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STRIP INTERCROPPING OF YELLOW LUPINE WITH OATS AND SPRING TRITICALE: PROXIMITY EFFECT

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ABSTRACT

Background. The work uses the results from two field experiments on mixed sowings carried out in the years 2005–2012 at the experimental station in Mochełek (53°13' N; 17°51' E). The aim of the studies was to find the response of yellow lupine to the neighbouring occurrence of oats and spring triticale, as well as the effect of Fabaceae on spring cereals and an estimation of the production effects of strip intercropping of those species.

Material and methods. The experimental factor was the position of a plant row on the plot: four rows into the plot away from the neighbouring species. The first row (contact row) was situated 12.5 cm away from the first row of the neighbouring species. The experimental unit was the subsequent plant rows, each 4 meter-long. The proximity of yellow lupine and oat plants was studied in the first experiment and yellow lupine and spring triticale in the second experiment.

Results. The proximity of oats was unfavourable to yellow lupine plants, and the effect was statistically confirmed in the row directly adjacent to oats. A negative effect also occurred in the subsequent row, although it was smaller and in most cases not significant. The proximity of spring triticale was also unfavourable to yellow lupine plants, but to a smaller extent than in the case of oats and was limited only to the first, directly adjacent row of yellow lupine. On the other hand spring triticale, and especially oats, responded positively to the proximity of yellow lupine, but the effect occurred only in the first plant row.

Conclusion. It was estimated that in strip intercropping of oats with yellow lupine and of spring triticale with yellow lupine, with 3 meter-long strips, up to 13.9% higher oat yields and 5.57% triticale yields may be obtained, but at the same time lower, by 0.62-2.13%, yellow lupine yields may be obtained than in pure sowing.

Key words: Fabaceae, interspecific effect, spring cereals, strip intercropping system

INTRODUCTION

Mixed sowing, especially of cereal and Fabaceae, composed of two or three equivalent species is an important pro-ecological element of contemporary agriculture (Knudsen *et al.*, 2004; Corre-Hellou *et al.*, 2006; Li *et al.*, 2009). Multi-species fields, thanks to the presence of plants with diversified biology, use environmental resources in a better way and increase the agricultural biodiversity of a production space (Hauggaard-Nielsen *et al.*, 2001; Sainju *et al.*, 2010; Brooker *et al.*, 2015). Also, the higher yield stability in variable habitat and agrotechnical conditions is an advantage of mixtures (Rudnicki, 2005; Tsubo *et al.*, 2005). In these type of plant community, however, numerous competitive effects occur, both in the under- and above-ground parts (Sobkowicz, 2005; Lamb *et al.*, 2007; Gałęzewski, 2010a, b). Their

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identification and evaluation is difficult and requires the use of mathematical competition measures, which usually relate the results to the effects that occur in pure sowings of the particular mixture components. Several dozens of such indicators have been presented by Weigelt and Jolliffe (2003).

Another method of mixed sowing is the strip intercropping system. It consists of growing long but narrow neighbouring single-species strips of different plants (Burczyk, 2003). The above definition also corresponds to the sowing of single-species plants in the interrows of a second species, for example pea in maize (Hu *et al.*, 2016). Studies on the conditions and effects of the strip intercropping system have been carried out in various foreign centres (Sanchez *et al.*, 2010; Gou *et al.*, 2016; Liu *et al.*, 2017), as well as in Polish stations (Burczyk, 1999; Głowacka, 2010; Głowacka, 2014). Results from those studies indicate that although there is a reciprocal favourable plant effect, the close proximity may limit plant yield (Fortin *et al.*, 1994; Iragavarapu and Randall, 1996; Jurik and Van, 2004). However, the occurrence of plants near strongly dominant species, in spite of decreasing their yield, may favourably affect the chemical composition of their seeds (Liu *et al.*, 2016). This cultivation method gives the possibility to find the reciprocal effects of neighbouring species. Interspecific effects are limited to one or several rows of neighbouring plants and are easier to evaluate than in the case of several plant species in one row. Neighbouring effect may be studied by simply comparing plants in the adjacent rows to the plants in the middle of a single-species strip. Border effect is evaluated in the same way (Braun, 1978; Stawiana--Kosiorek *et al.*, 2003; Gałęzewski *et al.*, 2013).

