

THE CONSEQUENT INFLUENCE OF CROP ROTATION AND SIX-YEAR-LONG SPRING BARLEY MONOCULTURE ON YIELDS AND WEED INFESTATION OF WHITE MUSTARD AND OATS

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Abstract

The present study was conducted in the years 2007–2008, after 6-year-long experiments in the cultivation of spring barley in a crop rotation system and in monoculture. The other experimental factor was the spring barley protection method. Intensive protection involved comprehensive treatment of barley (in-crop harrowing, seed dressing, application of herbicides, fungicides, a retardant and an insecticide). Extensive protection consisted only in in-crop harrowing, without the application of crop protection agents, except for seed dressing. The above mentioned factors formed the background for the study on the cultivation of white mustard and oats, as phytosanitary species, in successive years. In the test plants, no mineral fertilization and crop protection were applied. Such agricultural method enabled an objective assessment of the consequent effect of monoculture, crop rotation and crop treatments. A hypothesis was made that the cultivation of the phytosanitary plants in the stand after 6-year-long barley monoculture would allow obtaining the level of yields and weed infestation similar to those of the crop rotation treatments. It was also assumed that the cultivation of white mustard and oats would eliminate differences in plant productivity caused by the negative influence of extensive protection.

It was proved that the cultivation of the phytosanitary plants eliminated the negative influence of monoculture on the level of their yields and weed infestation. However, the test plants did not compensate negative consequences of extensive protection. In spite of this, white mustard and oats effectively competed with weeds, and the number and weight of weeds in a crop canopy did not cause a dramatic decline in yields. In the test plant canopy, the following short-lived weeds were predominant: *Chenopodium album*, *Galinsoga parviflora*, *Echinochloa crus-galli*. The absence of herbicide application resulted in the compensation of perennial species: *Elymus repens* and *Cirsium arvense*.

Key words: spring barley, monoculture, crop rotation, protection method, consequent influence, white mustard, oats, yielding, weed infestation

INTRODUCTION

In crop rotations with large cereal proportions, in particular in monoculture, there occur a number of negative phenomena resulting, among other things, in a decline in competitiveness of crop plants relative to weed flora. Increased weed infestation of a crop canopy is in turn one of the main reasons for their reduced productivity (Deryło and Pawłowski, 1982; Deryło, 1994). Spring barley is a species sensitive to monoculture and related weed pressure (Wesołowski et al. 2003; Blecharczyk et al. 2005). Proper crop sequencing, based on environmental factors, coupled with appropriate agricultural practices applied with it, ensures to a large extent a successive increase in yields and a reduction in weed infestation (Zawiślak, 1997; Adamiak, 2007). In the opinion of some authors (Kwiatkowski, 2004a; Stupnicka-Rodzyńkiewicz et al. 2004), comprehensive mechanical and chemical protection of spring barley only partially compensates the effects of inappropriate crop sequencing. The cultivation of phytosanitary plants (mustard, oats) can be included among factors which reverse the negative effects of barley or wheat monoculture. As shown by the studies of Oleszek (1994) and Murawa et al. (2004), white mustard, thanks to certain peculiar allelopathic substances, may inhibit germination and even growth of some weed species in a natural way. Oats, compared to other cereals, reacts weaker to monoculture and its cultivation after other grain plants. In strongly cereal-based crop rotations, it may perform the role of a phytosanitary and regenerating plant (Jelinowski, 1979; Adamiak, 1992; Adamiak and Adamiak, 1994).

The above arguments allowed us to make a hypothesis that the cultivation of white mustard and

oats in successive years in the stand after 6-year-long spring barley monoculture would enable the regeneration of this stand (the level of yields and weed infestation) similar to that obtained in treatments with the consequent influence of crop rotation. An assumption was also made that the cultivation of the phytosanitary plants would eliminate differences in plant productivity and weed infestation, associated with the consequent effect of two protection levels.

The aim of the present study was to assess the condition of weed flora in a white mustard and barley canopy as well as to analyse yields of these species grown for seeds, under different conditions of long-term crop succession and under different crop protection methods.

MATERIALS AND METHODS

Field investigations were conducted in the years 2007-2008 after 6-year-long (2001-2006) experiments in the cultivation of spring barley in a crop rotation system and in monoculture. A strict field experiment was established at the Czesławice Experimental Farm, belonging to the University of Life Sciences in Lublin, Poland, using the split-plot method in 3 replicates in plots with an area of 27 m². The experiment was set up on grey-brown podzolic soil formed from loess (soil quality class II).

