www.czasopisma.pan.pl PAN POLSKA AKADEMIA NAUK www.journals.pan.pl

JOURNAL OF PLANT PROTECTION RESEARCH Vol. 53, No. 3 (2013)

DOI: 10.2478/jppr-2013-0031

THE MORPHOLOGICAL FEATURES AND CANOPY PARAMETERS AS FACTORS AFFECTING THE COMPETITION BETWEEN WINTER WHEAT VARIETIES AND WEEDS

Beata Feledyn-Szewczyk, Krzysztof Jończyk, Adam Berbeć*

Institute of Soil Science and Plant Cultivation – State Research Institute
Czartoryskich 8, 24-100 Puławy, Poland

Received: March 13, 2013
Accepted: September 8, 2013

Abstract: The aim of the study was to determine the relationship between morphological features and canopy parameters of winter wheat varieties and weed infestation. The 2-year-long field experiments were conducted at 3 locations, on 13 varieties of winter wheat cultivated on organic farms. The response of the tested cultivars to weed infestation was similar regardless of the location. The number of weeds did not differ significantly between the wheat varieties and was similar in all locations and years of the study (109–122 plants/m^2). The weed dry matter was significantly lower in Chomentowo (38 g/m^2) compared to Osiny and Chwałowice (66 and 85 g/m^2). Nateja and Legenda wheat varieties showed the biggest competitiveness against weeds in both years and locations, whereas Alcazar, Boomer and Jenga were characterized as having the least competitive ability. Natula, Kohelia, Batuta and Ostroga wheat varieties showed a different response to weed infestation over the years. The analysis of correlation and cluster analysis showed that wheat dry matter, plant density, and wheat height had the greatest impact on the number and dry matter of weeds. There was no significant correlation between number of tillers per plant and weed infestation parameters measured in the dough stage.

Key words: competitiveness, morphological features, organic agriculture, weed infestation, winter wheat varieties

INTRODUCTION

Over the last decade, the agricultural area dedicated to organic crop production has shown a continuous growth in a number of European countries. Weed control is an important element of agricultural practices in the organic farming system, where the use of herbicides is forbidden. Selection of wheat varieties with a higher competitive ability against weeds is one of the direct methods to reduce weed infestation and weed seed bank in the soil (Christensen 1995; Eisele and Köpke 1997; Davies and Welsh 2001). Selection of cereal varieties suited to organic agriculture requires a different approach to that used in the conventional high input system. This is because there are fewer opportunities to compensate for a limited yield caused by disease, low nutrients and weeds in organic agriculture, and there is a need to adopt to highly variable environmental conditions across a diversity of organic agriculture systems (Hoad *et al*. 2008; Wolfe *et al*. 2008).

The results of research conducted in Canada, Australia, and Europe indicate that the competitiveness of cereals against weeds depends mostly on crop density (row width and number of plants in a row), the direction of rows as well as the morphological features of varieties (Carlson and Hill 1985; Satorre and Snaydon 1992; Håkansson 1997; Hucl 1998; Seavers and Wright 1999; O'Donovan *et al*. 2000; O'Donovan *et al*. 2005; Owczarczuk *et al*. 2005; Krawczyk *et al*. 2008; Feledyn-Szewczyk 2009). The competitive ability of cereal varieties are affected by the plant height, leaf area, mean foliage tip angle, rate of growth, duration of the foliage connected with the susceptibility due to disease, and allelopathic properties (Challaiah Burnside *et al*. 1986; Balyan *et al*. 1993; Christensen 1995; Lemerle *et al*. 1996; Eisele and Köpke 1997; Seavers and Wright 1999; Kraska 2006; Parylak *et al*. 2006; Bertholdsson 2011).

Different cereal varieties vary in their potential to compete with weeds due to the differences in overall shading ability of the cereals (Christensen 1995; Lemerle *et al*. 1996; Hucl 1998; O'Donovan *et al*. 2000; O'Donovan *et al*. 2007; Krawczyk *et al*. 2008; Feledyn-Szewczyk 2011). Cereals competing with weeds in conventional plant breeding has been given a low priority. Modern varieties show a lower competitiveness against weeds in comparison with older varieties. There is a need for varieties which are suited to organic and other less intensive crop production systems. The selection of genotypes with good weed suppression is important (Didon 2002; Feledyn-Szewczyk 2009).

