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THE EFFECTIVENESS OF WEED REGULATION METHODS IN SPRING WHEAT CULTIVATED IN INTEGRATED, CONVENTIONAL AND ORGANIC CROP PRODUCTION SYSTEMS

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Abstract: The research was conducted from 2008 to 2010, and compared the influence of different weed control methods used in spring wheat on the structure of the weed communities and the crop yield. The study was carried out at the Experimental Station of the Institute of Soil Science and Plant Cultivation – State Research Institute in Osiny as part of a long-term trial where these crop production systems had been compared since 1994. In the conventional and integrated systems, spring wheat was grown in a pure stand, whereas in the organic system, the wheat was grown with undersown clover and grasses. In the conventional system, herbicides were applied two times in a growing season, but in the integrated system – only once. The effectiveness of weed management was lower in the organic system than in other systems, but the dry matter of weeds did not exceed 60 g/m^2. In the integrated system, the average dry matter of weeds in spring wheat was 4 times lower, and in the conventional system 10 times lower than in the organic system. Weed diversity was the largest in spring wheat cultivated in the organic system. In the conventional and integrated systems, compensation of some weed species was observed (*Viola arvensis*, *Fallopia convolvulus*, *Equisetum arvense*). The comparison of weed communities using Sorenson's indices revealed more of a similarity between systems in terms of number of weed species than in the number of individuals. Such results imply that qualitative changes are slower than quantitative ones. The yield of grain was the biggest in the integrated system (5.5 t/ha of average). It was 35% higher than in the organic system, and 20% higher than in conventional ones.

Key words: crop production systems, spring wheat, weed control, weeds

INTRODUCTION

Different farming systems existing in modern agriculture are characterised by various strategies of weed control (Kuś 1995). In the conventional system, weed management is based on herbicide application. The aim of weed control in the organic and integrated systems is not a complete elimination of weeds in the plant canopy, but the limitation of the infestation to the level that does not cause a yield decrease. In organic agriculture, the use of herbicides is forbidden, therefore, more attention is paid to agrotechnical methods of weed control as well as mechanical, biological and physical ones (Eisele 1998; Hucl 1998; O'Donovan *et al*. 2007). The integrated system of weed control (IWM – Integrated Weed Managenent) combines effective, environmentally safe, and socially acceptable methods in order to maintain the weed population below the economic threshold of harmfulness (Thill 1991; Duer 1996). The integrated system is based on crop rotation, and carefully performed agrotechnical practices. Other methods, mainly chemical, are used when the expected losses caused by weeds are greater than the cost of treatment. Selected herbicides of lower toxicity which quickly decompose in the environment, are preferred in the integrated system. Rotation of herbicides, which protects against the development of weed resistance to an active herbicide substance, is also used. An important element of the integrated weed control strategy is to reduce the number of herbicide treatments and the application of herbicide doses. They are meant to be reduced below that previously recommended and are meant to provide the same efficiency (Adamczewski and Dobrzański 1997; Stevenson *et al.* 2000). Splitting doses of herbicides, spraying only in the rows of plants, and precise weed control using the newest techniques of detection are used in the integrated system (Melander *et al.* 2005; Dobrzański and Adamczewski 2006, 2009). The Decision Support System (DSS) is a very important element of IWM for plant protection (PC – Plant Protection). The use of the DSS allows for the forecasting of the weed emergence, and the choice of the most effective method of weed control so that excessive use of herbicides can be avoided (Thill *et al.* 1991; Forcella *et al.* 1993; Jensen and Nielsen 2000).

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The aim of our research was to evaluate the effectiveness of different weed management methods used in the integrated, conventional and organic systems, based on the analysis of weed infestation and yielding of spring wheat.

MATERIALS AND METHODS

The study was carried out in the 2008–2010 time period, at the Experimental Station of the Institute of Soil Science and Plant Cultivation – State Research Institute in Osiny (Lublin voivodeship) (51°28′N, 22°04′E). The study was part of a long-term trial, where organic, integrated and conventional crop production systems had been compared since 1994. The systems were characterised by different crop rotations and agricultural practices. In the organic system, a 5-field crop rotation was used: potato, spring wheat with clover and grass, clover and grass (two years), winter wheat and intercrop (mustard). The integrated system was based on a 4-field crop rotation: potato, spring wheat, faba bean, winter wheat and intercrop (mustard). In the conventional system, the most simplified crop rotation was carried out: winter rape, winter wheat, spring wheat. In the organic system, mineral fertilizers and chemical weed control were not used. Compost was used only once in crop rotation under potato (30 t/ha). In the integrated system, fertilization was 20–30% lower than in the conventional system, and less chemical plant protection treatments were applied.