The following factors formed the background of the study:

I. Crop sequence:

A. crop rotation (potato^{xx} – spring barley – horse bean – winter wheat),

B. 6-year-long spring barley monoculture.

II. Spring barley protection method:

a. intensive: harrowing before emergence and at the 3-4 leaf stage, seed dressing – Raxil 060 FS (*tebuconazol*), application of herbicides – Chwastox Turbo 340 SL (*MCPA* + *dicamba*) and Puma Uniwersal 069 EW (*fenoxaprop-P-ethyl* + *mefenpyr-diethyl*), fungicides – Tilt Plus 400 EC (*propiconazole* + *fenpropidin*) and Alert 375 SC (*flusilazole* + *carbendazim*), insecticide – Decis 0.25 EC (*deltamethrin*), growth retardant – Flordimex 420 SL (*ethephon*),

b. extensive: harrowing before emergence and at the 3-4 leaf stage, no application of chemical crop protection agents, except for seed dressing – Raxil 060 FS.

All crop protection agents were used on dates and at doses in accordance with recommendations of the Plant Protection Institute in Poznań, Poland. Mineral fertilization of spring barley, both in crop rotation and monoculture, was identical and it was as follows: N – 60, P₂O₅ – 70, K₂O – 90 kg × ha⁻¹. Organic fertilization (manure) in crop rotation was applied for potato

(35 t × ha⁻¹), whereas under barley monoculture it was applied once every 3 years (35 t × ha⁻¹). With respect to the other crop plants grown in crop rotation (potato, horse bean, winter wheat), mechanical treatments and crop protection agents specific for every plant species were also applied. Soil tillage for barley and the other plant species grown in crop rotation followed agricultural practice rules.

The test plants in this experiment were as follows: white mustard in 2007 (cv. Borowska – 20 kg × ha⁻¹) and oats in 2008 (cv. Kasztelan – 200 kg × ha⁻¹). In the investigated plants, no mineral fertilization or plant protection were used, except for seed dressing (Raxil 069 FS) and intervention treatment with an insecticide in white mustard (Decis 0.25 EC). Such agricultural method (no fertilization and chemical protection) used with respect to the test plants under assessment was designed to enable an objective assessment of the consequent effect of the investigated factors, i.e. crop sequence and crop treatments.

Soil tillage, the quantity and date of sowing of the test plants (white mustard, oats) were within proper agricultural practice standards. The assessment of weed infestation was made using the botanical gravimetric method, during the full growing season of the test plants (mustard – flowering stage, oats – heading stage), thus, during the period of greatest accumulation of biomass by weeds in a canopy. Before weighing, mustard and oats seed yields were brought to the same moisture content level – 14%. The research results were statistically verified, determining the significance of differences using Tukey's test.

RESEARCH RESULTS AND DISCUSSION

White mustard seed yield was significantly differentiated by the investigated experimental factors (Tab. 1). The cultivation of this plant in the stand after spring barley under the Norfolk crop rotation system resulted in seed yield higher by 51% than that found in the treatments with the consequent influence of monoculture. The influence of protection method in the spring barley canopy proved to be even more evident. Intensive protection, irrespective of the forecrop, provided mustard seed yield larger by 51% compared to the extensive protection treatments. The stand after spring barley grown in crop rotation and intensively protected guaranteed the largest white mustard seed yield (1.82 t × ha⁻¹). The lowest mustard productivity was found in the stand after extensively protected spring barley in monoculture (only 0.71 t × ha⁻¹).

Oats, as the other test plant, showed smaller variations in yields resulting from crop succession (Tab. 1). It can be explained by the fact that white mustard,

Table 1
The influence of crop rotation, monoculture and spring barley protection method on yields of succeeding crops.

