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CEREAL MIXTURES – AN EFFECTIVE WEED MANAGEMENT TOOL

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Abstract: Field experiments carried out in the 2005–2007 time period were aimed at assessing the use of competitive potential against weeds of spring cereals cultivated in mixtures, for the purpose of reducing the herbicide application selected for the research. In the experiments, a mixture of the active substances, florasulam + 2,4 D (Mustang 306 SE), was applied at a recommended dose (0.5 l/ha) and then at a reduced dose (0.3 l/ha). The research objects were the spring wheat cultivar Bryza, spring barley cultivar Antek, and oat cultivar Cwał. The cereals were grown in two-species mixtures, and in pure sowing. The effect of a decreased herbicide dose was compared to the effect of the recommended dose, and the control. The research included two-time analysis of crop weed infestation (weed species composition, number, and fresh weight of weeds), determination of the number of productive culms, number of grains per ear (panicle), the thousand grain weight, and grain yield of spring cereals. The obtained results confirmed that spring cereals cultivated in mixtures had a higher competitive potential against weeds in comparison with individual species which were pure sowed. The use of the reduced herbicide dose proved to be effective in weed control and ensured a significant increase in grain yields of spring cereals. The applied herbicide doses did not affect grain number per ear and the thousand grain weight.

Key words: barley, cereal mixtures, decreased herbicide doses, florasulam + 2,4-D oat, wheat

INTRODUCTION

A very high proportion of cereals in the cropping system means that a search must be done for a means of buffering the effects of their excessive concentration in crop rotation. Cereal cultivation in mixtures may be a solution to the problem. Biodiversity of mixed cultivation resulting from various morphological and physiological traits, soil, climate, and agrotechnical requirements may definitely enable complementary utilization of site factors. In turn, favorable conditions are created for an increase in crop productivity or at least improvement of the stability of yielding in years. According to Michalski (1994), the cultivation of cereals in mixtures in comparison with pure stand, results in reduced weed infestation. A high proportion of cereals in the Polish cropping system, including a considerable surface area of spring cereal crops, substantiates that research done which takes into consideration the various soil conditions in these agrophytocenoses.

At present, chemical methods are a basis of weed control. However, more and more frequently, weeds are not being considered in terms of total control but in terms of regulation of weed infestation (Adamczewski and Dobrzański 1997). The use of herbicides does not always result in total weed elimination. Low weed density, below the weed infestation threshold, does not pose a direct threat to cultivated plants and may even favorably affect plant growth and yielding (Duer 1996). Regulation of weed infestation in a mixed stand is possible due to the considerable competitive abilities. Such abilities result from the better stand density of mixtures, more dense soil coverage, and a small number of niches for weeds (Idziak and Michalski 2003). The question arises of whether or not it is possible to decrease a herbicide dose as a result of cereal mixture cultivation. Cereal mixtures naturally compete more intensively with weeds without an adverse influence on the mixtures' effectiveness and yields. Recommended herbicide doses were determined to enable weed control without causing damage to cultivated plants. However, under optimal weather and soil conditions, weed control may be achieved as a result of an application of lower than recommended herbicide doses (Domaradzki 2003).

Economic, agroecological, and ecotoxicological aspects were taken into account in the experiments. Use of herbicides is substantiated in integrated weed control only when economic losses caused by weeds are greater than the cost of the treatment. Excessive use of herbicides may contribute to quantitative changes in weed species composition (Rola and Rola 2001). Effective control of only some weed species in a weed association leads to changes toward associations with uncontrolled species as dominants (Aldrich 1997). An opportunity for maintaining a weed population is the idea behind balanced development, *e.g.* by using decreased doses of plant protection agents.

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Research on the subject of cereal mixture cultivation, carried out by different researchers, focused on the aspects associated with: yielding of cereal mixtures (Sobkowicz 2001), reduced prevalence of cereal diseases (Gacek *et al*. 2000), reduced prevalence of pests (Rudnicki 1994), or the influence of cereal mixtures on weed infestation (Michalski 1994; Idziak and Michalski 2003). However, there are no reports on the use of decreased herbicide doses in the cultivation of cereal mixtures.

The aim of the study was to determine the possibility of reducing weed infestation using the natural potential of spring cereals cultivated in mixtures, and using reduced herbicide doses.

The hypothesis of the study assumed that cereal cultivation in mixtures will enable reduction in the used herbicide rate without significant losses in grain yield. It was assumed that this would happen due to the greater competitive abilities of the cereals in comparison with weeds.

MATERIALS AND METHODS

Description of experiments

Strict field experiments were carried out in the 2005–2007 season, in the Field Experimental Station in Winna Góra, ca. 60 km from Poznań. The experiments assessed the possibility of using a reduced dose of the herbicide Mustang 306 SE (Dow AgroSciences Polska Sp. z o.o.) in the cultivation of spring cereal mixtures.

Cereals were grown in mixtures and pure stand. The effect of a decreased herbicide dose was compared to the recommended dose and to the untreated control (without herbicide use). The subject of the research was the spring wheat cultivar Bryza, spring barley cultivar Antek, and the oat cultivar Cwał.

