INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
14–121/2015/17–1–181–186
http://www.fspublishers.org

Full Length Article

Influence of Different Herbicides on the Performance of Spring Barley (*Hordeum vulgare*) Cultivars in Lower Silesia Region, Poland

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Abstract

Knowledge about yield variability of crop cultivar is very useful regarding its selection and for cultivation in a target region, as well as under specific cultivation regime. In this study, the yield variability of spring barley cultivars grown on different soils in South-West Poland with respect to herbicides was investigated. Field studies were conducted in over a three-year period (2010-2012). They included four spring barley cultivars (Westminster, Antek, Eunova, Conchita) and three weeding treatment: (i) the mixture of 2.4-D with fluroxypyr (450 g ha^{-1} + 112.5 g ha^{-1}), (ii) the mixture of aminopyralid with florasulam (9.99 g ha^{-1} + 4.99 g ha^{-1}), (iii) no herbicide (manually weeded check). Experiment was set up on two different soils - black soil and podsolic soil. Analysis of variance proved greater impact of soil than weather conditions on yield variability of barley cultivars. It also showed the significant genotypic-environmental interaction of the examined cultivars under diversified weeding treatments. On black soil, the highest yield was recorded for Eunova cultivar whereas on podsolic soil it was noted for Conchita cultivar, irrespective of weeding. Eunova cultivar showed significant yield variability for the mixture aminopyralid + florasulam usage and, therefore, this herbicide is not recommended for this cultivar. Among the examined cultivars, Westminster featured distinct reaction to diversified environmental conditions and proved considerable yield variability across years and places, irrespective of weed control.

Keywords: Spring barley; Cultivars; Yield variability; Genotype-environment interaction; Herbicides

Introduction

Grain of spring barley is a valuable feed ingredient and basic component for brewing industry, while only small part of its cultivation area is designed for human feeding. In Poland, spring barley cultivation area constitutes 11% of all cereals. Gradually increasing cereals territory in Poland contributes to spring barley cultivation on both heavy and light soil. Studies on yield variability of crop cultivars proved considerable genotype-environment (G × E) interaction between the yield of spring barley varieties dependently on soil-climate conditions (Oleksiak and Mańkowski, 2007). The G × E interaction consists in diverse response of cultivars to changeable environmental conditions in places, years and cultivation regimes (Annicchiarico *et al*., 2005; Przystalski *et al*., 2008). Therefore, barley cultivars, widely adapted to diversified soil-climate environments play a crucial role in plant breeding. Degree of cultivar wide adaptation points to the probability of the yield enlarged by a definite value in relation to average yield in particular region of cultivation. Desirable cultivar should produce stable yield in all habitats of the target region and give stable yield over the years (Yan and Tinker, 2005). In all environments, dynamically stable genotype provides the yield significantly different from average yield of all genotypes by a constant value. In turn, static stable genotype maintains fixed yield level under all environments (Jankowski *et al*., 2006). In some cases, genotypes narrowly adapted to specific environment, characterizing high repeatability across years can be also desirable (Ceccarelli and Grando, 2007; Kaya *et al*., 2006).

Crop protection against weeds enables to obtain a full yield potential of particular barley cultivar, because it prevents yield loss due to competition for light, water and nutrients (Hussain *et al*., 2003). Herbicide usage is the most effective tool for weed control in spring barley, but its effect is modified by some agricultural practices and the weather conditions (Kumaratilake and Preston, 2005; Bhullar *et al.*, 2013). On the other hand, chemical weed control is not always completely selective for crop. Detrimental effect of herbicides on crop can reflect in plant injuries, reduced plant height and diminished yield (Kieloch and Rola, 2011; Soltani *et al.*, 2012).

