The effect of growing mixtures of spring barley cultivars on pest occurrence and yields

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ABSTRACT. Experiments were conducted in the 2010 and 2011 growing seasons at two locations differing in their edaphic and meteorological conditions to assess the effects of mixtures of spring barley cultivars on the occurrence of harmful pests and yields. The most significant pests in the experiment on spring barley in pure sowings and mixtures were cereal leaf beetles (*Oulema* spp.), with bird cherry-oat aphids (*Rhopalosiphum padi*) and grain aphids (*Sitobion avenae*) being somewhat fewer in number. With some mixtures, numbers of cereal leaf beetle larvae, bird cherry-oat aphids and grain aphids in comparison with pure stands were reduced. Grain yields from mixtures increased in comparison with those from pure sowings up to 6.48 dt·ha⁻¹ in 2010 and up to 3.99 dt ha⁻¹ in 2011.

KEY WORDS: spring barley, mixtures of cereal cultivars, cereal pests, yield.

INTRODUCTION

Protection systems for plant cultivation should include all available methods of pest control, but at the same time should take into consideration the natural processes of self-regulation that occur in agro-systems and try to support those processes (GACEK 2000). One of the methods of protecting plants from harmful insect species may be to introduce an alternative form of growing plants into production practice, i.e. sowing mixtures. Sowing mixtures (mainly cereal and cereal-leguminous) became widespread in Poland in the 1990s. By “mixtures” we mean both interspecific mixtures and inter-cultivar mixtures within the same

species. In recent years, mixtures (cereal and cereal-leguminous) have constituted 17-18% of the entire cereal cultivation acreage (www.stat.gov.pl).

Cereal mixtures may provide both organic and conventional producers with a more sustainable approach to improving yield levels and stability, as well as buffering against pests and diseases (MAHMOOD et al. 1991, MANTHEY & FEHRMANN 1993, KAUT et al. 2008). The most important advantage of growing cereal mixtures is the introduction of biodiversity which, because of the distinctive features of the introduced plants, makes better use of the environment's resources without disrupting its biological balance (MICHALSKI et al. 2004, SZEMPLIŃSKI & BUDZYŃSKI 2011). Moreover, in contrast to cultivar monocultures, a variety of biological (genetic and epidemiological) pest reducing mechanisms are active in genetically diverse sowing mixtures. The biological diversity within mixtures enables these to make better use of the habitat and agro-technical conditions; this is reflected in the higher and more stable yields compared to those of cultivars sown separately (GACEK & NADZIAK 2000, TRATWAL & WALCZAK 2010, WALCZAK et al. 2011). Numerous research results have shown that growing cereal mixtures reduces the pest infestation of a plantation (JACKOWSKI & HUREJ 1999, 2000, IDZIAK & MICHALSKI 2004, JAKUBIAK & GAŁĘZEWSKI 2007, GAŁĘZEWSKI 2008, WALCZAK et al. 2009, WALCZAK et al. 2011).

The aim of this research was to assess the effect of inter-cultivar spring barley sowing mixtures on pest occurrence and yield.

MATERIAL AND METHODS

The experiments were conducted during two growing seasons (2010 and 2011) in two locations with different soils and meteorological conditions, i.e. the Bąków site of "Plant Breeding Smolice Ltd. – IHAR Group" (Opole province 50°57'21" N 18°18'30" E) and the Research Station for Variety Testing at Kościelna Wieś (Wielkopolska province 51°47'08" N 18°00'34" E). The experimental material consisted of five cultivars of spring barley: Antek, Basza, Blask, Skarb and Rubinek, as well as all possible mixtures within the group. The sowing norm was 300 grains m⁻² and the proportions of the mixture components were 1:1 or 1:1:1 in the case of two or three-component mixtures. Varieties were selected on the basis of similar height, morphological differences in leaf shape and cultivation acreage.

The experiments were conducted in four replicates in a configuration of complete blocks on plots of 10 m² (10 m × 1 m) (Bąków) and 15 m² (10 m × 1.5 m) (Kościelna Wieś). During a growing season, the occurrence of pests on plants was determined every 7-10 days. No fungicides or insecticides were applied. The experiment at Bąków in 2010 was conducted in podzolic soil (podzols; FAO-WRB 2006.2007; class IVa, complex III); the

forecrop was winter rape. In the next growing season the experiment was also done in podzolic soil after winter rape (class IIIb, complex III). In both years fertilisers were applied: N–18 kg·ha⁻¹, P–60 kg·ha⁻¹, K–90 kg·ha⁻¹, followed by N–156 kg·ha⁻¹ applied as manure or fertiliser to the soil surface. In both growing seasons at Kościelna Wieś the experiments were conducted on an acid brown soil (cambisols; FAO-WRB 2006.2007; class IIa, complex II). We applied the following amounts of fertiliser: N–18 kg·ha⁻¹, P–80 kg·ha⁻¹, K–120 kg·ha⁻¹ and next N–156 kg·ha⁻¹. The forecrop was maize.

The abundance of pests was determined by analysing 6 straws at 5 randomly selected locations per plot (a total of 30 straws or ears) in all plots in each replicate: the numbers of cereal leaf beetles, aphids and leaf-mining flies were recorded. Then the percentage of reduction was calculated for the more numerous pests by comparing the numbers of pests on e.g. the Antek/Blask mixture to the numbers of pests on pure stands of Antek and Blask. The yields were determined for all plots. After harvesting with a combine harvester, the yield from each plot was weighed and converted into dt·ha⁻¹.

