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Effects of adjuvants and carriers on propoxycarbazone and pyroxsulam efficacy on *Bromus sterilis* in winter wheat

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ABSTRACT

Bromus species are annual winter weeds from the Poaceae family which have become troublesome weeds of winter cereals. The herbicides propoxycarbazone and pyroxsulam are widely used for control of *B. sterilis.* The objective of this study was to determine the effect of different types of adjuvants and carriers on the efficacy of pyroxsulam and propoxycarbazone on *B. sterilis*. Small plot field trials were carried out in North Bohemia, Central Europe during 2011–2013. The tested carriers and adjuvants affected the efficacy of both herbicides and the seed production of *B. sterilis.* Urea ammonium nitrate was a less effective carrier than water (differences 5–30%). The most effective adjuvant was methylated seed oil (MSO), whose addition into the application water solution increased the herbicide efficacy of propoxycarbazone by 5–35%. Efficacy of the herbicide pyroxsulam was increased by adjuvant MSO by 10–30%. Nonionic surfactant increased herbicide efficacy only in 2013 (by 17%). Effect of organosilicone surfactant on the herbicide efficacy was negative (lower efficacy). Seed production of *B. sterilis* on untreated plots ranged between 20 000 and 50 000 seeds/m^2 in experimental years. Seed production was the lowest on plots treated by the herbicide plus MSO (1300–4500 seed/m^2).

Keywords: spring appliaction of herbicide, urea ammonium nitrate, heptamethyltrisiloxane, isodecyl alcohol ethoxylate, methyl ester of rapeseed oil

Bromus species are annual winter weeds from the Poaceae family which have become troublesome weeds of winter cereals in reduced tillage systems and in continuous cereals crop rotations (Stone et al. 2006, Ostlie and Howatt 2013, Sarani et al. 2014). The most important areas of their distribution are in South and North America, Central and Western Europe, and South Australia (Allen and Meyer 2002, Andersson et al. 2002, Kleemann and Gill 2009). The most important *Bromus* species in Europe is *Bromus sterilis* (L). In the Czech Republic, the first occurrence of *B. sterilis* was recorded during the 1980's (Mikulka 1987) and the importance of *B. sterilis* has grown dramatically during the past 10 years. The spreading of *Bromus* usually starts from the field margins (Petersen 2006), where soil preparation is less intensive. Competition ability of *B. sterilis* can cause yield losses in winter wheat ranging from 30–60% (Gehring et al. 2006). In addition to reducing yields, *B. sterilis* causes lodging and complicates harvest (Moray et al. 2003).

Bromus sterilis is especially very difficult to control in winter cereals, because of its rapid population dynamics and an absence of efficient herbicides. Propoxycarbazone, pyroxsulam, mesosulfuron, and sulfosulfuron are widely used for control of *B. sterilis* in Europe (Geier et al. 2002, Monaco and Creech 2004, Gehring et al. 2006, Geier et al. 2011, Sbatella et al. 2011). All these herbicides inhibit the plant enzyme acetolactate synthase (ALS), which is essential for synthesis of the branched-chain amino acids valine, leucine, and isoleucine. Inhibition of amino acid production subsequently inhibits cell division and causes death in susceptible plants. The use of special ALS inhibitors for control of *Bromus* is often not as good as expected. More experience and better recom-

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mendations are needed to improve the efficacy of these herbicides (Petersen 2006). Reddy et al. (2013) tested all the aforementioned herbicides in field experiments in two application terms. None of the tested herbicides controlled *B. tectorum* with efficacy greater than 80%. Pyroxsulam and propoxycarbazone demonstrated the best efficacy. According to Meinlschmidt et al. (2006), weather conditions during and after application of *B. sterilis* are more important than growth stage of weed at herbicide application. They found that in dry years only split applications comprised an effective method of control. Although treated *Bromus* plants were strongly suppressed, they were nevertheless able to produce fertile seeds.

Many populations of *Bromus* resistant to ALS inhibitors (mainly *B. rigidus* and *B. tectorum*) have been detected, especially in North America and Australia (Park and Mallory-Smith 2005, Owen et al. 2012). Therefore, stubble tillage (including the use of glyphosate) is an important part of a *Bromus* management strategy (Petersen 2006).

The hairy surface of *B. sterilis* leaves reduces wettability and efficacy of ALS inhibitors, especially of water-dispersible granules formulations. Adjuvant needs to be added to improve herbicide efficacy (Augustin 2004, Gehring et al. 2006).

The main objective of this study was to determine the effect of different types of adjuvants and carriers on the efficacy of pyroxsulam and propoxycarbazone on *B. sterilis* and seed production of *B. sterilis*.

