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PROXIMITY EFFECT OF SPRING CEREALS AND LEGUMES IN STRIP INTERCROPPING. PART III. RESPONSE OF BARLEY TO THE PROXIMITY OF WHEAT, TRITICALE, PEA 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 neighbouring rows of different plant species. The aim of the experiments was to find out the response of spring barley to the neighbouring occurrence of spring wheat, spring triticale, pea and yellow lupine and to estimate the production effects of strip intercropping of barley in the proximity of those species.
Material and methods. In this study, the results of field experiments on mixed sowings carried out in the years 2008–2010 at Mochełek near Bydgoszcz (53°13' N; 17°51' E) were used. Experimental factor was the position of plant row on the plot: four rows into the plot away from the respective neighbouring species. First row (contact row) was situated 12.5 cm away from the first row of the respective neighbouring species. Experimental unit was subsequent plant rows, each 4 meters long.
Results. Proximity of spring wheat and spring triticale was unfavourable to the growth and yield of spring barley, especially in the row directly adjacent to the field with the above species. No significant effect was found of the vicinity of pea to spring barley plants. Estimated decrease in barley yield in strip intercropping, with 3-m-wide strips and bilateral proximity of wheat, triticale and pea, would amount to 2.76%, 4.25% and 3.21%, respectively. However, the direct neighbourhood of yellow lupine caused a slight increase in the plant mass, including straw, the number of grains per spike and grain yield, but only in the first row. Estimated increase in the yield of spring barley grown in strip intercropping with yellow lupine, with 3-m--wide strips, was small and would amount to only 0.58%.
Conclusion. Selection of plant species adjacent to spring barley in strip intercropping has a significant effect on results of its cultivation.

Key words: competition, interspecific effect, proximity effect, strip intercropping, vicinity effect

INTRODUCTION

Barley grain is mainly used for fodder, only a small part of its production is used for other purposes. Due to the small winter hardiness of winter forms of plants and a higher fibre content in the chemical composition of the grain, the spring form of this species is mainly grown. However, it is definitely more sensitive to water shortages in spring and summer. The yielding instability of spring barley in variable weather conditions in the years makes it one of the main components of cereal and grain-legume mixtures in Poland.

Mixed intercropping generally provides more stable yields than pure sowing of individual components of mixtures [Rudnicki, 2005; Tsubo *et*

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al., 2005], which results from a better use of environmental resources in high variability of soil and weather conditions [Fukai and Trenbath, 1993; Hauggaard-Nielsen *et al.*, 2001; Sainju *et al.*, 2010; Gałęzewski *et al.*, 2012; Brooker *et al.*, 2015]. While the advantage is greater yielding stability of mixed intercropping, the biggest drawback is the instability of the species composition of yield. Unfortunately, it deviates very often from the proportion of species in the seed material. This results, among others, in difficulty in balancing fodders [Theunissen, 2004]. This variability is mainly the result of the diverse competitive potential of the species making up the mixture [Sobkowicz, 2005; Lamb *et al.*, 2007; Gałęzewski, 2010a, b]. In addition, the cultivation of various plant species at the same place and time often prevents applications of plant protection products and makes it difficult to optimize mineral fertilization.

The mentioned disadvantages of mixed intercropping can be partially eliminated by replacing them with strip intercropping. Thanks to this, biodiversity of the agroecosystem and the possibility of using positive interspecies interactions are preserved, and with the appropriate width of strips, it is possible to implement agrotechnical recommendations for particular species [Burczyk, 2003; Gałęzewski *et al.*, 2017; Sanchez *et al.*, 2010; Głowacka 2014; Gou *et al.*, 2016; Liu *et al.*, 2017]. Unfortunately, the close proximity of strongly competing plants may turn out to be unfavourable. The solution is to separate them with a technological path and to use the border effect [Fortin *et al.*, 1994, Iragavarapu and Randall, 1996; Jurik and Van, 2004]. Therefore, the hypothesis was assumed that the reasonableness of barley strip intercropping will depend on the selection of neighbouring species.

The aim of the present study was to find out the response of spring barley to the vicinity of spring wheat, spring triticale, pea and yellow lupine and to estimate its yield in strip intercropping with these plant species.