The first aim of the research was to assess how competitive 13 winter wheat varieties were against weeds. The second aim was to determine the relationship between the morphological features and canopy structure of the wheat varieties, and the level of weed infestation.

*Corresponding address:
bszewczyk@iung.pulawy.pl

MATERIALS AND METHODS

The study was conducted in the 2011–2012 time period, at organic farms in 3 locations, in Poland: The Experimental Station of the Institute of Soil Science and Plant Cultivation – State Research Institute in Osiny (Lublin voivodeship), the experimental organic farm of The Radom Agricultural Advisory Center in Chwałowice (Masovian voivodeship), and a private organic farm in Chomentowo (Podlasie voivodeship). In 2012, winter wheat was damaged by frost in Osiny. In each location, the following 13 varieties of winter wheat were cultivated: Akteur, Alcazar, Boomer, Kohelia, Legenda, Natula, Ostka Strzelecka, Ostroga, Batuta, Bogatka, Jenga, Jantarka, Nateja. One-factor experiments were established, in completely randomized blocks, in 4 replications for each variety. The characteristics of the habitat conditions are presented in table 1. The varieties of wheat were sown in the amount of 5 mln grains/ha at the optimum sowing date for each location. According to organic agriculture rules, mineral nitrogen fertilizers and other agrochemicals were not used. Weeds were controlled mechanically, using a weeding harrow twice, at the tillering stage of wheat.

Table 1. The characteristics of habitat conditions

Items	Location of organic farms		
	Osiny, Lublin voivodeship	Chwałowice, Masovian voivodeship	Chomentowo, Podlasie voivodeship
Soil type	luvisol	cambisol	leached cambisol
Texture	loamy sand on sandy loam	silt loam	silt on sandy loam
Forecrop	clover and grasses	garden radish	clover and grasses

Weather conditions during the 2010–2011 growing season were characterized by an unfavorable distribution of rainfall during critical stages of plant growth. The drought prior to the sowing time and low rainfall in October resulted in an unequal emergence of winter wheat, especially in Osiny and Chwałowice. Winter wheat fields in Osiny and Chwałowice were partially damaged by frost. Autumn 2011 was dry, which made sowing and germination of winter wheat difficult. Very low temperatures in February 2012, in the absence of snow cover, resulted in large losses of winter wheat in Osiny and resignation from the trial site. In other locations the weather conditions in 2012 were suitable for the growth and development of winter wheat.

The number of weeds and their dry matter were assessed in the dough stage of wheat (BBCH 85-87), on an area of 0.5 m^2, in four replications for each variety. Biometric analysis included measurements of the height and number of tillers for 30 plants as well as wheat plant density and wheat dry matter from an area of 1 m^2, each in four replications, and done in the dough stage. The biometric features were measured in Osiny in 2011, but winter wheat was damaged by frost in Osiny in 2012 so the analyses were done in Chwałowice.

Two-factor analysis of variation for a completely randomized model with interaction, was used. The significance of differences between means was verified by Tukey's test at $\alpha = 0.05$. In order to estimate how the features of winter wheat varieties influence the parameters of infestation, Spearman's correlation coefficients between number of weeds and their dry matter, and the morphological features and canopy parameters for tested varieties were assessed. Cluster analysis using the furthest neighbour method was done in order to divide the samples into groups with similar characteristics. Calculations were performed using Statgraphic Plus version 2.1.

RESULTS

The response of the tested wheat varieties on weed infestation was similar regardless of the location of the experiment. There was no statistically significant interaction between the varieties and locations as far as the number of weeds and the dry matter of weeds was concerned, in both years of the study (Table 2). The weed abundance did not differ significantly between varieties and was very similar in all the studied locations and during the years studied (109–122 plants/m^2).

Weed dry matter was significantly lower in winter wheat cultivated in Chomentowo compared to Osiny and Chwałowice. These results may have to do with better winter survival and bigger wheat plant density in Chomentowo (Table 3). Average dry matter of weeds in wheat ranged from 38 g/m^2 in Chomentowo to 85 g/m^2 in Chwałowice. In 2011, Nateja and Jantarka wheat varieties were characterized by significantly lower weed dry matter than Natula.