Chemical protection against weeds is a factor significantly modifying G × E interaction. Previous investigation showed diversified cereals response to herbicide treatment according to its active ingredient and the

To cite this paper: Kieloch, R. and R. Weber, 2015. Influence of Different Herbicides on the Performance of Spring Barley (Hordeum vulgare) Cultivars in Lower Silesia Region, Poland. *Int. J. Agric. Biol*., 17: 181–186

term of spraying (Kong *et al*., 2009; Singh *et al*., 2013). Variable reaction to herbicides was also recorded for different spring barley cultivars as the result of inherent properties and their interaction with environmental conditions (Ramsey *et al*., 2010; Bhullar *et al*., 2013). Therefore, knowing cultivar reaction to different herbicide under specific conditions is helpful in cultivar selection for a given region. Herbicides effect is connected with both the weather conditions and soil properties. Scientific literature describes herbicide activity in soil, including degradation and mobility (Kucharski and Sadowski, 2009; Si *et al*., 2009), but no information can be found about effect of soil type on herbicide selectivity for cereals.

Majority of scientific papers are focused on winter wheat cultivars response to changeable environmental conditions or cultivation technology due to its domination in crop structure, but little is known about barley reaction. Moreover, little is known about influence of soil properties on herbicides effect on crop. Therefore, the aim of this study was the analysis of yield variability of spring barley cultivars grown on different soils in Lower Silesia region (Poland). Additionally, effects of herbicides activity depending on cultivar and environmental conditions were evaluated.

Materials and Methods

Field experiment was carried out in the years 2010 – 2012, at two places in Lower Silesia (South – West Poland). Both experimental sites differed with respect to soil conditions. In the first place – Jelcz-Laskowice (N51°1'45.6922", E70°21'1.5267") the soil type was podsolic soil that consisted of 72% sand, 18% clay and 10% silt, with organic matter 1.25% and pH 4.6. The second experimental site – Turów (N50°59'30.2615, E17°3'58.0343") was set up on black soil containing 15% sand, 39% clay and 46% silt. Organic matter amounted to 2.35% and pH 6.05. Preceding crop in both places was winter wheat. In both places, a seedbed was prepared using conventional tillage method. Just after harvest, gruber was used at the depth of 15 cm and then string roller. Before winter, ploughing at the depth of 25 cm was performed. In the spring, just before sowing, tillage aggregate with cultivator and string roller was applied. Each year, spring barley was sown in the last decade of March (29th March 2010, 23rd March 2011, 28th March 2012), at the density of 350 plants m^{-2} in Jelcz-Laskowice and 300 plants m^{-2} in Turów. In the first location, the field was fertilized with 55 kg ha^{-1} N, 50 kg ha^{-1} P_2O_5, 70 kg ha^{-1} K_2O. The second experimental site was fertilized as follows: 108 kg ha^{-1} N, 36 kg ha^{-1} P_2O_5, 96 kg ha^{-1} K_2O. In both experimental sites, chemical protection against fungi using the mixture of propiconazole and cyproconazole was implemented as a preventive treatment.

The experiment followed a split-block pattern with four replications**.** Individual plot size was 16 m^2 (2 m x 8 m). There were three weeding treatment (i) check – hand weeding, (ii) 450 g ha^{-1} of 2.4-D + 112.5 g ha^{-1} of fluroxypyr – herbicide Gold 450 EC, (iii) 9.99 g ha^{-1} of aminopyralid and 4.99 g ha^{-1} of florasulam – herbicide Dragon 450 WG) and four spring barley cultivars i. Westminster, ii. Antek, iii. Eunova, iv. Conchita) were randomized within each block. Barley cultivars tested in this study are commonly cultivated in Poland and herbicides are usually applied by farmers to broadleaved weed control.