In the fields of spring wheat, 4 varieties were sown, namely Vinjett, Bombona, Parabola, and Tybalt, but this paper presents the average data for the spring wheat. In conventional and integrated systems, spring wheat was cultivated in a pure stand (250 kg/ha). In the organic system spring wheat was cultivated in a mixture with clover and grasses (spring wheat – 180 kg/ha, red clover – 10 kg/ha, white clover – 3 kg/ha, meadow fescue – 10 kg/ha, perennial ryegrass – 10 kg/ha). Undersown crop was a factor which increased the competitiveness of the spring wheat canopy due to weeds. In the conventional and integrated systems, weed infestation was controlled by herbicides. The threshold of harmfulness values were taken into account. In the integrated system, only one application of herbicides was done against dicotyledonous plants. In the conventional system, additional sprayings against monocotyledonous plants were performed (Table 1).

The weather in the years of the research and the weather which took place over many years were compared and presented in table 2.

Good temperature and moisture condition for the growth and development of spring wheat and undersown crop in 2008 favored the development of a compact canopy that effectively competed with weeds. Lack of precipitation after sowing in 2009, and frost until mid-May had an influence on the germination of wheat. The number of plants per area unit was low, especially in the organic system. Such a low number affected the competitiveness of the canopy due to weeds. Bad weather conditions and frost in the spring of 2010 caused poorer germination of wheat and undersown clover and grass. The growing season was characterized by an unfavorable distribution of temperature and precipitation: heavy rainfall in May, high temperatures and drought in June and July (Table 2).

The assessment of weed infestation included weed species composition as well as the number of weeds and their dry matter. The assessment was done in the dough stage of spring wheat, developing stage, according to the BBCH scale – 85–87 (Adamczewski and Matysiak 2005) on an area of 0.5 m^2. For each system, 16 replications were done. Plant species were indentified according to Rutkowski's key (2004). The yield of grain and number of ears per unit area were assessed. The structure of weed communities was also analysed using ecological indices: Shannon's diversity index (H′), Simpson's dominance index (SI) and Sorenson's indices of similarity (Shannon and Weaver 1963 quoted by Zanin *et al.* 1992; Magurran 1988 quoted by Zanin *et al.* 1997).

The analysis of variance was done separately for each year of the study. The significance of differences was eval-

Table 1. Weed control practices in spring wheat cultivated in different crop production systems

Growing seasons	Crop production system		
	organic	integrated	conventional
2008	–	2,4-D+florasulam (Mustang 306 SE) 0,6 l/ha	2,4-D+florasulam (Mustang 306 SE) 0,6 l/ha Fenoksaprop-P-ethyl (Puma Universal) 1,0 l/ha
2009	–	2,4-D+florasulam (Mustang 306 SE) 0,6 l/ha	2,4-D+florasulam (Mustang 306 SE) 0,6 l/ha Fenoksaprop-P-ethyl (Puma Universal) 1,0 l/ha
2010	–	2,4-D+florasulam (Mustang 306 SE) 0,6 l/ha	2,4-D+florasulam (Mustang 306 SE) 0,6 l/ha Fenoksaprop-P-ethyl (Puma Universal) 1,0 l/ha

Table 2. Average monthly temperature of air [°C] and sum of precipitation [mm] in Osiny in 2008–2010 compared to many years (1951–2007) for growing period of spring wheat

Months	Temperature [°C]				Precipitation [mm]			
	2008	2009	2010	1951–2007	2008	2009	2010	1951–2007
III	3.9	2.2	3.0	1.7	38.7	60.8	13.4	30
IV	9.5	11.0	9.3	7.9	42.9	2.1	17.2	40
V	13.5	13.7	14.3	13.5	83.3	63.2	110.2	57
VI	18.2	16.6	18.3	16.8	42.3	95.8	47.8	70
VII	18.8	20.1	22.1	18.5	93.6	69.0	42.6	84

uated using Tukey test at the α = 0,05 significance level. One-factor analysis of variation for a completely randomized system was used where crop production system was the classification factor and the variables studied were: the number of weeds and their dry matter as well as grain yield of spring wheat, and number of ears. As the number of weeds did not have a normal distribution, logarithmic transformation of data was performed prior to the analysis of variance. The significance of differences between systems were marked with letters, the non-significant differences were marked with the same letters. Calculations were performed using Statgraphic Plus version 2.1.