MATERIAL AND METHODS

The present study is a part of research on the proximity effect of spring cereals and legumes carried out in the Department of Agronomy of the University of Science and Technology in Bydgoszcz. Source material consists of the results of a multiple, one-factor field experiment aimed at finding the effect of growing spring barley 'Antek' in the direct vicinity of spring wheat 'Bombona', spring triticale 'Dublet', pea 'Ramrod' and yellow lupine 'Lidar'. The experiment was carried out at the Experimental Station of the Faculty of Agriculture and Biotechnology in Mochełek (53°13' N; 17°51' E) in the region of low average total precipitation – about 500 mm. The experiment was established in a split-block design in four replications. Plots were 150 cm wide and consisted of 12 plant rows with a density of 12.5 cm. The experimental factor was the location of a spring barley plant row on the plot – four rows into the plot from the neighbouring species. The first row (contact row) was 12.5 cm apart from the first row of the neighbouring species. The experimental unit was subsequent plant rows, four metres long each. Based on the results of the previous studies [Gałęzewski *et al.*, 2017], the fourth plant row was assumed as being free from the proximity effects – representing the interior of the field. Plots were situated with their longer sides on the north-south axis.

The experiment was conducted in 2008–2010. All plant species were sown at one date. Depending on the year, this was from 25th March to 5th April. In order to obtain the equal distance between plants in a given row, cereal grain was placed in points on sowing tapes (made from blotting paper) at a density of 45 plants·mb^{-1} (360 szt·m^{-2}). Sowing tapes were placed in the soil at a depth of 4 cm. Lupine and pea seeds were sown manually at a density of 10 plants·running m^{-1} (80 seeds·m^{-2}).

The experiments were located on light soil – Luvisol (LV), with the structure of loamy sand [IUSS Working Group WRB, 2015] in the field after winter oilseed rape. C_{org} content amounted to 6.2–6.6 g·kg^{-1} DM of soil, depending on the year of the study, and the content of available forms of P and K was 63–69 and 94–172 mg·kg^{-1}, respectively. Soil pH (1M KCl) was within the range 5.2–6.6. During spring soil cultivation, 30 kg·ha^{-1} P, 66 kg·ha^{-1} K and 34 kg·ha^{-1} N were applied. Top-dressing nitrogen fertilization was applied only for cereals at a rate of 34 kg N·ha^{-1} at the tillering stage. Protection against weeds for all treatments was a foliar application of linuron – Afalon 450SC in a dose of 1 $dm^3 \cdot ha^{-1}$.

Before harvest, barley plant density was evaluated for the entire length of the particular rows. Plant harvest was carried out manually, separately for each row. Response of barley plants to location in relation to the neighbouring species was determined based on the following elements: height of the longest stem, straw mass, aboveground plant mass, spike density, grain number per spike, mass of 1000 grains and grain yield. All the plants from the entire length of all the studied rows were used for the evaluation.

In the statistical processing of data from single experiments, analysis of variance was used, in the model appropriate for a split-block design, with Tukey's HSD test. In multiple experiments (synthesis), calculated F was determined based on recreated error extended by the interaction of the factor and the 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 the negative effect of the neighbouring species on barley. PE > 1 indicated the positive effect of the neighbouring species on barley. Due to the lack of interaction between the factor and the study years, for the majority of the characteristics of the tested species, average results from the study years were presented in this study.

Estimated yield for every running metre of 3-metre-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 metres assumed for the estimation resulted from the working width of the standard sowing machines used in agricultural practice. Plot width of 1.5 m resulted from minimizing the effect of soil changeability on the experiment and from the lack of necessity to duplicate the results from internal field rows.

RESULTS

Response of spring barley to the proximity of spring wheat was mostly unfavourable. This is demonstrated by the PE index of the characteristics of plants in the first, second and third rows, which mostly amounted to values less than one (Table 1). Effect of the direct proximity of spring wheat on the height of barley spring plants was not proved. However, there was a tendency for the barley height to increase in subsequent rows to wheat. In the row directly neighbouring with wheat, barley had the spike density lower by 17.3% and mass of 1000 grains lower by 4.1% than in the fourth row. The confirmed negative effect of proximity of wheat for barley was, however, limited only to the first row of plants. The number of grains per spike of barley plants directly neighbouring with wheat was 9.8% lower than in the fourth row, but it did not differ significantly from the number of grains per spike of plants from the second and third rows. The straw mass decreased with approaching barley rows to wheat. These differences, however, were not confirmed statistically. It was found that the yield of barley grain in the first row, directly neighbouring with wheat, was 16.6% lower than in the fourth row, while the plant yield was lower by as much as 19.7%. However, no significant difference was found in grain yield and biomass of plants growing in the first and second rows.