Herbicides were applied at the stage of 4-5 leaves of barley. To avoid adverse impact of weed infestation on yield, experiment was set up on poorly weeded fields and weeds were removed by hand from untreated plots a few days before spraying. Herbicides were applied using a plot sprayer "Gloria" equipped with four Tee Jet 11003 VS flat fan nozzles. The sprayer was operated at speed 3.6 km ha^{-1} and pressure 0, 25 MPa, producing a spray volume of 250 L ha^{-1}. At the stage of complete maturity, barley was harvested using a harvester Nurserymaster Elite Z 035. In 2010, barley in Turów was harvested on 11th August and in Jelcz-Laskowice on 12th August. In 2011, harvest took place on 06th August 06 in Turów and 03rd August in Jelcz-Laskowice. In the last experimental year (2012), barley was harvested on 25th July in Turów and on 01st August in Jelcz-Laskowice. Grain yield from each plot was estimated and calculated over 14% of grain moisture.

Meteorological Data

The meteorological data shown in Table 1 refer only to Jelcz-Laskowice, because of similar weather characteristics of both places (short distance between both experimental sites - appr. 30 km). The data include mean temperatures and sums of rainfall for each month from March to August. The weather conditions in experimental region varied between years. The most favourable for barley growth was 2011, characterized by optimal temperature and sufficient rainfall for plant growth and maturation. Heavy rainfall in July occurred shortly before harvest and did not affect grain yield. The weather conditions in 2010 were the most unfavourable due to lower temperature in comparison to those recorded for May in the remaining years and heavy rainfall resulting in temporary flooding of experimental fields. On the contrary, water deficit which occurred in April and May 2012 was a limiting factor for barley growth.

Table 1: Meteorological data for experimental region (South-West Poland)

Month	Temperature (°C)			Rainfall (mm)		
	2010	2011	2012	2010	2011	2012
III	4.0	4.3	6.0	39.3	25.6	13.9
IV	9.2	11.5	9.7	45.4	26.5	19.6
V	12.6	14.3	15.5	127.1	41.1	15.9
VI	17.6	18.8	17.5	44.4	72.9	92.9
VII	21.7	17.9	19.9	116.8	103.4	78.3
VIII	19.4	19.1	19.1	83.4	76.4	68.5

Statistical Analysis

Statistical analysis was performed using computer program Sergen 3. The significance of differences between the yield of examined cultivars under the influence of particular weeding treatment were compared to overall mean of yields from analysed experiment.

Analysis of yield variability was performed according to the model:

$$Y_{ijk*} = \mu_i + \alpha^E_i(j,k) + e_{ijk*},$$

Where, μ_i - represents average„ true" potential yield of cultivar "i" taken over all places and years of experiment.

$\alpha^E_i(j,k)$ – refers to potential response of cultivar "i" to the particular environmental conditions of the experiment at place "j" in year "k".

e_{ijk*} - represents „weighted mean error" for cultivar „i" from place "j" and year "k".

Results

Temporary flooding in 2010 and rainfall deficit in 2012, as well as different soil water capacity in experimental sites, contributed to significant diversification of spring barley cultivars yield. Preliminary analysis of variance (ANOVA) for each place proved significant differences in cultivars yield dependently on environmental conditions and crop protection against weeds (Table 2). In Turów, Eunova cultivar featured the highest yield as compared to other cultivars, irrespective of weeding treatment, whereas in Jelcz-Laskowice the highest yield was obtained for Conchita cultivar. ANOVA for three-years synthesis enabled evaluation of cultivars yield variability (under the influence of different weeding treatment) in particular years and environments due to verification of the following hypotheses: 1. equality of all main effects for years, 2. equality of all main effects for cultivars under the influence of various weeding treatments, 3. equality of all main effects for places, 4. lack of the interaction between cultivars under the influence of weeding treatment and place, 5. lack of the interaction between cultivars under the influence of weeding treatment and years, 6. lack of the interaction between cultivars under the influence of weeding treatment and environments–(years x places).

