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Influence of herbicides on yield stability of winter wheat cultivars under different sowing rates

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Abstract

Yield variability of selected winter wheat cultivars under different sowing rate and selected application, was investigated during 2006-2008, in the Lower Silesia region (South-West Poland). Experiments with two varieties, two levels of sowing rate and seven herbicides, including untreated object were set up on the same field, using split-plot method. For evaluation of yield stability Kang's yield-stability statistic (YS) was applied. Examined herbicides did not influence grain yield of both cultivars, at standard wheat density (450 seeds/m^2). Under low density, Kobra Plus variety showed variable reaction to herbicides. Iodosulfuron methyl sodium + diflufenican + mezosulfuron methyl, mecoprop + MCPA + dicamba and iodosulfuron methyl sodium + amidosulfuron resulted in yield increment in comparison with untreated object, whilst dicamba + triasulfuron gave opposing effect. Yield stability at different herbicide objects during 3-years period was considerably variable and dependent on cultivar and sowing rate. Yield of both cultivars, obtained from plots treated with iodosulfuron methyl sodium + diflufenican + mezosulfuron methyl, iodosulfuron methyl sodium + amidosulfuron and mecoprop + MCPA + dicamba, under low density was comparable with standard sowing.

Keywords: Wheat; Cultivar; Yield stability; Sowing rate; Herbicides.

Introduction

Permanent cereals mono-cropping in Poland and West Europe contributes to changes in intensity of particular weed species. Continued cultivation of cereal monoculture and application of herbicides with the same mode of action and active ingredient is a main reason for development of resistant biotypes in weeds and abundance of some weed species in a given site (Preston, 2004; Gerhard and Massa, 2011). For example, Wesołowski and Boniek (2004) reported abundance of *Setaria viridis* and *Echinochloa crus-galli* as result of multiple iodosulfuron methyl sodium application. Similarly, Marczewska (2006) found *Apera spica-venti* L. biotypes resistant to chlorsulfuron in the South-West Poland.

Winter wheat cultivars are distinguished by different competitiveness against weed population. Differences in competition among cultivars may be related to morphological characters affecting light interception such as canopy closure, plant height, tiller number which is cultivar-specific (Paynter and Hills, 2009). More competitive varieties grow very fast at the early growth stages and therefore inhibit weed emergence and development reducing their plant density (Drews et al., 2009). Moreover, weed density may be considerably limitated by crop root exudates (Wu et al., 2007). The other important factor affecting weed infestation is a crop sowing rate. Increased plant density has a detrimental effect on weed biomass and density (Kristensen et al., 2008). A large number of winter wheat cultivars in EU countries pose a threat to variable response to herbicide. Cultivar susceptibility to herbicide is hardly affected by a weather condition during vegetative growth period, type of herbicide and sowing rate (Drews et al., 2009). According to previous investigation loss of grain yield of herbicide-susceptible cultivars may be ranged from 5 to 16% (Crocks et al., 2004).

A wheat cultivar, that is highly adaptive to soil and weather conditions typical for target environment, should feature high and stable yield and characterized by yield stability over years (Navabi et al., 2006). Experimental work on plant breeding interpret wide cultivar adaptation as a combination of average genotypic yield assessment with Shukla stability variance, which measures cultivar yield stability (Annicchiarico, 2002; Solomon et al., 2008).

The aim of this study was to analyze the yield stability of two winter wheat cultivars in relation to sowing rates and herbicides.

Materials and Methods

Plant material

The field studies were conducted over 3-years, from 2006 to 2008, in the Lower Silesia region, Poland. The investigation was carried out on black soil, following winter oilseed rape. Experiments with two winter wheat varieties-

Tonacja and Kobra Plus were established adjacently in the same field, using split-plot pattern, with four replications. The two cultivars are varied in their morphology, maturity, environmental and economical properties. The first experimental factor was sowing rate, that included two levels-300 seeds/m^2 (low density) and 450 seeds/m^2 (standard density). Within the first experimental factor, seven herbicides were randomized (Table 1).

Table 1. Herbicides and their doses used in the experiment in terms of variable sowing rate of two winter wheat cultivars.

