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The influence of some herbicides on seed production in standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes)

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Abstract

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A study was conducted in the experimental field of the Institute of Forage Crops – Pleven during the 2015-2017 on a slightly leached chernozem soil under non-irrigating conditions to determine the selectivity of some herbicides to standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) seed production year (second year of stand growing). It was established that Accurate 60 WG (600 g/kg metsulfuron methyl) – 10 g/ha, Ally Max (143 g/kg metsulfuron + 143 g/kg tribenuron methyl) – 30 g/ha, Arat (250 g/kg tritosulfuron + 500 g/kg dicamba) – 150 g/ha, Biathlon 4D (54 g/kg florasulam + 714 g/kg tritosulfuron) + Adjuvant Dash– 40 + 1000 ml/ha, Buctril Universal (280 g/l bromoxynil + 280 g/l 2,4-D) – 800 ml/ha and Granstar Super 50 SG (250 g/kg tribenuron methyl + 250 g/kg thifensulfuron methyl) – 40 g/ha applied to the growth stage BBCH 22-23 for the control of broadleaf weeds in the seed production year are highly selective to standard wheatgrass variety Morava and do not affect the yield and quality of the seeds. At the mixed weed infestance (monocotyledonous and dicotyledonous weeds) during the seed production year (second year of stand growing) of standard wheatgrass, two-component selective herbicides can be used – Merlin flex (240 g/l isoxaflutole + 240 g/l cyprotsulfamide) 420 ml/ha and Pacifica WG (30 g/kg mesosulfuron, 10 g/kg iodosulfuron-methyl sodium, 90 g/kg mefenpyr-diethyl) + Adjuvant Biopower – 350 + 700 ml/ha. Herbicides Axial one (45 g/l pinoxadene + 5 g/l florasulam) – 1000 ml/ha cause a phytotoxic effect, reduce seed yield and degrade quality of standard wheatgrass seed. The herbicide tolerance of standard wheatgrass to key herbicides with complex action (for weed control against annual monocotyledonous and dicotyledonous weeds) has been determined, which could serve as a means of increasing the efficiency of the breeding process.

Keywords: standard wheatgrass; herbicides; selectivity; seed production

Introduction

Standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) is the economically main forage grass sown in Europe, New Zealand, and in the temperate regions of Japan, Australia, South Africa and South America. Standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) is one of the most important grasses in the temperate regions of the Europe, Iran, New Zealand, Japan, Australia, South Africa and South America. This drought-resistant grass is an excellent source of forage and habitat for livestock and wildlife and it is valued for weed control, habitat use, soil stabilization and watershed management. Standard wheatgrass is generally adapted to sub-humid to arid climatic conditions in steppe or desert regions (Jelyazkov et al., 2000; Radeva et al., 2001; Katova, 2007a, 2007b; Jafari et al., 2008; Behtari & De Luis, 2012; Katova, 2012b; Shanjani et al., 2013; Rigby, 2016).

The first created in Bulgaria and in the EU *Agropyron desertorum* (Fisch.) Schultes variety – Morava was registered in the year 2010. The variety was registered on the Official Variety List of the Republic of Bulgaria for the years 2012-2018, on the corresponding OECD list for the years 2010-2018 and

received a certificate from the Patent Office of the Republic of Bulgaria in 2010 (Katova et al., 2010; Katova, 2012a).

Agropyron desertorum (Fisch.) Schultes variety Morava is characterized with a very high persistence for more than ten years, winter hardiness, drought resistance, leaf disease resistance and tolerance to high summer temperatures. The variety is multifunctional, suitable for hay, hay-pasture use, for erosion control and and scape architecture. It can be used as a component of hay mixtures with alfalfa or sainfoin (Naydenova et al., 2002; Katova et al., 2010; Katova, 2012a).

Weed control has an important role in standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes), which is why used herbicides occupy the largest share of pesticide use (Dimitrova, 1984; 2007; Pehrson and Sowell, 2011; Schrabauer et al., 2014; Katova et al., 2018).

As showed the studies of Sij et al. (2007) and Dimitrova & Katova (2011), a typical biological property of standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) and other members of the group of perennial grasses, is their slow growth and development during the year of stand establishment and highly sensitive to entanglement for weed infesting during seeds formation. In those periods, plants have low competitiveness to weeds and are very sensitive to weed infestance. That is why establishing stands of good density, persistence of production of high quality seeds require efficient, scientifically integrated weed control.