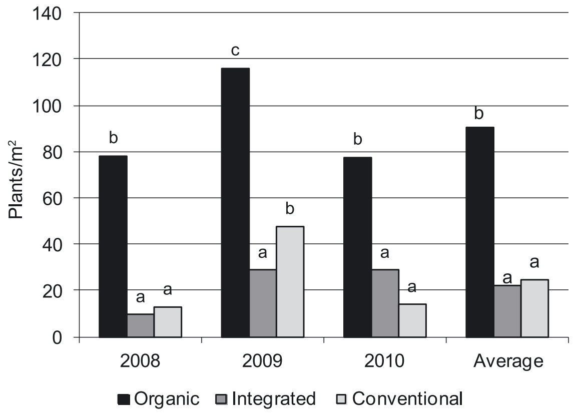
RESULTS

The effectiveness of weed control methods in spring wheat was the lowest in the organic system, compared to the other systems where herbicide strategies were realized. In each year of the study, the number of weeds in spring wheat and the dry matter of the weeds were significantly the highest in the organic system (Table 3, Fig. 1, 2). The number of weeds reached from 78 individuals per 1 m^2 in 2008 and 2010, to 116 individuals per 1 m^2 in 2009. The amount of dry matter of weeds in spring wheat was the smallest in 2008, only 8 g/m^2. These

Table 3. The number of weeds [plants/m^2] in spring wheat cultivated in different crop production systems

No.	Weed species	Systems and years of the research											
		organic				integrated				conventional			
		2008	2009	2010	average	2008	2009	2010	average	2008	2009	2010	average
1.	*Chenopodium album* L.	27.4	59.8	27.6	38.3	0.9	5.1		2.0	0.4	1.7	0.1	0.7
2.	*Stellaria media* (L.) Vill.	17.8	33.4	13.1	21.4				0.0	0.8	0.5	0.1	0.5
3.	*Fallopia convolvulus* (L.) A. Löve	13.1	4.8	3.8	7.2	6.4			2.1	1.6		1.0	0.9
4.	*Viola arvensis* Murray	6.8	1.5	4.5	4.3		8.5	0.3	2.9	4.5	36.0	8.1	16.2
5.	*Anthemis arvensis* L.	3.1		7.9	3.7				0.0	2.6	0.1	0.9	1.2
6.	*Galium aparine* L.	1.4	5.9	6.3	4.5	1.1			0.4	0.6	1.4	2.1	1.4
7.	*Myosotis arvensis* (L.) Hill.	1.1	0.5	0.4	0.7				0.0		0.4		0.1
8.	*Plantago lanceolata* L.	1.1			0.4				0.0				0.0
9.	*Lapsana communis* L.	0.8	3.6	0.8	1.7				0.0	0.1		0.1	0.1
10.	*Plantago major* L.	0.5			0.2				0.0				0.0
11.	*Capsella bursa-pastoris* (L.) Med.	0.9	0.1	4.8	1.9				0.0		0.3		0.1
12.	*Galinsoga parviflora* Cav.	0.9		0.1	0.3				0.0				0.0
13.	*Cirsium arvense* (L.) Scop.	0.5	1.3	2.8	1.5		0.8	0.3	0.4			0.1	*
14.	*Melandrium album* (Mill.) Garcke	0.6		0.1	0.2				0.0	0.1			*
15.	*Polygonum aviculare* L.	0.6		2.1	0.9		0.3		0.1				0.0
16.	*Vicia hirsute* (L.) S.F. Gray	0.4	3.8	0.1	1.4				0.0				0.0
17.	*Taraxacum officinale* Weber				0.0		0.1		*	0.1			*
18.	*Geranium molle* L.	0.3	0.1	0.3	0.2	0.6	0.3		0.3	0.3	3.9	0.6	1.6
19.	*Conyza canadensis* L.	0.1	0.1		0.1				0.0				0.0
20.	*Erodium cicutarium* (L.) L'Hér.				0.0				0.0		0.3		0.1
21.	*Fumaria officinalis* L.			0.1	0.0		4.4	1.4	1.9				0.0
22.	*Anchusa arvensis* L.				0.0	0.1			*				0.0
23.	*Papaver rhoeas* L.			0.3	0.1				0.0		0.1	0.4	0.2
24.	*Veronica persica* Poir.				0.0				0.0	0.1			*
25.	*Lamium purpureum* L.		1.1		0.4		0.4		0.1	0.5			0.2
26.	*Euphorbia helioscopia* L.		0.3		0.1				0.0				0.0
27.	*Polygonum persicaria* L.			0.3	0.1		0.3		0.1				0.0
28.	*Sonchus arvensis* L.				0.0		0.4		0.1	0.3	1.3	0.1	0.6
29.	*Galeopsis tetrahit* L.				0.0				0.0	0.1			*
30.	*Brassica napus* L.				0.0				0.0		0.3		0.1
31.	*Convolvulus arvensis* L.				0.0				0.0		0.1		*
32.	*Anagallis arvensis* L.				0.0				0.0		0.6		0.2
	Dicotyledonous	77.4	116.1	75.1	89.5	9.1	20.6	2.0	10.6	12.1	47.0	13.6	24.3
33.	*Apera spica-venti* (L.) P.B.	0.1		0.4	0.2		0.1		*			0.3	0.1
34.	*Echinochloa crus-galli* (L.) P.B.	0.3			0.1	0.4	4.0	4.9	3.1		0.4		0.1
35.	*Elymus repens* (L.) P.B.	0.4			0.1			2.9	1.0	0.4			0.1
36.	*Poa annua* L.				0.0		0.4		0.1				0.0
37.	*Alopecurus pratensis* L.				0.0				0.0		0.1		*
	Monocotyledonous	0.8	0	0.4	0.4	0.4	4.5	7.8	4.2	0.4	0.5	0.3	0.4
38.	*Equisetum arvense* L.			2.1	0.7		3.6	18.9	7.5	0.3	0.1		0.1
Total		78.2	116.1	77.6	90.6	9.5	28.7	28.7	22.3	12.8	47.6	13.9	24.8
Number of weed species		21	14	20	27	6	14	6	18	16	17	12	27

