89bc	0.57b	0.56a	1.13b
10.8/43.2 cm	0.51a	0.67a	1.18a	0.27c	0.57a	0.84c	0.66b	0.48a	1.14b

Within columns, means followed by the same letter do not differ significantly according to LSD (0.05) test.

Row spacing ´ pea cultivar interaction was significant for land equivalent ratio (LER) calculated based on aboveground plant dry matter yields at flowering stage of pea in 2005 and 2006 (Fig. 2). Barley-Fidelia intercrop with alternate 10.8/43.2 cm row spacing of the cereal showed significantly higher yield advantage over sole crops than other mixtures with the pea cultivar in 2005 while in 2006 the highest LER was noted in mixture with 10.8 cm row spacing of the cereal. Among barley-Wiato intercrops that one with barley sown in rows spaced 21.6 cm apart had significantly higher LER than both mixtures with alternate row spacing of barley in 2006. No difference in LER was noted between barley-Wiato intercrops in 2005.

When averaged over pea cultivars, RY_{barley} calculated on the basis of aboveground plant dry matter yield at flowering stage of pea was significantly higher in mixture with the cereal sown in rows spaced 10.8 cm apart than in both mixtures with alternate row spacing in 2006 while in 2007 it was significantly higher than RY_{barley} in all other mixtures (Tab. 3). No difference in RY_{barley} was found in 2005. Relative yield of pea was unaffected by barley row configuration in 2007. High relative yields of barley sown in rows spaced 10.8 cm apart in mixture in 2006 and 2007 greatly contributed to the dry matter yield advantage (LER) of the mixtures, and the LERs were significantly higher than LERs of mixtures with other row configuration of the cereal component (Tab. 3). Irrespective of sowing method of barley in mixture, RY_{barley}, RY_{pea} and LER calculated on the basis of dry matter yield at pea flowering were unaffected by intercropped pea cultivar in 2005, 2006 and 2007 (data not shown).

Mixtures lodged little in 2005 and no significant difference was noted in that year (data not shown). The intercrops most heavily lodged in 2006 (Tab. 4). During formation of pods on pea plants in 2006 mixture of barley with tall pea cultivar Fidelia lodged significantly more than mixture with medium-tall cultivar Wiato and there was no effect of barley row arrangement on plant lodging. Significant barley row spacing ´ pea cultivar interaction shows that at full maturity of intercrop in 2006, barley-Wiato mixture with the cereal sown in rows spaced 10.8 cm apart lodged significantly less than other mixtures with the cultivar. Among barley-Fidelia mixtures, the same was true for mixture in which barley was sown in rows spaced 21.6 cm apart. Irrespective of pea cultivar, at full maturity in 2006 and during formation of pods on pea plants in 2007 the mixture with barley sown in alternate rows of 10.8/43.2 cm lodged significantly more than both mixtures with uniformly spaced rows of the cereal. No difference in lodging was noted at full maturity in 2007 (data not shown).

Table 4. Lodging score of barley-pea mixtures

Treatment		2006 pod formation stage	2006 full maturity stage – mixture with pea cultivar: Wiato	2006 full maturity stage – mixture with pea cultivar: Fidelia	2006 full maturity stage – mean	2007 pod formation stage
		[points]				
Barley row spacing in mixture	10.8 cm	30(5.54)a	46(6.83)b	67(8.19)a	57(7.51)b	3(1.85)b
	21.6 cm	37(6.11)a	74(8.60)a	46(6.80)b	60(7.70)b	5(2.37)b
	10.8/32.4 cm	49(7.01)a	68(8.25)a	71(8.48)a	70(8.37)ab	8(2.90)ab
	10.8/43.2 cm	49(7.06)a	80(8.95)a	73(8.60)a	77(8.78)a	15(3.94)a
Mixture with pea cultivar	Wiato	26(5.14)b	–		67(8.16)a	9(2.96)a
	Fidelia	60(7.72)a			64(8.02)a	7(2.57)a

Original data were √(x+0.5) transformed before analysis of variance and the means are presented in parentheses. The values before parentheses are back-transformed means rounded to unity. A score of 0(0.71) indicates no plant lodging, and a score of 100(10.02) indicates completely lodged plants. Within columns, treatment means followed by the same letter do not differ significantly according to LSD (0.05) test.

There was significant interaction between barley row arrangement and pea cultivar for grain yield in 2005 (Tab. 5). Barley-Wiato mixture with the cereal sown in row spacing of 21.6 cm yielded significantly less grain than any other mixture with the pea cultivar. Among barley-Fidelia mixtures the same was true for mixture in which barley was sown in alternate row spacing of 10.8/32.4 cm. When averaged over pea cultivars, mixtures with the most contrasting row arrangement of the cereal component (row spacing of 10.8 and 10.8/43.2 cm) yielded significantly higher than two other intercrops in 2005. In 2006 mixture with barley row spacing of 10.8/32.4 cm yielded significantly less grain compared to other mixtures. No significant difference was noted in grain yield in 2007. When averaged over row spacing, barley-Wiato mixture gave significantly higher grain yields than barley-Fidelia intercrop in 2005 and 2006 while no difference was observed in 2007.