The results were analysed statistically. Three-way analysis of variance (ANOVA) was applied to check the null hypothesis of no influence of locations, years and cultivars/mixtures as well as the hypotheses of the lack of influence of interaction of locations × years, locations × cultivars/mixtures, years × cultivars and locations × years × cultivars/mixtures on the number of cereal leaf beetles and yields. One-way ANOVA was applied to check the hypothesis of no effect of cultivars/mixtures on aphid abundance in 2010. In the second year of the experiment (2011) two-way (locations, cultivars/mixtures) ANOVA was applied to determine which factors had an influence on the abundance of aphids. Mean values and standard deviations were estimated. Relevant contrast analyses were applied to determine the differences between the cultivars and their mixtures, and between two-component mixtures and three-component mixtures with respect to these factors. Pearson's linear correlations of these factors were assessed on the basis of the relevant correlation coefficients (KOZAK et al. 2010, SZULC et al. 2011), determined from cultivar averages calculated for each location and each year separately. All statistical analyses were performed using *GenStat v. 7.1* software (PAYNE et al. 2003).

RESULTS

The most abundant pests on spring barley plots were larvae of the cereal leaf beetle. Less frequent pests included bird cherry-oat aphids and grain aphids, whose occurrence was noted at the end of the cereal growing period in 2011 (Tables 1-4).

Other pests, which occurred in small numbers included leaf-mining flies (Agromyzidae), thrips (Thripidae), bishop's mitre shieldbugs (*Aelia acuminata* LINNAEUS,

1758) and tortoise bugs (*Eurygaster maura* LINNAEUS, 1758). There were also sporadic appearances of leafhoppers (*Cicadellidae*), chloropid gnat flies (*Chlorops pumilionis* BJERKANDER, 1778) and tortricid moths (*Cnephasia* spp.).

Table 1. Average abundance/reduction of cereal leaf beetle larvae (*Oulema* spp.) ($\pm$ standard deviation) on spring barley in pure sowings and mixtures in the 2010 growing season.

Combinations	Cereal leaf beetle larvae			
	Kościelna Wieś		Bąków	
	Average number of larvae / 30 straws	Abundance reduction %	Average number of larvae / 30 straws	Abundance reduction %
Basza	7.25 $\pm$ 2.63		9.5 $\pm$ 2.38	
Blask	6.0 $\pm$ 2.944		10.0 $\pm$ 5.416	
Antek	4.75 $\pm$ 4.573		6.5 $\pm$ 1.732	
Skarb	6.5 $\pm$ 3.697		9.25 $\pm$ 2.5	
Rubinek	9.25 $\pm$ 3.403		7.5 $\pm$ 2.646	
Basza/Blask	5.25 $\pm$ 2.986	20.75	11.75 $\pm$ 4.924	no reduction
Antek/Basza	5.5 $\pm$ 3.0	8.33	7.75 $\pm$ 2.217	3.12
Basza/Skarb	6.75 $\pm$ 3.686	1.81	7.75 $\pm$ 3.304	17.33
Basza/Rubinek	5.75 $\pm$ 4.349	30.30	11.25 $\pm$ 5.123	no reduction
Antek/Blask	9.5 $\pm$ 4.435	no reduction	4.75 $\pm$ 2.217	42.42
Antek/Skarb	7.5 $\pm$ 3.317	no reduction	8.25 $\pm$ 3.403	no reduction
Antek/Rubinek	7.25 $\pm$ 2.217	no reduction	9.25 $\pm$ 3.202	no reduction
Blask/Skarb	5.75 $\pm$ 3.202	8.0	9.0 $\pm$ 1.826	6.49
Blask/Rubinek	6.75 $\pm$ 2.217	11.47	9.25 $\pm$ 4.787	no reduction
Rubinek/Skarb	3.75 $\pm$ 3.304	51.74	9.25 $\pm$ 3.403	no reduction
Antek/Basza/Blask	7.75 $\pm$ 3.862	no reduction	10.0 $\pm$ 4.082	no reduction
Antek/Blask/Skarb	9.25 $\pm$ 2.986	no reduction	11.5 $\pm$ 3.697	no reduction
Antek/Basza/Rubinek	7.25 $\pm$ 4.573	no reduction	14.5 $\pm$ 3.109	no reduction
Antek/Blask/Rubinek	8.0 $\pm$ 3.742	no reduction	12.75 $\pm$ 4.573	no reduction
Antek/Basza/Skarb	6.0 $\pm$ 2.0	1.71	12.75 $\pm$ 3.403	no reduction
Blask/Rubinek/Skarb	8.0 $\pm$ 4.243	no reduction	16.5 $\pm$ 4.655	no reduction
Basza/Blask/Rubinek	8.25 $\pm$ 4.031	no reduction	13.0 $\pm$ 3.83	no reduction
Antek/Rubinek/Skarb	11.0 $\pm$ 5.292	no reduction	13.25 $\pm$ 4.349	no reduction
Basza/Blask/Skarb	11.25 $\pm$ 6.602	no reduction	8.75 $\pm$ 3.594	7.77
Basza/Rubinek/Skarb	8.0 $\pm$ 4.967	no reduction	15.75 $\pm$ 3.948	no reduction

Cereal leaf beetle larvae

In the 2010 growing season at Kościelna Wieś the abundance of cereal leaf beetle larvae in the experiment involving spring barley and its mixtures was reduced in the following mixtures: Basza/Blask, Antek/Basza, Basza/Skarb, Basza/Rubinek, Blask/Skarb,

Blask/Rubinek, Rubinek/Skarb and Antek/Basza/Skarb ($p < 0.05$). Likewise, at Bąków there was a reduction in numbers of cereal leaf beetle in the following mixtures: Antek/Basza, Basza/Skarb, Antek/Blask, Blask/Skarb and Basza/Blask/Skarb ($p < 0.05$) (Table 1).

In the 2011 growing season at Kościelna Wieś there was a reduction in cereal leaf beetle numbers in the experiment involving spring barley and the following mixtures: Basza/Blask, Antek/Basza, Basza/Skarb, Basza/Rubinek, Antek/Blask, Antek/Skarb, Antek/Rubinek, Blask/Skarb, Blask/Rubinek, Rubinek/Skarb, as well as Antek/Blask/Skarb and Antek/Blask/Rubinek ($p < 0.05$). At Bąków the cereal leaf beetle abundance was lower in the following mixtures: Basza/Blask, Antek/Basza, Basza/Skarb, Antek/Blask, Antek/Skarb, Antek/Rubinek, Blask/Rubinek and Rubinek/Skarb ($p < 0.05$) (Table 2).