Experimental plots having a surface area of 16.5 m^2 (length – 11 m, width – 1.5 m) were placed in a split-plot design in four repetitions, with two factors: I – herbicide dose, II – cereal cultivation method, located in the soil of a good rye complex, in grey-brown podzolic soil derived from light loamy sand, deposited on light loam of quality class IVa (year 2005) and on good wheat complex soil, on grey-brown podzolic soil derived from heavy loamy sand, deposited on medium loam of quality class IIIa (2006 and 2007). Soil pH amounted to 5.8–6.1 depending on the year of the research. Humus content ranged from 1.2 to 1.3%. Sowing of spring cereals took place in the middle and end of April depending on the years. Harvesting took place at the full maturity stage (BBCH 89). Cereals were planted in mixtures of percentage compositions with the individual components of 50% + 50%, and in pure stand (spring wheat 180 kg/ha, spring barley 140 kg/ha, oat 160 kg/ha). Mineral fertilization in the individual years was as follows: 160.0 kg/ha N, 75.0 kg/ha P and 75.0 kg/ha K in 2005, 140.0 kg/ha N, 75.0 kg/ha P and 75.0 kg/ha K in 2006, and 78.5 kg/ha N, 49.0 kg/ha P and 70.0 kg/ ha K in 2007. Forecrops for spring cereals included winter wheat in 2005 and 2006, and sugar beet in 2007. In addition, standard cultivation measures were employed each year for spring cereals as well as seed dressing. Fungicide and insecticide protection were provided. Herbicide Mustang 306 SE (300 gai/L 2,4 D EHE (Ethyl-hepthyl Ester) + flurasulam 6,25 gai/L) was applied in doses of 0.5 l/ha (recommended dose) and 0.3 l/ha (reduced dose). Florasulam represents a group of inhibitors of acetolactate synthase (ALS) (group HRAC: B), while substance 2,4 D is included in the group of synthetic auxins – also called synthetic growth regulators. Herbicide treatments were carried out at the 3–5 leaf stage of spring cereals (BBCH 13-15) using a ”Gloria” knapsack sprayer with: Tee Jet XR11003-type nozzles, number of nozzles – 4, nozzle spacing – 50 cm, mounting of sprayer boom – 50 cm, pressure was 1.5 bar and application rate of 200 l/ha.

Observations and measurements

Analysis of weed infestation

Analysis of weed infestation was conducted with the quantitative and weight method. The sample area of each plot was determined with a 25 × 50 cm frame at two randomly selected sites. Species of the collected weeds were identified, counted, and their fresh weight was assessed. The analysis was carried out twice during the cereal vegetation period – after 3–4 weeks from the date of treatment (BBCH 37-39) and 7–8 weeks after the treatment (BBCH 73–75). The obtained results were expressed per surface area of 1 m^2.

Cereal productive tillering

Productive tillering was determined on the basis of plant samples collected before cereal harvesting from sample areas of each experimental plot determined with a 25 × 50 cm frame at two randomly selected sites. Cereal productive tillering was assessed on the basis of the number of fertile culms. The obtained results were then expressed per surface area of 1 m^2.

Grain number per ear

Grain number per ear was determined on the basis of 25 ears collected from each experimental plot which were then thrashed. Grain number per ear was determined with a seed counter from the Research Institute of the Bakery Industry. The results were presented as grain number per one ear (panicle).

Thousand grain yield

The thousand grain yield was determined on the basis of samples of collected cereal grain yield. For each plot, 200 grains were counted out three times, using a seed counter, and then weighed. The mean result of the measurements was then expressed per thousand grain weight.

Cereal grain yield

Grain was collected with a Wintersteiger plot combine, then weighed. Grain moisture content was assessed with a grain-moisture meter. Yields collected from plots were expressed tons per 1 ha at a standard moisture content of 14%.

Statistical data analysis

The results obtained in individual repetitions were subjected to analysis of variance, and then detailed hypotheses were verified against alternative hypotheses with Tukey's test. Absolute value of the difference between average objects was compared with the value of the lowest significant difference determined at the significance level $\alpha = 0.05$.

Meteorological conditions

Meteorological conditions were assessed on the basis of measurements carried out in the field meteorological station located in the Field Experimental Station in Winna Góra. The conditions varied during the years of the research (Table 1, 2). The greatest precipitation in the vegetation season of spring cereals was noted in 2007 – 378.0 mm. The amount of precipitation that year was higher by 115.4 mm in comparison with the multiannual period. However, the lowest precipitation was 52.8 mm lower than in the multiannual period observed in 2005. This means the lowest precipitation was 209.8 mm. Mean daily air temperature for the whole vegetation period of cereals ranged from 15.9°C (in 2005) to 16.5°C (in 2006), and for the multiannual period it amounted to 16.0°C.