The tested varieties differed in morphological features and canopy parameters, which influenced the ability of the wheat varieties to compete with weeds. Legenda, Nateja, and Natula were characterized by the greatest height while Alcazar, Boomer, and Jenga were the shortest varieties (Table 4). The number of tillers per plant measured in the dough stage, did not differ significantly between varieties (Table 4).

Nateja, Kohelia, and Batuta wheat varieties were characterized by the greatest number of plants per unit area while Ostka Strzelecka, Bogatka, and Akteur by the lowest number (Table 5). There was a statistically significant interaction between varieties and years/locations for this feature. Wheat dry matter content was the smallest for Ostka Strzelecka, Jenga, Alcazar, and Boomer. Wheat dry matter content was the largest for Legenda, Nateja, Jantarka, and Batuta.

Cluster analysis was done separately for 2011 (Osiny) and 2012 (Chwałowice) so as to divide the varieties according to the level of weed infestation, selected morphological features, and canopy parameters (Tables 6, 7). The smallest number and dry matter of weeds were noted in varieties characterized by the biggest amount of dry wheat matter and plant density as well as plants which were taller. These findings indicate that these features had the greatest impact on competitiveness with weeds, which was confirmed in correlation analysis (Table 8). Nateja and Legenda wheat varieties had the biggest com-

Table 2. The number of weeds (plants/m^2) in tested winter wheat varieties in different locations and years of the research

Varieties	Location of farms and years						
	Chwałowice			Chomentowo			Osiny
	2011	2012	average	2011	2012	average	2011
Akteur	123.5	124.0	123.8	118.0	109.0	113.5	116.0
Alcazar	123.5	147.5	135.5	108.0	102.0	105.0	133.0
Batuta	128.0	157.5	142.8	133.5	123.0	128.3	115.0
Bogatka	124.0	100.0	112.0	122.5	116.0	119.3	97.5
Boomer	119.0	169.5	144.3	140.0	112.5	126.3	147.5
Jantarka	125.5	122.5	124.0	112.0	121.5	116.8	102.0
Jenga	103.5	108.0	105.8	124.5	118.0	121.3	134.5
Kohelia	93.5	127.0	110.3	109.0	99.2	104.1	94.5
Legenda	145.5	106.0	125.8	130.0	107.5	118.8	104.5
Nateja	101.0	96.0	98.5	120.0	109.0	114.5	98.0
Natula	118.0	86.0	102.0	117.0	91.5	104.3	138.5
Ostka Strzelecka	107.5	130.5	119.0	107.5	98.5	103.0	137.0
Ostroga	119.5	110.0	114.8	110.0	105.5	107.8	111.0
average	117.8	121.9	119.9	119.4	108.7	114.0	117.6
The results of ANOVA analysis	LSD for varieties – ns*, years – ns, interaction – ns			LSD for varieties – ns, years – ns, interaction – ns			LSD for varieties – ns
	2011: LSD for varieties – ns, locations – ns, interaction – ns						
	2012: LSD for varieties – ns, locations – 13.0, interaction – ns						

*ns – not significant differences at $\alpha = 0.05$ according to Tukey's test

Table. 3. Weed dry matter (g/m^2) in tested winter wheat varieties in different locations and years of the research

Varieties	Location of farms and years						
	Chwałowice			Chomentowo			Osiny
	2011	2012	average	2011	2012	average	2011
Akteur	73.0	119.9	96.5	33.5	38.7	36.1	53.1
Alcazar	83.2	129.0	106.1	59.5	36.5	48.0	71.9
Batuta	74.6	90.1	82.4	26.2	48.0	37.1	78.5
Bogatka	77.3	94.3	85.8	29.2	54.5	41.9	57.8
Boomer	64.3	136.7	100.5	41.4	43.2	42.3	75.8
Jantarka	85.8	78.9	82.4	17.1	57.9	37.5	43.5
Jenga	77.6	124.7	101.2	54.8	29.1	42.0	66.9
Kohelia	55.2	89.8	72.5	27.9	18.8	23.4	50.5
Legenda	96.3	93.1	94.7	39.0	25.0	32.0	49.0
Nateja	59.5	55.5	57.5	17.3	27.7	22.5	31.3
Natula	77.9	70.0	74.0	52.9	36.7	44.8	126.5
Ostka Strzelecka	61.0	93.4	77.2	68.2	29.8	49.0	94.1
Ostroga	65.0	70.4	67.7	41.1	34.7	37.9	63.6
average	73.13	95.8	84.5	39.11	36.9	38.0	66.3
The results of ANOVA analysis	LSD for varieties – ns*. years – 13.5. interaction – ns			LSD for varieties – ns. years – ns. interaction – 40.1			LSD for varieties – ns
	2011: LSD for varieties – 44.8. locations – 15.1. interaction – ns						
	2012: LSD for varieties – ns. locations – 11.8. interaction – ns						

