Acta Sci. Pol. Agricultura 17(2) 2018, 81–89

www.agricultura.acta.utp.edu.pl pISSN 1644-0625 eISSN 2300-8504 DOI: 10.37660/aspagr.2018.17.2.3

ORIGINAL PAPER

Received: 15.05.2018
Received in revised form: 22.07.2018
Accepted: 23.07.2018

PROXIMITY EFFECT OF SPRING CEREALS AND LEGUMES IN STRIP INTERCROPPING. PART II. RESPONSE OF PEA TO THE PROXIMITY OF WHEAT, TRITICALE, BARLEY, AND YELLOW LUPINE

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ABSTRACT

Background. Strip intercropping brings together the advantages of pure sowing and intercropping, but its production value depends on the reciprocal effect of the various species at the contact point of adjacent rows. The aim of the experiment was to establish the response of pea to the neighbouring occurrence of spring wheat, spring triticale, spring barley, and yellow lupine and the estimation of the production effect of strip intercropping of pea in the proximity of those species.
Material and methods. In the experiment, the results of field experiments on mixed sowings carried out in the years 2008–2010 at the experimental station in Mochełek near Bydgoszcz (53^{o}13’ N; 17^{o}51’ E) were used. Experimental factor was the position of plant row on the plot: four rows into the plot away from the outermost row with respective neighbouring species. First row of pea (contact row) was situated 12.5 cm away from the first row of respective neighbouring species. Experimental unit was subsequent plant rows, each 4 meters long.
Results. Proximity of wheat, triticale, barley, and lupine was unfavourable to pea. It occurred the most strongly in the first plant row and decreased in the subsequent, farther rows. The most unfavourable proximity for pea in strip intercropping proved to be barley. In the row adjacent to this species, pea grain yield was lower than in the fourth row by 59.4%. In the subsequent rows, also a tendency for seed yield decrease was noted, namely in the second row by 26.9% and in the third row by 9.2%. Confirmed unfavourable proximity effect for wheat and triticale included first and second pea rows. The least unfavourable vicinity for pea was that of yellow lupine.
Conclusion. When introducing pea to strip intercropping with cereals, its yield may be lower by 3.5% (one-sided proximity of triticale) to 7.9% (proximity of barley), which decreases the proportion of pea seeds in the total yield of strip intercropping.

Key words: interspecific effect, morphological characteristics, proximity effect, strip intercropping, vicinity effect, yield

INTRODUCTION

One of the methods of increasing biodiversity is plant cultivation in mixtures (Knudsen *et al.*, 2004; Kotwica, 2008). There are several basic methods of plant cultivation in mixtures: relay intercropping, mixed intercropping, strip intercropping, and row intercropping; different species may be cultivated using the above methods. In spite of the advantages, mixture growing has not found wider application in the world. One of the reasons for this is instability of the composition of joint mixture yield, which results

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from different intensification of the effect of interspecific competition in changeable weather conditions in the particular production seasons (Sobkowicz, 2005; Lamb *et al.*, 2007; Gałęzewski, 2010a and b). Since yield from mixed intercropping is mostly used as fodder, the above fact makes it difficult to balance nutritional doses for animals (Theunissen, 1997). Therefore, one ought to aim at limiting the unfavourable effect of interspecific competition. In mixed intercropping, choice of component sowing proportions is a possibility of regulation of competition effect intensity (Weigelt and Jolliffe, 2003; Gałęzewski *et al.*, 2012). Rudnicki (1997) also suggests the possibility to regulate the above occurrence through the choice of proper cultivars, indicating the method of estimation of yellow and blue lupine cultivars' usefulness evaluation for growth in mixtures with spring cereals. In multispecies strip intercropping, besides choosing the sowing density of the particular species, competition effects may be modified through the selection of neighbouring species. One of the best strip intercroppings recognized in literature is maize and soya cultivation or maize and soya split by a strip of cereal, for example wheat, barley, or oats (West and Griffith, 1992; Fortin *et al.*, 1994; Jurik and Van, 2004; Iragavarapu and Randall, 1996; Liu *et al.*, 2017). In the case of unfavourable effect of the neighbouring species on one another, it may be minimalized by introducing a technological path – an unsown strip, several centimetres wide, that separates species which do not tolerate one another. The method is related to the border effect, as a result of which plants that grow in rows adjacent to the path have the possibility to use the nutrient, light and water resources of the unsown area (Gałęzewski *et al.* 2013).

