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Article

Downy Brome (*Bromus tectorum* L.) and Broadleaf Weed Control in Winter Wheat with Acetolactate Synthase-Inhibiting Herbicides

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Abstract: A study was conducted for three seasons in northwest Kansas, USA to evaluate acetolactate synthase (ALS)-inhibiting herbicides for downy brome (*Bromus tectorum* L.) and winter annual broadleaf weed control in winter wheat. Herbicides included pyroxsulam at 18.4 g ai ha^{-1}, propoxycarbazone-Na at 44 g ai ha^{-1}, premixed propoxycarbazone-Na & mesosulfuron-methyl at 27 g ai ha^{-1}, and sulfosulfuron at 35 g ai ha^{-1}. The herbicides were applied postemergence in fall and spring seasons. Averaged over time of application, no herbicide controlled downy brome more than 78% in any year. When downy brome densities were high, control was less than 60%. Pyroxsulam controlled downy brome greater than or similar to other herbicides tested. Flixweed (*Descurainia sophia* L.), blue mustard [*Chorispora tenella* (Pallas) DC.], and henbit (*Lamium amplexicaule* L.) control did not differ among herbicide treatments. All herbicides tested controlled flixweed and blue mustard at least 87% and 94%, respectively. However, none of the herbicides controlled henbit more than 73%. Fall herbicide applications improved weed control compared to early spring applications; improvement ranged from 3% to 31% depending on the weed species. Henbit control was greatly decreased by delaying herbicide applications until spring compared to fall applications (49% *vs.* 80% control). Herbicide injury was observed in only two instances. The injury was ≤13% with no difference between herbicides and the injury did not impact final plant height or grain yield.

Keywords: blue mustard; downy brome; flixweed; henbit; propoxycarbazone-Na; pyroxsulam; sulfosulfuron

1. Introduction

Wheat (*Triticum aestivum* L.) is the most important cereal grain crop in the USA, where it was planted on 23 million ha in 2012 [1]. Around 75% of the wheat grown in the USA is winter wheat. Weeds compete with wheat for water, light, space and nutrients. Their interference can cause significant yield reduction in winter wheat. Common broadleaf weeds found in winter wheat growing regions of the central U.S. include blue mustard [*Chorispora tenella* (Pallas) DC.], henbit (*Lamium amplexicaule* L.), flixweed [*Descurainia sophia* (L.) Webb. Ex Prantl], bushy wallflower (*Erysimum repandum* L.), field pennycress (*Thlaspi arvense* L.), wild buckwheat (*Polygonum convolvulus* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik.], and pinnate tansymustard [*Descurainia pinnata* (Walt.) Britt.]. Season-long competition of 11, 33, and 98 blue mustard plants m^{-2} reduced wheat grain yields by 28%, 42%, and 51%, respectively [2]. Conley and Bradley (2005) [3] reported 13% and 38% yield reductions because of henbit interference at 82 and 155 plants m^{-2}, respectively. Northam *et al.* (1993) [4] also reported wheat grain yield loss of 48% with 221 henbit plants m^{-2}. Bushy wallflower population at 272 plants m^{-2} reduced winter wheat yield by 25% [5].

Winter annual grasses in wheat typically are more difficult to control than broadleaf weeds. Important grass weeds found in winter wheat are downy brome (*Bromus tectorum* L.), cheat (*Bromus secalinus* L.), Japanese brome (*Bromus japonicus* Thunb. ex Murr.), jointed goatgrass (*Aegilops cylindrica* L.) and feral rye (*Secale cereal* L.). Winter annual grass weed interference with winter wheat usually is greatest when weeds emerge simultaneously or soon after wheat emergence. Downy brome emerging within 2–3 weeks after winter wheat emergence was more competitive and caused greater yield losses than later emerging plants in the central U.S. Great Plains [6] and southern Alberta, Canada [7]. Low densities of 24, 40, and 65 downy brome plants m^{-2} reduced wheat yields by 10%, 15%, and 20%, respectively, when emerging within 14 days after wheat emergence [6]. Downy brome densities occasionally exceed 400 plants m^{-2} and may cause crop failure if not controlled. Densities of 4 to 5 feral rye plants m^{-2} emerging in fall and competing with winter wheat reduced net profits 50% of the time [8]. Densities as low as 1 to 2 feral rye plants m^{-2} sometimes exceeded economic thresholds. Apart from crop yield reductions, weeds can also slow harvest, increase equipment repair costs, and lower quality of grain. Hence, winter annual weed control is very important to maximize wheat yield potential.