	300 seeds/m^2	450 seeds/m^2
Tonacja	T_1	T_1
	T_2	T_2
	T_3	T_3
	T_4	T_4
	T_5	T_5
	T_6	T_6
	T_7	T_7
Kobra	T_1	T_1
	T_2	T_2
	T_3	T_3
	T_4	T_4
	T_5	T_5
	T_6	T_6
	T_7	T_7

Explanation: (T_1) check, (T_2) pendimethalin + isoproturon at doses of 1000 + 500 g*/ha^{-1}, (T_3) iodosulfuron methyl sodium + diflufenican + mezosulfuron methyl at doses of 3+150+9 g*/ha^{-1}, (T_4) MCPA + mecoprop + dicamba at doses of 400+80+600 g*/ha^{-1}, (T_5) dicamba + triasulfuron at doses of 118,62+7,38 g*/ha^{-1}, (T_6) iodosulfuron methyl sodium + amidosulfuron 3,75+15 g*/ha^{-1}, (T_7) 2,4-D + dicamba at doses of 1252,5+97,5 g*/ha^{-1}.

During the first experimental season (2005/06) wheat was planted in the last decade of October, while during the following seasons (2006/07 and 2007/08) in the second decade of October. All agricultural practices, including cultivation, fertilization and plant protection, were performed according to general recommendation for winter wheat cultivation.

Each experimental plot was 6 m length and 2 m wide. Experiments were set up on the field naturally infested by a small number of low-competitive weed species, such as: *Capsella bursa-pastoris*, *Lamium purpureum*, *Stellaria media*, *Spergula arvensis*, *Viola arvensis*, *Thlaspi arvense*, with low population of *Anthemis arvensis* and *Galium aparine*. To avoid adverse impact of weed infestation on grain yield, weeds were removed by hand from both treated and untreated plots, a few days before spraying.

The mixtures of pendimethalin + isoproturon and iodosulfuron methyl sodium + diflufenican + mezosulfuron methyl were applied in the autumn, when wheat plants were at 2-4 leaves stage. The remaining herbicides were applied in the spring time, at full tillering of wheat. The herbicides were applied using a knapsack sprayer "Gloria" equipped with four Tee Jet 11003 VS flat fan nozzles. The sprayer was operated at speed of 3.6 km*h^{-1} and pressure of 0.25 MPa, producing a spray volume of 250 l*ha^{-1}.

Wheat was harvested at complete maturity stage using a Nurserymaster Elite Z 035 harvester. At harvest grain yield from each plot was determined and calculated at 14% grain moisture content.

Statistical analysis

Grain yield of winter wheat cultivars treated with herbicides was compared with check. Statistical analysis was made using computer programs Sergen 4 and Explan, that are commonly used for assessment of yield variability compared to defined standards. In present study the untreated plots were considered as a standard for each comparison. Wheat yield stability was evaluated using Kang's yield-stability statistic (YS). YS calculation comprises a few steps, as follows (Kang, 1993; Mądry, 2002):

1. calculation of average cultivars yield for experimental period (y_i) and assignment of diminishing ranks, ending with 1.
2. LSD calculation to prove differences between average yield of cultivars (y_i).
3. corrected ranks ($Y_i^{'}$) calculation (Kang, 1993).
4. calculation of variance stability for individual cultivars and verification of null hypothesis H_{oi} : $\sigma^2_{ge(i)}=0$ for each cultivar at significance level $\alpha=0.05$ using F-test.
5. assignment of corrected value (S_i) for cultivars in the case of significant interactive variance $\sigma^2_{ge(i)}$ and zero value in the case of lack interactive variance deviation from zero at $\alpha=0.10$.
6. summing corrected ranks ($Y_i^{'}$) and corrections (S_i) to finally obtain statistic values (YS_i).
7. YS mean value calculation, according to equation:

a. $YS=(\sum_{i=1}^{I} YS_i) / I$, where I means cultivars number

8. selection of cultivars with $YS_i > YS$, approving them as broadly adapting.

Results

Yield of winter wheat varieties obtained from plots under low density was considerably variable compared to standard sowing. Tonacja cultivar showed less deviation from untreated object, independently of type of herbicide (Table 2). F value for the interaction of yield × experimental years points out equalization of each year yield, independent of herbicide. Calculated Kang's yield-stability statistic (YS) found out that, herbicides T_2, T_4 and T_6 contributed to high and uniform grain yield for Tonacja cultivar during the experimental period.

For Kobra Plus cultivar there was significant yield increase in comparison with check under low density, when wheat was sprayed by herbicides T_3, T_4 and T_6 (Table 2). Yield reduction was observed only in the case of herbicide T_5 application. Grain yield of Kobra Plus cultivar, obtained from plots sprayed by herbicides T_3, T_4 and T_6 was also high and uniform compared to the other herbicides (T_2, T_5 and T_7), that is confirmed by high YS value for T_3, T_4 and T_6 in comparison with T_2, T_5 and T_7.