Specification	Test plants					
	White mustard – seed yield (t ha ⁻¹)			Oats – grain yield (t ha ⁻¹)		
	PI*	PE**	mean	PI	PE	mean
Spring barley in crop rotation	1.82	0.96	1.39	3.19	2.24	2.71
Spring barley in monoculture	1.55	0.71	1.13	3.02	2.15	2.58
Mean	1.68	0.83	–	3.10	2.19	–
LSD _{0.05} for:						
crop sequence =			0.241			ns
protection method =			0.365			0.452
interaction:						
crop sequence x protection method =			0.319			ns

PI* – intensive protection of barley

PE** – extensive protection of barley

ns – not significant

Table 2
The influence of crop rotation, monoculture and spring barley protection method on the number of weeds (per 1 m²) in a succeeding crop canopy.

Specification	Test plants					
	White mustard			Oats		
	PI*	PE**	mean	PI	PE	mean
Spring barley in crop rotation	94.9	122.6	108.7	68.2	116.9	92.5
Spring barley in monoculture	111.5	143.4	127.4	95.6	120.2	107.9
Mean	103.2	133.0	–	81.9	118.5	–
LSD _{0.05} for:						
crop sequence =			15.32			14.73
protection method =			17.67			17.94
interaction:						
crop sequence x protection method =			14.72			13.34

Explanations in Table 1

as the immediate forecrop of oats, simultaneously performed the role of a phytosanitary plant and had a modifying effect on its yielding, to which attention is drawn by some authors (Pawłowski and Deryło, 1988; Murawa et al. 2004). In the treatments with spring barley monoculture, oats yield was smaller only by 5% compared to crop rotation. But significantly lower productivity of white mustard (by 29%) in the extensive protection treatments was noted compared to comprehensive (mechanical and chemical) protection.

The number of weeds in the test plant canopies also depended significantly on the investigated factors (Tab. 2). The lowest number of weeds was recorded in the crop rotation with intensive protection, both in the mustard and oats canopy. In the stand after spring barley monoculture, the number of weeds was larger by, respectively, 15% (mustard) and 14% (oats) compared to crop rotation. The application of plant protection agents (including herbicides) in spring barley crops, irrespective of crop succession, caused the number

Table 3
The influence of crop rotation, monoculture and spring barley protection method on air-dry weight of weeds (g m²) in a succeeding crop canopy.

Specification	Test plants					
	White mustard			Oats		
	PI*	PE**	mean	PI	PE	mean
Spring barley in crop rotation	76.4	87.6	82.0	70.2	84.4	77.3
Spring barley in monoculture	80.9	94.8	87.8	72.8	86.9	79.8
Mean	78.6	91.2	–	71.5	85.6	–
LSD _{0.05} for:						
crop sequence =			ns			ns
protection method =			10.58			11.25
interaction:						
crop sequence x protection method =			ns			ns

Explanations in Table 1

Table 4
The simple correlation coefficient (r) between air-dry weight of weeds in a canopy and yields of succeeding crops.

Specification	Test plants					
	White mustard			Oats		
	PI*	PE**	mean	PI	PE	mean
Spring barley in crop rotation	-0.41	-0.75*	-0.58*	-0.36	-0.45	-0.40
Spring barley in monoculture	-0.66*	-0.82*	-0.74*	-0.38	-0.50	-0.44
Mean	-0.53*	-0.78*	-	-0.37	-0.47	-

Explanations in Table 1

* significant correlation coefficient

of weeds in the intensive protection treatments to be smaller by 22% (mustard) and 31% (oats) compared to the extensive protection treatments.

The crop sequence system did not result in any great differences in air-dry weight of weeds in the white mustard and oats canopy (Tab. 3). A tendency towards larger weight of weeds (by 7% – mustard, 3% – oats) in monoculture compared to crop rotation was only noted. However, the introduction of the phytosanitary test plants did not compensate the negative consequent influence of extensive protection of the crop canopy. Air-dry weight of weeds determined under such conditions was larger by 14% (mustard) and 16% (oats) compared to the treatments in which intensive protection of spring barley was applied. However, it should be noted that the cultivation of phytosanitary

crops in successive years eliminated the negative effect of monoculture and extensive protection of the canopy, in particular in the case of weight of weeds in the oats canopy. As a result, the effect of air-dry weight of weeds on oats productivity was similar in particular treatments, which is confirmed by the calculated correlation coefficients (Tab. 4).