However, there is a need for further studies on the effects of plant neighbouring, especially since the results depend on the response of individual species as well as on habitat and agrotechnical factors such as the strip width of the particular species cultivation (Gałęzewski *et al.*, 2012). In Poland, in view of the high proportion of cereal, and cereal and Fabaceae mixtures in the sowing structure, this type of study appears to be particularly justified. The study hypothesis assumed was that the response of yellow lupine to the proximity of spring cereals would depend on the species, and that the effect of lupine on oats may be different from that on spring triticale.

The aim of the studies was to find the response of yellow lupine to the neighbouring occurrence of oats and spring triticale, as well as the effect of Fabaceae on spring cereals and to make an estimation of the production effects of strip intercropping of those species.

MATERIAL AND METHODS

The present work is part of a series of studies on mixed sowing of spring cereals and coarse-seeded Fabaceae carried out at the Department of Plant Production and Experimenting of the University of Science and Technology in Bydgoszcz in the years 2005–2012. Source material consisted of the results of two multiple (three-year-long) one-factor field experiments, the aim of which was finding the neighbouring effect of three cultivated plant species. In the first experiment, the neighbouring effect of yellow lupine and oats was evaluated, and in the second experiment of yellow lupine and spring triticale. Both experiments were carried out at the Experimental Station of the Faculty of Agriculture and Biotechnology in Mochełek (53°13’ N; 17°51’ E), using common methodology. 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 (adjacent) 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. Previous research on the neighbouring effect has indicated that the effect extends to two or three rows of neighbouring plant species. Therefore, in the present research, the fourth plant row was assumed as being free from the neighbouring effect and occurring in conditions characteristic for field interior. Plots were situated with their longer side on a north-south axis.

All species were sown on one date. Depending on the year, sowing took place between March 21st and 30th. 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 a depth of 4 cm. Lupine seeds were sown manually at the density of 10 plants per linear meter (80 plants m^{-2}).

The experiments were located on class IVa-IVb soil on the post after spring barley. 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.

After emergence, plant density was evaluated for all plant species, and before harvest for yellow lupine with formed pods and for triticale spikes and oat panicles for the entire length of the particular rows. The difference in yellow lupine density after emergence and before harvest was used for the evaluation of plant losses during growth. Plant harvest was carried out manually, separately for each row. All plants from the same species collected from the entire row length were used for the evaluation of the biometrical characteristics included in the Results section.

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. Neighbouring effect 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). The similarity of the response of yellow lupine and spring cereals to the neighbouring effect in subsequently repeated experiments was the reason for presenting average results from the study years in the present research.

Estimated yield differences from every running meter of three-meter-wide strips, depending on the type of proximity, at row spacing of 12.5 cm, resulted from the following formulas:

yield at no proximity = $24 \cdot x_4$ (1)

yield at one-sided proximity = $x_1 + x_2 + x_3 + 21 \cdot x_4$ (2)

yield at two-sided proximity = $2 \cdot x_1 + 2 \cdot x_2 + 2 \cdot x_3 + 18 \cdot x_4$ (3)

where:

x_1 – yield in the first row from the neighbouring species,

x_2 – yield in the second row from the neighbouring species,

x_3 – yield in the third row from the neighbouring species,

x_4 – yield in the fourth row from the neighbouring species (inside the field).

RESULTS

Study results (Table 1) indicate that oats proximity was unfavourable to yellow lupine. In the conditions of the experiment, on average in the study years, yellow lupine plant losses were high. Inside the field (fourth row), from emergence to harvest, plant losses amounted to 22.5%. The presence of oat plants in the immediate vicinity of lupine escalated this phenomenon. In rows 1 and 2 plant losses were significantly higher and amounted to 38.1% and 30.6%, respectively. A consequence of lower yellow lupine plant density in the row located directly next to oats was a statistically confirmed decrease in straw mass and whole plant mass from that row. Also, single lupine plants were characterized by a lower number and mass of pods per plant, as well as seed yield. Also, in the second row, biometric plant characteristics pointed to worse habitat conditions and yellow lupine structure than in the fourth row, which was the control row, although the difference was lower than in the first row and not proven statistically. Yellow lupine seed yield in the row directly adjacent to oats was lower than inside the field by 28.5%, and in the second row by 8.5%.