Selective postemergent herbicidal control of winter annual weeds, especially grass species, in winter wheat usually is best when herbicides are applied in the fall when plants are growing rapidly but before grass weeds become well tillered. However, growers prefer to delay herbicide application until early spring to assess wheat winterkill and decide if they will allow the winter wheat to reach full maturity [9]. Acetolactate synthase (ALS)-inhibiting herbicides have been primary herbicides for broadleaf weed control in winter wheat for more than three decades and for winter annual grass control for nearly two decades. ALS-inhibiting herbicides are widely used because of their low doses, low environmental impact, low mammalian toxicity, and high efficacy [10]. Chlorsulfuron, metsulfuron, thifensulfuron, triasulfuron and tribenuron are registered for weed control in wheat. These herbicides provide good broadleaf weed control efficacy, but have little or no activity on brome species (*Bromus* spp.) [11]. Sulfosulfuron, propoxycarbazone-Na, and pyroxsulam selectively control both grass and broadleaf weeds in wheat. Sulfosulfuron (Maverick®, Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167, USA), a sulfonylurea herbicide, was introduced in 1998 [12] and was the first herbicide registered primarily to control winter annual grasses in wheat [11]. Propoxycarbazone-Na (Olympus®, Bayer CropScience LP, 2 T.W. Alexander Drive, P.O. Box 12014, Research Triangle Park RTP, NC 27709, USA), a sulfonylaminocarbonyltriazolinone herbicide, was registered for use in wheat in 2004 [13]. Premixed propoxycarbazone-Na & mesosulfuron-methyl (Olympus®Flex, Bayer CropScience LP) is another ALS-inhibiting herbicide that was registered in 2005 [14]. Mesosulfuron-methyl belongs to the sulfonylurea family. Pyroxsulam (PowerFlex®, Dow AgroSciences LLC., 9330 Zionsville Road, Indianapolis, IN 46268, USA) is a relatively new ALS-inhibiting herbicide registered for use in wheat in 2008 [15]; it belongs to the triazolopyrimidine sulfonamide family of herbicides.

The objectives of this study were (1) to compare weed control efficacy of sulfosulfuron, propoxycarbazone-Na, propoxycarbazone-Na plus mesosulfuron, and pyroxsulam in winter wheat and (2) to determine the effect of herbicide application timing on weed control.

2. Material and Methods

Field experiments were conducted for three winter wheat growing seasons in 2008–2009, 2010–2011, and 2011–2012 at the Kansas State University Agricultural Research Center near Hays, Kansas in the central USA. Soil characteristics, wheat cultivars used, seeding rate, planting and spraying dates are shown in Table 1. Wheat seed was planted 5 to 6 cm deep into tilled soil with a row spacing of 25 cm. Plots were 2.5 m wide by 6.7 m long with 10 rows of wheat. Nitrogen at 60 kg ha^{-1} was injected into the soil as urea ammonium nitrate before planting in all three years.

Experimental design was a randomized complete block with four replications. Treatments included pyroxsulam at 18.4 g ai ha^{-1}, propoxycarbazone-Na at 44 g ai ha^{-1}, premixed propoxycarbazone-Na & mesosulfuron-methyl at 27 g ai ha^{-1}, and sulfosulfuron at 35 g ai ha^{-1}. A non-ionic surfactant (Activator 90, Loveland Product, Inc., 7251 W. 4th St., Greeley, CO 80632, USA) at 0.5% v/v was included in all treatments, and ammonium sulfate (S-Sul Sprayable, American Plant Food Corp., P.O. Box 584, Galena Park, TX 77547, USA) at 1.7 kg ha^{-1} was included with propoxycarbazone-Na & mesosulfuron and pyroxsulam treatments. Each treatment was applied postemergence to winter wheat in fall (fall-POST) or spring (spring-POST). Herbicides were broadcast applied using backpack or tractor-mounted plot sprayers calibrated to deliver 117 to 134 L ha^{-1} at 207 kPa pressure.

Table 1. Soil characteristics, planting, spraying and weed density information, Hays, KS, USA, 2008–2012.

	2008–2009	**2010–2011**	**2011–2012**
Soil type	Roxbury silt loam	Crete silty clay loam	Roxbury silt loam
Soil pH	7.7	6.5	8.0
Organic matter (%)	2.4	1.8	1.5
Wheat cultivar	KS03HW6-1	Danby	KS08HW35-1 CL
Seed rate (kg ha^{-1})	63	67	68
Planting date	10/02/2008	10/11/2010	10/05/2011
Fall-POST spray date	11/19/2008	11/15/2010	11/23/2011
Downy brome density m^{-2}	20	25–50	100
Flixweed density m^{-2}	1–5	-	20
Henbit density m^{-2}	100	-	100
Blue mustard density m^{-2}	10–30	-	25
Spring-Post spray date	03/25/2009	04/08/2011	03/06/2012
Downy brome density m^{-2}	20	25–50	50
Flixweed density m^{-2}	1–5	-	20
Henbit density m^{-2}	50	-	100
Blue mustard density m^{-2}	10	-	100