In the white mustard canopy, the number of weed species after various forecrops was 24-27, whereas in the oats canopy – 22-24 (Tab. 5). The largest amount of dominant weed species was found in the stand after Norfolk crop rotation (white mustard), whereas the lowest amount in the oats canopy grown after 6-year-long barley monoculture. *Chenopodium album*, *Echinochloa crus-galli*, *Stellaria media* occurred in greatest numbers in the canopy of both test

Table 5
Dominant weed species in a test plant canopy, irrespective of the protection method.

Specification	Test plants					
	White mustard			Oats		
	Jm	Jp	mean	Jm	Jp	mean
Number of dominant weed species per 1 m ²						
1. <i>Chenopodium album</i> L.	30.3	20.6	25.4	20.6	16.7	18.6
2. <i>Galinsoga parviflora</i> Cav.	19.7	15.2	17.4	11.3	10.4	10.8
3. <i>Echinochloa crus-galli</i> (L.)P. Beauv.	18.6	14.9	16.7	20.3	16.0	18.1
4. <i>Stellaria media</i> (L.) Vill.	11.3	9.8	10.5	13.4	10.2	11.8
5. <i>Polygonum lapathifolium</i> L.	10.5	6.7	8.6	8.5	7.6	8.0
6. <i>Capsella bursa-pastoris</i> (L.) Medik.	9.9	7.4	8.6	8.4	7.9	8.1
7. <i>Elymus repens</i> (L.) Gould	7.1	3.9	5.5	10.2	6.4	8.3
8. <i>Cirsium arvense</i> (L.) Scop.	6.4	6.0	6.2	7.2	7.0	7.1
Other species	13.2	23.5	18.3	8.0	10.3	9.1
Total number of weeds	127.4	108.7	118.0	107.9	92.5	100.2
Number of weed species	24	27	25	22	24	23

Jm – spring barley in monoculture

Jp – spring barley in crop rotation

plants. Perennial species (*Elymus repens*, *Cirsium arvense*) did not pose great threat; nevertheless, their intensified occurrence was found in the oats canopy. Among the short-lived species, the compensation of *Echinochloa crus-galli* and *Stellaria media* was also noted. However, the proportions of the other dominant weed species in the oats canopy were reduced: by 27% (*Chenopodium album*), 38% (*Galinsoga parviflora*) and 50% (other species not specified in the table).

The results of the present study illustrate that the test plants (mustard, oats) responded by a larger decline in yield to the consequent influence of the absence of chemical protection of spring barley crops than to the negative influence of monoculture. White mustard shows similar yields regardless of the forecrop, due to its resistance to fungal diseases and high ability to compete with weeds. For this reason, it is often sown as a stubble crop in cereal monocultures (Oleszek, 1994; Kwiatkowski, 2004b). Adamiak and Adamiak (1994, 1999) note that oats does not show significant differences in yields related to an increased proportion of cereals in a crop rotation. Lower weed infestation of oats and marginal infection by the fungal disease complex determine the great yield-protective importance of this plant.

Yielding of the phytosanitary plants in question was negatively correlated with the level of their weed infestation, which was the highest in the stand after the extensively protected spring barley monoculture (Tab. 4). Pawłowski and Wesołowski (1996) demonstrate that quantitative weed infestation of spring barley and of succeeding crops cultivated is determined to a large extent by spring weeds – *Chenopodium album*, *Stellaria media*, *Poa annua*, *Echinochloa crus-galli*. The regulation of weed population size, and thereby decreasing their competitiveness relative to a crop plant, depends to a large degree on the proper crop sequence. Crop rotation and also some succeeding crops (mustard, oats), thanks to their phytosanitary effect on soil and allelopathic responses, inhibit in a natural way the development of some weeds. Deryło (1994) as well as Kwiatkowski and Wesołowski (2004) are of opinion that the application of comprehensive crop protection (forecrops) has a significant effect on the limitation of weed infestation of succeeding crops. Oleszek (1994) proves that substances contained in mustard (glucosinolates, isothiocyanates) reduce the population size of weeds such as *Chenopodium album*, *Galium aparine*, *Matricaria maritima* ssp. *inodora*,

Capsella bursa-pastoris. Nevertheless, mustard press cakes mixed with soil have the greatest allelopathic effect. Hence, it can be presumed that the weed control activity of this plant in the present study was revealed only after its harvest and the ploughing-in of post-harvest residues and it limited weed infestation of the next crop grown in this stand (oats). Jędruszczak et al. (2005) note that in years characterised by low temperature and wet weather (May – July), late emerging weeds (*Galinsoga parviflora*, *Echinochloa crus-galli*, *Gnaphalium uliginosum*), being the core of dominant species, occur in greatest numbers in a white mustard canopy. It is attested by the competitiveness of white mustard grown under good soil culture conditions and proper agricultural practice, even without any weed destruction, which finds reflection in the paper in question. In addition, the authors claim that growing white mustard after cereals, on poor soils of low culture, causes increased weed infestation and requires chemical weed control.