Understanding herbicide tolerance of breeding lines and new varieties could help breeders to develop selection strategies that maximize herbicide tolerance in new varieties with high productivity. However, little is known about herbicide tolerance variability in standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) (Leon & Tillman, 2015).

Relevant studies for standard wheatgrass are very scarce, because of which this research was carried out. The aim of the study was to identify selective herbicides for standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) to be applied during stand seed production in new variety Morava and to determine herbicide tolerance to key herbicides which could serve as a means of increasing the efficiency of the breeding process.

Materials and Methods

During the period of 2015-2017 a study was conducted in the experimental field of the Institute of Forage Crops – Pleven on a slightly leached chernozem soil under non-irrigating conditions. The experiment was set up using the long plot method in three replicates with the size of the harvested plot of 5 m^2. Treatments of the trial are shown in Table 1.

The herbicidal formulations used in this study were registered for weed control in cereal-grain grown crops in Bulgaria with herbicide action against dicotyledonous weeds (Accurate 60 WG, Ally Max, Arrat, Biathlon 4D + Adjuvant Dash, Buctril Universal and Granstar Super 50 SG), annual monocotyledonous weeds (Axial 050 EK) and with complex action (Axial One, Merlin Flexx and Pacifica WG + Adjuvant Biopower).

The first variety of standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) – Morava created in Bulgaria, was used in the field experiment. It is created at the Institute of Forage Crops – Pleven (Katova et al., 2010; Katova, 2012a).

Table 1. Trial treatments – herbicides and dose of an application

Treatments	Herbicides		Dose of commercial product, ml(g)/ha	Dose of active ingredient, ml(g)/ha
1	Control (untreated) K_u		–	–
2	Axial 050 EK	45 g/l pinoxadene	800	40
3	Axial One	45 g/l pinoxadene + 5 g/l florasulam	1000	50
4	Accurate 60 WG	600 g/kg metsulfuron methyl	10	6
5	Ally Max	143 g/kg metsulfuron + 143 g/kg tribenuron methyl	30	8.6
6	Arrat	250 g/kg tritosulfuron + 500 g/kg dicamba	150	112.5
7	Biathlon 4D + Adjuvant Dash	54 g/kg florasulam + 714 g/kg tritosulfuron	40+1000	30.7+1000
8	Buctril Universal	280 g/l bromoxynil + 280 g/l 2,4-D	800	448
9	Granstar Super 50 SG	250 g/kg tribenuron methyl + 250 g/kg thifensulfuron methyl	40	20
10	Merlin Flexx	240 g/l isoxaflutole + 240 g/l cyprotsulfamide	420	100.8
11	Pacifica WG + Adjuvant Biopower	30 g/kg mesosulfuron-methyl + 10 g/kg odosulfuron-methyl sodium + 90 g/kg mefenpyr-diethyl	350+700	14+700

Agropyron desertorum (Fisch.) Schultes, variety Morava, was sown in the early spring at inter-row distance of 36 cm and sowing rate of 15 kg/ha. Stockpiling fertilizing was done with P_2O_5 – 100 kg/ha and N – 120 kg/ha (½ in spring + ½ in autumn each year).

The application of the all herbicides were conducted with 400 l/ha water solutions using a spreading machine „PTP 18" with conic nozzle, pressure P max 3 bar, V max 1.64 l, and Q max 0.64 l/min, at the early spring at the shooting growth stage (BBCH 21-34).

The following characteristics were assessed: phytotoxicity on herbicides to the standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) on 7, 14, 21 and 30 days after application (DAA), using the 1-9 scale of the EWRS (EuropeanWeed Research Society) (score 1 – no damage; score 9 – completely destroyed crop); ground cover (*GC*) (0 – 100% for each treatments) (Stall, 2002); structural analysis of the elements of productivity in 45 generative stems for each variant; number of generative stems per m^2, seed yield and 1000 seed weight. Major agro-climatic characteristics of the period of study were recorded: rainfall amount (mm) and average 24^{-hour} air temperature (°C). De Martonne aridity index (*Iar-DM*) was used to characterize the aridity during the year for seed production of standard wheatgrass.

All experimental data were statistically processed using the software STATGRAPHICS Plus for Windows Version 2.1. and Statistika version 10.

Results and Discussion

The estimation of the complex effect of some major meteorological indicators – rainfall amount and average year air temperatures, with regard to biological requirements of standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes), shows that the studied years differ significantly (Table 2).