MATERIAL AND METHODS

Small plot field trials were carried out in North Bohemia, Central Europe (300 m a.s.l.; 50°45'N, 13°91'E) during 2011–2013. Winter wheat (cv. Federer) was sown on 12 October 2011, 4 October 2012, and 8 October 2013. Winter wheat had been the previous crop in all experimental years and grass weed control had not been used. The plots were established in randomized blocks with three replications. Plot size was 1.5 × 8 m, row width 0.125 m, and depth of sowing 0.02 m. The entire experimental area was treated with pendimethalin (Stomp 400 SC) in autumn at application rate 1000 g/ha of active ingredient (ai) for control of broadleaf weeds. *B. sterilis* occurred at density 20–40 plants/m^2 in 2011 and 2013 and at 10–20 plants/m^2 in 2012.

Herbicide treatments were applied in spring at the beginning of *B. sterilis* tillering and at full tillering of wheat (10 April 2011, 27 March 2012, 18 April 2013) when maximum daily air temperature had increased to 10°C for more than 5 days. The herbicides propoxycarbazone (Attribut SG 70, 700 g/kg ai) and pyroxsulam (Corello, 75 g/kg ai) were tested using different carriers (urea ammonium nitrate and water) and three different adjuvants: MERO (methyl ester of rapeseed oil, 733 g/L ai), Trend 90 (isodecyl alcohol ethoxylate, 900 g/L ai), and Silwet L 77 (heptamethyltrisiloxane, 840 g/L ai). The experimental treatments are described in Table 1. A small-plot sprayer was

Table 1. Treatment list

Herbicide/Adjuvant	Rate ai per hectare (g)	Carrier (200 L/ha)
Untreated check	–	–
Propoxycarbazone	42	water
Pyroxsulam	19	water
Propoxycarbazone	42	UAN
Pyroxsulam	19	UAN
Propoxycarbazone + methyl ester of rapeseed oil	42 + 733	water
Pyroxsulam + methyl ester of rapeseed oil	19 + 733	water
Propoxycarbazone + isodecyl alcohol ethoxylate	42 + 180	water
Pyroxsulam + isodecyl alcohol ethoxylate	19 + 180	water
Propoxycarbazone + heptamethyltrisiloxane	42 + 84	water
Pyroxsulam + heptamethyltrisiloxane	19 + 84	water

ai – active ingredient; UAN – urea ammonium nitrate

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Table 2. Meteorological characteristics following application of herbicides

Meteorological characteristic		2011	2012	2013
Total precipitation (mm)	10 days AT*	0.8	6.1	9.9
	1 month AT**	29.2	33.0	49.8
	May	35.7	23.4	106.5
	June	60.0	46.8	173.4
Mean temperature (°C)	10 days AT*	9.8	8.8	14.4
	1 month AT**	11.3	8.5	14.3
	May	15.0	16.0	12.7
	June	22.7	18.1	16.8

*10–19 April 2011, 3 March–5 April 2012, 18–27 April 2013; **10 April–9 May 2011, 3 March–26 April 2012, 18 April–17 May 2013. AT – after treatments

used to apply the herbicides. The spray volume applied was 200 L/ha. Lurmark 015 F 110 nozzles were used and application pressure was 0.25 MPa. Meteorological data from 10 days and 1 month after the applications are shown in Table 2.

Herbicide efficacy was assessed by an estimation method using a percentage scale from 0–100% (0% – untreated; 100% – full control) according to the guideline 1/93 (3) of the European and Mediterranean Plant Protection Organisation (EPPO). The final assessment was performed 5–6 weeks after treatments, when *B. sterilis* had flowered. Seed production was recorded shortly before ripening of *B. sterilis* (at the beginning of July). All *B. sterilis* plants were removed from an area of 1 m^2 per each plot and seeds on plants were counted.

The experimental data were evaluated using the software package Statgraphics Plus 4.0. Both one-way and multifactorial ANOVA were used. The contrasts between treatments were verified by the *LSD* test ($\alpha = 0.05$). The Bartlett's test was used to test whether efficacy data did not violate the assumption of homogeneity of variance. Because in one case Bartlett's test showed the data to be heterogeneous, arcsine square root percent transformation was carried out and the multiple comparisons test was applied to the transformed data.

RESULTS AND DISCUSSION

Efficacy of the herbicide propoxycarbazone on *B. sterilis* was strongly affected by weather conditions and ranged from 46–74% in individual experimental years. The range of differences in the efficacy of pyroxsulam among experimental years was somewhat smaller (52–73%). There were no statistically significant differences in the efficacy and seed production of *B. sterilis* between the tested herbicides in all experimental years (Table 3). Similar efficacy had been recorded by Reddy et al. (2013), who had tested the effect of pyroxsulam and propoxycarbazone with nonionic surfactant on *B. tectorum* at autumn and spring applications.