Similarly to oats, spring triticale also negatively affected neighbouring yellow lupine plants (Table 2). In the row directly adjacent to spring triticale, there was a loss of 25.4% of yellow lupine plants during growth. The losses in rows 2 and 3 were also significantly higher than in the fourth row (14.6%). The negative effect of spring triticale on yellow lupine was also visible in the reduction of straw mass, whole plant mass, and seed yield, although it concerned only the first row, directly adjacent to the cereal. On the other hand, there was no proximity effect of spring triticale on the number and mass of pods per plant and mass of 1000 seeds of yellow lupine. The proximity effect index calculated for the particular biometric characteristics indicates that spring triticale affected yellow lupine plants to a lesser extent than oats.

The proximity of yellow lupine favourably affected oats, especially plants in the first row. They had significantly higher total mass, as well as the mass of straw and panicles, and higher grain yield than plants from the second and subsequent rows away from Fabaceae (Table 3). Grain yield in the row directly adjacent to lupine was almost 2.5 times higher than in the fourth row. A positive effect of yellow lupine on oats yield also occurred in the second row. Grain yield in it was 15.2% higher than inside the field (fourth row), although it was not statistically proven. Any effect of Fabaceae on the mass of 1000 grains of oats was not confirmed, although a clear tendency for higher panicle density was observed.

The response of spring triticale to the vicinity of yellow lupine was also favourable (Table 4). The positive effect of such a joint occurrence was expressed in a higher mass of whole plants, straw and spikes, and a higher grain yield. Grain yield in the row directly adjacent to yellow lupine was higher by nearly 43% than the yield in the fourth row. The proximity effect index of grain yield of oats, as well as other significantly diversified biometric characteristics, were higher than for those of spring triticale.

The proximity effect of yellow lupine and spring cereals may be of practical value when those species grow next to each other in strip intercropping. With strips 3 m wide, which is the working width of a standard sowing machine, yield of oats adjacent on two sides to yellow lupine may be 13.9% higher, and with one-sided proximity it may be 6.9% higher than in the case of a uniform cereal field (Table 5). The relative yield increase of spring triticale was lower and amounted to 5.57% and 2.79%, respectively. At the same time, yield of jointly occurring yellow lupine with two-sided proximity of oats was lower only by 2.13%, and for spring triticale was lower by 0.62%.

Table 1. Response of yellow lupine plants to the proximity of oats

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Plant losses from the field	%	38.1a*	30.6b	25.3bc	22.5c
	PE**	1.69	1.36	1.12	1.00
Straw mass	(g·running m^{-1})	22.3b	30.9ab	35.8a	36.1a
	PE	0.62	0.86	0.99	1.00
Plant mass	(g·running m^{-1})	39.5b	52.5ab	62.4a	60.0a
	PE	0.66	0.88	1.04	1.00
Pod number per plant	plant number	2.95b	3.48a	3.80a	3.52a
	PE	0.84	0.99	1.08	1.00
Pod mass per plant	g	2.41b	2.84ab	3.22a	2.93a
	PE	0.82	0.97	1.10	1.00
Mass of 1000 seeds	g	128.6a	129.3a	132.2a	130.5a
	PE	0.99	0.99	1.01	1.00
Seed yield	(g·running m^{-1})	9.3c	11.9b	14.4a	13.0ab
	PE	0.71	0.92	1.11	1.00

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

Table 2. Response of yellow lupine plants to the proximity of spring triticale

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Plant losses from the field	%	25.4a*	19.6b	21.3b	14.6c
	PE**	1.74	1.34	1.46	1.00
Straw mass	(g·running m^{-1})	27.2b	36.5a	38.1a	39.0a
	PE	0.70	0.94	0.98	1.00
Plant mass	(g·running m^{-1})	55.6b	68.1a	69.9a	70.3a
	PE	0.79	0.97	0.99	1.00
Pod number per plant	plant number	4.01a	4.24a	4.05a	4.25a
	PE	0.94	1.00	0.95	1.00
Pod mass per plant	g	3.36a	3.65a	3.80a	3.51a
	PE	0.96	1.04	1.08	1.00
Mass of 1000 seeds	g	126.7a	134.3a	135.7a	135.0a
	PE	0.94	0.99	1.01	1.00
Seed yield	(g·running m^{-1})	15.2b	17.0a	17.1a	16.9a
	PE	0.90	1.01	1.02	1.00