In the present study, weeds did not dominate the white mustard canopy. In spite of the absence of chemical protection of the crop, the weight of a single weed, irrespective of the investigated factors, was ca. 0.75 g, on the average, and similar tendencies were also observed in the oats crop. Observations of weed infestation conducted by Adamiak and Adamiak (1999) showed that the introduction of oats into a crop rotation limited the occurrence of weeds. Oats competed with weeds better than other spring cereal species as well as some leguminous plants (horse bean).

CONCLUSIONS

1. Spring barley grown in crop rotation and intensively protected showed the most beneficial consequent effect on yields and weed infestation of white mustard and oats. The greatest decline in yields of the test plants was observed in the stand after six-year-long extensively protected monoculture of spring barley
2. The introduction of phytosanitary plants into cultivation over successive two years eliminated the negative influence of barley monoculture, resulting in the level of oats yields and weed infestation similar to that in the stand after crop rotation, but it did not compensate the negative consequences of extensive protection.
3. The cultivation of white mustard, and then oats, irrespective of the investigated factors, in spite of the absence of herbicide application, maintained weed infestation of the canopy at a level which did not create a risk of a dramatic decline in productivity of these crop plants.
4. The following short-lived weed species: *Chenopodium album*, *Galinsoga parviflora* and *Echinochloa*

crus-galli, were predominant in the canopy of the test plants. The deprivation of chemical protection of the canopy resulted in intensified occurrence of perennial species (*Elymus repens*, *Cirsium arvense*).

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Następczy wpływ płodozmianu i sześciolletniej monokultury jęczmienia jarego na plonowanie oraz zachwaszczenie gorczycy białej i owsa

Streszczenie

Badania przeprowadzono w latach 2007-2008, po 6-letnich doświadczeniach z uprawą jęczmienia jarego w płodozmianie i monokulturze. Drugim czynnikiem eksperymentu był sposób pielęgnacji jęczmienia jarego. Intensywna pielęgnacja polegała na kompleksowej ochronie jęczmienia (bronowanie zasiewów, zaprawianie nasion, stosowanie herbicydów, fungicydów, retardanta i insektycydu). Ekstensywna pielęgnacja sprowadzała się tylko do bronowania zasiewów, bez stosowania środków ochrony roślin, poza zaprawą nasienną. Powyższe czynniki były temem badań z uprawą w kolejnych latach gorczycy białej i owsa, jako gatunków fitosanitarnych. W roślinach testowych nie stosowano nawożenia mineralnego i ochrony roślin. Taki sposób agrotechniki umożliwiał obiektywną ocenę następczego oddziaływania monokultury, płodozmianu i zabiegów pielęgnacyjnych. Przyjęto hipotezę, że uprawa roślin fitosanitarnych w stanowisku po 6-letniej monokulturze jęczmienia pozwoli na uzyskanie poziomu plonów i zachwaszczenia zbliżonego do obiektów płodozmianu. Założono również, że uprawa gorczycy białej i owsa zniweluje różnice w produktywności roślin spowodowane negatywnym wpływem ekstensywnej pielęgnacji.

Dowodzono, że uprawa roślin fitosanitarnych niwelowała negatywny wpływ monokultury na poziom ich plonowania i zachwaszczenia. Rośliny testowe nie kompensowały jednak ujemnych następstw ekstensywnej pielęgnacji. Pomimo tego, gorczyca biała i owies skutecznie konkurowały z chwastami, a liczba i masa chwastów w łanie nie powodowały gwałtownego spadku plonów. W łanie roślin testowych dominowały chwasty krótkotrwałe: *Chenopodium album*, *Galinsoga parviflora*, *Echinochloa crus-galli*. Brak stosowania herbicydów skutkowało kompensacją gatunków wieloletnich: *Elymus repens* i *Cirsium arvense*.