Table 5. Grain yield of barley-pea mixtures

Treatment		2005 mixture with pea cultivar: Wiato	2005 mixture with pea cultivar: Fidelia	2005 mean	2006	2007
		[t ha^{-1}]				
Barley row spacing in mixture	10.8 cm	3.66a	3.47a	3.57a	2.29a	2.55a
	21.6 cm	3.41b	3.32b	3.37b	2.25a	2.19a
	10.8/32.4 cm	3.62a	3.09c	3.36b	1.72b	2.16a
	10.8/43.2 cm	3.68a	3.37ab	3.53a	2.21a	2.17a
	Wiato			3.59a	2.34a	2.30a

Mixture with pea cultivar	Fidelia	–	3.31b	1.89b	2.23a
Within columns, treatment means followed by the same letter do not differ significantly according to LSD (0.05) test					

The interaction between experimental factors demonstrates that in 2005 due to the high separation of components in mixture with barley sown in alternate row spacing of 10.8/43.2 cm, the competitive effect of the cereal on Fidelia pea was lower than facilitative (supporting) effect (Fig. 3). This resulted in greater grain yield of the cultivar in the mixture than in pure stand (RY_{pea} > 1.0) and significantly greater RY_{pea} and LER than those of the other mixtures with the cultivar.

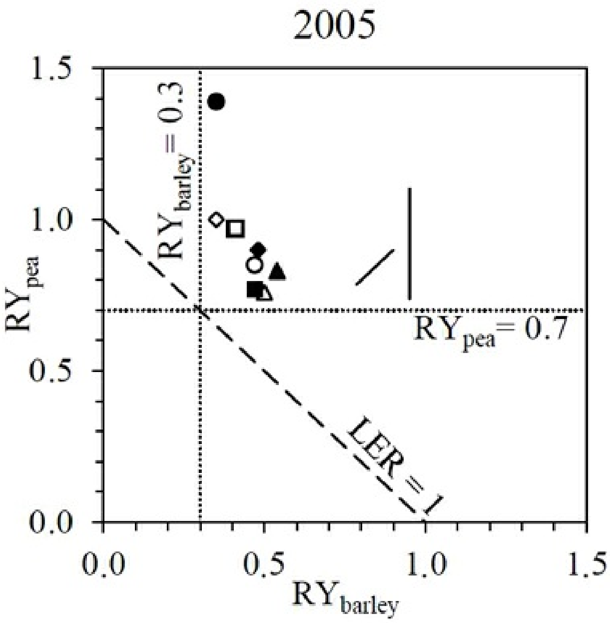

Fig. 3. Interaction between row spacing of barley and pea cultivar for relative yield of pea (RY_{pea}) and the land equivalent ratio (LER) calculated on the basis of grain yields in 2005. Symbols represent row spacing of barley in mixture: 10.8 cm (triangles), 21.6 cm (diamonds), 10.8/32.4 cm (squares), 10.8/43.2 cm (circles). Open symbols barley-Wiato mixture, closed symbols barley-Fidelia mixture. Solid vertical and diagonal bars represent the LSD(0.05) for the RY_{pea} and LER comparison respectively. No significant difference was detected for relative yield of barley (RY_{barley}) in 2005

When averaged over pea cultivars, the response of the legume to row configuration of barley in mixture did not differ significantly in the experiment (Tab. 6). Relative grain yield of barley (RY_{barley}) sown in rows spaced 10.8 and 21.6 cm apart in 2006 was significantly higher than that in mixture with alternate 10.8/32.4 cm rows of the cereal. In 2007, in mixture with narrow row spacing of barley, it was significantly higher than those of the other mixtures. Irrespective of row spacing, RY_{barley} did not differ during all the years of the experiment showing that the response of barley to competition from Wiato or Fidelia pea in mixture was similar. In terms of grain yield, Fidelia pea was weaker competitor with barley than Wiato in 2006 and 2007. The net facilitative influence of barley on Wiato grain production (RY_{pea} > 1.0) was noted in 2006.