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

Table 3. Response of oat plants to the proximity of yellow lupine

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Panicle density	plant·running m^{-1}	51.2a*	43.3a	40.8a	40.3a
	PE **	1.27	1.07	1.01	1.00
Plant mass	(g·running m^{-1})	171.7a	85.1b	81.2b	76.2b
	PE	2.25	1.12	1.07	1.00
Straw mass	(g·running m^{-1})	85.2a	45.1b	42.8b	41.9b
	PE	2.03	1.08	1.02	1.00
Panicle mass	(g·running m^{-1})	86.4a	40.0b	38.4b	34.3b
	PE	2.52	1.17	1.12	1.00
Mass of 1000 grains	g	29.6a	29.3a	28.9a	29.0a
	PE	1.02	1.01	1.00	1.00
Grain yield	(g·running m^{-1})	71.4a	33.4b	30.5b	29.0b
	PE	2.46	1.15	1.05	1.00

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

Table 4. Response of triticale plants to the proximity of yellow lupine

Characteristic	Unit	Subsequent plot row			
		1	2	3	4
Spike density	plant·running m^{-1}	44.5a*	41.4a	42.1a	40.8a
	PE **	1.09	1.01	1.03	1.00
Plant mass	(g·running m^{-1})	113.2a	88.1ab	83.5ab	73.0b
	PE	1.55	1.21	1.14	1.00
Straw mass	(g·running m^{-1})	65.7a	50.9ab	48.3ab	41.0b
	PE	1.60	1.24	1.18	1.00
Spike mass	(g·running m^{-1})	47.5a	37.2b	35.3b	32.0b
	PE	1.48	1.16	1.10	1.00
Mass of 1000 grains	g	35.5a	34.8a	34.2a	34.0a
	PE	1.04	1.02	1.01	1.00
Grain yield	(g·running m^{-1})	35.8a	28.9b	27.3b	25.1b
	PE	1.43	1.15	1.09	1.00

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

Table 5. Estimated differences in yield per linear meter for 3 m wide strips depending on the type of proximity

Cultivation		Oats	Spring triticale	Yellow lupine	Yellow lupine
Neighbouring species		yellow lupine		oats	spring triticale
No proximity	yield (g·running m^{-1})	696	602	311	405
One-sided proximity	yield (g·running m^{-1})	744	619	308	404
	yield difference (g)	48.4	16.8	-3.3	-1.3
	yield difference (%)	6.95	2.79	-1.07	-0.31
Two-sided proximity	yield (g·running m^{-1})	793	635	305	402
	yield difference (g)	96.8	33.6	-6.6	-2.6
	yield difference (%)	13.9	5.58	-2.14	-0.62

DISCUSSION

Results of previous research point to the mutual and complex interactions that occur between cereals and both coarse- and small-seeded Fabaceae plants in mixed sowings (Michalska *et al.*, 2008; Jastrzębska *et al.*, 2015). However, there has been a lack of studies on the effects of strip intercropping of oats or spring cereals and Fabaceae. On the other hand the negative effect of maize in the proximity of soya plants has been frequently noted. According to studies by other authors (West and Griffith, 1992; Fortin *et al.*, 1994), the occurrence of maize next to soya caused a decrease in its seed yield by 10-30%. At the same time maize, depending on the position of its row of plants versus soya plants, gave a yield higher by 10–40% than from plants inside the field. According to Fortin *et al.* (1994), the unfavourable effect of maize on soya may be decreased by introducing between the species a narrow strip of oats or barley. Soya cultivation is unreliable in the conditions of central Europe and an alternative, among others, is yellow lupine. As demonstrated by the results of the present research, a similar arrangement in the case of substituting soya with yellow lupine would not give the expected results because the neighbouring effect of oats on yellow lupine was unfavourable. Yellow lupine in close proximity to oats, like next to spring triticale, gave a lower yield than from plants inside the field. At the same time, in both experiments, the distance of lupine from oats as well as, to a lesser extent, from spring triticale showed a clear tendency for higher yellow lupine yield in rows 3 and 4. The effect was repeated in all the study years, which is reflected in the average results from the years presented in this work. A probable explanation for this phenomenon may be the fact that the negative effect of cereal proximity on lupine was visible still in the second row, and, therefore, the plants involved in interspecific competition with oats or triticale had a decreased intraspecific competitive potential in relation to plants growing in the third row.