Literature lacks complex elaboration on the neighbouring effect in strip intercropping, which would compare many cultivated plant species with one another in the same habitat conditions. Present article is a part of wider research on the above problem. The aim of the present part of the study was to establish the response of pea to the vicinity of spring wheat, spring triticale, spring barley, and yellow lupine and to estimate pea yield in strip intercropping.

MATERIAL AND METHODS

The present work is part of studies on the proximity effect of spring cereals and legumes carried out at the Department of Plant Production and Experimenting of the University of Science and Technology in Bydgoszcz. Source material consisted of the results of multiple, one-factor field experiments, carried out in the years 2008–2010, the aim of which was finding the proximity effect of growing pea 'Ramrod' in the direct vicinity of spring wheat 'Bombona', spring triticale 'Dublet', spring barley 'Antek', and yellow lupine 'Lidar'. The experiment was carried out at the Experimental Station of the Faculty of Agriculture and Biotechnology in Mochełek ($53^o13'$ N; $17^o51'$ E) in the region of low average precipitation sum (circa 500 mm). Experimental plots were set up in a split--block design in four repetitions. One repetition consisted of two directly adjacent plots with two different plant species. Plots were 150 cm wide and consisted of 12 plant rows at the density of 12.5 cm. The experimental factor was the location of a plant row on the plot: four rows into the plot of the neighbouring species. The first row (contact row) was separated by 12.5 cm from the first row of the neighbouring species. The experimental unit was subsequent plant rows, each of which was 4 meters long. On the basis of the results of previous research (Gałęzewski *et al.*, 2017), fourth plant row was assumed as being free from the proximity effect, representing field interior. Plots were situated with their longer side on a north-south axis.

All plant species were sown on one date. Depending on the year, sowing took place between March 25th and April 5th. In order to obtain equal distance between plants in a given row, cereal grain was placed in points on sowing tapes (made from blotting paper) at the density of 45 plants per linear meter (360 plants$\cdot$m^{-2}). Sowing tapes were placed in the soil at the depth of 4 cm. Lupine and pea seeds were sown manually at the density of 10 plants per linear meter (80 plants$\cdot$m^{-2}).

The experiments in the particular years were located on light soil, good rye complex, class IVa–IVb, on the post after winter rapeseed. C_{org} content reached, depending on the study year, from 6.2 to 6.6 g$\cdot$kg^{-1} dry matter of soil, and the contents of the assimilable forms of P and K reached, respectively, 63 to 69 and 94 to 172 $mg \cdot kg^{-1}$. Soil pH (1M KCl) ranged from 5.2 to 6.6. During spring soil cultivation, 30 $kg \cdot ha^{-1}$ P, 66 $kg \cdot ha^{-1}$ K, and 34 $kg \cdot ha^{-1}$ N were applied. Top-dressing nitrogen fertilization was applied only for cereals at the dose of 34 $kg \cdot ha^{-1}$ N at the tillering stage.

Before harvest, pea plant density was evaluated for the entire length of the particular rows. Plant harvest was carried out manually, separately for each row. Response of pea plants to its location in relation to the neighbouring species was determined on the basis of the following elements: plant density, number of pods per plant, grain number per pod, mass of 1000 grains, grain yield, straw mass, and plant mass (of the above-ground plant parts). For the evaluation, all the plants from the entire length of all the studied rows were used.