The PE index values indicate that the neighbourhood of triticale, similar to the neighbourhood of wheat, was not favourable for barley (Table 2). This negative effect, however, did not obtain statistical confirmation in the plant height, the number of grains per spike and the mass of 1000 grains, although the values of individual characteristics indicate the existence of such a tendency. Nevertheless, the direct neighbourhood of triticale resulted in a reduction of barley spike density by 17.4% compared to the density in the fourth row and by 15.7% and 16.1%, respectively, in the third and second rows. The particularly strong negative effect of triticale on barley growing in its immediate vicinity was manifested by a reduction in grain yield by 24.9% in relation to plants growing in the fourth row. Plants in the second and third row did not differ significantly in respect of yielding from plants in the first and fourth rows. A similar reaction of barley to the neighbourhood of triticale was recorded in the case of straw and whole plant yields, although their reduction in the first row in relation to the fourth row was smaller than in the case of grain, i.e. 13.1% and 18.1%, respectively.

There was no significant neighbouring effect of pea on any of the barley characteristics determined (Table 3). While in the case of grain yield, plant mass, spike density and plant height, pea neighbourhood showed a tendency to adversely affect barley, in the case of straw mass, mass of thousand grains and the number of grains per ear, these tendencies were favourable.

Almost each determined characteristic of spring barley occurring in the immediate vicinity of yellow lupine obtained significantly higher values than that of barley growing in the second, third and fourth rows (Table 4). This indicates a favourable neighbourhood of lupine for barley, which resulted in a 20.9% higher grain yield in a row adjacent to lupine than in the fourth row.

In the production conditions, assuming the strip width of 3 m, the estimated yields of spring barley located between two strips of yellow lupine could increase by only 0.58% in relation to a single species field of barley (Table 5). One-sided neighbourhood would give even smaller positive effects. Growing barley in strip intercropping with pea, wheat or triticale, one would expect a yield loss of about 1.34% (one-sided proximity with wheat) to 4.25% (two-sided proximity with triticale)

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

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Height	cm	41.9a*	43.8a	44.9a	45.2a
	PE**	0.93	0.97	0.99	1.00
Spike density	(spike·m^{-1})	65.6b	76.4a	78.7a	79.3a
	PE	0.83	0.96	0.99	1.00
Number of grains per spike	grain	13.8b	14.0ab	15.0ab	15.3a
	PE	0.90	0.92	0.98	1.00
Mass of 1000 grains	g	32.5b	33.5a	33.8a	33.9a
	PE	0.96	0.99	1,00	1.00
Grain yield	(g·running m^{-1})	37.7b	41.2ab	42.2ab	45.2a
	PE	0.83	0.91	0.93	1.00
Straw mass	(g·running m^{-1})	48.7a	56.2a	60.5a	62.3a
	PE	0.78	0.9	0.97	1.00
Plant mass	(g·running m^{-1})	86.3b	97.4ab	102.7a	107.5a
	PE	0.80	0.91	0.96	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 spring barley plants to the vicinity of spring triticale

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Height	cm	42.7a*	44.2a	45.5a	45.5a
	PE**	0.94	0.97	1.00	1.00
Spike density	(spike·m^{-1})	64.2b	76.5a	76.2a	77.7a
	PE	0.83	0.98	0.98	1.00
Number of grains per spike	grain	13.9a	14.3a	15.3a	15.1a
	PE	0.92	0.95	1.01	1.00
Mass of 1000 grains	g	34.2a	34.2a	33.5a	34.7a
	PE	0.99	0.99	0.97	1.00
Grain yield	(g·running m^{-1})	34.3b	39.4ab	40.1ab	45.7a
	PE	0.75	0.86	0.88	1.00
Straw mass	(g·running m^{-1})	54.5b	58ab	59.9ab	62.7a
	PE	0.87	0.93	0.96	1.00
Plant mass	(g·running m^{-1})	88.8c	97.4bc	100.1ab	108.4a
	PE	0.82	0.90	0.92	1.00

* the same letter in a given row indicates the lack of significant diversification of the results according to the Tekey's HSD test, at $P < 0.05$