The competitive advantage of cereals over Fabaceae and the strong effects of intraspecific competition in their mixtures are demonstrated in the results of earlier research by Kotwica 1994 and Gałęzewski (2010a, 2010b). Those authors found that competition between triticale and lupine, and oats and lupine in mixed fields is characterized by strong asymmetry. The competitive potential of a single yellow lupine plant in relation to cereal was higher than that of a single oat or triticale plant in relation to lupine, although cereals were the dominant species, and their competitive advantage over lupine resulted from their higher density.

The asymmetric response of the spring cereals oats and triticale to the close proximity of yellow lupine and Fabaceae strips on joint occurrence of cereals, demonstrated by yield size, indicates that the strip intercropping system may be a method of increasing productivity.

CONCLUSIONS

1. The close proximity of oats was unfavourable for the growth and yield of yellow lupine plants, especially in the row situated directly next to the oats, and to a lesser, not significant extent, also in the second row.
2. The unfavourable proximity effect of spring triticale on yellow lupine was lower than for that of oats and was limited to the first, directly adjacent plant row.
3. Both oat and spring triticale plants that grew in the first row next to yellow lupine responded favourably to its proximity. The response of oats was stronger than that of spring triticale.
4. The estimated increase in the yield of oats and spring triticale grown in strip intercropping with yellow lupine, with 3 m wide rows, would be significantly higher than the decrease in yellow lupine yield in those sowings in comparison with single-species fields.

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SIEW PASOWY ŁUBINU ŻÓŁTEGO Z OWSEM I PSZENŻYTEM JARYM – ODDZIAŁYWANIE SĄSIEDZKIE

Streszczenie

W pracy wykorzystano wyniki dwóch doświadczeń polowych wykonanych w ramach badań nad siewami mieszanymi realizowanymi w latach 2005–2012 w stacji doświadczanej w Mochełku (53°13' N; 17°51' E). Celem eksperymentów było poznanie reakcji łubinu żółtego na sąsiedzkie występowanie owsa i pszenżyta jarego oraz oddziaływania rośliny bobowatej na zboża jare wraz z oszacowaniem efektów produkcyjnych uprawy pasowej tych gatunków. 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. Badano sąsiedztwo roślin łubinu żółtego i owsa (doświadczanie 1) oraz łubinu żółtego i pszenżyta jarego (doświadczenie 2). Sąsiedztwo owsa było niekorzystne dla roślin łubinu żółtego, a efekt ten został potwierdzony statystycznie w rzędzie bezpośrednio sąsiadującym z owsem. Negatywne skutki wystąpiły także w kolejnym rzędzie, choć były słabsze i na ogół nieistotne. Sąsiedztwo pszenżyta jarego było również niekorzystne dla roślin łubinu żółtego, ale w mniejszym stopniu niż w przypadku owsa, i ograniczało się tylko do pierwszego, bezpośrednio sąsiadującego rzędu łubinu żółtego. Pszenżyto jare, a zwłaszcza owies pozytywnie reagowały natomiast na sąsiedztwo łubinu żółtego, ale efekt ten wystąpił wyłącznie w pierwszym rzędzie roślin. Oszacowano, że przy uprawie pasowej owsa z łubinem żółtym i pszenżyta jarego z łubinem żółtym, przy pasach szerokości 3 m, można by uzyskać większe plony owsa o 13,9% i pszenżyta o 5,57%, ale jednocześnie mniejsze o 0,62-2,13% plony łubinu żółtego niż przy siewach jednogatunkowych.

Słowa kluczowe: oddziaływania międzygatunkowe, rośliny bobowate, uprawa pasowa, zboża jare