In the statistical processing of data from single experiments, analysis of variance was used, model appropriate for split-block design, with the Tukey's HSD test. In multiple experiments (synthesis), calculated F was determined on the basis of recreated error extended by the interaction of factor and years. The packet of statistical programs ANALWAR-5.2-FR was used. For every characteristic, proximity effect (PE) index was calculated as a quotient of the value of a characteristic that occurred, respectively, in one of the first three rows from the neighbouring species and in the fourth row (inside the field). PE = 1 indicated the lack of proximity effect (neutrality of the tested species). PE < 1 indicated negative effect of the neighbouring species on pea. PE > 1 indicated positive effect of the neighbouring species on pea. Lack of interaction between the factor and the study years, for the majority of the characteristics of the tested species, caused the presentation in the work of average results from the study years.

Estimated yield from every running meter of 3-meter-wide strips (24 rows), depending on the type of proximity, at row spacing of 12.5 cm, resulted from the following formulas:

– yield at no proximity = $24 \cdot x_4$,
– yield at one-sided proximity = $x_1 + x_2 + x_3 + 21 \cdot x_4$,
– yield at two-sided proximity = $2 \cdot x_1 + 2 \cdot x_2 + 2 \cdot x_3 + 18 \cdot x_4$,

where: $x_{1\text{-}4}$ – yield in the subsequent row away from the neighbouring species.

The width of 3 meters, set for the estimation, resulted from the working width of standard sowing machines used in agricultural practice. Plot width of 1.5 m resulted from minimalizing the effect of soil changeability on the experiment and from the lack of necessity to manifold the results from internal field rows.

RESULTS

Proximity effect of wheat was unfavourable to pea. This was demonstrated by the PE index values, which in the first, second and third row had values below one for the majority of the observed characteristics (Table 1). Pea plant density in the row directly neighbouring with wheat was lower by 16.7% than in the fourth row. The above unfavourable response of pea still occurred in the second and third row, but to a lesser extent than in the first row. Among the studied characteristics, only in the case of pod number per plant no negative effect of wheat vicinity was confirmed. For the remaining characteristics, there was a regularity of them assuming the lowest values in plants grown in the first row, and their increase in the subsequent rows away from wheat (Table 1). Both the grain number per pod and mass of 1000 grains of plants grown in the row adjacent to wheat were lower by 15.9% and 11.3%, respectively, than in the fourth row. Also in the second and third row, pea demonstrated statistically unconfirmed tendency for lower grain number per pod and the grains had lower mass than in the fourth row. Grain yield, straw mass, and plant mass in the nearest row to wheat were significantly lower than in the third and fourth row. Proximity effect demonstrated itself negatively the most strongly in the case of grain yield (PE = 0.54). Pea plants growing the closest to wheat developed grain yield lower by 46.2%, and in the second row by 35.9% than in the fourth row.

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In the conducted experiment, the most unfavourable for pea demonstrated to be the vicinity of barley. This was proven by usually lower than in the case of wheat and triticale vicinity values of the PE index, especially for grain yield, straw mass and plant mass (Tables 1, 2 and 3). In spite of the tendency to increase the values of all the characteristics of pea further from barley, significant differences were confirmed usually between the first and fourth row (Table 3). Barley caused the highest reduction in grain yield among all the studied neighbouring species. From pea plants grown in the first row, grain yield lower by 59.4% was obtained than in the fourth row. In the second row, the difference was also high and reached 26.9%.

Table 1. Response of pea plants to the vicinity of spring wheat

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Plant density	(plant·running m^{-1})	11.0 c*	12.0 b	12.2 b	13.2 a
	PE**	0.83	0.91	0.93	1.00
Grain number per pod	grain number	2.44 b	2.61 ab	2.80 ab	2.90 a
	PE	0.84	0.90	0.97	1.00
Pod number per plant	pod number	3.50 a	3.46 a	3.70 a	3.66 a
	PE	0.96	0.95	1.01	1.00
Mass of 1000 grains	g	189 b	197 ab	207 ab	213 a
	PE	0.89	0.92	0.97	1.00
Seed yield	(g·running m^{-1})	14.7 c	17.5 bc	24.8 ab	27.3 a
	PE	0.54	0.64	0.91	1.00
Straw mass	(g·running m^{-1})	19.6 c	22.7 bc	29.5 ab	32.3 a
	PE	0.61	0.70	0.91	1.00
Plant mass	(g·running m^{-1})	34.2 c	40.2 bc	54.2 ab	59.6 a
	PE	0.57	0.67	0.91	1.00