Table 2. Average abundance/reduction of cereal leaf beetle larvae (*Oulema* spp.) on spring barley in pure sowings and mixtures in the 2011 growing season.

Combinations	Cereal leaf beetle larvae			
	Kościelna Wieś		Bąków	
	Average number of larvae / 30 straws	Abundance reduction %	Average number of larvae / 30 straws	Abundance reduction %
Basza	11.25 ± 3.304		3.0 ± 0.816	
Blask	14.75 ± 6.397		3.75 ± 0.5	
Antek	15.0 ± 4.83		3.75 ± 0.5	
Skarb	10.25 ± 3.202		2.5 ± 1.0	
Rubinek	9.5 ± 1.291		3.0 ± 1.826	
Basza/Blask	7.5 ± 2.887	42.30	2.75 ± 2.217	18.51
Antek/Basza	9.5 ± 4.796	27.61	2.5 ± 1.915	25.92
Basza/Skarb	9.5 ± 4.726	11.62	2.5 ± 1.291	23.07
Basza/Rubinek	7.75 ± 3.862	25.30	3.5 ± 1.0	no reduction
Antek/Blask	8.75 ± 1.258	41.17	3.25 ± 2.63	13.33
Antek/Skarb	11.5 ± 4.435	8.91	3.25 ± 1.5	10.34
Antek/Rubinek	9.0 ± 3.83	22.44	3.0 ± 1.414	11.11
Blask/Skarb	8.25 ± 0.5	34.0	5.25 ± 3.202	no reduction
Blask/Rubinek	10.75 ± 7.228	11.34	2.5 ± 1.0	25.92
Rubinek/Skarb	9.0 ± 4.546	8.86	1.75 ± 2.217	46.15
Antek/Basza/Blask	14.25 ± 7.182	no reduction	4.5 ± 1.0	no reduction
Antek/Blask/Skarb	12.0 ± 1.414	9.09	6.0 ± 2.449	no reduction
Antek/Basza/Rubinek	12.25 ± 4.646	no reduction	6.25 ± 4.573	no reduction
Antek/Blask/Rubinek	10.75 ± 4.5	16.98	4.0 ± 1.414	no reduction
Antek/Basza/Skarb	12.25 ± 4.349	no reduction	8.5 ± 2.517	no reduction
Blask/Rubinek/Skarb	12.25 ± 6.021	no reduction	3.5 ± 2.646	no reduction
Basza/Blask/Rubinek	13.5 ± 5.802	no reduction	4.75 ± 1.708	no reduction
Antek/Rubinek/Skarb	15.0 ± 4	no reduction	6.0 ± 4.32	no reduction
Basza/Blask/Skarb	13.0 ± 4.967	no reduction	4.0 ± 2.582	no reduction
Basza/Rubinek/Skarb	13.25 ± 4.113	no reduction	3.5 ± 2.082	no reduction

Table 3. Assessment of differences between the cultivars and their mixtures with regard to the analysed features as a result of contrast analysis

Contrast	Yield			Cereal leaf beetles						Aphids	
	B [#] 2010	B 2011	KW [#] 2010	KW 2011	B 2010	B 2011	KW 2010	KW 2011	B 2011	KW 2010	KW 2011
Basza – mixtures of Basza	-13.2***	0.3	-0.8	-5.1	-2.9	0.3	-2.2	5.4*	-1.1	1.1	-2.1
Blask – mixtures of Blask	-6.1**	1.4	0.9	-6.3	-3.7	-1.3	-1.6	-1.5	-4.0	3.2	-1.9
Antek – mixtures of Antek	-4.9*	-1.5	-0.1	-0.7	-0.5	1.0	0.1	2.9	5.2	-1.0	-5.5
Skarb – mixtures of Skarb	-2.9	2.1	-0.4	1.5	3.7	3.0*	-0.3	1.4	-2.5	0.5	24.3***
Rubinek – mixtures of Rubinek	-1.8	0.5	0.3	-4.5	2.7	5.0***	-1.6	1.1	9.5	0.8	9.1
Cultivars – all mixtures	-5.3***	0.57	0.2	-2.7	-0.11	1.51**	-1.3	1.8	1.4	0.71	4.9
Cultivars – two- component mixtures	-2.8*	0.69	1.2	-1.5	0.0	1.1	-2.2*	1.4	1.6	-0.2	5.5
Cultivars – three- component mixtures	-7.8***	0.45	-0.9	-4.0*	-0.3	19.2**	-0.4	2.1	1.2	1.62	4.3
Two-component and three-component mixtures	-5.02***	-0.24	-2.09*	-2.5	-0.28	0.83	1.8*	0.7	-0.4	1.83*	-1.2

B – Bąków, KW – Kościelna Wieś

* P < 0.05

** P < 0.01

*** P < 0.001

ANOVA indicated the significant influence of locations ($F_{1,300} = 33.74$, $p < 0.001$), years ($F_{1,300} = 12.30$, $p < 0.001$), cultivars/mixtures ($F_{24,300} = 2.70$, $p < 0.001$) and the locations $\times$ years interaction of ($F_{1,300} = 204.57$, $p < 0.001$) on the abundance of cereal leaf beetles. With regard to the abundance of cereal leaf beetles, the majority of significant contrasts were noted at Bąków in 2011 (Table 3). This implies means that using mixtures does reduce the numbers of cereal leaf beetles. The situation was similar in the case of aphids, especially at Kościelna Wieś, in the second year of this research.

Table 4. Average abundance/reduction of bird cherry-oat aphids on leaves and stalks of spring barley in pure sowings and mixtures in the 2010 growing season.