The tested carriers significantly affected the efficacy of both tested herbicides and the seed production of *B. sterilis* in 2011 and 2012 (Table 4), in which years lower temperatures and precipitation occurred 10 days after application (Table 2).

Table 3. Efficacy of tested herbicides and seed production of *Bromus sterilis*

Herbicide	2011	2012	2013
Efficacy (%)			
Propoxycarbazone	74^a	46^a	66^a
Pyroxsulam	68^a	52^a	73^a
P-value	0.1006	0.6045	0.1711
Seed production (seed/m^2)			
Untreated check	$60\,700^b$	$20\,716^b$	$34\,208^b$
Propoxycarbazone	9216^a	$10\,610^{ab}$	8688^a
Pyroxsulam	$14\,592^a$	7596^a	6945^a
P-value	0.0000	0.0553	0.0000

The effect of herbicides was studied on plots using water as carrier without adjuvants. Values followed by different letters are significantly different compared to corresponding column values as determined using the Tukey's test ($\alpha = 0.05$)

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Table 4. Effect of the tested carrier on herbicide efficacy and seed production of *Bromus sterilis*

Carrier	2011	2012	2013
Efficacy (%)			
Water	72^{b}	53^{b}	53^{a}
UAN	60^{a}	23^{a}	48^{a}
P-value	0.0118	0.0120	0.5014
Seed production (seed/m^2)			
Untreated check	60 700^{c}	20 716^{b}	34 208^{b}
Water	10 118^{a}	6486^{a}	16 871^{a}
UAN	23 584^{b}	17 515^{b}	18 208^{a}
P-value	0.0000	0.0045	0.0036

The effect was studied on plots treated by both tested herbicides, which were applied without adjuvants. Values followed by different letters are significantly different compared to corresponding column values as determined using the Tukey's test (α = 0.05). UAN – urea ammonium nitrate

Urea ammonium nitrate (UAN) was less effective than water, especially in 2012 (when herbicide efficacy was just 23%). In 2013, the efficacy of both tested herbicides was also lower when UAN was used as a carrier, but this lower efficacy was not statistically significant (*P*-value = 0.5014). Miller et al. (1999) recorded just the opposite effect, as leaf uptake of sulfosulfuron by *B. tectorum* and *B. japonicus* had been higher when UAN was used as a carrier. Theire was, however, a laboratory experiment. In a field study, Olson et al. (2000) had shown a positive effect of UAN on the efficacy of sulfosulfuron on *B. tectorum* and *B. secalinus* only at the lower tested application rate (23 g/ha ai). No effect of UAN as a carrier on the efficacy of foramsulfuron on *Sorghum halepense* was detected by Shahbazi et al. (2014). A positive effect of UAN on the efficacy of penoxsulam on *Echinochloa crus-galli* was described by Pearson et al. (2008). In that case, UAN was used as an adjuvant (2%) and the addition of another adjuvant increased the efficacy of penoxsulam even more.

Tested adjuvants significantly affected herbicides efficacy in all experimental years, but the largest differences among the tested adjuvants were recorded in 2013 (Table 5), when the air temperature after application was highest (Table 2). The most effective adjuvant was methylated seed oil (MSO), whose addition into the application water solution significantly increased the herbicide efficacy of propoxycarbazone in 2012 and 2013 (by 28% and 35%, respectively). Efficacy of the herbicide pyroxsulam was significantly increased by adjuvant MSO only in 2013 (by 30%). In 2011, the addition of MSO did not significantly increase the efficacy of both tested herbicides (Table 6). Nonionic surfactant (NIS) significantly increased herbicide efficacy only in 2013 (Table 5). Effect of organosilicone surfactant (OS) on the herbicide efficacy was negative in 2011 and 2013. In these 2 years, efficacy of both tested herbicides applied with OS was significantly lower compared to the efficacy of solo application of these herbicides (Table 6). Differences in efficacy of both tested herbicides between OS and MSO were significant in all experimental years (the efficacy for MSO being higher by 18, 45, and 14% across the test

Table 5. Effect of adjuvant on herbicide efficacy and seed production of *Bromus sterilis*