RESULTS AND DISCUSSION

In 2005, altogether 14 weed species were observed. However, the site was dominated by one species, *i.e. Chenopodium album*, which accounted for 81.3–91.0%. Other species which were quite numerous in the experiment, included *Galium aparine* (on average, 4.4%) and *Viola arvensis* (on average, 4.7%). Other species accounted for 0.2–2.9%. In 2006, eleven species were noted, of which the following two were predominant: *Ch. album* (64.3– 67.8%) and *Viola arvensis* (29.4–33.3%). Other species accounted for 0.2–1.2% of the weed association. In 2007, only 9 weed species were found, and as in the previous year, two of them were predominant: *Ch. album* (76.6–83.7%) and *V. arvensis* (14.7–22.1%). The percentage of other species did not exceed 1.5%.

In the present study, assessment of the possibility of using decreased doses of the herbicide Mustang 306 SE (florasulam + 2,4 D) on spring cereals cultivated in mixtures, was made. The authors were encouraged to carry out the research because of the reports on the weed control effect of cereal mixtures by many authors (Wanic 1997; Sobkowicz 1999; Wenda-Piesik and Rudnicki 2000).

The effectiveness of the use of reduced herbicide doses was confirmed in studies by many authors (Doma-

Table 1. Mean monthly daily air temperature [°C] during the 2005–2007 vegetation period of spring cereals, in comparison with the multiannual period (1990–2004)

Years	IV	V	VI	VII	VIII	Mean of IV–VIII
	Temperature [°C] – monthly daily means					
2005	9.3	13.9	17.6	20.7	17.9	15.9
2006	9.1	13.8	18.5	23.9	17.3	16.5
2007	9.8	14.7	18.7	18.5	18.5	16.1
Mean of the multiannual period	9.4	14.5	17.0	19.5	19.6	16.0
Years	Deviation from mean [°C]					
2005	–0.1	–0.6	+0.6	+1.2	–1.7	+0.1
2006	–0.3	–0.7	+1.5	+4.4	–2.3	+0.5
2007	+0.4	+0.2	+1.7	–1.0	–1.1	+0.1

Table 2. Amount of precipitation by month [mm] during the 2005–2007 vegetation period of spring cereals, in comparison with the multiannual period (1990–2004)

Years	IV	V	VI	VII	VIII	Sum of IV–VIII
	Precipitation [mm] – monthly amounts					
2005	26.8	67.5	4.4	45.2	65.9	209.8
2006	61.8	47.5	14.3	20.3	115.2	259.1
2007	13.0	78.6	88.0	136.3	62.1	378.0
Mean of the multiannual period	29.1	47.0	56.1	78.2	52.2	262.6
Years	Deviation from mean [mm]					
2005	–2.3	+20.5	–51.7	–33.0	+13.7	–52.8
2006	+32.7	+0.5	–41.8	–57.9	+63.0	–3.5
2007	–16.1	+31.6	+31.9	+58.1	+9.9	+115.4

radzki and Rola 2000; Böstrom 2002; Domaradzki 2003; Malecka and Bremanis 2006). Research results demonstrated the possibility of a reduction of up to 35% of the recommended herbicide dose applied on spring cereals, without significant yield losses and increased weed infestation (Rydhal 1999; Talgre *et al*. 2004). An argument for using reduced herbicide doses in spring cereal cultivation is that, at the moment of treatment, weeds in these crops enter earlier developmental stages when compared to winter cereals.

The field experiments confirmed the hypothesis proposed in the study about herbicidal effectiveness of reduced herbicide doses in spring cereal mixtures.

Mustang 306 SE application at a dose of 0.3 l/ha reduced the number and fresh weight of weeds in a similar way as the higher dose, *i.e.* 0.5 l/ha (Table 3 and 4). The herbicidal effectiveness of the lower dose (0.3 l/ha) was ca. 70% (reduction in weed number) and ca. 90% (reduction in weed fresh weight), while the difference between the doses of 0.5 and 0.3 l/ha was merely several percent. Dose of 0.3 l/ha, reduced weed weight in mixtures more efficiently than in pure sowing. The effectiveness of the herbicide Mustang 306 SE in individual mixtures was similar.

The usefulness of the herbicide Mustang 306 SE applied at reduced doses on spring barley and spring wheat, was confirmed earlier by Talgre *et al*. (2008) and Auskalnis and Kadzys (2006).

In the research, there is an observed higher effectiveness of reduced herbicide doses in cereal mixtures than in pure sowing of individual components. The research supports the thesis about the greater competitiveness of

Table 3. The 2005–2007 weed numbers, in the years 2005–2007 [No./m]