Combinations	Bird cherry-oat aphids	
	Kościelna Wieś	
	Average number of aphids / 30 straws	Abundance reduction %
Basza	1.5 ± 0.577	
Blask	1.0 ± 0	
Antek	4.25 ± 4.573	
Skarb	1.5 ± 0.577	
Rubinek	3.0 ± 0.816	
Basza/Blask	1.5 ± 1.915	no reduction
Antek/Basza	5.0 ± 10	no reduction
Basza/Skarb	0.75 ± 1.5	50.0
Basza/Rubinek	1.75 ± 1.5	22.22
Antek/Blask	3 ± 0.816	no reduction
Antek/Skarb	3 ± 0.816	no reduction
Antek/Rubinek	4.25 ± 1.708	no reduction
Blask/Skarb	1.0 ± 0	20.0
Blask/Rubinek	1.5 ± 0.577	25.0
Rubinek/Skarb	2.25 ± 0.957	no reduction
Antek/Basza/Blask	1.0 ± 1.414	55.10
Antek/Blask/Skarb	13.25 ± 13.401	no reduction
Antek/Basza/Rubinek	3.5 ± 1.291	no reduction
Antek/Blask/Rubinek	2.5 ± 1.291	8.17
Antek/Basza/Skarb	2.5 ± 1.291	no reduction
Blask/Rubinek/Skarb	1.25 ± 0.957	31.12
Basza/Blask/Rubinek	1.75 ± 0.957	0.82
Antek/Rubinek/Skarb	2.75 ± 0.5	4.77
Basza/Blask/Skarb	1.0 ± 0.816	24.24
Basza/Rubinek/Skarb	2.25 ± 0.957	no reduction

Aphids

The observed abundance of bird cherry-oat aphids in the experiments involving spring barley and its mixtures was also small owing to the unfavourable weather conditions (excessive rainfall). A reduction in their abundance was noted only at Kościelna Wieś in the following mixtures: Basza/Skarb, Basza/Rubinek, Blask/Skarb, Blask/Rubinek, Antek/Basza/Blask, Antek/Blask/Rubinek, Blask/Rubinek/Skarb, Basza/Blask/Rubinek, Antek/Rubinek/Skarb, Basza/Blask/Skarb (Table 4). Numbers of grain aphids were also small.

Table 5. Average abundance/reduction of grain aphids on ears of spring barley in pure sowings and mixtures in the 2011 growing season.

Combinations	Grain aphids			
	Kościelna Wieś		Baków	
	Average number of grain aphids / 30 straws	Abundance reduction %	Average number of grain aphids / 30 straws	Abundance reduction %
Basza	13.75 ± 18.715		7.0 ± 3.367	
Blask	2.5 ± 2.082		18.25 ± 11.026	
Antek	2.75 ± 4.856		9.5 ± 5.745	
Skarb	4.5 ± 3.697		8.25 ± 6.551	
Rubinek	5.5 ± 9.11		8.0 ± 3.559	
Basza/Blask	0.25 ± 0.5	96.92	5.0 ± 3.559	60.39
Antek/Basza	4.5 ± 4.796	45.45	8.0 ± 8.641	3.03
Basza/Skarb	4.0 ± 6.055	56.16	9.75 ± 10.874	no reduction
Basza/Rubinek	8.75 ± 5.909	9.09	14.75 ± 17.858	no reduction
Antek/Blask	1.5 ± 1.915	42.85	8.75 ± 7.136	36.93
Antek/Skarb	1.25 ± 0.957	65.51	19.0 ± 6.481	no reduction
Antek/Rubinek	1.25 ± 0.957	69.69	6.0 ± 3.742	31.42
Blask/Skarb	3.75 ± 3.096	no reduction	12.25 ± 11.815	7.54
Blask/Rubinek	10.0 ± 6.976	no reduction	9.0 ± 7.165	31.42
Rubinek/Skarb	3.75 ± 4.5	28.57	9.75 ± 5.679	no reduction
Antek/Basza/Blask	3.0 ± 2.708	52.15	19.0 ± 20.461	no reduction
Antek/Blask/Skarb	4.25 ± 5.315	no reduction	8.0 ± 6.164	32.65
Antek/Basza/Rubinek	30.5 ± 21.142	no reduction	7.5 ± 7.416	7.23
Antek/Blask/Rubinek	6.75 ± 4.924	no reduction	19.75 ± 14.953	no reduction
Antek/Basza/Skarb	14.5 ± 10.661	no reduction	19.25 ± 18.228	no reduction
Blask/Rubinek/Skarb	5.75 ± 4.856	no reduction	10.5 ± 8.66	7.77
Basza/Blask/Rubinek	5.5 ± 4.435	23.37	8.5 ± 7.047	22.53
Antek/Rubinek/Skarb	13.25 ± 10.404	no reduction	18.75 ± 15.84	no reduction
Basza/Blask/Skarb	8.0 ± 4.243	no reduction	9.25 ± 6.652	11.62
Basza/Rubinek/Skarb	19.0 ± 19.026	no reduction	13.5 ± 5.066	no reduction

At Kościelna Wieś grain aphid abundance in the experiment involving spring barley and its mixtures was lower in the following mixtures: Basza/Blask, Antek/Basza, Basza/Skarb, Basza/Rubinek, Antek/Blask, Antek/Skarb, Antek/Rubinek, Rubinek/Skarb, Antek/Basza/Blask and Basza/Blask/Rubinek ($p < 0.05$).

At Bąków grain aphid abundance was reduced in the following mixtures: Basza/Blask, Antek/Basza, Antek/Blask, Antek/Rubinek, Blask/Skarb, Blask/Rubinek, Antek/Blask/Skarb, Antek/Basza/Rubinek, Blask/Rubinek/Skarb, Basza/Blask/Rubinek and Basza/Blask/Skarb ($p < 0.05$) (Table 5).

The abundance of aphids was determined by the kind of cultivars/mixtures ($F_{24,75} = 3.77$, $p < 0.001$ and $F_{24,150} = 1.64$, $p = 0.040$ for the first and second replicates respectively) and the locations ($F_{1,150} = 10.76$, $p = 0.001$) in the second year of the experiment (Table 3).