*number of weeds below 0.05 per m^2



a, b, c – values marked with the same letters do not differ significantly according to Tukey's test ($\alpha = 0.05$)

Fig. 1. Number of weeds in spring wheat cultivated in different crop production systems

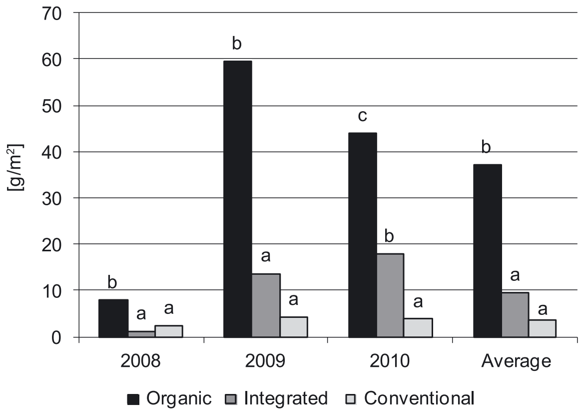


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Fig. 2. Dry matter of weeds in spring wheat cultivated in different crop production systems

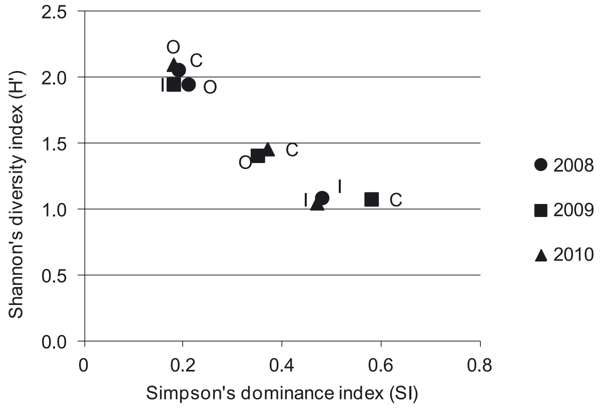


Fig. 3. Shannon's diversity index (H') and Simpson's dominance index (SI) for weed flora of spring wheat in different crop production systems (O – organic, I – integrated, C – conventional)