In 2008–2009 and 2011–2012, the predominant weeds were downy brome, henbit, flixweed and blue mustard. Downy brome was the only species present in 2010–2011. Generally, wheat was 5 to 10 cm tall with 1 to 2 tillers at time of fall-POST applications and 7.5 to 15 cm tall with 2 to 5 tillers at time of spring-POST applications. Downy brome was 2.5 to 7.5 cm tall with 0 to 2 tillers and 5 to 12.5 cm tall with 2 to 3 tillers at fall-POST and spring-POST timings, respectively. Likewise, henbit was 1 to 2.5 cm tall with 2 to 8 leaves and 2.5 to 7.5 cm tall with 5 to 15 leaves at fall-POST and spring-POST timings, respectively. Blue mustard was 2.5 to 5 cm tall with 4 to 10 leaves at fall-POST and 5 to 10 cm tall with 10 to 20 leaves at spring-POST timings. Flixweed was 1 to 2 cm tall with 2 to 4 leaves at fall-POST and 2.5 to 5 cm tall with 8 to 10 leaves at spring-POST application time.

Weed control and crop injury were rated based on composite visual estimations of density reduction, growth inhibition, and foliar injury on a scale of 0 (no effect) to 100 (plant death). Minimum of four weeks' time after spring applications was maintained before taking weed control ratings. Weed control ratings were determined 221, 205 and 197 days after planting (DAP) in 2008–2009, 2010–2011 and 2011–2012, respectively. Wheat injury was visually assessed 2 weeks after fall-POST and spring-POST applications in each year. Plant heights at maturity were determined in 2008–2009 and 2011–2012 by measuring from the soil surface to the tip of the panicle on three randomly selected main culms in each plot. Plant heights were not recorded in 2010–2011. Grain yields were determined by harvesting the six center rows of each plot with a plot combine and adjusting seed weight to 12.5% moisture content.

Data were analyzed using the general linear model procedure of SAS (Statistical Analysis Systems Institute, Cary, NC, USA) and means were separated at the 5% significance level using Fisher's protected LSD. Percent weed control and wheat injury data were arcsine transformed before analysis. The non-treated control treatment was omitted from weed control and crop injury analyses, but included in the analysis of plant height and wheat grain yields. Data were pooled over years when there was no year-by-herbicide or year-by-time of application interaction.

3. Results and Discussion

There was no three-way interaction or time of application-by-herbicide interaction for any weed species (Table 2). Year-by-herbicide interaction was significant for downy brome and flixweed. Year-by-time of application was significant only for flixweed.

Table 2. Analysis of variance (ANOVA) results for weed control [a,b].

Source	Downy brome	Flixweed	Henbit	Blue mustard
Year	***	***	***	***
Time of application	*	NS	***	***
Year × time of application	NS	***	NS	NS
Herbicide	***	NS	NS	NS
Year x herbicide	**	**	NS	NS
Time of application × herbicide	NS	NS	NS	NS
Year × time of application × herbicide	NS	NS	NS	NS

[a] Abbreviation: NS, not significant; [b] Results of ANOVA based upon arcsine-transformed data; * $P = 0.05–0.01$; **$P = 0.01–0.001$; *** $P = 0.001–0.0001$.

3.1. Downy Brome Control

Results are discussed by year because of a year by herbicide interaction (Table 2). No treatment controlled downy brome more than 80% in 2008–2009 and 2010–2011 or more than 60% in 2011–2012. Differences in control between herbicides in 2011–2012 were not significant (Table 3). Poor control of downy brome in 2011–2012 compared to other two seasons likely was due to two to four-times higher weed density. Overall, pyroxsulam controlled downy brome better than all the other herbicides in one season and better than all but propoxycarbazone-Na in another season. In 2008–2009, downy brome control with pyroxsulam was 78% compared to 63% to 69% with propoxycarbazone-Na, propoxycarbazone-Na & mesosulfuron-methyl, and sulfosulfuron. In 2010–2011, pyroxsulam and propoxycarbazone-Na controlled downy brome (72% and 77%, respectively) better than propoxycarbazone-Na & mesosulfuron-methyl (57%) or sulfosulfuron (63%). In a similar study also in Kansas, pyroxsulam applied in fall controlled downy brome similar to or greater than propoxycarbazone-Na, propoxycarbazone-Na & mesosulfuron-methyl, and sulfosulfuron [11]. In our study, averaged over treatments, downy brome control decreased when application timing was delayed until spring (Table 4). Fall and spring applications of herbicides controlled downy brome 65% and

59%, respectively. Results of this study agree with previous reports of decreased downy brome control with sulfosulfuron or propoxycarbazone-Na as application time was delayed [16,17]. Blackshaw and Hamman (1998) [18] reported more than 85% downy brome control with sulfosulfuron at 19 to 33 g ai ha^{-1} applied fall-POST, whereas spring-POST application of sulfosulfuron at 60 g ai ha^{-1} only suppressed growth of downy brome. Geier *et al.* (2011) [11] also reported better downy brome control with all four ALS-inhibiting herbicides tested in our study when applied in fall than spring.