*ns – not significant differences at $\alpha = 0.05$ according to Tukey's test

Table 4. The selected morphological features of winter wheat varieties in the dough stage

Varieties	Number of tillers per plant			Height [cm]		
	2011	2012	average	2011	2012	average
Akteur	1.65	1.52	1.59	88.3	88.5	88.4
Alcazar	1.50	1.52	1.51	67.8	71.5	69.7
Batuta	1.28	1.42	1.35	84.6	85.0	84.8
Bogatka	1.47	1.50	1.49	84.5	83.5	84.0
Boomer	1.59	1.57	1.58	72.2	71.7	72.0
Jantarka	1.64	1.66	1.65	81.0	82.3	81.6
Jenga	1.58	1.33	1.46	69.3	72.9	71.1
Kohelia	1.14	1.44	1.29	87.0	88.2	87.6
Legenda	1.38	1.62	1.50	100.2	96.1	98.2
Nateja	1.24	1.63	1.44	89.0	100.3	94.6
Natula	1.68	1.47	1.58	89.5	90.8	90.1
Ostka Strzelecka	1.41	1.58	1.50	83.6	86.5	85.1
Ostroga	1.50	1.31	1.41	79.5	76.8	78.2
average	1.47	1.50	1.48	82.8	84.2	83.5
The results of ANOVA analysis	LSD for varieties – ns*, years – ns, interaction – ns			LSD for varieties – 11.4, years – ns, interaction – ns		

*ns – not significant differences at $\alpha = 0.05$ according to Tukey's test

Table 5. The selected canopy parameters of winter wheat varieties in the dough stage

Varieties	Density of wheat plants [plants/m^2]			Dry matter of wheat [g/m^2]		
	2011	2012	average	2011	2012	average
Akteur	213.0	189.0	201.0	1008.4	824.1	916.3
Alcazar	237.0	202.0	219.5	846.0	757.1	801.6
Batuta	267.0	258.0	262.5	1023.8	985.3	1004.6
Bogatka	217.0	184.0	200.5	933.6	741.2	837.4
Boomer	224.0	224.0	224.0	860.6	756.8	808.7
Jantarka	216.0	226.0	221.0	1000.6	1103.1	1051.9
Jenga	231.0	273.0	252.0	698.7	798.7	748.7
Kohelia	285.0	249.0	267.0	904.1	1026.0	965.1
Legenda	275.0	188.0	231.5	1248.6	993.6	1121.1
Nateja	290.0	264.0	277.0	928.5	1190.2	1059.4
Natula	195.0	284.0	239.5	923.7	1064.3	994.0
Ostka Strzelecka	203.0	161.0	182.0	709.2	766.3	737.8
Ostroga	288.0	214.0	251.0	1160.2	789.1	974.7
average	243.9	224.0	234.0	935.1	907.4	921.3
The results of ANOVA analysis	LSD for varieties – 78.4. years – ns*. interaction – 91.1			LSD for varieties – 339.6. years – ns. interaction – ns		

*ns – not significant differences at $\alpha = 0.05$ according to Tukey's test

Table 6. The results of cluster analysis based on parameters of weed infestation, selected morphological features, and canopy parameters for tested varieties in 2011. in Osiny

Cluster	Number of weeds	Dry matter of weeds	Tillering	Height	Density of wheat	Dry matter of wheat	Varieties
1	104.6	54.9	1.3	88.1	281.0	1053.0	Kohelia, Legenda, Batuta, Mateja, Ostroga
2	123.6	66.2	1.5	78.1	220.1	865.2	Acteur, Alkazar, Boomem, Ostka Strzelecka, Bogatka, Jenga, Jantarka
3	138.5	126.5	1.7	89.5	195.0	923.7	Natula

Table 7. The results of cluster analysis based on parameters of weed infestation, selected morphological features, and canopy parameters for tested varieties in 2012, in Chwałowice