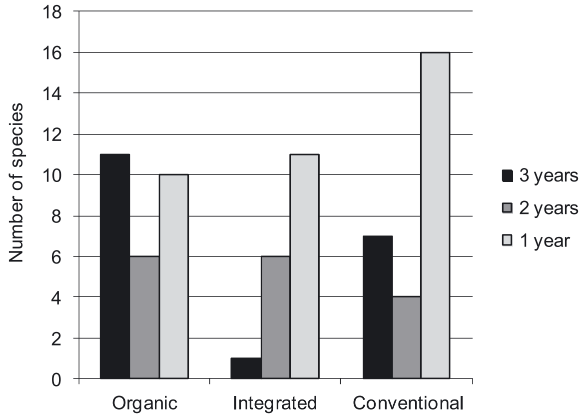


Fig. 4. Frequency of weed species occurrence in the years of research in different crop production systems

Year	System	Qualitative indices of similarity								
		2008			2009			2010		
		O	I	C	O	I	C	O	I	C
2008	O	×	36	53	67	39	46	76	21	58
	I	21	×	36	40	30	35	31	17	44
	C	25	26	×	45	47	48	55	27	57
2009	O	57	44	9	×	36	45	59	20	54
	I	25	8	30	10	×	39	53	50	46
	C	19	11	23	7	30	×	49	26	55
2010	O	75	14	25	58	26	15	×	31	63
	I	2	2	5	1	33	2	5	×	22
	C	24	24	57	8	41	34	21	2	×
		Quantitative indices of similarity								

Fig. 5. Qualitative and quantitative indices of weed similarity in spring wheat (in %) in different crop production systems (O – organic, I – integrated, C – conventional)

figures suggest the effectiveness of clover and grass undersown in spring wheat in weed control in the good weather conditions of 2008 (Table 1, Fig. 2). In the following years, the amount of dry matter of weeds was bigger: 60 g/m^2 in 2009 and 44 g/m^2 in 2010. The bad weather conditions caused a poorer germination of both the wheat and the undersown crop. There was a smaller amount of plants per unit area and as a result worse competitiveness of the canopy due to weeds. (Fig. 2, 7). The amount of dry matter of weeds was the smallest in spring wheat cultivated in the conventional system, on average, amounting to 3.5 g/m^2. It was 10 times lower than for the organic system. In the integrated system, the dry matter of weeds ranged from 1.2 g/m^2 in 2008 to 18 g/m^2 in 2010, which was caused by an increasing share of *E. arvense* in the weed community. The differences in the number of weeds and their dry matter during the research years in the integrated and conventional systems, were determined by the efficacy of the herbicides and the weed species composition.

Spring wheat grown in the organic system was accompanied by dicotyledonous species, mainly *Chenopodium album* and *Stellaria media* (Table 3). The most monocotyledonous weeds occurred in the integrated system, but the amount was below the threshold of harmfulness (0.4–8 ind./m^2). The weeds were represented mainly by *Echinochloa crus-galli* and *Elymus repens* (Table 3). An increasing share of *E. arvense* in the integrated system was associated with a local distortion of air-water relations in the soil. In addition, this species is moderately susceptible to the 2,4-D + florasulam herbicide mixture (Mustang 306 SE), used in all three years of the research study.

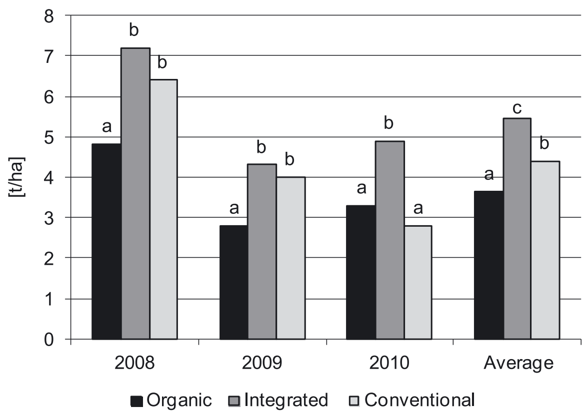
Weed flora diversity was the highest in spring wheat grown in the organic system, where from 14 to 21 species were found depending on the year (Table 3). There were only from 6 to 14 species of weeds in spring wheat cultivated in the integrated system.