In general, the correlation analysis did not indicate any correlation between the features analysed in the experiment. The only such case was observed at Bąków in 2011 when the abundance of aphids was significantly correlated with the abundance of cereal leaf beetles ($r = 0.4048$, $p = 0.0447$) (Table 3).

Yield

The grain yield was statistically significantly affected by locations ($F_{1,300} = 398.44$, $p < 0.001$), years ($F_{1,300} = 478.36$, $p < 0.001$), cultivars/mixtures ($F_{24,300} = 2.26$, $p < 0.001$), the locations $\times$ years interaction ($F_{1,300} = 256.18$, $p < 0.001$) and the locations $\times$ years $\times$ cultivars/mixtures interaction ($F_{24,300} = 1.86$, $p = 0.010$). The grain yield in the mixtures was obtained by calculating the value of the expected yield – the average yield from pure sowings of the mixture components separately – compared to the yield obtained from the mixture (Table 3).

In 2010 the yield from pure sowings of the spring barley cultivars at Bąków varied between $45.78 \text{ dt} \cdot \text{ha}^{-1}$ (Antek) and $63.68 \text{ dt} \cdot \text{ha}^{-1}$ (Skarb). Among the mixtures, a yield in excess of $60 \text{ dt} \cdot \text{ha}^{-1}$ was obtained from the following combinations: Basza/Skarb, Blask/Rubinek, Rubinek/Skarb, Blask/Rubinek/Skarb, Antek/Rubinek/Skarb and Basza/Rubinek/Skarb (Table 5). With the exception of two combinations (Basza/Blask and Blask/Skarb) there was an increase in the yield obtained from mixtures as opposed to pure sowings from $0.55 \text{ dt} \cdot \text{ha}^{-1}$ (Basza/Blask/Rubinek) to $3.86 \text{ dt} \cdot \text{ha}^{-1}$ (Basza/Skarb) (Table 6).

Table 6. Grain yield of spring barley cultivars ($\text{dt}\cdot\text{ha}^{-1}$) and their mixtures at Bąków in the 2010 growing season.

Combination	Yield	Average from pure sowings	Yield increase
Basza	54.60 ± 3.93		
Blask	53.93 ± 2.319		
Antek	45.78 ± 4.323		
Skarb	63.68 ± 4.529		
Rubinek	62.17 ± 3.597		
Basza/Blask	54.2 ± 8.774	54.26	-0.26
Antek/Basza	52.6 ± 3.601	50.19	+2.41
Basza/Skarb	63.0 ± 3.04	59.14	+3.86
Basza/Rubinek	59.55 ± 5.566	58.39	+1.16
Antek/Blask	52.28 ± 2.728	49.85	+2.43
Antek/Skarb	55.58 ± 4.225	54.73	+0.85
Antek/Rubinek	54.83 ± 4.978	53.98	+0.85
Blask/Skarb	58.2 ± 3.556	58.80	-0.60
Blask/Rubinek	60.03 ± 3.662	58.05	+1.98
Rubinek/Skarb	65.32 ± 4.578	62.93	+2.40
Antek/Basza/Blask	54.1 ± 2.072	51.44	+2.66
Antek/Blask/Skarb	56.15 ± 5.508	54.46	+1.69
Antek/Basza/Rubinek	57.33 ± 1.613	54.19	+3.14
Antek/Blask/Rubinek	56.88 ± 1.408	53.96	+2.92
Antek/Basza/Skarb	57.15 ± 3.997	54.96	+2.19
Blask/Rubinek/Skarb	62.3 ± 4.657	59.93	+2.37
Basza/Blask/Rubinek	57.45 ± 5.024	56.90	+0.55
Antek/Rubinek/Skarb	60.42 ± 1.245	57.21	+3.22
Basza/Blask/Skarb	59.08 ± 2.53	57.40	+1.68
Basza/Rubinek/Skarb	63.45 ± 3.575	60.15	+3.30

In the same experiment conducted at Kościelna Wieś particular cultivars of spring barley produced yields between $53.71 \text{ dt}\cdot\text{ha}^{-1}$ (Basza) and $62.36 \text{ dt}\cdot\text{ha}^{-1}$ (Blask); these values were higher than the ones obtained at Bąków. The inter-cultivar mixtures produced yields between $57.06 \text{ dt}\cdot\text{ha}^{-1}$ (Antek/Rubinek/Skarb) and $62.98 \text{ dt}\cdot\text{ha}^{-1}$ (Blask/Skarb). With the exception of four combinations (Antek/Blask/Rubinek, Blask/Rubinek/Skarb, Basza/Blask/Rubinek and Antek/Rubinek/Skarb) there was an increase in the yield obtained from mixtures as opposed to pure sowings at levels between $0.57 \text{ dt}\cdot\text{ha}^{-1}$ (Basza/Blask) and $6.48 \text{ dt}\cdot\text{ha}^{-1}$ (Basza/Skarb) (Table 7).

In 2011 the yields of the particular spring barley cultivars were lower than in 2010 at both Bąków and Kościelna Wieś.

Table 7. Grain yield of spring barley cultivars ($\text{dt}\cdot\text{ha}^{-1}$) and their mixtures at Kościelna Wieś in the 2010 growing season.