Cluster	Number of weeds	Dry matter of weeds	Tillering	Height	Density of wheat	Dry matter of wheat	Varieties
1	90.3	62.8	1.6	95.6	274.0	1127.3	Natula, Nateja
2	116.5	95.2	1.6	87.4	189.6	885.6	Akteur, Legenda, Ostka Strzelecka, Bogatka, Jantarka
3	137.1	106.8	1.4	77.7	236.7	852.2	Alcazar, Boomer, Kohelia, Ostroga, Batuta, Jenga

Table 8. Correlation coefficients between number and dry matter of weeds and some morphological features and canopy parameters for all tested varieties and years in the dough stage (N = 104)

Parameters	Number of tillers per plant	Height	Density of wheat	Dry matter of wheat
Number of weeds	–0.049	–0.306*	–0.247*	–0.373*
Dry matter of weeds	–0.027	–0.201*	–0.290*	–0.334*

* significant correlation at $\alpha = 0.05$

petitive ability against weeds in both the study years and locations whereas Alcazar, Boomer and Jenga were characterized with the smallest suppression (Tables 6, 7). Natula showed a different reaction to infestation in the years and locations. In 2011, in Osiny, this variety was characterized by the highest abundance and weed dry matter, but in 2012, in Chomentowo, Natula was included in the group of varieties with the lowest level of infestation. Different responses to weed infestation in the years and locations were also shown by Kohelia, Batuta, and Ostroga (Tables 6, 7).

The analysis of correlation showed that wheat dry matter had the greatest impact on number and weed dry matter (Table 8), which corresponded with the results of the cluster analysis (Tables 6, 7). Moreover, density of wheat and wheat height significantly influenced the weed infestation. The was no significant correlation between number of tillers per plant and weed infestation parameters measured in the dough stage (Table 8).

DISCUSSION

The strategy of weed regulation in organic farming is based on increasing the competitiveness of the crop canopy against weeds. The literature shows that winter wheat varieties suitable for cultivation in organic farming should be characterized by a rapid early growth rate, large leaf area, high number of tillers, taller plants, wide leaf area angle as well as low susceptibility to disease (Lemerle *et al*. 1996; Eisele and Köpke 1997; Bertholdsson 2005; Krawczyk *et al*. 2008; Wolfe *et al*. 2008).

This study of 13 winter wheat varieties has proven the relationships between the parameters of canopy and morphological characteristics, which determine the varieties' competitiveness with weeds, and the level of weed infestation. The analysis of correlation, and the cluster analysis, showed that density and wheat dry matter as well as plant height had the greatest impact on number and weed dry matter which was also observed during the study of other varieties (Feledyn-Szewczyk 2013). There was no significant correlation between the number of tillers per plants and weed infestation parameters during the dough stage of winter wheat.

Some authors suggest that plant height is the main reason for the differences in competitiveness with weeds (Challaiah Burnside 1986; Balyan *et al*. 1993; Hucl 1998; Feledyn-Szewczyk B. 2009). Other authors believe this factor is of marginal significance (Wicks *et al*. 1986; Satorre and Snaydon 1992). In the study done by Kraska (2006), the Tonacja wheat variety was 50% more weedy than the Turnia variety which was 8–10 cm higher. *Apera spica-venti* produced 4-times less seeds in the canopies of wheat varieties characterized by a long stem, in comparison with lower varieties (Praczyk and Adamczewski 1994). The research on spring barley competitiveness against *Avena fatua* conducted in Canada, showed that production of weed seeds was greater in shorter, naked varieties, indicating that these varieties were less competitive with weeds than higherhusk varieties (Carlson and Hill 1985). Taller varieties also gave higher yields, making them more useful for integrated farming systems and other low-cost systems, such as organic farming. Recent research on wheat and barley varieties showed that differences between plant density influence the competitive ability more than plant height and other morphological features (O'Donovan *et al*. 2005). Increasing the seeding rate improved competition with weeds growing in barley (O'Donovan *et al*. 1999) and wheat (Carlson and Hill 1985; Blackshaw *et al*. 2000; Krawczyk *et al*. 2008).