The total rainfall amount during the period of study can be presented in the following ascending order: 2016 < 2015 < 2017 and in reverse dependence on regard to average year air temperatures: 2017 < 2016 < 2015. The agro-meteorological conditions during the years of study showed deviations for temperature (0.9 to 18°C) and rainfall amount (from 12.0 to 43.0%), as compared to those for the multi-year period (1964–2014) (Table 2).

Assessing the complex impact of meteorological factors (rainfall and air temperatures) according De Martonne aridity index *(Iar-DM*), periods during the study years can be classified conventionally as 2015 and 2016 are moderately arid, respectively I_{ar}-DM_{2016} – 27.0 and I_{ar}-DM_{2015} – 29.9, and 2017 is slightly humid (*Iar-DM* – 35.0) (Table 2).

The results of selectivity evaluation (Table 3) showed that the applied postemergence herbicides on standard wheatgrass (in growth stage BBCH 21-34) in the year seed production had low phytotoxic effect (score 1.5-2) or were very small or absent when compared with the untreated control. The herbicides Acurate 60 WG – 10 g/ha, Ally Max – 30.0 g/ha, Biathlon 4D + Dash – 40+1000 ml/ha, Granstar Super 50 SG – 40 g/ha, Merlin Flex – 420 ml/ha and Pacifica WG + Biopower – 350 + 700 ml/ha had high selectivity from 7 DAT until the end of vegetation (score 1).

Phytotoxic effects of Axial 050 EK – 1000 ml/ha, Axial One – 1000 ml/ha and Arrat – 1000 ml/ha were observed as a bit of chlorosis (2-3 scores). Leaf discoloration was restored by the 30^{-th} DAT but suppression of growth persisted (Table 3).

The ground cover (*GC*) values at standard wheatgrass (*Agropyron desertorum* (Fisch. Schultes) ranged within relatively narrow limits (from 50 to 100%), depending mainly on the ontogenetic development of culture and were not substantially altered under the influence of applied herbicides (Table 4).

The herbicides action was reflected on the plant growth and development and structural elements of productivity of standard wheatgrass (Table 5). After treatment of standard wheatgrass with Axial 050 EK – 800 ml/ha, Axial One – 800 ml/ha and Arrat – 1000 ml/ha, a decrease in the number (from 15.7 to 57.8%) and height (from 20.7 to 28.82%) of the generative stems was observed, the differences being statistically proven (P = 0.05) compared to the untreated control.

However, Dimitrova and Katova (2011 and 2013) found in their studies, that the application of a lower dose of 6000

Table 2. Rainfall amount (mm), air temperature (°C) and De Martonne aridity index (I_{ar}-*DM*) for the study period

Years	Rainfall (mm)		Average year air temperature (°C)		Index of aridity (I_{ar}-*DM*) for the period (I – XII)
	I – XII	Deviation, %	I – XII	Deviation, °C	
2015	707.5	126.7	13.7	1.8	29.8
2016	625.4	112.0	13.2	1.3	27.0
2017	798.0	143.0	12.8	0.9	35.0
Average period (1964–2014)	558.2	100.0	11.9	0.0	25.5

Table 3. Selectivity of the herbicides to standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) for the period 2015-2017

Treatments	Herbicides	Dose of commercial product, ml(g)/ha	Phytotoxicity damage score (according to EWRS)			
			7 DAT	14 DAT	21 DAT	30 DAT
1	Control (untreated) K_u		1	1	1	1
2	Axial 050 EK	800	1	2	2	1
3	Axial One	1000	1	3	2.5	1
4	Accurate 60 WG	10	1	1	1	1
5	Ally Max	30	1	1	1	1
6	Arrat	150	1	1.5	2	1
7	Biathlon 4D + Dash	40+1000	1	1	1	1
8	Buctril Universal	800	1	1	1	1
9	Granstar Super 50 SG	40	1	1	1	1
10	Merlin Flexx	420	1	1	1	1
11	Pacifica WG + Biopower	350+700	1	1	1	1

Legend: EWRS scale (1-9): score 1 – no damage, score 9 – completely destroyed crop; DAT – day after treatment

Table 4. Ground cover of standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) after treatment with herbicides for the period 2015-2017

Treatments	Herbicides	Dose of commercial product, ml(g)/ha	Ground cover, %				
			0 DBA	7 DAT	14 DAT	21 DAT	30 DAT
1	Control (untreated) K_u		50	50	65	80	85
2	Axial 050 EK	800	50	50	65	80	85
3	Axial One	1000	50	50	65	80	85
4	Accurate 60 WG	10	50	50	65	80	85
5	Ally Max	30	50	55	70	85	90
6	Arrat	150	50	50	65	80	85
7	Biathlon 4D + Dash	40+1000	50	50	65	85	100
8	Buctril Universal	800	50	50	65	80	85
9	Granstar Super 50 SG	40	50	50	65	80	85
10	Merlin Flexx	420	50	50	70	80	85
11	Pacifica WG + Biopower	350+700	50	50	65	80	85