Cereal sowing method	Herbicide dose [l/ha]	Years 2005		2006		2007		Average from years	
		I*	II**	I	II	I	II	I	II
W	0	652	419	454	340	195	230	434	330
B	0	383	304	394	293	179	193	318	263
O	0	466	386	439	314	187	206	364	302
W+ B	0	419	279	300	223	168	183	296	228
W + O	0	602	291	298	261	180	198	360	250
B + O	0	278	252	242	206	168	177	229	211
W	0.5	173	34	183	37	39	38	132	36
B	0.5	95	14	131	23	32	27	86	21
O	0.5	150	28	169	38	35	18	118	28
W + B	0.5	84	21	125	22	27	20	79	21
W + O	0.5	128	32	129	33	35	29	97	31
B + O	0.5	78	16	112	14	28	11	72	13
W	0.3	206	95	183	62	62	53	150	70
B	0.3	116	38	160	44	43	49	106	43
O	0.3	148	76	170	55	46	38	121	56
W + B	0.3	150	47	153	51	57	43	120	47
W + O	0.3	179	62	159	55	47	41	128	53
B + O	0.3	129	34	139	49	49	35	106	39
Average for dose (A):									
	0	467	322	354	273	179	198	333	264
	0.5	118	24	141	28	32	24	97	25
	0.3	155	58	160	53	51	43	122	52
Average for sowing method (B):									
W		344	183	273	146	99	107	238	145
B		198	118	228	120	85	90	170	109
O		255	163	259	136	89	87	201	129
W + B		218	115	193	99	84	82	165	99
W + O		303	128	195	116	87	89	195	111
B + O		162	100	164	90	81	74	134	88
LSD (0.05) – A[1]		15.3	8.1	9.9	9.4	3.1	4.4	5.0	9.4
LSD (0.05) – B[2]		23.8	10.6	9.7	7.4	5.0	4.9	14.7	7.8
LSD (0.05) – A(B)[3]		53.2	24.7	25.2	21.4	11.1	12.1	29.7	21.6
LSD (0.05) – B(A)[4]		51.3	22.8	21.0	15.9	10.8	10.5	31.2	16.5

*I – weed infestation analysis 3–4 weeks after treatment
**II – weed infestation analysis 7–8 weeks after treatment
[1]the least significant difference for herbicide dose (A)
[2]the least significant difference for cereal sowing method (B)
[3]the least significant difference for A and B interaction, for constant B
[4]the least significant difference for A and B interaction, for constant A
W – wheat; B – barley; O – oat

Table 4. The 2005–2007 weed fresh weights [g/m]

Cereal sowing method	Herbicide dose [l/ha]	Years 2005 I*	2005 II**	2006 I	2006 II	2007 I	2007 II	Average from years I	Average from years II
W	0	1151.4	1673.3	253.3	191.3	169.6	400.7	524.7	755.1
B	0	724.0	906.6	231.7	156.0	143.0	221.3	366.2	428.0
O	0	944.1	1107.6	243.7	166.9	158.0	282.6	448.6	519.0
W + B	0	704.7	770.7	225.4	131.3	127.3	217.5	352.5	373.2
W + O	0	842.4	733.2	224.8	138.2	143.8	235.9	403.7	369.1
B + O	0	577.1	670.7	210.9	123.5	123.5	184.2	303.9	326.2
W	0.5	70.9	30.5	69.0	14.9	11.1	9.3	50.3	18.2
B	0.5	35.4	13.2	53.5	6.2	6.5	4.2	31.8	7.9
O	0.5	60.0	28.9	61.0	8.4	6.8	4.1	42.6	13.8
W + B	0.5	28.7	13.0	46.7	5.1	4.3	2.7	26.6	6.9
W + O	0.5	38.3	20.9	56.3	7.6	4.8	6.6	33.1	11.7
B + O	0.5	29.3	10.4	41.3	2.9	4.2	2.0	25.0	5.1
W	0.3	85.7	59.5	71.5	31.7	15.6	18.7	57.6	36.6
B	0.3	56.4	34.9	57.8	23.2	12.5	8.6	42.2	22.2
O	0.3	76.6	52.4	68.1	27.1	13.3	12.1	52.7	30.5
W + B	0.3	50.6	30.5	53.1	16.7	8.0	6.0	37.2	17.7
W + O	0.3	55.9	33.5	62.4	15.3	13.1	10.4	43.8	19.7
B + O	0.3	45.7	26.8	49.1	18.0	10.3	5.1	35.0	16.6
Average for dose (A):									
	0	824.0	977.0	231.6	151.2	144.2	257.1	399.9	461.7
	0.5	43.8	19.5	54.6	7.5	6.3	4.8	34.9	10.6
	0.3	61.8	39.6	60.3	22.0	12.1	10.1	44.8	23.9
Average for sowing method (B):									
W		436.0	587.8	131.2	79.3	65.4	142.9	210.9	270.0
B		271.9	318.2	114.3	61.8	54.0	78.0	146.8	152.7
O		360.3	396.3	124.3	67.5	59.4	99.6	181.3	187.8
W + B		261.3	271.4	108.4	51.1	46.5	75.4	138.8	132.6
W + O		312.2	262.5	114.5	53.7	53.9	84.3	160.2	133.5
B + O		217.4	236.0	100.4	48.1	46.0	63.8	121.3	116.0
LSD (0.05) – A[1]		21.79	13.84	3.65	18.73	1.77	7.92	13.55	11.31
LSD (0.05) – B[2]		30.24	26.57	5.30	26.18	3.22	7.29	17.33	21.34
LSD (0.05) – (B)[3]		69.521	57.02	12.04	60.06	6.97	19.47	40.26	45.28
LSD (0.05) – B(A)[4]		65.19	57.28	11.42	56.44	6.93	15.72	36.80	45.31

Explanations: see table 3

cereal mixtures against weeds. Parylak *et al*. 1999; Sobkowicz (1999) state that plants cultivated in mixtures usually exhibit stronger competitiveness against weeds because such plants take advantage for exploting more efficiently the ambient conditions and the plants have better adaptive properties.