Combination	Yield	Average from pure sowings	Yield increase
Basza	53.71 ± 3.946		
Blask	62.36 ± 6.627		
Antek	59.53 ± 2.785		
Skarb	58.11 ± 4.531		
Rubinek	58.68 ± 4.954		
Basza/Blask	58.61 ± 4.04	58.03	+0.57
Antek/Basza	60.52 ± 4.156	56.62	+3.90
Basza/Skarb	62.39 ± 2.518	55.91	+6.48
Basza/Rubinek	59.88 ± 2.974	56.19	+3.69
Antek/Blask	59.08 ± 3.261	60.94	+0.96
Antek/Skarb	59.71 ± 2.835	58.82	+0.89
Antek/Rubinek	59.83 ± 3.392	59.10	+0.73
Blask/Skarb	62.98 ± 3.665	60.23	+2.75
Blask/Rubinek	62.97 ± 2.652	60.52	+2.45
Rubinek/Skarb	59.14 ± 2.072	58.39	+0.75
Antek/Basza/Blask	59.58 ± 2.642	58.53	+1.05
Antek/Blask/Skarb	61.52 ± 5.686	60.00	+1.52
Antek/Basza/Rubinek	59.36 ± 3.256	57.31	+2.05
Antek/Blask/Rubinek	57.77 ± 2.751	60.19	-2.49
Antek/Basza/Skarb	59.55 ± 4.378	57.12	+2.43
Blask/Rubinek/Skarb	57.29 ± 3.594	59.72	-2.43
Basza/Blask/Rubinek	57.76 ± 5.139	58.25	-0.49
Antek/Rubinek/Skarb	57.06 ± 6.135	58.77	-1.71
Basza/Blask/Skarb	59.73 ± 1.347	58.06	+1.67
Basza/Rubinek/Skarb	61.91 ± 7.596	56.83	+5.08

The pure sowings of spring barley cultivars at Bąków produced yields between $35.38 \text{ dt}\cdot\text{ha}^{-1}$ (Blask) and $40.88 \text{ dt}\cdot\text{ha}^{-1}$ (Rubinek). Among the mixtures, a yield above $40 \text{ dt}\cdot\text{ha}^{-1}$ was obtained from the following combinations: Basza/Rubinek, Antek/Rubinek, Rubinek/Skarb, Antek/Basza/Rubinek and Antek/Rubinek/Skarb (Table 7). With the exception of five combinations (Basza/Blask, Basza/Skarb, Blask/Rubinek, Basza/Blask/Skarb and Basza/Rubinek/Skarb) there was an increase in the yields obtained from mixtures as opposed to pure sowings at levels between $0.03 \text{ dt}\cdot\text{ha}^{-1}$ (Antek/Basza/Blask') and $2.57 \text{ dt}\cdot\text{ha}^{-1}$ (Basza/Rubinek) (Table 8).

Table 8. Grain yield of spring barley cultivars ($\text{dt}\cdot\text{ha}^{-1}$) and their mixtures at Bąków in the 2011 growing season.

Combination	Yield	Average from pure sowings	Yield increase
Basza	36.73 ± 4.917		
Blask	35.38 ± 2.537		
Antek	39.55 ± 3.637		
Skarb	39.38 ± 2.966		
Rubinek	40.88 ± 3.348		
Basza/Blask	35.67 ± 2.894	36.06	-0.38
Antek/Basza	39.97 ± 6.289	38.14	+1.84
Basza/Skarb	37.9 ± 5.05	38.06	-0.16
Basza/Rubinek	41.38 ± 3.439	38.81	+2.57
Antek/Blask	37.63 ± 2.155	37.47	+0.16
Antek/Skarb	39.93 ± 1.509	39.47	+0.46
Antek/Rubinek	41.92 ± 3.115	40.22	+1.71
Blask/Skarb	38.58 ± 3.918	37.38	+1.2
Blask/Rubinek	38.02 ± 2.457	38.13	-0.10
Rubinek/Skarb	40.38 ± 2.5	40.13	+0.25
Antek/Basza/Blask	37.25 ± 2.774	37.22	+0.03
Antek/Blask/Skarb	38.4 ± 4.298	38.10	+0.30
Antek/Basza/Rubinek	40.67 ± 2.147	39.04	+1.64
Antek/Blask/Rubinek	39.02 ± 2.576	38.60	+0.43
Antek/Basza/Skarb	39.0 ± 2.969	38.55	+0.45
Blask/Rubinek/Skarb	38.6 ± 1.768	38.55	+0.05
Basza/Blask/Rubinek	39.6 ± 2.606	37.66	+1.94
Antek/Rubinek/Skarb	40.8 ± 3.385	39.94	+0.86
Basza/Blask/Skarb	36.35 ± 3.793	37.16	-0.81
Basza/Rubinek/Skarb	37.92 ± 2.147	39.00	-1.07

In the same experiment conducted at Kościelna Wieś the particular cultivars of spring barley produced yields between $51.67 \text{ dt}\cdot\text{ha}^{-1}$ (Antek) and $61.74 \text{ dt}\cdot\text{ha}^{-1}$ (Rubinek); these values were higher than those obtained at Bąków. The inter-cultivar mixtures produced yields between $51.68 \text{ dt}\cdot\text{ha}^{-1}$ (Antek/Skarb) and $60.97 \text{ dt}\cdot\text{ha}^{-1}$ (Basza/Blask/Skarb). At Kościelna Wieś both pure sowings and mixtures of spring barley cultivars gave bigger yields than at Bąków, but only eight combinations indicated an increase in yield as compared to pure sowings. The increase in yield obtained from a mixture as opposed to a pure sowing varied between $0.98 \text{ dt}\cdot\text{ha}^{-1}$ (Blask/Skarb) and $3.99 \text{ dt}\cdot\text{ha}^{-1}$ (Basza/Blask/Skarb) (Table 9).

Table 9. Grain yield of spring barley cultivars ($\text{dt}\cdot\text{ha}^{-1}$) and their mixtures at Kościelna Wieś in the 2011 growing season.