Table 2. Yield variability in relation to herbicide applied under low wheat density.

Treatment	Average Yield ($t^* ha^{-1}$)	Main effects	F for the main effect	F for the interaction years×herbicides	Kang stability YS
			Tonacja		
T_1	8.51	0.00	-	-	-2
T_2	8.51	0.00	0.00	2.28	3^*
T_3	8.71	0.20	0.23	4.38	2
T_4	8.83	0.32	1.12	2.34	8^*
T_5	8.46	-0.06	0.51	0.15	-1
T_6	8.73	0.22	1.92	0.65	7^*
T_7	8.32	-0.19	0.52	1.73	0
			Boundary value YS=2.4		
			Kobra		
T_1	8.84	0.00	-	-	2
T_2	8.86	0.02	0.57	0.03	3^*
T_3	9.26	0.42	4.00^*	1.62	7^*
T_4	9.30	0.46	16.81^{**}	0.45	8^*
T_5	8.43	-0.41	4.06^*	1.51	0
T_6	9.21	0.37	14.52^{**}	0.34	6^*
T_7	8.72	-0.12	0.20	2.70^*	-1
			Boundary value YS=2.8		

* significance at α=0.05, ** significance at α=0.01.

T_1…T_7 - see Table 1.

Wheat yield under standard sowing was less variable than under low density (Table 3). Herbicides did not affect grain yield of both varieties, markedly. F value for the interaction of yield with experimental years, at relevant herbicides, pointed out the effect of herbicides T_3 and T_6 on significant yield variability of Tonacja cultivar over the 3-years period. High and stable grain yield was attained on plots treated with herbicides T_4, T_5 and T_7.

Kobra Plus cultivar featured considerable yield variation in plots where herbicides T_2 and T_4 were applied. High and stable grain yield was attained where herbicides T_3 and T_7 were used (Table 3).

Table 3. Yield variability in relation to herbicide applied under standard wheat density.

Treatment	Average yield ($t^* ha^{-1}$)	Main effects	F for the main effect	F for the interaction years×herbicides	Kang stability YS
			Tonacja		
T_1	9.01	0.00	-	-	-2
T_2	9.34	0.33	1.78	1.58	-1
T_3	9.06	0.04	0.01	6.81**	-6
T_4	9.22	0.21	0.53	2.10	4*
T_5	9.18	0.17	0.77	0.90	3*
T_6	9.52	0.51	1.41	4.67**	0*
T_7	9.01	0.00	0.00	0.20	1*
			Boundary value YS= -0.8		
			Kobra		
T_1	9.58	0.00	-	-	6*
T_2	9.44	-0.13	0.18	3.68*	1
T_3	9.61	0.03	0.012	0.34	7*
T_4	9.58	0.00	0.00	3.93	5*
T_5	9.06	-0.52	0.99	10.04**	-8
T_6	9.53	-0.04	0.84	0.09	4*
T_7	9.62	0.04	0.15	0.49	6*
			Boundary value YS= 3.0		

* significance at α=0.05, ** significance at α=0.01.
$T_1 \ldots T_7$ - see Table 1.

Table 4 compared the reaction of cultivars to changes in sowing rates. For Tonacja cultivar, under standard sowing, significantly higher grain yield was obtained from plots that were sprayed by herbicides T_2 and T_7. The remaining herbicides did not varied considerably with respect to grain yield, under both low and standard sowing. Essential shortage of Kobra Plus cultivar yielding at the sowing rate of 300 seeds/m^2 as result of herbicides T_2 and T_5 treatment and also at herbicide-free plots was observed.

Table 4. Significance of differences in yield of winter wheat cultivars between standard and low plants density.

Object	Main effect	F for main effect	F value for interaction years × herbicides
		Tonacja	
T_1	0.50	17.31*	0.36
T_2	0.83	14.10*	1.24
T_3	0.34	2.25	1.33
T_4	0.39	6.77	0.56
T_5	0.72	4.92	2.67*
T_6	0.79	4.92	3.18*
T_7	0.69	53.76*	0.08
		Kobra	
T_1	0.73	4.44*	4.40
T_2	0.58	44.33**	0.27
T_3	0.34	0.49	8.81*
T_4	0.28	0.82	3.42
T_5	0.62	8.27*	1.70
T_6	0.32	0.56	6.74*
T_7	0.90	1.87	15.73*

* significance at α=0.05, ** significance at α=0.01.
$T_1 \ldots T_7$ - see Table 1.