* the same letter in a given row indicates the lack of significant diversification of the results
** proximity effect index, see Material and Methods

Table 2. Response of pea plants to the vicinity of spring triticale

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Plant density	(plant·running m^{-1})	10.4 c*	12 b	13.6 a	13.1 ab
	PE**	0.79	0.92	1.04	1.00
Grain number per pod	grain number	2.49 a	2.68 a	2.91 a	3.14 a
	PE	0.79	0.85	0.93	1.00
Pod number per plant	pod number	3.37 a	3.61 a	3.63 a	3.86 a
	PE	0.87	0.94	0.94	1.00
Mass of 1000 grains	g	189 c	199 bc	209 ab	214 a
	PE	0.89	0.93	0.98	1.00
Seed yield	(g·running m^{-1})	15.5 c	18 bc	25.8 ab	27.5 a
	PE	0.56	0.66	0.94	1.00
Straw mass	(g·running m^{-1})	20.3 b	23.9 ab	30.5 a	32.7 a
	PE	0.62	0.73	0.93	1.00
Plant mass	(g·running m^{-1})	35.7 c	41.9 bc	56.3 ab	60.2 a
	PE	0.59	0.70	0.93	1.00

* the same letter in a given row indicates the lack of significant diversification of the results
** proximity effect index, see Material and Methods

Table 3. Response of pea plants to the vicinity of spring barley

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Plant density	(plant·running m^{-1})	8.8 b*	13.5 a	13.4 a	12.8 a
	PE**	0.69	1.05	1.05	1.00
Grain number per pod	grain number	2.33 b	2.72 ab	2.84 ab	2.93 a
	PE	0.80	0.93	0.97	1.00
Pod number per plant	pod number	3.49 ab	3.44 b	3.98 ab	4.03 a
	PE	0.86	0.85	0.99	1.00
Mass of 1000 grains	g	194.8 b	202 b	212.9 a	213.4 a
	PE	0.91	0.95	1.00	1.00
Seed yield	(g·running m^{-1})	11.0 b	19.8 ab	24.6 a	27.1 a
	PE	0.41	0.73	0.91	1.00
Straw mass	(g·running m^{-1})	17.2 b	26.4 ab	29.7 a	32.0 a
	PE	0.54	0.82	0.93	1.00
Plant mass	(g·running m^{-1})	28.2 b	46.2 ab	54.3 a	59.1 a
	PE	0.48	0.78	0.92	1.00

* the same letter in a given row indicates the lack of significant diversification of the results
** proximity effect index, see Material and Methods

Lupine demonstrated to be the least competitive in relation to pea, which was proven by relatively high PE values. Only in the case of pod number per plant and the mass of 1000 grains, negative effect of the vicinity of lupine on pea was confirmed (Table 4). Although usually the particular values of pea characteristics in the row adjacent to lupine were lower than in the subsequent rows, the differences were relatively smaller than in the case of the vicinity of pea with cereals. Proximity effect of pea with other species may be of practical significance in the case of strip intercropping. Assuming the use of 3-m-wide sowing machine for cultivation, estimated yield of pea grown in the strip neighbouring from both sides with other species may be lower by 4.27% (vicinity of lupine) to 7.95% (vicinity of barley) (Table 5). In the case of one-sided vicinity, analogical decrease in pea yield may reach 2.13% to 3.97%. Regarding the effect on yield, the least favourable for pea is the vicinity of spring barley.