Table 6. Relative yield of species (RY_{barley} and RY_{pea}) and the land equivalent ratio (LER) calculated based on grain yields

Treatment		2005			2006			2007		
		RY_{barley}	RY_{pea}	LER	RY_{barley}	RY_{pea}	LER	RY_{barley}	RY_{pea}	LER
Barley row spacing in mixture	10.8 cm	0.52a	0.80a	1.32b	0.49a	1.30a	1.79a	0.59a	0.61a	1.20a
	21.6 cm	0.41a	0.95a	1.36b	0.49a	1.23a	1.72a	0.43b	0.74a	1.17a
	10.8/32.4 cm	0.44a	0.87a	1.31b	0.31b	1.15a	1.46a	0.42b	0.71a	1.13a
	10.8/43.2 cm	0.41a	1.12a	1.53a	0.39ab	1.49a	1.88a	0.48b	0.56a	1.04a
Mixture with pea cultivar	Wiato	0.43a	0.89a	1.32a	0.43a	1.65a	2.08a	0.45a	0.84a	1.29a
	Fidelia	0.46a	0.97a	1.43a	0.41a	0.94b	1.35b	0.51a	0.46b	0.97b
Within columns, treatment means followed by the same letter do not differ significantly according to LSD (0.05) test										

The land equivalent ratio (LER) calculated on the basis of grain yield was significantly higher for mixture with 10.8/43.2 cm row spacing of barley than for other intercrops in 2005. It was however unaffected by row arrangement of the cereal component in 2006 and 2007. Irrespective of barley row configuration, LER for barley-Wiato mixture was higher than that of barley-Fidelia intercrop in 2006 and 2007. It should be also noted that barley-Wiato mixture showed yield advantage over pure stands

(LER > 1) in 2007 while barley-Fidelia intercrop did not.

DISCUSSION

The results of the experiment show that in 2006 and 2007 more uniform patterns of intercropping barley and pea (barley row spacing of 10.8 and 21.6 cm) allowed for better utilization of available space by component species and higher production of aboveground plant dry matter by the intercrops at pea flowering stage than by intercrops with barley sown in alternate rows. This may have been due to combined effect of two factors: first, more regularly distributed plants of barley per unit area and second, more regularly intermixed plants of component species. O'Donovan et al. [22] reported higher silage yield of barley harvested two weeks after heading using 23 cm row spacing than using rows spaced 30 cm apart. They attributed the result to the weaker competition between barley plants (intraspecific competition) in narrow rows than in wide rows. Weiner et al. [30] emphasize that high intraspecific competition between crowding plants in a row of a crop reduces the ability of the crop to compete with weeds (interspecific competition), while row spacing is less important when weed pressure is low. Results of the present study only partially support the concept of Weiner et al. [30]. In 2006 and 2007 at flowering stage of pea, RY_{barley} was significantly higher in the intercrop with regular 10.8 cm row spacing of the cereal than in other mixtures and this good barley performance resulted in the highest LER. It means that the decrease in intraspecific competition in barley due to more regular spatial arrangement of the cereal plants did not translate into its increased competitiveness against pea because RY_{pea} was not reduced. Our results from 2006 and 2007 agree with those of Chen et al. [6] who noted that at flowering/pod-setting stage of pea, the most productive barley-pea intercrop comprised regularly spaced rows with plants of both species mixed in a row, while the least productive was the configuration with alternate four rows of barley with four rows of pea. This supports general rationale behind mixtures, when the high degree of components intermixing translates into their greater productivity due to resource complementarity. At pea flowering, resource complementarity was likely the main cause of the yield advantage of mixtures over pure stands in this study. This is because the lodging of plants did not occur until the stage, thus the biomass yield was not affected by the phenomenon.

Reason for different plant dry matter yields of mixtures at flowering stage of pea in 2005 compared to those in 2006 and 2007 is unclear. We hypothesize that high precipitation in May 2005 facilitated vegetative growth of green forage/dry seed type pea cultivar Fidelia in wide strips of intercrop with alternate 10.8/43.2 cm rows of barley. This superior performance of Fidelia contributed to high plant dry matter yield and LER of the mixture in 2005. The importance of water for effective growth of pea was demonstrated in a modelling study by Launay et al. [15] in which competitive ability of pea when intercropped with barley was strongly enhanced by adequate soil moisture during nodulation. Our results are in agreement with study of Cousens et al. [7] on competition between grass species. They observed that better water conditions later during growing season favoured initially worse competitor leading to change in competitive hierarchy while in dry seasons the hierarchy remain unchanged.

The competitive dominance of barley in mixtures at pea flowering ($RY_{barley} > 0.3$ and $RY_{pea} < 0.7$) observed in this study is in agreement with findings of other authors [6, 10]. But the expected effect of species separation in the intercrop on the reduction of competitive pressure of cereal on the legume was rather weak. Increasing intraspecific competition in barley by using other row arrangement than regular 10.8 cm row spacing, together with greater space available for pea in those methods of sowing did not benefit markedly growth of the legume. This weak response of pea to separation from barley in 2006 and 2007 may be partially explained by research of Hauggard-Nielsen et al. [6] and Mao et al. [17] who demonstrated substantial lateral root growth of cereals in intercrops increasing their competitive ability. Those studies suggest that in the present experiment during the vegetative growth of the intercrop, barley was able to compete effectively with pea underground preempting nutrients and water from soil under the rows with legume even in the mixture with rows spaced 10.8/43.2 cm apart.