Analysis of the results of the present research shows clearly that Mustang 306 SE at a dose of 0.3 l/ha proved to be more efficient in the wheat-barley mixture and the wheat-oat mixture in comparison with sole wheat, and more efficient in the barley-oat mixture in comparison with oat in pure stand. However, the reduction in the number and fresh weight of weeds was not statistically confirmed each year.

Among other things, species composition of a weed association occurring in a given cultivation is the precondition of the herbicide treatment's effectiveness and especially of treatments with the use of reduced doses. In the years of the research, weed association was dominated mainly by one species, *i.e. Ch. album*. *Brassica napus* ssp. *oleifera*, *G. aparine* and *V. arvensis* were also quite numerous. The named weed species (except for *V. arvensis*, which is medium-sensitive) are numbered among weeds sensitive to mixtures of florasulam + 2,4 D.

As it is stated by Kudsk (1989, 2002), highly sensitive weed species may be controlled with doses two to four times lower in comparison with species considered as less sensitive. Usefulness of reduced herbicide doses for the control of dicotyledonous weeds, including *Ch. album* predominant in the experiments, was confirmed in studies by Auskalnis and Kadzys (2006), Domaradzki (2006).

Cultivation of cereals in mixtures has many advantages, emphasized in studies by many authors (Gacek *et al*. 2000; Idziak *et al*. 2007; Michalski 1994; Michalski *et al*. 2000; Parylak 2003; Rudnicki 1994; Sobkowicz 1999;

Szumiło and Rachoń 2007; Wasilewski 1999). Among other things the advantages include better yielding stability when compared to pure sowing, less exposure to diseases and pests, and lower weed infestation.

The assessment of the natural competitive abilities of cereals cultivated in mixtures against weeds was possible in the part of the field experiments where no herbicides were used. On the basis of the obtained results, it is clearly noticeable that the cereal mixtures reduced weed infestation of more than at least one of the components included in the mixture (Table 3 and 4). The wheat-barley mixture and the wheat-oat mixture reduced the number of weeds in comparison with wheat grown alone, or, in some cases, also in comparison with oat in pure stand. The barley-oat mixture most frequently reduced the number of weeds, with regard to both components. Of the superiority of cereal cultivation in mixtures with untreated control, was also visible in fresh weight of weeds. In most cases (analyses and years), the cereal mixtures significantly reduced weed weight when compared to both mixture components in pure stand. Moreover, it was noted that in both experiments, the least weed-infested cereal mixture (as to the number and fresh weight of weeds) was the barley-oat mixture, then the wheat-barley mixture, while the most weeds were found in the wheat-oat mixture.

On average, for the years of the research, the use of herbicide Mustang 306 SE at a dose of 0.3 l/ha, caused an increase in the number of productive culms per surface area of 1 m^2 (Table 5).

In addition, the wheat-barley mixture was characterized by greater ear density than wheat in pure sowing, the wheat-oat mixture in comparison with both components grown individually, and the barley-oat mixture in comparison with oat alone. For comparison, the use of

Table 5. The 2005–2007 spring cereal productivity stem numbers [No./m]

Cereal sowing method	Herbicide dose [l/ha]	Years			Average from years
		2005	2006	2007	
W	0	288	203	209	266
B	0	453	322	419	398
O	0	462	319	423	401
W + B	0	470 (174+296)	276 (107+168)	416 (171+245)	387 (151+237)
W + O	0	315 (126+189)	329 (138+191)	341 (150+191)	328 (138+190)
B + O	0	430 (245+185)	379 (193+186)	398 (211+187)	402 (216+186)
W	0.5	586	344	485	472
B	0.5	723	528	698	650
O	0.5	484	539	645	556
W + B	0.5	767 (291+476)	403 (181+222)	596 (238+358)	589 (237+352)
W + O	0.5	646 (284+362)	470 (226+244)	643 (315+328)	586 (275+311)
B + O	0.5	645 (329+316)	579 (330+249)	656 (367+288)	626 (349+269)
W	0.3	604	340	484	476
B	0.3	653	525	677	618
O	0.3	477	461	516	485
W + B	0.3	563 (225+338)	391 (172+219)	527 (195+332)	494 (197+296)
W + O	0.3	589 (283+306)	490 (235+255)	626 (300+326)	568 (273+295)
B + O	0.3	592 (338+255)	509 (295+214)	616 (351+265)	572 (328+244)
Average for dose (A):					
	0	419	305	367	364
	0.5	642	477	620	580
	0.3	580	452	574	535
Average for sowing method (B):					
W		526	295	392	405
B		610	458	598	555
O		474	440	528	481
W + B		600 (230+370)	357 (154+203)	513 (201+312)	490 (195+295)
W + O		517 (231+286)	430 (200+230)	537 (255+281)	494 (229+266)
B + O		556 (291+220)	489 (273+216)	556 (310+247)	534 (291+228)
LSD (0.05) – A[1]		12.6	4.5	5.2	23.8
LSD (0.05) – B[2]		22.0	9.5	7.3	25.8
LSD (0.05) – A(B)[3]		48.0	20.1	16.7	63.4
LSD (0.05) – B(A)[4]		47.5	20.5	15.7	54.7

Explanations: see table 3

the recommended herbicide dose in mixtures increased the number of productive culms when compared to a one mixture component. In the conducted field experiments, the number of productive culms per unit area was the element most influencing the spring cereal yields.