Hypotheses about equality of main effects for years, places, environments and cultivars under diversified protection against weeds were rejected at a significance level α=0.01 or α=0.05 (Table 3). Considerable yield diversification for cultivars and environments at both places and under diversified weeding treatment was proved. Significant interaction between cultivars and environments indicates substantial influence of climate conditions on spring barley cultivars yield in particular places in 2010 – 2012. Diversified response of cultivars to changeable environmental conditions cannot be explained by linear regression of particular cultivars yield in relation to environment effects. Significant deviations from the regression indicate that interaction between cultivars and environments cannot be described by simple regression.

Table 2: Yields (t ha^{-1}) of spring barley cultivars dependently on weeding treatment and experimental site

Weeding treatments	Westminster	Antek	Eunova	Conchita	Mean
Experimental site: Turów (means from 2010-2012)					
Check (Hand weeding)	4.75	4.88	5.23	5.22	5.02
Gold 450 EC	4.73	4.95	5.11	4.97	4.94
Dragon 450 WG	4.82	4.88	5.34	4.96	5.00
Mean	4.77	4.90	5.23	5.05	4.99
LSD	0.258				n.s.
Experimental site: Jelcz-Laskowice (means from 2010-2012)					
Check (Hand weeding)	3.24	3.74	4.30	4.58	3.97
Gold 450 EC	3.16	3.53	3.78	4.33	3.70
Dragon 450 WG	3.18	3.72	4.18	4.48	3.89
Mean	3.19	3.66	4.09	4.46	3.85
LSD	0.424				n.s.

n.s. – not significant differences

Table 3: Mean square variation in the general analysis of variance

Source of variation	Degrees of freedom	Mean square
Years	2	20.97*
Experimental sites	1	23.17**
Environments (Years x Experimental sites)	2	26.77**
Cultivars under weeding treatments	11	0.68*
Cultivars under weeding treatments x Years	22	0.26*
Cultivars under weeding treatments x Experimental sites	11	0.23*
Cultivars under weeding treatments x Environments	22	0.24*
Regression on explanatory variable	11	0.44*
Regression deviation	11	0.35*
Experimental error	198	0.05

$*p<0.05$, $**p<0.01$

Table 4 contains mean deviations of particular cultivars yield under the influence of weeding treatment from total mean value and their interaction with environment. Under diversified protection against weeds, Conchita cultivar featured highly positive main effect, giving considerably higher yield in comparison with the other cultivars. On the contrary, Westminster proved to give significantly lower yield regardless weeding treatment and therefore, this cultivar is not recommended for cultivation in the examined region. It also featured high F values for the interaction with environment which proves significant diversification of this cultivars yield across years and places.

Evaluation of the examined environments with respect to G × E interaction was performed using separate F-statistic for the elements corresponding with particular deviations between cultivars under the influence of a given weeding treatment. Appropriate F-statistic value, expressed as percentage of F-statistic for G × E interaction, calculated for

Table 4: Testing of particular genotypes and their interaction with years and experimental sites

Cultivars under weeding treatment	Standard variant		
	Estimation for main effect	F–stat. for main effect	F-stat. for interaction with environment
Westminster – Check (WES.K)	-0.425	5.88*	13.74*
Westminster – Gold 450 EC (WES.G)	-0.474	8.00*	10.69*
Westminster – Dragon 450 WG (WES.D)	-0.419	6.83*	13.68*
Antek – Check (ANT.K)	-0.108	1.48	1.13
Antek – Gold 450 EC (ANT.G)	-0.176	3.68	1.20
Antek – Dragon 450 WG (ANT.D)	-0.119	1.62	0.36
Eunova – Check (EUN.K)	0.343	2.80	6.00*
Eunova – Gold 450 EC (EUN.G)	0.030	0.05	2.40
Eunova – Dragon 450 WG (EUN.D)	0.340	1.92	8.55*
Conchita – Check (CON.K)	0.484	9.19*	3.63*
Conchita – Gold 450 EC (CON.G)	0.228	12.97*	0.23
Conchita – Dragon 450 WG (CON.D)	0.298	5.81*	2.17
Critical values for individual testing		4.51	3.04