** proximity effect index, see Material and Methods

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

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Height	cm	43.3a	45.2a	44.9a	45.3a
	PE**	0.96	1.00	0.99	1.00
Spike density	(spike·m^{-1})	75,0a	67,0a	78.1a	78.1a
	PE	0.96	0.86	1.00	1.00
Number of grains per spike	grain	16.3a	14.8a	14.5a	15.2a
	PE	1.07	0.97	0.95	1.00
Mass of 1000 grains	g	34.9a	34.2a	32.7a	33.8a
	PE	1.03	1.01	0.97	1.00
Grain yield	(g·running m^{-1})	36.8a	36.6a	42.7a	44.4a
	PE	0.83	0.82	0.96	1.00
Straw mass	(g·running m^{-1})	64.5a	57.5a	61.4a	61.2a
	PE	1.05	0.94	1.00	1.00
Plant mass	(g·running m^{-1})	101.3a	94.1a	104.2a	105.6a
	PE	0.96	0.89	0.99	1.00

* the same letter in a given row indicates the lack of significant diversification of the results according to the Tekey's HSD test, at $P < 0.05$

** proximity effect index, see Material and Methods

Table 4. Response of spring barley plants to the vicinity of yellow lupine

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Height	cm	49.0a*	45.3b	45b	45.1b
	PE**	1.09	1.00	1.00	1.00
Spike density	(spike·m^{-1})	110.2a	76.4b	85.3b	78.0b
	PE	1.41	0.98	1.09	1.00
Number of grains per spike	grain	17.7a	13.9b	15.7ab	15.4b
	PE	1.15	0.9	1.02	1.00
Mass of 1000 grains	g	36.4a	32.7b	33.4b	34.2ab
	PE	1.06	0.96	0.98	1.00
Grain yield	(g·running m^{-1})	53.9a	40.0b	43ab	44.6ab
	PE	1.21	0.9	0.96	1.00
Straw mass	(g·running m^{-1})	91.3a	54.8b	64.1b	63.0b
	PE	1.45	0.87	1.02	1.00
Plant mass	(g·running m^{-1})	145.2a	94.7b	107.1b	107.6b
	PE	1.35	0.88	1.00	1.00

* the same letter in a given row indicates the lack of significant diversification of the results according to the Tekey's HSD test, at $P < 0.05$
** proximity effect index, see Material and Methods

Table 5. Estimated spring barley yield [g] for every running meter of 3-m-wide strips depending on the type of proximity

Proximity	Characteristic	Neighbouring species			
		wheat	triticale	pea	lupine
No proximity	yield	1085	1097	1066	1070
One-sided proximity	yield	1070	1074	1049	1074
	difference in yield, g	-14.5	-23.3	-17.1	3.1
	difference in yield, %	-1.34	-2.12	-1.60	0.29
Two-sided proximity	yield	1056	1050	1031	1077
	difference in yield, g	-29.0	-46.6	-34.2	6.2
	difference in yield, %	-2.67	-4.25	-3.21	0.58

DISCUSSION

Research on strip intercropping with barley was conducted by other authors [Li *et al.*, 2011]. In the literature, however, there are no reports allowing for direct referring the present study results to the results of other studies, as information about strip intercropping with such species as maize and soy is most common [Hu *et al.*, 2016; Yang *et al.*, 2017; Yang *et al.*, 2014]. However, the results of the present study can indirectly relate to inter-species interactions of barley in mixed sowing. Treder *et al.* [2008a, b] showed that the common cultivation of cereals negatively affects their morphological characteristics and grain yield. This effect is more apparent in generative characteristics, and less in vegetative ones. The authors showed that barley was a stronger competitor for wheat than wheat for barley. However, the presence of wheat in the vicinity of barley caused a lower increase in above-ground barley biomass during tillering, earing and maturing stages. Tobiasz-Salach *et al.* [2011] also came to similar conclusions. Such results are also confirmed by the present study, in which it was shown that neither the neighbourhood of wheat nor triticale was beneficial for barley. Thus, this confirms the validity of strip intercropping of these species. The solution eliminating this problem is the separation of unfavourably interacting species with a technological path. The pathway between the strips of different species eliminates or reduces mutual interactions between them, and losses resulting from the presence of unsown space can be eliminated by the border effect [Romani *et al.*, 1993; Gałęzewski *et al.*, 2013]. The negative effect of pea on barley was not confirmed in the present study, although such trends were observed. Tofinga *et al.* [1993] prove that pea is a stronger competitor than barley. Michalska *et al.* [2008] also reached similar conclusions, although the intensity of interspecies competition varied at different growth stages and soil conditions. In the present study, the straw yield of barley in the presence of pea was slightly changed, and the grain yield underwent much larger changes. This suggests that pea competition towards barley had different intensities at individual growth stages. Despite the fact that pea belongs to legumes, Corre-Hellou *et al.* [2006] and Wanic *et al.* [2012] found that pea and barley compete with each other for nitrogen contained in the soil. This phenomenon has already been observed from the tillering stage of barley and intensified until the end of growing season, and pea turned out to be a stronger competitor. Ghaley *et al.* [2005] and Lauk and Lauk [2008] also report on the unfavourable effect of pea on other cereal species grown in a mixture. Rudnicki and Kotwica [2007] showed stronger interspecific competition of spring cereals than lupines, despite the greater strength of competitive effects of a single lupine plant than a single cereal crop. In a study by Kotwica and Rudnicki [2004], yellow lupine was worse to compete with cereals in mixtures, including spring barley, rather than pea. The authors justified this by showing a smaller proportion of lupine seeds in yields of mixtures than pea. However, oats turned out to be the most competing spring cereal with yellow lupine in mixtures In the present study, the neighbourhood of lupine proved to be beneficial for barley. Similar positive cereal reactions to the neighbourhood of lupine were found in earlier studies by authors [Gałęzewski *et al.*, 2017].