Legend: EWRS scale (1-9): score 1 – no damage, score 9 – completely destroyed crop; DBT – day before application, DAT – day after treatment

ml/ha of the herbicide Axial 050 EC 45 (g/l pinoxadene) did not indicate a phytotoxic effect on a standard wheatgrass, which allowed the herbicide to be used to weed control against monocotyledonous plants.

The selective herbicides (Accurate 60 WG, Ally Max, Biathlon 4D + Adjuvant Dash, Buctril Universal, Granstar Super 50 SG, Merlin Flexx and Pacifica WG + Adjuvant Biopower) apllied at standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) does not reduce the number (from 94.5 to 109.3%) and height (from 83.4 to 107.7%) of the reproductive stems of the standard wheatgrass, compared to the untreated control, and differences had no statistical significance.

Exceptions to the described dependence were found after treatment with Axial 050 EK – 800 ml/ha, Axial One – 1000 ml/ha and Arrat – 150 g/ha, where a statistically proven reduction was found at the number of seeds of ear and the mass per 1000 seeds and could be explained by the phytotoxic effect of the tested herbicides.

There are no statistical differences in the length of ear of the standard wheatgrass in all treatments from 4.6 to 6.2, average 5.3 cm and differences had no statistical significance at $P = 0.05$.

According to the 1000 seed weight on *Agropyron desertorum* (Fisch.) Schultes there were no regular differences and it was from 1.75 to 1.85 g except for the variants with visible

Table 5. Influence of the herbicides on structural elements of seed productivity of standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) after treatment with herbicides for the period 2015-2017

Treatments	Herbicides	Dose of commercial product, ml(g)/ha	Generative stems		length of ear, cm	number of seeds per ear	1000 seeds weight, g
			number, m^2	height, cm			
1	Control (untreated) K_u		1804de	68.5^{cd}	5.8^{cd}	44.9^{b}	1.85^{d}
2	Axial050 EK	800	908^{a}	49.2^{ab}	5.0^{a-c}	38.4^{a}	1.65^{b}
3	Axial One	1000	762^{ab}	52.6^{ab}	4.8^{a-c}	35.7^{a}	1.50^{a}
4	Accurate 60 WG	10	1822^{cd}	63.3^{bc}	5.4^{cd}	44.6b	1.85^{d}
5	Ally Max	30	1972^{bc}	63.7c^{d}	5.5^{d}	46.7^{ab}	1.85^{d}
6	Arrat	150	1521^{ab}	54.3^{b-d}	5.4^{b-d}	42.7^{a}	1.55^{a}
7	Biathlon 4D + Dash	40 + 1000	1550^{d}	65.5^{d}	6.2^{c-e}	43.5^{b}	1.85^{d}
8	Buctril Universal	800	1782^{cd}	65.9 $^{b-d}$	4.6^{abc}	37.6^{b}	1.85^{d}
9	Granstar Super 50 SG	40	1792^{cd}	63.0^{bc}	5.2^{bcd}	42.4^{b}	1.85^{d}
10	Merlin Flexx	420	1842^{e}	73.8^{e}	5.0^{d}	47.4^{b}	1.85^{d}
11	Pacifica WG + Biopower	350 + 700	1704^{d}	63.8^{a-c}	5.1^{bcd}	43.6^{b}	1.75^{cd}
	Mini		762	49.2	4.6	35.7	1.50
	Max		1972	73.8	6.2	47.4	1.85
	Average		1587	62.2	5.3	42.5	1.76

Legend: Means with different letters differ at P < 0.05 level of probability by LSD test

phytotoxicity after applied herbicides Axial 050 EK (1.65), Axial One (1.50 g) and Arrat (1.55 g) where the differences in the studied indicator are statistically proven at P = 0.05.

The herbicides for control of dicotyledonous weeds (Accurate 60 WG, Ally Max, Arrat, Biathlon 4D + Adjuvant Dash, Buctril Universal and Granstar Super 50 SG), monocotyledonous and dicotyledonous weeds (Merlin Flexx, Pacifica WG + Adjuvant Biopower) and monocotyledonous (Axial 050 EK) had high selectivity, regardless of the established weak to moderate phytotoxicity (score 2-2.5) 21 DAT of the herbicides (Axial 050 EK) do not inhibit of length of ear and seeds production with the exception of the herbicide Axial One applied at a dose 1000 ml/ha.