*p<0.05

general analysis of variance shows, which part of this interaction refers to particular deviations. In order to graphically present the environments on sheet, the first two main components showing evaluation of yield variability between cultivars under the influence of weeding treatment calculated for each place were used. Fig. 1 shows the arrangement of environments on sheet in main components layout. The environment characterized by high share in G × E interaction is a long distance from the outset of coordinate system. The yield of cultivars in this environment considerably differs from average yields obtained in each experimental year. Considering the position of points in Fig. 2, it is evident that both places and the soil-weather conditions in each year played a crucial role in diversification of cultivars yield. This finding is based on long distances between places in particular years.

The analysis of dual components enables the assessment of G × E structure interaction with respect to cultivars under weeding treatment (object). The location of individual objects in the system of principal components is illustrated in Fig. 2. The value of the interaction between cultivars and environments is shown by the length of vector starting from the point of each cultivar under weeding variant and finishing at the onset of the system. Analyzing the graph, it is possible to notice that Antek and Conchita cultivars did not interact with environments with respect to yield variability under diversified weeding variant. These cultivars gave stable yield independently on weeding treatment. The second group, regarding the response to weeding treatment, is represented by Eunova cultivar which showed variable yielding under the mixture of aminopyralid with florasulam. Completely different reaction to environmental conditions characterized Westminster cultivar. It featured the highest share in squares of deviations sum for G × E interaction. Therefore, it can be concluded that regardless the protection against weeds, Westminster cultivar is characterized by high yield variability in particular places and years.

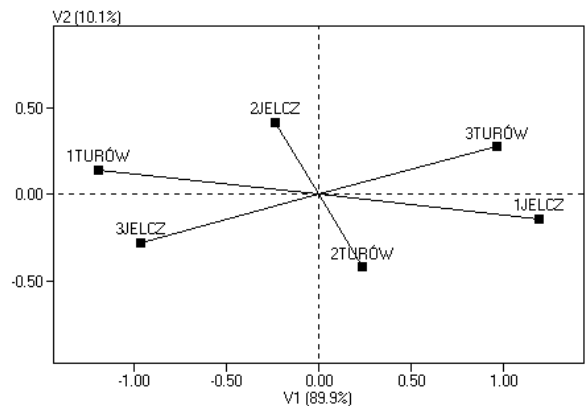

Fig. 1: Variability of spring barley yield with respect to experimental sites and years in the system of principal components. 1 – 2010 year; 2 – 2011 year; 3 – 2012 year

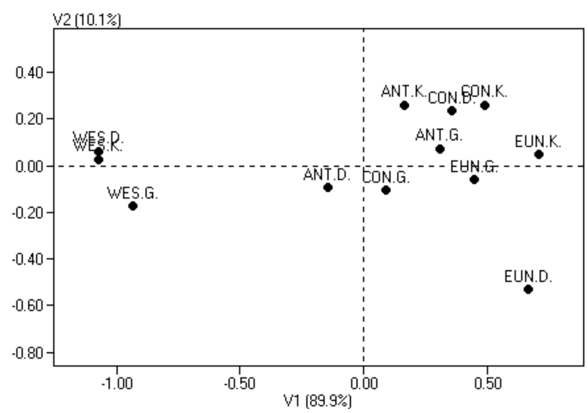

Fig. 2: Yield variability of spring barley cultivars under different weeding treatment in the system of principal components

WES.K. (Westminster – Check), WES.G. (Westminster – Gold 450 EC), WES.D. (Westminster – Dragon 450 WG), ANT.K. (Antek – Check), ANT.G. (Antek – Gold 450 EC), ANT. D. (Antek – Dragon 450 WG), EUN.K. (Eunova – Check), EUN.G. (Eunova – Gold 450 EC), EUN.D. (Eunova – Dragon 450 WG), CON.K. (Conchita – Check), CON.G. (Conchita – Gold 450 EC), CON.D. (Conchita – Dragon 450 WG)