CONCLUSIONS

1. Vicinity of spring wheat and spring triticale was unfavourable to the growth and development of spring barley. Plant mass and grain yield in the row directly neighbouring with those species were significantly lower than those inside the field.
2. No significant effect of the vicinity of pea on the biometric characteristics, yield components and yields of spring barley was found.
3. Spring barley that grew directly next to yellow lupine responded favourably to its vicinity. This manifested itself in a significant increase in the value of all biometric characteristics of plants.
4. Estimated increase in the yield of spring barley grown in strip intercropping with yellow lupine, at 3-m-wide strips, would amount to only 0.58% at two-sided proximity and would be lower by a half at one-sided proximity. Wheat, triticale and pea neighbouring with barley would cause a reduction in its yield for two-sided proximity by 2.76%, 4.25% and 3.21%, respectively.

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

Streszczenie

Uprawa pasowa łączy ze sobą zalety siewów czystych i upraw współrzędnych, jednak jej produkcyjne walory zależą od oddziaływań wzajemnych na styku sąsiadujących ze sobą rzędów różnych gatunków roślin. Celem eksperymentów było poznanie reakcji jęczmienia jarego na sąsiedzkie występowanie pszenicy, pszenżyta, grochu i łubinu żółtego oraz oszacowanie efektów produkcyjnych uprawy pasowej jęczmienia w sąsiedztwie roślin 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 położenie rzędu roślin na poletku – cztery rzędy w głąb poletka od gatunku sąsiedzkiego. Rząd pierwszy (stykowy) – oddalony był o 12,5 cm od pierwszego rzędu gatunku sąsiedzkiego. Jednostką doświadczalną były kolejne rzędy roślin o długości czterech metrów każdy. Sąsiedztwo pszenicy jarej i pszenżyta jarego było niekorzystne dla wzrostu i plonowania jęczmienia jarego, zwłaszcza w rzędzie występującym bezpośrednio obok łanu wskazanych gatunków. Nie potwierdzono statystycznie wpływu sąsiedztwa grochu na rośliny jęczmienia. Szacowane zmniejszenie plonu jęczmienia w uprawie pasowej, przy pasach szerokości trzech metrów i dwustronnym sąsiedztwem pszenicy, pszenżyta i grochu, wyniosłoby odpowiednio 2,76%, 4,25% i 3,21%. Bezpośrednie sąsiedztwo łubinu żółtego spowodowało natomiast niewielkie zwiększenie masy roślin, w tym słomy, liczby ziaren w kłosie i plonu ziarna, ale tylko w pierwszym rzędzie. Oszacowany wzrost plonu jęczmienia jarego uprawianego pasowo z łubinem żółtym, przy pasach szerokości 3 m, był niewielki i wyniósłby zaledwie 0,58%. Dobór gatunków roślin sąsiadujących z jęczmieniem jarym w uprawie pasowej ma istotny wpływ na efekty jego uprawy.

Słowa kluczowe: efekt bliskości, efekt sąsiedztwa, konkurencja, oddziaływania międzygatunkowe, uprawa pasowa roślin