Shannon's index values confirmed the greatest variety of weed flora in spring wheat grown in the organic system (1.41–2.10). The index depends not only on the number of species in the community, but also the proportions of the number of individuals. Lower values of this index occurred in the conventional (1.08–2.06) and the integrated system (1.05–1.95) (Fig. 3). Simpson's index indicated the dominance of one or more weed species in the community in the conventional and integrated systems. High values of Simpson's dominance index occurred in the conventional system in 2009 (0.58) and in the integrated system in 2008 and 2010. The high values were caused by a large share of *Viola arvensis* in the weed community in the conventional system and *Fallopia convolvulus* and *E. arvense* in the integrated system (Fig. 3, Table 3).

During the 3-year study, the same number of weed species was recorded in the organic and conventional systems (27). In the organic system, however, a higher stability of occurrence of particular species and similarity between communities were observed (Fig. 4, 5). In the organic system, 11 species occurred in the three years of the study (41% of all species in this system), while in the conventional system – 7 (26%) and in the integrated system, only one (6%). In the conventional system, 16 species occurred only in one year (59% of all species in this system) (Fig. 4).

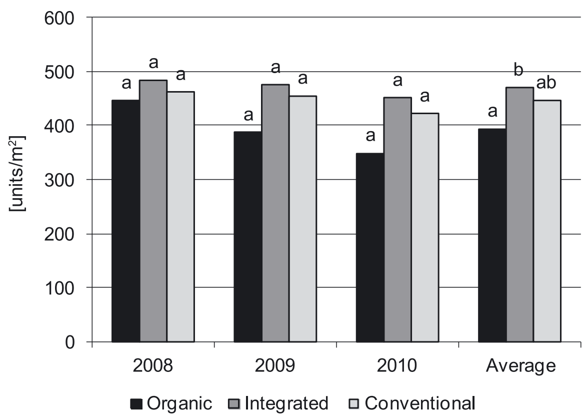
Sorenson's indicators confirmed that among the studied systems, the largest similarity during the years was characteristic of the organic system. Such a confirmation indicates a greater stability in the weed communities in the organic system compared to systems where herbicides were used (Fig. 5). It was found that the values of the qualitative index were higher in comparison to the quantitative ones (Fig. 5). These results suggests a greater similarity between the systems in the species composition of the weed communities than in their numbers. It may also indicate that qualitative changes in weed communities under different production systems run slower than quantitative changes.

In all three years of the study, the highest grain yield of spring wheat was recorded in the integrated system (on average, 5.5 t/ha). It was 35% higher than in the organic system and 20% higher than in the conventional



a, b, c – values marked with teh same letter do not differ significantly according to Tukey's test ($\alpha = 0.05$)

Fig. 6. The grain yield of spring wheat cultivated in different crop production systems



a, b – explanation as on fig. 6

Fig. 7. Number of ears of spring wheat cultivated in different crop production systems

one (Fig. 6). The reason for lower yields of wheat in 2009 and 2010 were the unfavorable weather conditions. The weather affected plant and ear densities and reduced the competitive ability of the crop in relation to the weeds (Fig. 7). Lower grain yield in the conventional system in 2010 was additionally caused by a defective drainage system and locally stagnant water on the surface of the field in spring. There were parts of a sandy soil area where signs of water shortage for plants were observed from the beginning of July (Fig. 6).

The density of ears was the highest in the integrated system (Fig. 7). The smallest number of ears were found in wheat grown in the organic system. Intermediate values of this component of the yield were recorded in the conventional system.

DISCUSSION

Effectiveness of weed control treatments in spring wheat, measured by the number and dry matter of weeds in the dough stage, was significantly lower in the organic system compared to the integrated and conventional systems. The degree of infestation was influenced by weather conditions which affected the emergence and further growth of both wheat and the undersown crop. A compact canopy of clover and grass in 2008, increased the competitiveness of wheat in the organic system. The result was a reduction of the weed dry matter to 8 g/m^2. This indicates the high effectiveness of weed control in spring wheat in the organic system. The high effectiveness was the result of a 5-year rotation, a successful undersown clover with grasses, and a compact canopy of wheat with a high ability to compete with weeds. These results were confirmed by other studies and previous observations conducted as part of the same long-term experiment (Feledyn-Szewczyk and Duer 2006; Hauggaard-Nielsen *et al.* 2006; Parylak *et al.* 2006). By contrast, the rare canopy of wheat in 2009, poorly competed with weeds.