Discussion

Analysis of variance confirmed significant impact of environmental conditions on yield variability of spring barley cultivars. Moreover, analysis of principal components proved changeable cultivars response to diversified soil and weather conditions. Similar relationship was proved for sixteen spring barley cultivars grown in Iran, which allowed dividing the examined area into mega-environments according to cultivars yield level and its variability (Dehghani *et al*., 2006). Hernandez-Segundo *et al.* (2009), in long-term study involving 235 sites from many countries, also reported the significant genotypic-environmental for barley cultivars. In the present study Westminster cultivar featured the greatest yield variability under the examined environments as compared to the remaining ones. This property is probably due to its greater vulnerability to unfavourable water conditions, both drought, as well as flooding, during the growing season. This factor could also cause variable response of other cultivars, as far as yield level was concerned. Water stress, like drought or excessive rainfall affects cereals growth negatively and leads to yield decrease, especially in low-tolerant cultivars (Araus, 2002; Anderson, 2010; Ingver *et al*., 2010). In this study, different herbicide effect on variability of particular cultivars in years and places was also noted. This diversity could results from different weather conditions at the time of herbicide treatment in each experimental year. Previous papers reported that herbicides activity considerably subjected to the climate conditions around the time of spraying, as they affected herbicide uptake, translocation and metabolism in plants (Fausey and Renner, 2001; Thompson and Nissen, 2002). Thus, herbicide treatment could affect the examined barley cultivars in a different way. Moreover, in the present study, cultivar inherent tolerance to particular herbicide could be significantly diversified. This finding is confirmed by close proximity of points on graphs reflecting reaction of Westminster cultivar compared to other ones, under different weeding variants.

Diversified herbicides effect on barley was also related to soil conditions. Sorption complex of heavy soil is more capable to bind herbicides than light soil. Thus, herbicide availability for plants is limited. In turn, under light soil condition, more herbicide is available for plants (Kucharski and Sadowski, 2009), which can result in yield reduction.

Crop tolerance to herbicide is strongly influenced by the weather conditions not only around the time of spraying, but also all over the growing season. Therefore, its reaction can be diverse across long-term period (Ramsey *et al*., 2010; Kieloch and Rola, 2011). Optimal conditions for barley growth contribute to vigorous status and, thus, increase crop tolerance to biotic and abiotic stress. Opposite, long-term environmental stresses such as drought or flooding weaken the plants, particularly sensitive cultivars, and make them more vulnerable to harmful herbicides effect (Carvalho *et al.,* 2009; Kieloch and Rola 2011).

The present study involved two completely different soil type – light, highly permeable in Jelcz-Laskowice and heavy, low-permeable in Turów. In place with heavy soil, excessive rainfall in 2010 contributed to poorer yielding in comparison with other years, because water excess did not penetrate soil profile and consequently, stagnate water caused temporary flooding of barley. Soil properties in the second place allowed drainage of water excess and therefore, plants were not stressed and the yielding level was similar to those obtained in the following years. Conversely, low rainfall in 2012 contributed to low grain yield of barley grown on podsolic soil (data not shown).

Conclusion

The results showed significant interaction between the examined spring barley cultivars and environmental conditions. Diversified herbicide activity for particular cultivars was more affected by soil properties than the weather conditions. Due to research results it was possible to separate cultivars both featuring higher yield variability (Westminster) and producing stable yields (Antek) in target region. Additionally, this study provided information relevant to influence of herbicides on cultivars variability. Barley treated with the mixture of 2.4-D and fluroxypyr gave more stable yields in examined environments than those sprayed by the mixture of aminopyralid and florasulam. Eunova cultivar proved considerable yield variability under the mixture aminopyralid + florasulam usage, therefore this product is not recommended to be used for this cultivar.

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(Received 08 February 2014; Accepted 02 June 2014)