Greater productive tillering of the barley-oat mixture was confirmed also by a study by Szumiło and Rachoń (2007), although Michalski (1991) and Rudnicki and Wasilewski (1994) noted a similar number of barley tillers in a mixture and pure sowing.

On average, for the years, the doses of 0.5 l/ha and 0.3 l/ha of the herbicide Mustang 306 SE did not affect the number of productive culms of the mixtures with oat. The dose effect, however, was different in the individual years of the research. Spring wheat generated more productive culms after the use of the herbicide Mustang 306 SE in the mixture with oat, than with barley, and responded the other way round to the presence of the other species in the untreated control. Spring barley in the plots where the herbicides were used at a reduced dose (0.3 l/ha), was characterized by a greater number of culms in the mixture with oat than with barley. The opposite situation was observed after the use of the recommended dose (0.5 l/ha), and in the control. As a result of using both doses of the herbicide Mustang 306 SE, oat was the species which generated more panicles per unit area in the mixture with wheat than in the mixture with barley. However, the number of oat panicles in the control plots was similar in the both mixtures.

Reported before by Idziak *et al*. (2007) and Sobkowicz (2003), barley grown in the mixture with oat (50% + 50%) exhibited better tillering than in pure sowing. Oat also showed higher tillering in the mixture than when grown individually.

On average, for the years of the research, no significant influence of the herbicide Mustang 306 SE and methods of cereal cultivation (pure sowing and mixtures) on the number of grain per ear (panicle) of wheat, barley, and oat was found (Table 6).

Table 6. The 2005–2007 grain numbers in wheat, barley, and oat ears (panicle) [No.]

Cereal sowing method	Herbicide dose [l/ha]	Years									Average from years		
		2005			2006			2007					
		W[a]	B[b]	O[c]	W	B	O	W	B	O	W	B	O
W	0	23	–	–	34	–	–	30	–	–	29	–	–
B	0	–	17	–	–	20	–	–	20	–	–	19	–
O	0	–	–	22	–	–	25	–	–	22	–	–	23
W + B	0	24	18	–	32	20	–	26	20	–	27	19	–
W + O	0	27	–	28	31	–	24	27	–	20	28	–	24
B + O	0	–	19	24	–	19	28	–	19	23	–	19	25
W	0.5	23	–	–	38	–	–	30	–	–	30	–	–
B	0.5	–	19	–	–	18	–	–	19	–	–	19	–
O	0.5	–	–	23	–	–	24	–	–	25	–	–	24
W + B	0.5	26	19	–	38	17	–	27	20	–	30	18	–
W + O	0.5	21	–	24	33	–	23	27	–	24	27	–	24
B + O	0.5	–	19	22	–	18	29	–	19	27	–	19	26
W	0.3	24	–	–	34	–	–	30	–	–	29	–	–
B	0.3	–	19	–	–	21	–	–	20	–	–	20	–
O	0.3	–	–	30	–	–	26	–	–	27	–	–	28
W + B	0.3	29	18	–	35	19	–	32	20	–	32	19	–
W + O	0.3	27	–	22	33	–	24	28	–	26	29	–	24
B + O	0.3	–	18	25	–	20	27	–	19	26	–	19	26
Average for dose (A):													
	0	25	18	25	32	20	26	28	20	22	28	19	24
	0.5	23	19	23	35	18	25	28	19	25	29	19	24
	0.3	27	18	26	35	20	26	31	20	26	31	19	26
Average for sowing method (B):													
W		23	–	–	38	–	–	30	–	–	30	–	–
B		–	18	–	–	20	–	–	20	–	–	19	–
O		–	–	25	–	–	25	–	–	25	–	–	25
W + B		26	18	–	38	19	–	28	20	–	31	19	–
W + O		25	–	25	33	–	24	27	–	23	28	–	24
B + O		–	18	24	–	19	28	–	19	25	–	19	26
LSD (0.05) – A[1]		3.6	ns	ns	ns	ns	ns	ns	ns	2.4	ns	ns	ns
LSD (0.05) – B[2]		ns	ns	ns	ns	ns	ns	1.9	ns	ns	ns	ns	ns
LSD (0.05) – A(B)[3]		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD (0.05) – B(A)[4]		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns – not significant difference

[a]spring wheat, [b]spring barley, [c]oat

[1–4] see table 3

Leszczyńska (1999), Rudnicki and Wasilewski (1994), Sobkowicz (2003) demonstrated in their studies, that oat generated a significantly higher number of grains per panicle in pure sowing than in mixtures with barley and wheat.

An increase in the number of grains of barley grown in a mixture with oat in comparison with barley in pure sowing was observed by Sobkowicz (2003), and in a mixture with wheat by Rudnicki and Wasilewski (1994).

In the individual years of the research, the influence of the used herbicides and methods of cereal cultivation on the thousand grain weight of wheat, barley, and oat was diverse (Table 7).