The studies showed that among modern varieties, there are some with high competitive potential against weeds, such as Nateja and Legenda, which were characterized by more plant density, wheat dry matter as well as taller plants. Alcazar, Boomer, and Jenga wheat varieties had the smallest competitive ability against weeds. Natula, Kohelia, Batuta, and Ostroga showed a different reaction to weed infestation during the study years. It suggests that the study should be carried out over a longer period of time to establish the differences between varieties.

The competitiveness of winter wheat against weeds is also influenced by other morphological features, for

example leaf area, leaf area angle, architecture of the canopy and allelopathic effects, which were not tested in this study. According to Bertholdsson (2005, 2011) it is difficult to separate allelopathy from other characteristics of crop competitive ability. Moreover, the importance of some features could change if they are compensated for by other traits (Wolfe *et al*. 2008). In the process of selecting cereal varieties for the organic farming system, the competitive ability of the varieties against weeds should be considered. Other features also influence the yield, for example early nitrogen uptake efficiency, and should be taken into consideration (Christensen 1995; Wolfe *et al*. 2008).

CONCLUSIONS

1. The study showed the relationships between the canopy parameters, the morphological features of winter wheat varieties, and the level of weed infestation.
2. The number of weeds and weed dry matter were mainly influenced by density, wheat dry matter, and plant height.
3. There was no significant correlation between tillering of wheat and the level of weed infestation measured in the dough stage.
4. The most competitive against weeds were Nateja and Legenda wheat varieties, which were characterized by large plant density and wheat dry matter, as well as taller wheat plants. Alcazar, Boomer and Jenga wheat varieties had the smallest competitive ability against weeds.

REFERENCES

Balyan R.S., Malik R.K., Panwar R.S., Singh S. 1993. Competitive ability of winter wheat cultivars with wild oat (*Avena ludoviciana*). Weed Sci. 39 (2): 154–158.

Bertholdsson N.-O. 2005. Early vigour and allelopathy – two useful traits for enhanced barley and wheat competitiveness against weeds. Weed Res. 45 (2): 94–102.

Bertholdsson N.-O. 2011. Use of multivariate statistics to separate the allelopathic and competitive factors influencing weed suppression ability in winter wheat. Weed Res. 51 (3): 273–283.

Blackshaw R.E., Semach G.P., O'Donovan J.T. 2000. Utilization of wheat seed rate to manage redstem filaree (*Erodium cicutarium*) in a zero-till cropping system. Weed Technol. 14 (2): 389–396.

Carlson H.L., Hill J.E. 1985. Wild oat (*Avena fatua*) competition in spring wheat: plant density effects. Weed Sci. 33 (2): 176–181.

Challaiah Burnside O.C., Wicks G.A., Johnson V.A. 1986. Competition between winter wheat (*Triticum aestivum*) cultivars and downy brome (*Bromus tectorum*). Weed Sci. 34 (5): 689–693.

Christensen S. 1995. Weed suppression ability of spring barley varieties. Weed Res. 35 (4): 241–247.

Davies D.H.K., Welsh J.P. 2001. Weed control in organic cereals and pulses. p. 77–114. In: "Organic Cereals and Pulses" (D. Younie, B.R. Taylor, J.P. Welsh, J.M. Wilkinson, eds.). Chalcombe Publications, Lincoln, 172 pp.

Didon U.M.E. 2002. Variation between barley cultivars in early response to weed competition. J. Agron. Crop Sci. 188 (3): 176–184.

Eisele J.-A., Köpke U. 1997. Choice of cultivars in organic farming: New criteria for winter wheat ideotypes. Pflanzenbauwissenschaften 1: 19–24.

Feledyn-Szewczyk B. 2009. Comparison of the competitiveness of modern and old winter wheat varieties in relations to weeds. J. Res. Appl. Agric. Eng. 54 (3): 60–67.

Feledyn-Szewczyk B. 2011. The weed infestation of spring wheat varieties cultivated in organic system. J. Res. Appl. Agric. Eng. 56 (3): 71–76.

Feledyn-Szewczyk B. 2013. The influence of morphological features of spelt wheat (*Triticum aestivum* ssp. *spelta*) and common wheat (*Triticum aestivum* ssp. *vulgare*) varieties on the competitiveness against weeds in organic farming system. J. Food Agric. Environ. 11 (1): 416–421.

Håkansson S. 1997. Competitive effects and competitiveness in annual plant stands. Measurement methods and problems related to plant density. Swed. J. Agric. Res. 27 (2): 53–73.