Discussion

This study showed no differences in grain yield among herbicide treatments under standard sowing, however variable cultivar reaction was found under low plant density. Differences in response of winter wheat varieties to plant protection regime have been also reported previously (Jończyk, 2002). Findings of other researchers (Gooding et al., 2002; Lithourgidis et al., 2006) pointed out, that reduced sowing rate of some wheat cultivars, under proper plant protection treatments, may contribute considerably to higher or comparable grain yield. Turk et al. (2003) are of the opinion, that rather higher sowing rate is recommended, because of greater crop competition against weeds. The present study did not prove any influence of herbicides on wheat yield under standard sowing. Similarly, Olsen et al. (2005) reported, that chemical weed control at higher wheat density had only slight impact on grain yield enhancement.

The detrimental effect of the mixture triasulfuron + dicamba on Kobra Plus cultivar, under low density, confirms variable reaction of wheat varieties to herbicides. Wheat injuries and yield loss influenced by phytotoxic action of herbicides was described in many papers. In the literature, Orr et al. (1996) reported significant wheat yield loss, up to 27%, after application of auxinic herbicides, such as 2,4-D and MCPA + dicamba. Similarly, Kieloch and Rola (2011) described wheat yield reduction under hard winter conditions due to a negative plant response to the application of mixture of pendimethalin + isoproturon.

Active ingredient of herbicide should not influence grain yield of particular cultivar variably, independently on environmental conditions. Stability of herbicide action under various climate-soil conditions is a basic criterion for selection of a proper herbicide for weed control. Unfortunately, many scientific papers concerning the impact of herbicides on yield, its components and quality, do not consider their variation during whole experimental period (Podolska and Sułek, 2010; Kieloch et al., 2010), but strongly outlined importance of the weather and soil conditions in phytotoxic effect of herbicides (Kieloch and Rola, 2011). The main factors affecting wheat yield variability are temperature and rainfall during the vegetation season (Weikai and Hunt, 2001; Brancourt and Lecomte, 2003). Genotypic × environmental interaction is a widespread phenomenon consisting of various reaction of cultivars to changeable environmental conditions in locations, years, systems and cultivations (Murphy et al., 2009; Romay et al., 2010). According to investigation of Brancourt and Lecomete (2003), genotypic-environmental interaction influenced (by 77%) variation of 13 wheat straines in France. However, results obtained from this study prove that genotypic × environmental interaction was hardly related to sowing rate of wheat cultivar and kind of herbicide used for weed control.

Polish agrarian structure features large diversification in farm size, with majority of small-area, extensive farms (<10 ha), in which seeds renovation is especially slow and takes place every 6-10 years. Therefore there is a risk of cultivar degeneration or seed impurity. Both varieties have been registered and commonly cultivated in the Lower Silesia region for over a dozen years, which may be a reason of their genetic drift and variable response to pesticides. Herbicides used in present experiment belong to different chemical group and in consideration of their high efficacy, they are widely and frequently used by Polish farmers for winter wheat weeding. Examined cultivars are highly accommodated to environmental conditions of the considered region and therefore herbicides poorly affected their yield variability. The lack of wheat response to herbicides proves genotypic stability of examined cultivars despite of their long-term cultivation in South-West Poland.

Kang's yield-stability statistic (YS) is regularly used for analysis of yield stability of a particular genotype by assessing their wide adaptation to a target environment or region (Kang, 1993; Kang, 1997). This measure is a confluence of two parameters-mean genotypic value from sites and stability variance, however in this experiment Kang's yield-stability statistics is a combination of 3-years average yield with stability variance of a given herbicide. Kang’s value enables selection of cultivars which reaction is the most approximated to norm of wide adaptation. Broad adaptation of cultivar is an ability for relatively high productivity, expressed as high yield production under variable environmental conditions (Joshi et al., 2007). Experimental objects-cultivar yield under the influence of particular herbicide-with the highest value of YS, can be classified as the best adjusted to changeable weather conditions and broadly adapted for growing on the area of the target region (Ober et al., 2004). They give high and steady yield during 3-years investigation, under the influence of specific herbicide. Analysis of genotypic × environmental interaction by evaluation of cultivars broad adaptation has been reported in numerous descriptions (Eberhard and Russell, 1966; Kang and Pham, 1991; Sharma et al., 2007). From practical point of view, cultivars that are characterized by broad adaptation to changeable environment are preferred by farmers in many countries due to less risk of yield loss under adverse habitat or herbicide effect (Weber and Zalewski, 2006; Stefanova and Buirchell, 2010).

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