Intercrops with the most contrasting spatial arrangements of rows of barley (10.8 vs. 10.8/43.2 cm row spacing) produced similar grain yield during 3-year period of the study implying that the separation of pea plants from plants of barley in mixture does not decrease the ability of the cereal to provide sufficient support for the legume preventing it from lodging and yield decrease. Plant lodging has been rarely assessed in cereal-pea mixtures. Kontturi et al. [14] pointed out that in oat-pea intercrop, preventive function of the cereal was important only for lodging-prone cultivars. They used however semi-leafless cultivars of pea that are less susceptible to lodging than leafy ones [2, 27]. Wenda-Piesik and Rudnicki [31] suggest that the response of pea to cereal support differs even between cultivars of the same plant morphology. The authors [24] found only slight increase in lodging of barley-pea mixture comprising tall leafy cultivar compared to mixture with medium tall leafy cultivar, which is in agreement with the results of this study.

In the present experiment the worst performing barley-pea intercrop was that with the cereal sown in alternate rows spaced 10.8/32.4 cm apart. Perhaps the degree of species separation weakened complementary resource use by component species, but did not reduce enough competitive effect of barley on pea.

The occurrence of the aboveground facilitation of pea by barley (mechanical support) during last stages of growth had little effect on the treatment differences in the performance of the legume compared to the differences observed among the intercrops at pea flowering. Results show that in 2005 the 43.2 cm wide strip between rows of barley weakened competitive effect of the cereal on pea, allowing Fidelia to yield more grain in 2005 when it was enough water for plants during intensive vegetative growth.

Our results show that the type of pea cultivar was more important than plant height of the legume when interspecific interactions are concerned. In two out of three years, intercrops with dry seed type medium tall cultivar Wiato yielded more grain than those with green forage/dry seed type tall cultivar Fidelia and were more efficient compared to pure stands. Wiato was also more tolerant to competition from barley which is in agreement with earlier study [23].

It is difficult to assess to what extent pea due to tendency to lodging interfered with growth of barley in the intercrop. The differences between values of dry matter RY_{barley} at pea flowering and grain RY_{barley} were small and the relative grain yields of barley were still above 0.3 indicating that the cereal better performed in mixture with pea than in pure stand. Different findings were reported by Karpenstein-Machan and Stuelpnagel [13] who observed that lodging pea interfered with the growth of rye resulting in lower productivity of the mixture. In the present experiment, values noted for grain RY_{barley} confirm the observation from pea flowering stage that the cereal to be efficient needs regular spatial arrangement of plants and high degree of physical intermingling with the legume. It seems that maturing and tending to collapse plants of pea exerted the physical pressure on barley (interference), which was similar in intercrops differing in row arrangement of the cereal. According to Brinkman et al. [4] the high density of barley plants per unit of row makes them more prone to lodging due to thinner base of stem. It was not observed in the present study even in the intercrop with alternate rows of barley spaced 10.8/43.2 cm apart, in which 2.5 times more seeds of the cereal were sown per unit of row than in the intercrop with uniform 10.8 cm row spacing. The result may be explained by the reduced seeding density of barley in mixture (30% of pure stand) and low productivity of barley and pea on loamy sand soil, both resulting in light ears and pods.

CONCLUSIONS

1. In unproductive environment of light soil the partial separation of components in barley-pea intercrop may reduce biomass and grain yield of the intercrop.
2. Barley benefits from high degree of component intermixing. When species separation is large, the reduced competition from barley allows pea to yield higher provided that there is sufficient amount of water for vegetative growth of the legume.
3. The onset of additional bidirectional interactions between barley and pea after pea flowering stage (facilitation/direct interference) made almost no change in the response of the species to treatments used in the study when compared to their response observed at pea flowering stage.
4. Medium-tall pea cultivar Wiato was more reliable component in mixture with barley than tall cultivar Fidelia. It was more tolerant to competition from the cereal and contributed more than Fidelia to mixture yield advantage over sole cropped components.

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Piotr Sobkowicz
Department of Agroecosystems and Green Areas Management, Wrocław University of Environmental and Life Sciences, Poland
pl. Grunwaldzki 24a
50-363 Wrocław
Poland
email: piotr.sobkowicz@up.wroc.pl

Ewa Tendziagolska
Department of Agroecosystems and Green Areas Management, Wrocław University of Environmental and Life Sciences, Poland
pl. Grunwaldzki 24a
50-363 Wrocław
Poland