Combination	Yield	Average from pure sowings	Yield increase
Basza	53.23 ± 9.294		
Blask	60.97 ± 12.569		
Antek	51.67 ± 4.916		
Skarb	56.74 ± 10.053		
Rubinek	61.74 ± 5.574		
Basza/Blask	53.45 ± 7.929	57.10	-3.65
Antek/Basza	51.8 ± 7.049	52.45	-0.65
Basza/Skarb	54.32 ± 5.985	54.89	-0.57
Basza/Rubinek	59.14 ± 7.148	57.48	+1.66
Antek/Blask	55.21 ± 11.249	56.32	-1.11
Antek/Skarb	51.68 ± 6.907	54.20	-2.52
Antek/Rubinek	53.89 ± 7.409	56.70	-2.81
Blask/Skarb	59.83 ± 9.879	58.85	+0.98
Blask/Rubinek	58.79 ± 4.684	61.35	-2.56
Rubinek/Skarb	57.26 ± 6.727	59.24	-1.98
Antek/Basza/Blask	56.45 ± 2.042	55.29	+1.16
Antek/Blask/Skarb	55.52 ± 8.902	56.46	-0.94
Antek/Basza/Rubinek	58.71 ± 5.115	55.55	+3.16
Antek/Blask/Rubinek	56.5 ± 4.775	58.13	-1.63
Antek/Basza/Skarb	53.71 ± 6.305	53.88	-0.17
Blask/Rubinek/Skarb	60.27 ± 5.975	59.82	+1.09
Basza/Blask/Rubinek	59.77 ± 6.814	58.65	+1.12
Antek/Rubinek/Skarb	59.08 ± 2.836	56.72	+2.36
Basza/Blask/Skarb	60.97 ± 2.179	56.98	+3.99
Basza/Rubinek/Skarb	55.65 ± 7.818	57.24	-1.59

The differences between the cultivars and their mixtures with respect to the analysed features in particular locations and years were assessed using relevant contrast values (Table 5). No significant difference in yields was noted at Bąków in 2011 for the Skarb cultivar and its mixtures, or for the Rubinek cultivar and its mixtures. For the remaining cultivars the yield was significantly larger when using mixtures rather than pure sowings (Table 3). Using three-component mixtures resulted in a bigger yield than that obtained from two-component mixtures. In the experiment at Kościelna Wieś only two contrasts regarding the grain yield were significant: between the two-component and three-component mixtures (in 2010) and between all five cultivars and all mixtures (in 2011).

DISCUSSION

According to some authors (TRENBATH 1993, BAILEY & LAZAROVITS 2003, KAUT et al. 2008) there are several mechanisms by which cereal mixtures can affect crop pests and diseases. Practically and experimentally it has been demonstrated (TRENBATH 1993, GACEK et al. 1997a, GACEK et al. 1997b, JACKOWSKI & HUREJ 1999, KAUT et al. 2008, WALCZAK et al. 2011) that components of mixtures are often less damaged by pests and disease organisms compared to pure stands. Many authors (TRENBATH 1993, KAUT et al. 2008) point out that the presence of associated plants in a mixture can lower the population growth rate of the attacking organisms. Firstly, the associates cause plants of the attacked component to be less suitable hosts; secondly, they interfere directly with the activities of the attacker; and finally, they change the environment within the intercrop so that natural enemies of the attacker are favoured (TRENBATH 1993).

The results of investigations by WALCZAK et al. (2009) show that cultivation of winter wheat in mixtures rather than pure stands resulted in increased yields (by up to $1.5 \text{ dt} \cdot \text{ha}^{-1}$ compared to pure stands) and reduced the population of cereal leaf beetles (by up to 41.6% in comparison to pure stands). In experiments carried out in the growing seasons 2007/2008 and 2008/2009 (WALCZAK et al. 2011) with three winter wheat cultivars – Bogatka, Sława and Nutka and their mixtures – it was found that *Oulema* spp. were the dominant species in both years. Reductions of 1-28.8% in the numbers of cereal leaf beetle larvae and of 0.7-47.1% in aphid numbers compared to pure stands were recorded with the mixtures. Yields also increased by up to $5.7 \text{ dt} \cdot \text{ha}^{-1}$ compared to pure stands. Field experiments conducted in 2006 and 2007 (GAŁĘZEWSKI 2008) with spring cereal mixtures (wheat, barley and oats) showed reductions in pest occurrence, namely larvae of *Oulema* spp. (6.1-39.7%) and aphids (2.2-62.4%) compared with pure stands. Yield increases of 0.3 – $8.0 \text{ dt} \cdot \text{ha}^{-1}$ were obtained in mixtures as compared to pure stands. The results of field experiments (JAKUBIAK & GAŁĘZEWSKI 2007) conducted in 2004 – 2005 with spring cereals (wheat, barley and oats) and their mixtures showed a reduction in *Oulema* spp. larvae in the mixtures (6.98%-36.77% compared to pure stands) and a yield increase of up to $2.3 \text{ dt} \cdot \text{ha}^{-1}$ in comparison with pure stands. In a field experiment carried out in 1996-1999 with spring barley and oats growing in mixtures in different proportions (75%/25%, 50%/50%) and in pure stands Idziak & Michalski (2004) showed that *Oulema* spp. damaged oats more often than spring barley. No influence of cereals growing in mixtures on damage caused by cereal leaf beetle larvae was observed. The extent of damage to plants in mixtures was the same as that to species cultivated in pure stands. JACKOWSKI & HUREJ (1999) stated that spring cereal mixtures (barley, wheat, oats) could reduce stand infestation by cereal aphids *Sitobion avenae* FABRICIUS, 1774. In an experiment with spring cereals (barley, oats and wheat) grown in five mixtures these same authors suggested that *Stenothrips graminum*

UZEL, 1895 responded to mixtures with more intensive aggregation on oat tillers, which resulted in the overall pest abundance being similar in mixtures and in pure stands of oats (JACKOWSKI & HUREJ 2000).