Hoad S., Topp C., Davies K. 2008. Selection of cereals for weed suppression in organic agriculture: a method based on cultivar sensitivity to weed growth. Euphytica 163 (3): 355–366.

Hucl P. 1998. Response to weed control by four spring wheat genotypes differing in competitive ability. Can. J. Plant Sci. 78 (1): 171–173.

Kraska P. 2006. Wpływ zróżnicowanych dawek herbicydów na zachwaszczenie pszenicy ozimej. [The influence of different herbicides doses on winter wheat infestation]. Prog. Plant Prot./Post. Ochr. Roślin 46 (2): 256–260.

Krawczyk R., Kaczmarek S., Kaniuczak Z. 2008. Wybrane metody agrotechniczne regulacji zachwaszczenia pszenicy ozimej uprawianej w ekologicznym i konwencjonalnym systemie produkcji. [Selected cultivation methods for weed infestation management in winter wheat cultivated in organic and conventional crop production systems]. p. 242–249. In: „Poszukiwanie nowych rozwiązań w ochronie upraw ekologicznych" (E. Matyaszczyk, ed.). [The search for new solutions in crop protection in organic agriculture]. Inst. Ochr. Roślin, Poznań, 393 pp.

Lemerle D., Verbeek B., Cousens R.D., Coombers N.E. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Res. 36 (6): 505–513.

O'Donovan J.T., Newman J.C., Harker K.N., Blackshow R.E., McAndrew D.W. 1999. Effect of barley plant density on wild oat interference, shoot biomass and seed yield under zero tillage. Can. J. Plant Sci. 79 (4): 655–662.

O'Donovan J.T., Harker K.N., Clayton G.W., Hall L.M. 2000. Wild oat (*Avena fatua*) interference in barley (*Hordeum vulgare*) is influenced by barley variety and seeding rate. Weed Technol. 14 (3): 624–629.

O'Donovan J.T., Blackshaw R.E., Harker K.N., Clayton G.W., McKenzie R. 2005. Variable plant establishment contributes to differences in competitiveness with wild oat among wheat and barley varieties. Can. J. Plant Sci. 85 (4): 771–776.

O'Donovan J.T., Blackshaw R.E., Harker K. N., Clayton G.W., Moyer J.R., Dosdall L.M., Maurice D.C., Turkington T.K. 2007. Integrated approaches to managing weeds in spring-sown crops in western Canada. Crop Prot. 26: 390–398.

Owczarczuk A., Snarska K., Jędruszczak M. 2005. Odmiana a zachwaszczenie łanu żyta ozimego. [Variety and weed infestation of winter rye]. Prog. Plant Prot./Post. Ochr. Roślin 45 (2): 970–973.

Parylak D., Zawieja J., Jędruszczak M., Stupnica-Rodzynkiewicz E., Dąbkowska T., Snarska K. 2006. Wykorzystanie zasiewów mieszanych, własności odmian lub zjawiska allelopatii w ograniczaniu zachwaszczenia. [Use of the mix crops, cultivar properties or allelopathy in weed control]. Prog. Plant Prot./ Post. Ochr. Roślin 46 (1): 33–44.

Praczyk T., Adamczewski K. 1994. Integrowany system zwalczania chwastów w uprawach rolniczych. [Integrated system of weed control in crops]. Mat. XXXIV Sesji Nauk. Inst. Ochr. Roślin, 1: 82–89.

Satorre E.H. and Snaydon R.W. 1992. A comparison of root and shoot competition between spring cereals and *Avena fatua* L. Weed Res. 32 (1): 45–55.

Seavers G.P., Wright K.J. 1999. Crop canopy development and structure influence weed supression. Weed Res. 39 (4): 319–328.

Wicks G.A., Ramsel R.E., Nordquist P.T., Smith J.W., Challaiah R.E. 1986. Impact of wheat cultivars on establishment and suppression of summer annual weeds. Agron. J. 78 (1): 59–62.

Wolfe M.S., Baresel J.P., Desclaux D., Goldringer I., Hoad S., Kovacs G., Löschenberger F., Miedaner T., Østergård H., Lammerts van Bueren E.T. 2008. Developments in breeding cereals for organic agriculture. Euphytica 163 (3): 323–346.