The weed infestation of cereals in the organic system is usually higher compared to other crop production systems which use herbicides (Tyr and Lacko-Bartošova 1998; Rola *et al.* 2000; Feledyn-Szewczyk and Duer 2007). However, when using proper agrotechnical measures in all rotation crops, it is possible to keep weeds at a level that will not cause significant yield decrease (Jańczak-Tabaszewska and Tyburski 1999; Kuś 1999; Feledyn-Szewczyk and Duer 2006). It can be assumed, that low level of infestation in 2008 and moderate ones in 2010 did not affect the grain yield of spring wheat. The results of another study suggest that the infestation of 96 weeds per 1 m^2, and a dry weight of 62 g/m^2 before harvest, causes a decline in the spring wheat yield (Kapeluszny 1994). In this study, such an infestation was observed only in 2009.

Weed flora diversity in different production systems, reflects the applied rotation and agricultural practices, especially weed control methods (Dyer 1995; Doucet *et al.* 1999). Intensification of agricultural production, related to the simplifications in the crop structure, and the large use of mineral fertilization and other means of production, mainly herbicides, can reduce weed diversity (Dyer 1995; Barberi *et al.* 1997; Doucet *et al.* 1999). The research results showed a similar number of species accompanying spring wheat in both the integrated and conventional systems. But in the organic system, a higher stability of particular species in time and a higher similarity between communities were observed. This means that the intensification of farming methods does not necessarily lead to the decline of these species, because the soil seed bank is their true reservoir. Previous studies conducted on these experimental fields indicate that the soil seed bank is richer in species than the above-ground flora (Feledyn-Szewczyk and Duer 2004). The stock of seeds in the soil, shaped the history of the field much longer than the duration of the experiment. The stock is like a buffer, which cannot be as easily changed as the weed communities occurring on the field. In a changing environment, the soil seed bank is a stabilizing factor that ensures the survival of many species (Falińska *et al.* 1994). According to Stupnicka-Rodzynkiewicz *et al.* (2004), the use of herbicides reduces the abundance of weeds, but not their diversity.

Sorenson indices showed that the similarity of weed species composition between systems was greater than the similarity in the number of individuals. This suggests that the qualitative changes in weed communities occur slower than the quantitative changes, which was also observed by Zanin *et al*. (1997) and Odum *et al*. (1994). Similar results have been provided by Rola (2002) who spent many years observing the occurrence of weeds in agroecosystems. The observations showed that qualitative changes are very rarely observed, while quantitative changes are very frequent.

In summary, the methods of weed control in spring wheat in all the investigated systems of production, are sufficiently effective in reducing weed infestation to a level that the weeds do not significantly affect the yield. It should be emphasized, that integrated methods of weed control are also more environmentally friendly than conventionsl ones and allow for reducing the frequency and doses of herbicides.

CONCLUSIONS

1. Effectiveness of weed control methods in spring wheat cultivated in the organic system was lower than in other systems where herbicides were used.
2. The level of weed infestation in the organic system depended on the competitiveness of wheat and the undersown crop. These factors were modified by weather conditions during the emergence and development of components of the mixture.
3. The number of weeds in spring wheat cultivated in the conventional and integrated system was, on average, 4-times smaller than in the organic system (22–24 units/m^2). The dry weight of weeds was also, on average, 4-times smaller in the integrated system (10 g/m^2) and 10-times smaller in the conventional system (3.5 g/m^2).
4. Weed species diversity was the largest in the organic system. In the conventional and integrated systems, compensation of certain weed species (*V. arvensis, F. convolvulus, E. arvense*) was observed.

5. The comparison of weed communities using Sorenson's indices revealed a bigger similarity between systems in terms of the number of weed species than in the number of individuals. This suggests that the qualitative changes are slower than the quantitative ones.
6. The methods of weed control in spring wheat in all the investigated systems of crop production were sufficiently effective in reducing weed infestation to a level where they did not significantly affect the yield.

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