CONCLUSIONS

1. In the 2010 and 2011 growing seasons the most significant pests in experiments on spring barley in pure sowings and mixtures were cereal leaf beetles (*Oulema* spp.), and, to a lesser extent, bird cherry-oat aphids (*Rhopalosiphum padi* LINNAEUS, 1758) and grain aphids (*Sitobion avenae*).
2. Despite the plant diversity within the plot, there was in most cases no reduction in the abundance of cereal leaf beetle larvae in mixtures during both growing seasons compared to pure sowings.
3. Plant diversity within the plot reduced the abundance of grain aphids (*Sitobion avenae*) only in some cases on grain ears in 2011 at Kościelna Wieś (9.09-96.92%) and Bąków (3.03-60.39%) as compared to pure sowings.
4. The yields of some spring barley combinations increased (0.55-6.48 dt·ha⁻¹ in 2010 and 0.03-3.99 dt·ha⁻¹ in 2011) in comparison with those of pure stands.
5. Growing cereal mixtures can be recommended for integrated and organic farming: chemical control is reduced (no insecticides), production costs are lower and the environment is protected.

REFERENCES

- BAILEY K.L., LAZAROVITS G. 2003. Suppressing soil-borne diseases with residue management and organic amendments. *Soil and Tillage Research* **72**(2): 169–180.
- GACEK E., CZEMBOR H.J., NADZIAK J. 1997a. Using cultivars mixtures to improve the health and increase the yield of winter wheat. *Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin* **201**: 81–93. (in Polish)
- GACEK E., JACKOWSKI J., NADZIAK J., HUREJ M. 1997b. The effect of growing wheat mixtures on the occurrence of pathogens, as well as grain aphids and thrips. *Zeszyty Naukowe AR we Wrocławiu, Konferencje XXII*, **361**: 177–188. (in Polish)
- GACEK E. 2000. Using plants' genetic diversity in combating diseases of cultivation plants. *Postępy Nauk Rolniczych* **5**: 17–25. (in Polish)
- GACEK E., NADZIAK J. 2000. Using cultivars mixtures to improve the health and increase the yield of spring barley. *Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin* **214**: 143–158. (in Polish)
- GAŁĘZEWSKI M. 2008. Pest occurrence on spring cereal mixtures. *Progress in Plant Protection* **48**(3): 831–835. (in Polish)

- IDZIAK R., MICHALSKI T. 2004. Thea harmfulness of *Oulema* spp. to spring barley, oat and their mixtures. *Progress in Plant Protection* **44**(2): 731–733. (in Polish)
- IUSS Working Group WRB, 2006. World Reference Base for Soil resources 2006. 2nd edition. World Soil resources Reports 103 FAO, Rome.
- JACKOWSKI J., HUREJ M. 1999. The effect of cereal species mixtures on the abundance and development of two cereal aphids: *Sitobion avenae* (F.) H.R.L. and *Rhopalosiphum padi* (L.). *Aphids and other homopterous insects* **7**: 209–222.
- JACKOWSKI J., HUREJ M. 2000. Thrips (Thysanoptera) on cereal species mixtures on the Opole region, Poland. *Polskie Pismo Entomologiczne* **69**(3): 377–388.
- JAKUBIAK S., GAŁĘZEWSKI M. 2007. Influence of spring cereal mixture cropping on weed infestation and quantity of selected pest insects. *Zeszyty Problemowe Postępów Nauk Rolniczych* **516**: 65–72. (in Polish)
- KAUT A.H.E.E., MASON H.E., NAVABI A., DONOVAN J.T., SPANER D. 2008. Organic and conventional management of mixtures of wheat and spring cereals. *Agronomy for Sustainable Development* **28**(3): 363–371.
- KOZAK M., BOCIANOWSKI J., SAKWOJĆ S., WNUK A. 2010. Call for more graphical elements in statistical teaching and consultancy. *Biometrical Letters* **47**(1): 57–68.
- MAHMOOD T., MARSHALL D., MC DANIEL M. E. 1991. Effect of winter wheat cultivar mixtures on leaf rust severity and grain yield. *Phytopathology* **81**(4): 470–474.
- MANTHEY R., FEHRMANN H. 1993. Effects of cultivar mixtures in wheat on fungal diseases, yield and profitability. *Crop Protection* **12**(1): 63–68.
- MICHALSKI T., KOWALIK I., IDZIAK R., HOROSZKIEWICZ-JANKA J. 2004. Mixtures as an ecological cereal cultivation method. [in:] Z. ZBYTEK (ed.). *Selected ecological issues in contemporary agriculture. Monograph, vol. 4. Przemysłowy Instytut Maszyn Rolniczych, Poznań*: 28–36. (in Polish)
- PAYNE R., MURREY D., HARDING S., BAIRD D., SOUTOU D., LANE P. 2003. *GenStat for Windows* (7th ed.) Introduction. VSN International. Oxford, England.
- SZULC P., BOCIANOWSKI J., RYBUS-ZAJĄC M. 2011. Correlation between traits and their influence on grain yield of “stay-green” maize hybrid (*Zea mays* L.). *Fresenius Environmental Bulletin* **20**(8): 2150–2155.
- SZEMPLIŃSKI W., BUDZYŃSKI W. 2011. Cereal mixtures in Polish scientific literature in the period 2003–2007. *Acta Scientiarum Polonorum, Agricultura* **10**(2): 127–140.
- TRATWAL A., ROSIAK K. 2010. Fungal diseases occurrence in winter wheat pure stands and mixtures. *Progress in Plant Protection* **50**(2): 963–968. (in Polish)
- TRATWAL A., WALCZAK F. 2010. Powdery mildew (*Blumeria graminis*) and pest occurrence reduction in spring cereals mixtures. *Journal of Plant Protection Research* **50**(3): 372–377.
- TRENBATH B.R. 1993. Intercropping for the management of pests and diseases. *Field Crops Research* **34**(3–4): 381–405.

WALCZAK F., TRATWAL A., ROSIAK K. 2009. The influence of winter wheat cultivation in mixtures and pure stands on plant yielding and the occurrence of powdery mildew (*Blumeria graminis* f. sp. *tritici*) and cereal pests. Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin **253**: 117–124. (in Polish)

WALCZAK F., TRATWAL A., ROIK K., BANDYK A., BOCIANOWSKI J. 2011. The influence of cultivars winter wheat mixtures on the occurrence of pests and yield. Fragmenta Agronomica **28**(4): 131–138. (in Polish)

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