Table 4. Response of pea plants to the vicinity of yellow lupine

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Plant density	(plant·running m^{-1})	13.5 a	13.7 a	14.1 a	12.7 a
	PE**	1.06	1.08	1.11	1.00
Grain number per pod	grain number	2.59 a	2.80 a	2.98 a	2.95 a
	PE	0.88	0.95	1.01	1.00
Pod number per plant	pod number	3.61 b	3.54 b	3.72 b	4.54 a
	PE	0.79	0.78	0.82	1.00
Mass of 1000 grains	g	197 b	206 ab	212 a	213 a
	PE	0.92	0.97	0.99	1.00
Seed yield	(g·running m^{-1})	19.5 a	21.8 a	26.3 a	27.2 a
	PE	0.72	0.80	0.97	1.00
Straw mass	(g·running m^{-1})	24.7 a	26.8 a	31.7 a	31.8 a
	PE	0.78	0.84	1.00	1.00
Plant mass	(g·running m^{-1})	44.2 a	48.6 a	58.0 a	59.0 a
	PE	0.75	0.82	0.98	1.00

* the same letter in a given row indicates the lack of significant diversification of the results
** proximity effect index, see Material and Methods

Table 5. Estimated pea yield (g) for every running meter of the 3-m-wide strips depending on the type of proximity

Proximity	Characteristic	Neighbouring species			
		triticale	barley	pea	lupine
No proximity	yield	656	661	650	652
One-sided proximity	yield	631	637	624	638
	difference in yield, g	-25.1	-23.2	-25.8	-13.9
	difference in yield, %	-3.83	-3.52	-3.97	-2.13
Two-sided proximity	yield	606	614	598	624
	difference in yield, g	-50.2	-46.5	-51.6	-27.8
	difference in yield, %	-7.65	-7.04	-7.95	-4.27

DISCUSSION

In literature, there is a lack of information that would make it possible to directly relate the present results to the results obtained by other authors. Negative response of pea grown in rows adjacent to others species demonstrated in the present study indicated the presence of competitive effect. The strongest negative effect on pea was found in the case of proximity to barley. In pot experiments on competition between pea and barley, other authors (Wanic *et al*., 2007; Michalska *et al*., 2008; Wanic *et al*., 2012) demonstrated that both species compete with one another with different intensity during different growth stages, and competition intensity is higher on heavy soil than on light soil. According to the quoted studies, competition between the above species on heavy soil occurs already at emergence, intensifies until the straw-shooting stage of barley, and lessens towards the end of growth. At the early stages of growth, barley is a stronger competitor, and at latter stages pea is. One of resource forms that barley and pea grown in a mixture compete for is nitrogen. However, Bedoussac and Justes (2010) do not recommend application of higher nitrogen doses in a mixture of wheat with pea. The claim that lower nitrogen fertilization makes it possible for competing plants to use the light in a tight field in a better way. In the conditions of greater nitrogen fertilization, competitiveness of wheat in relation to pea increases (Ghaley *et al*., 2005). Increase in pea sowing density in a mixture with wheat causes an increase in its competitiveness and decreases the proportion of wheat grain in joint yield of the mixture (Lauk and Lauk, 2008). Šarūnaitė *et al.* (2013) in their studies on mixtures of pea with wheat, triticale, and oats indicated that it is cereals that decide upon the productivity of a mixture and its competitiveness against weeds. In mixture cultivation, regardless of the cultivation method, pea is the more valuable component. It was found in the research by other authors that the vicinity of cereals did not affect pea favourably. Present study confirms the above regularity, and in strip intercropping statistically confirmed negative effect may reach two rows inside pea strip. In the case of unfavourable vicinity of species, it appears justified to separate the species in strip intercropping with a path 30 cm wide, which was suggested by the research of Romani *et al*. (1993) and by the studies on the border effect (Gałęzewski *et al*. 2013).