The experiment with the use of the herbicide Mustang 306 SE, showed a significant increase in the thousand kernel weight after the use of both doses (0.5 and 0.3 l/ha), when compared to the control.

Differences in the effect of the herbicide Mustang 306 SE at doses of 0.5 and 0.3 l/ha were noticeable only in some cases, which does not allow regularities to be demonstrated.

The different influences of herbicide use on the grain size can also be found in the literature. Krawczyk and Kaczmarek (2008) did not note differences in the grain weight of spring wheat after the application of herbicides at the recommended and reduced doses. Kapeluszny

Table 7. The 1000 grain number of wheat, barley and oat in the 2005–2007 period [g]

Cereal sowing method	Herbicide dose [l/ha]	Years									Average from years		
		2005			2006			2007					
		W[a]	B[b]	O[c]	W	B	O	W	B	O	W	B	O
W	0	32.4	–	–	29.7	–	–	27.5	–	–	29.9	–	–
B	0	–	36.1	–	–	47.1	–	–	40.1	–	–	41.1	–
O	0	–	–	30.9	–	–	28.0	–	–	29.0	–	–	29.3
W + B	0	33.6	39.2	–	30.9	47.9	–	35.2	43.7	–	33.2	43.6	–
W + O	0	33.2	–	31.5	26.8	–	27.1	32.6	–	34.2	30.9	–	30.9
B + O	0	–	37.7	32.2	–	42.0	28.3	–	49.7	33.1	–	43.1	31.2
W	0.5	31.3	–	–	31.0	–	–	30.6	–	–	31.0	–	–
B	0.5	–	38.1	–	–	46.6	–	–	39.3	–	–	41.3	–
O	0.5	–	–	32.4	–	–	29.9	–	–	30.2	–	–	30.8
W + B	0.5	33.6	40.1	–	32.2	49.2	–	40.3	51.2	–	35.4	46.9	–
W + O	0.5	32.2	–	31.9	27.1	–	29.6	41.7	–	30.0	33.7	–	30.5
B + O	0.5	–	38.3	32.7	–	45.3	30.8	–	41.7	30.8	–	41.8	31.4
W	0.3	32.4	–	–	29.7	–	–	29.5	–	–	30.5	–	–
B	0.3	–	38.0	–	–	47.3	–	–	45.0	–	–	43.4	–
O	0.3	–	–	30.6	–	–	28.3	–	–	28.1	–	–	29.0
W + B	0.3	32.7	39.5	–	31.2	47.5	–	36.1	46.7	–	33.3	44.6	–
W + O	0.3	33.6	–	31.1	29.4	–	28.5	35.4	–	32.5	32.8	–	30.7
B + O	0.3	–	36.5	32.4	–	44.8	30.3	–	48.6	36.5	–	43.3	33.1
Average for dose (A):													
	0	33.1	37.7	31.5	29.1	45.7	27.8	31.8	44.5	32.1	31.3	43.3	30.5
	0.5	32.4	38.8	32.3	30.1	47.0	30.1	37.6	44.1	30.3	33.3	43.8	30.9
	0.3	32.9	38.0	31.4	30.1	46.5	29.0	33.7	46.8	32.4	32.2	42.6	30.9
Average for sowing method (B):													
W		32.0	–	–	30.2	–	–	29.2	–	–	30.5	–	–
B		–	37.4	–	–	47.0	–	–	41.5	–	–	41.9	–
O		–	–	31.3	–	–	28.7	–	–	29.1	–	–	29.7
W + B		33.3	39.6	–	31.4	48.2	–	37.2	47.2	–	34.0	45.0	–
W + O		33.0	–	31.5	27.8	–	28.4	36.6	–	32.2	32.4	–	30.7
B + O		–	37.5	32.4	–	44.0	29.8	–	46.7	33.4	–	42.7	31.9
LSD (0.05) – A[1]		0.53	1.10	0.54	0.62	0.70	1.25	0.68	0.79	1.03	0.75	ns	ns
LSD (0.05) – B[2]		0.96	0.81	0.99	1.06	1.51	0.73	0.60	0.94	0.80	0.84	1.06	0.80
LSD (0.05) – A(B)[3]		ns	2.22	ns	2.24	3.10	2.29	1.52	2.14	2.14	1.92	3.20	ns
LSD (0.05) – B(A)[4]		2.27	1.92	ns	2.53	3.59	1.74	1.42	2.23	1.91	1.96	2.47	1.86

Explanations: see tables 3 and 6

(2003), though, demonstrated a significant increase in grain weight of spring cereals resulting from the use of a reduced herbicide dose, in comparison with the control.

In her experiments, Wanic (1994) did not note differences in the thousand grain weight of barley and oat grown in pure sowing and mixtures. Also in research by Idziak *et al*. (2007) and Szumiło and Rachoń (2007), the thousand grain weight of barley and oat did not change significantly with the method of cereal cultivation.

The effective reduction in weed infestation positively affected the size of the obtained spring cereal grain yields (Table 8). Analysis of the means of the research years, showed that the use of the herbicide Mustang 306 SE at a dose of 0.3 l/ha significantly increased yieldof spring cereals, in comparison with the untreated control.