Seed yield in the untreated control was 460.5 kg/ha, it had very close absolute values from 418.7 to 545.1 kg/ha. These differences had no statistical significance, which was evidence of the herbicides selectivity to the wheatgrass crop (Table 6).

Table 6. Influence of the herbicides on seed productivity of standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) after treatment with herbicides for the period 2015-2017

Treatments	Herbicides	Dose of commercial product, ml(g)/ha	Seed productivity, kg/ha	% C_u
1	Control (untreated) C_u		460.5^{b-d}	100
2	Axial 050 EK	800	442.7^{a-d}	96.1
3	Axial One	1000	336.3^{a}	73.0
4	Accurate 60 WG	10	437.7^{a-d}	95.0
5	Ally Max	30	440.5^{a-d}	95.7
6	Arrat	150	436.5^{a-c}	94.8
7	Biathlon 4D + Dash	40+1000	434.9^{a-c}	94.4
8	Buctril Universal	800	545.1^{d}	118.4
9	Granstar Super 50 SG	40	514.2^{cd}	111.7
10	Merlin Flexx	420	418.7^{a-c}	90.9
11	Pacifica WG + Biopower	350+700	461.0^{b-d}	100.1
	Mini		336.3	73.0
	Max		545.1	118.4
	Average		448.0	96.5

Legend: Means with different letters differ at P < 0.05 level of probability by LSD test

The phytotoxic effect of herbicide Axial One showed statistically significant reduced seed productivity (from 27.0%) in standard wheatgrass as the seeds were 336.3 kg/ha, compared to the untreated control of 460.5 kg/ha. Similar are the results obtained in the experimental work of Dimitrova and Katova (2011) and Katova and Dimitrova (2013), according to which the seed production in the second year of stand growing standard wheatgrass variety Morava showed higher resistance to the applied herbicides.

These results confirmed that standard wheatgrass (*Agropyron desertorum* (Fisch.) Schultes) breeding programs would greatly benefit from screening new variety with high productivity for tolerance to key herbicides and developing an herbicide-tolerance catalog (Leon & Tillman, 2015). This information can be used in new breeding programs to reduce the risk of developing cultivars with low herbicide tolerance especially considering that standard wheatgrass had lower tolerance than herbicides with complex action (for weed control against annual monocotyledonous and dicotyledonous weeds).

Conclusions

Accurate 60 WG (600 g/kg metsulfuron methyl) – 10 g/ha, Ally Max (143 g/kg metsulfuron + 143 g/kg tribenuron methyl) – 30 g/ha, Arat (250 g/kg tritosulfuron + 500 g/kg dicamba) – 150 g/ha, Biathlon 4D (54 g/kg florasulam + 714 g/kg tritosulfuron) + Adjuvant Dash – 40+1000 ml/ha, Buctril Universal (280 g/l bromoxynil + 280 g/l 2,4-D) – 800 ml/ha and Granstar Super 50 SG (250 g/kg tribenuron methyl + 250 g/kg thifensulfuron methyl) – 40 g/ha applied to the growth stage BBCH 22-23 for the control of broadleaf weeds in the seed production year are highly selective to *Agropyron desertorum* (Fisch.) Schultes variety Morava and do not affect the yield and quality of the seeds.

At the mixed weed infestance with monocotyledonous and dicotyledonous weeds during the seed production year (second year of stand growing) of *Agropyron desertorum* (Fisch.) Schultes, the two-component selective herbicides Merlin flex (240 g/l isoxaflutole + 240 g/l cyprotsulfamide) – 420 ml/ha and the Pacifica WG (30 g/kg mesosulfuron, 10 g/kg iodosulfuron-methyl sodium, 90 g/kg mefenpyr-diethyl) + Adjuvant Biopower – 350 + 700 ml/ha can be used.

Herbicides Axial one (45 g/l pinoxadene + 5 g/l florasulam) – 1000 ml/ha cause a phytotoxic effect, reduce yield of seeds and degrade the quality of seeds from *Agropyron desertorum* (Fisch.) Schultes.

The herbicide tolerance of standard wheatgrass to key herbicides with complex action (for weed control against annual monocotyledonous and dicotyledonous weeds) has been determined, which could serve as a means of increasing the efficiency of the breeding process.

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