CONCLUSIONS

1. Vicinity of wheat, triticale, barley, and lupine was unfavourable to pea. In pea row directly adjacent to those species, the PE index reached the lowest values for all characteristics and usually increased in subsequent rows.
2. The most unfavourable vicinity for pea in strip intercropping demonstrated to be the vicinity of barley, which decreased pea yield in the first row

by 59.4%, and in the second and third row by 26.9% and 9.2%, respectively.
3. Unfavourable effect of the vicinity of wheat and triticale for the majority of the studied pea characteristics was visible in the first and second row, although some plant characteristics were similar still in the third row to the plants from the second or first row.
4. The least unfavourable for pea was the vicinity of lupine. Negative effect of the this species on pea in the case of the majority of the characteristics, including yield, was not statistically confirmed.
5. In strip cropping of pea with cereals, decrease in pea yield may reach from 3.5% (one-sided vicinity of triticale) to 7.9% (vicinity of barley), which decreases the proportion of pea seeds in the joint yield of strip intercropping.

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ODDZIAŁYWANIA SĄSIEDZKIE ZBÓŻ JARYCH I ROŚLIN BOBOWATYCH GRUBONASIENNYCH W UPRAWIE PASOWEJ ROŚLIN. CZ. II REAKCJA GROCHU NA SĄSIEDZTWO PSZENICY, PSZENŻYTA, JĘCZMIENIA I ŁUBINU ŻÓŁTEGO

Streszczenie

Uprawa pasowa łączy zalety siewów czystych i upraw współrzędnych, jednak jej produkcyjne walory zależą od oddziaływań wzajemnych na styku sąsiadujących ze sobą rzędów różnych gatunków. Celem eksperymentu było poznanie reakcji grochu na sąsiedzkie występowanie pszenicy jarej, pszenżyta jarego, jęczmienia jarego i łubinu żółtego wraz z oszacowaniem możliwych efektów produkcyjnych uprawy pasowej grochu w sąsiedztwie tych gatunków. W pracy wykorzystano wyniki doświadczeń polowych wykonanych w ramach badań nad siewami mieszanymi realizowanymi w latach 2008–2010 w Mochełku k. Bydgoszczy (53^{o}13’ N; 17^{o}51’ E). Czynnikiem doświadczalnym było rozmieszczenie rzędów roślin na poletku – cztery rzędy w głąb poletka od rzędu skrajnego z odpowiednim gatunkiem sąsiedzkim. Rząd pierwszy (stykowy) grochu oddalony był o 12,5 cm od pierwszego rzędu odpowiedniego gatunku sąsiedzkiego. Jednostką doświadczalną były kolejne rzędy roślin o długości czterech metrów każdy. Sąsiedztwo pszenicy, pszenżyta, jęczmienia i łubinu było niekorzystne dla grochu, najsilniej ujawniało się w pierwszym rzędzie roślin i malało w kolejnych bardziej oddalonych rzędach. Najbardziej niekorzystnym sąsiedztwem dla grochu w uprawie pasowej okazał się jęczmień. W rzędzie sąsiadującym z tym gatunkiem plon nasion grochu był mniejszy o 59,4% niż w rzędzie czwartym. W kolejnych rzędach odnotowano również tendencję spadku plonu nasion, tj. w rzędzie drugim o 26,9%, a w trzecim o 9,2%. Potwierdzony niekorzystny efekt sąsiedztwa dla pszenicy i pszenżyta obejmował pierwszy i drugi rząd roślin grochu. Najmniej niekorzystnym sąsiedztwem dla grochu było sąsiedztwo łubinu żółtego. Wprowadzając groch do uprawy pasowej ze zbożami jego plon, może być mniejszy od 3,5% (jednostronne sąsiedztwo z pszenżytem) do 7,9% (sąsiedztwo z jęczmieniem), co zmniejsza udział nasion grochu w łącznym plonie uprawy pasowej.

Słowa kluczowe: cechy morfologiczne, efekt bliskości, efekt sąsiedztwa, oddziaływania międzygatunkowe, plon, uprawa pasowa