The usefulness of decreased herbicide doses applied in spring cereals without seeing a significant reduction in yields was confirmed also in studies by other authors (Domaradzki 2003; Kapeluszny 2003).

On average, for the years of the research, Mustang 306 SE used at decreased doses significantly increased yielding of cereals in mixtures when compared to a one mixture component. The wheat-barley mixture and the wheat-oat mixture were characterized by higher yields than wheat in pure sowing, while the barley-oat mixture produced greater yields than oat grown individually.

In a study by Sobkowicz (2003), a barley-oat mixture was also characterized by significantly higher yields, in comparison with oat in pure sowing. However, results of research by Michalski *et al*. (2000) did not show any significant differences in yielding of a barley-oat mixture (ratio of 50% + 50%) after the use of herbicide, in comparison with pure sowing of both components. Other results were obtained by Budzyński and Dubis (1994), who dem-

Table 8. The 2005–2007 spring cereal grain yields [t/ha]

Cereal sowing method	Herbicide dose [l/ha]	Years			Average from years
		2005	2006	2007	
W	0	2.52	1.91	1.86	2.09
B	0	3.12	3.07	3.30	3.16
O	0	3.00	2.21	2.68	2.63
W + B	0	3.39	2.74	3.64	3.26
W + O	0	3.07	2.42	2.98	2.82
B + O	0	3.39	3.10	3.46	3.32
W	0.5	4.42	4.12	4.52	4.35
B	0.5	5.10	4.73	5.21	5.02
O	0.5	4.74	4.55	4.93	4.74
W + B	0.5	4.97	4.60	5.49	5.02
W + O	0.5	4.69	4.23	5.10	4.67
B + O	0.5	5.30	5.13	5.63	5.35
W	0.3	4.28	4.02	4.06	4.12
B	0.3	5.01	4.85	5.74	5.20
O	0.3	4.67	4.40	4.97	4.68
W + B	0.3	4.83	4.50	5.29	4.87
W + O	0.3	4.66	4.15	5.05	4.62
B + O	0.3	5.08	4.70	5.46	5.08
Average for dose (A):					
	0	3.08	2.57	2.99	2.88
	0.5	4.87	4.56	5.14	4.86
	0.3	4.76	4.43	5.09	4.76
Average for sowing method (B):					
W		3.74	3.35	3.48	3.52
B		4.41	4.22	4.75	4.46
O		4.14	3.72	4.19	4.02
W + B		4.40	3.95	4.80	4.38
W + O		4.14	3.60	4.38	4.04
B + O		4.59	4.31	4.85	4.58
LSD (0.05) – A[1]		0.157	0.110	0.069	0.090
LSD (0.05) – B[2]		0.209	0.104	0.088	0.140
LSD (0.05) – A(B)[3]		0.487	0.274	0.208	0.309
LSD (0.05) – B(A)[4]		0.452	0.224	0.191	0.298

Explanations: see table 3

onstrated that yields of a barley-oat mixture are higher than the yields of barley in pure sowing. In the above noted experiment, barley was the species with a lower yield than oat. In our research, lower yields were noted for oat.

In the present research, no significant differences in yields were found between the doses of 0.5 l/ha and 0.3 l/ha of herbicide Mustang 306 SE. Irrespective of the used doses, the highest yields were obtained from the barley-oat mixture, and the lowest from the wheat-oat mixture. Differences in yielding of particular mixtures and mixtures in comparison with pure sowing of cereals, confirmed earlier results demonstrating reduced weed infestation due to herbicide application.

The highest mean yields per year in the conducted research were obtained in 2007, the next highest mean yields were in 2005, and the lowest in 2006. It was in 2006, that humid conditions during the individual vegetation seasons affected the yields.

CONCLUSIONS

1. The experiments confirmed the possibility of regulating weed infestation of spring cereal mixtures with the use of a decreased dose of the herbicide Mustang 306 SE – 0.3 l/ha (florasulam + 2,4 D).
2. Herbicidal effectiveness of Mustang 306 SE at a dose of 0.3 l/ha was similar to that of a dose of 0.5 l/ha.
3. The use of a decreased dose of the herbicide was more effective in mixtures, in comparison with pure sowing, which confirms the greater competitive ability of mixtures against weeds.
4. Those plots which were not under chemical protection of a mixture, exhibited less weed infestation than cereals in pure stand.
5. Among the assessed mixtures, the barley-oat mixture was the least weed-infested in the untreated control, while the wheat-oat mixture was infested the most.
6. The use of a decreased dose of the herbicide Mustang 306 SE, significantly increased cereal grain yields, in comparison with the control.
7. The herbicide applied at the reduced dose significantly increased productive tillering of cereals, which proved to be the element most affecting the grain size
8. The used herbicide doses and cultivation methods of cereals did not influence the number of grains per ear (panicle) of wheat, barley or oat.
9. The effect of the herbicide dose and methods of cereal cultivation in the individual years of the research on the thousand grain yield was diverse. However, the positive influence of humid conditions on increased kernel weight of wheat and barley in mixtures was noted.

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