Adjuvant	2011	2012	2013
Efficacy (%)			
Herbicide without adjuvant	72^{b}	53^{ab}	53^{a}
Herbicide + MSO	79^{b}	73^{b}	85^{c}
Herbicide + NIS	72^{b}	43^{ab}	70^{b}
Herbicide + OS	61^{a}	28^{a}	71^{b}
P-value	0.0004	0.0083	0.0000
Seed production (seed/m^2)			
Untreated check	50 700^{c}	20 716^{b}	34 208^{c}
Herbicide without adjuvant	10 118^{ab}	6486^{ab}	16 87^{b}
Herbicide + MSO	4476^{a}	1917^{a}	1301^{a}
Herbicide + NIS	12 206^{ab}	13 976^{ab}	5681^{a}
Herbicide + OS	20 816^{b}	14 033^{ab}	7413^{a}
P-value	0.0000	0.0022	0.0000

The effect was studied on plots where water was used as a carrier. Different herbicides were analysed together because no significant difference was found between them (Table 3). Values followed by different letters are significantly different compared to corresponding column values as determined using the Tukey's test (α = 0.05). MSO – methylated seed oil (methyl ester of rapeseed oil); NIS – nonionic surfactant (isodecyl alcohol ethoxylate); OS – organosilicone surfactant (heptamethyltrisiloxane)

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Table 6. Effect of tank mix combinations of both tested herbicides with different adjuvants on herbicide efficacy and seed production of *Bromus sterilis*

Herbicide	Adjuvant	2011	2012	2013
Efficacy (%)				
Propoxycarbazone	–	75^{b}	40^{bc}	47^{a}
Pyroxsulam	–	68^{ab}	65^{de}	58^{ab}
Propoxycarbazone	MSO	80^{b}	68^{de}	82^{bc}
Pyroxsulam	MSO	78^{b}	77^{e}	88^{c}
Propoxycarbazone	NIS	75^{b}	23^{ab}	67^{ab}
Pyroxsulam	NIS	68^{ab}	62^{cde}	73^{abc}
Propoxycarbazone	OS	65^{ab}	53^{ac}	68^{ab}
Pyroxsulam	OS	57^{a}	3^{a}	73^{abc}
P-value		0.0012	0.0000	0.0000
Seed production (seed/m^2)				
Untreated check		$60\,700^{c}$	$20\,716^{b}$	$34\,208^{d}$
Propoxycarbazone	–	8310^{a}	9142^{a}	$18\,830^{c}$
Pyroxsulam	–	$11\,925^{ab}$	3830^{a}	$14\,911^{bc}$
Propoxycarbazone	MSO	3408^{a}	2423^{a}	1520^{a}
Pyroxsulam	MSO	5544^{a}	1411^{a}	1081^{a}
Propoxycarbazone	NIS	9847^{ab}	$22\,676^{b}$	6751^{ab}
Pyroxsulam	NIS	$14\,565^{ab}$	5277^{a}	4611^{ab}
Propoxycarbazone	OS	$15\,300^{ab}$	8199^{a}	7650^{abc}
Pyroxsulam	OS	$26\,332^{b}$	$19\,866^{b}$	7176^{ab}
P-value		0.0000	0.0000	0.0000

The effect was studied on plots where water was used as a carrier. Values followed by different letters are significantly different compared to corresponding column values as determined by the Tukey's test (α = 0.05). MSO – methylated seed oil (methyl ester of rapeseed oil); NIS – nonionic surfactant (isodecyl alcohol ethoxylate); OS – organosilicone surfactant (heptamethyltrisiloxane)

years). Except for some organosilicone surfactants, Augustin (2004) had shown a positive effect for most of the tested adjuvants on the efficacy of propoxycarbazone on *B. sterilis*. Miller et al. (1999) had recorded higher adsorption of sulfosulfuron by *B. tectorum* and *B. japonicus* when OS was added to carrier compared to NIS and MSO in their laboratory experiment. In the field study, Olson et al. (2000) had shown a positive effect of MSO and NIS on the efficacy of sulfosulfuron on *B. tectorum* and *B. secalinus* (efficacy of greater than 75%).

Depending upon experimental year, seed production by *B. sterilis* on untreated plots ranged between 20 000 and 50 000 seeds/m^2. Seed production on untreated plots was affected mainly by *B. sterilis* density and partly by weather conditions (Table 3). Similar seed production data had been presented by Upadhyaya et al. (1986) for *B. tectorum*. Reproductive ability of *B. sterilis* was affected by herbicide efficacy. With increasing herbicide efficacy, seed production decreased. Seed production was the lowest on plots treated with the herbicide plus MSO (1300–4500 seed/m^2) and was just 4–9% of that compared to the untreated check.

In conclusion, the efficacy of herbicides pyroxsulam and propoxycarbazone was negatively affected by urea ammonium nitrate as a carrier and by organosilicone surfactant. Only methylated rapeseed oil adjuvant increased the efficacy of both tested herbicides. This adjuvant is especially suitable for control of *B. sterilis* in hot weather conditions shortly after application.

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