Table 3. Efficacy of acetolactate synthase (ALS)-inhibiting herbicides on downy brome and broadleaf weed control in winter wheat averaged across time of application, Hays, KS, USA, 2008–2012 [a].

Treatment [b]	Rate	Downy brome			Flixweed		Henbit	Blue mustard
		2008–2009	2010–2011	2011–2012	2008–2009	2011–2012	Pooled	Pooled
	g ai ha^{-1}	%						
Pyroxsulam	18.4	78	72	57	96	99	73	98
Propoxycarbazone-Na	44	65	77	53	91	98	59	97
Propoxycarbazone-Na & mesosulfuron-methyl	27	63	57	45	87	100	61	98
Sulfosulfuron	35	69	63	48	90	97	68	94
LSD (0.05)		7	8	NS	NS	NS	NS	NS

[a] Abbreviations: NS, non-significant; [b] All treatments include a non-ionic surfactant at 0.5% v/v; treatments pyroxsulam and propoxycarbazone plus mesosulfuron included ammonium sulfate at 1.7 kg ha^{-1}.

3.2. Broadleaf Weed Control

Main effect of herbicides on control of all three broadleaf weeds was non-significant, but time of application was significant (Table 2). Herbicide treatments controlled flixweed and blue mustard at least 87% and 94%, respectively (Table 3). No treatment controlled henbit more than 73%. Control of all three broadleaf weeds was lower when herbicide treatments were applied in spring compared to fall (Table 4). Fall applications controlled flixweed 94% and 100% in 2008–2009 and 2011–2012, respectively, compared to 86% and 97% control with spring applications. Similarly, blue mustard control was slightly greater with fall treatments (99%) compared to spring treatments (95%). Henbit control greatly decreased when application time was delayed until spring. Control of henbit with spring treatments was 49% compared to 80% with fall treatments. Our results are in agreement with previous reports on decreased blue mustard and henbit control with delayed ALS-inhibiting herbicide applications [11].

Table 4. Downy brome and broadleaf weed control in winter wheat as affected by time of application of herbicides averaged across herbicides, Hays, KS, 2008–2012.

	Downy brome	**Flixweed**		**Henbit**	**Blue mustard**
Time of application	Pooled	2008–2009	2011–2012	Pooled	Pooled
	--------------------------------%---------------------------------				
Fall	65	94	100	80	99
Spring	59	86	97	49	95
LSD (0.05)	2	4	2	11	3

3.3. Crop Injury, Plant Height and Grain Yields

No wheat injury was observed in response to herbicide treatments except in spring of 2009 and fall of 2010 (Table 5). Herbicide treatments, regardless of application time, caused 8 to 13% leaf chlorosis two weeks after treatment application. Leaf chlorosis did not differ among herbicide treatments. However, injury symptoms disappeared and wheat recovered completely within 3 to 4 weeks. Plant height at maturity and grain yields did not differ among herbicide treatments or between application times (data not shown). Herbicide treatments increased grain yields significantly (by 73%) compared to non-treated control only in 2011–2012. This likely was due to greater weed interference in 2011–2012 compared to other years.

Table 5. Wheat injury at 14 days after treatment caused by ALS-inhibiting herbicides applied in fall and spring seasons, Hays, KS [a, b].

		Time of application	
Treatment [c]	Rate	Fall	Spring
	g ai ha^{-1}	-----------------%---------------	
Pyroxsulam	18.4	10	10
Propoxycarbazone-Na	44	10	9
Propoxycarbazone-Na & mesosulfuron-methyl	27	13	10
Sulfosulfuron	35	8	10
LSD (0.05)		NS	NS

[a] Abbreviations: NS, non-significant; [b] Wheat injury was observed only in spring 2008–2009 and fall 2010–2011; [c] All treatments included a non-ionic surfactant at 0.5% v/v; treatments pyroxsulam and propoxycarbazone plus mesosulfuron include ammonium sulfate at 1.7 kg ha^{-1}.

4. Conclusions

None of the ALS-inhibiting herbicides that were evaluated in this study controlled downy brome as much as 80%. Pyroxsulam controlled downy brome better than or similar to propoxycarbazone-Na, premixed propoxycarbazone-Na & mesosulfuron-methyl, and sulfosulfuron. All herbicides controlled broadleaf weeds similarly. Flixweed and blue mustard were controlled at least 87% and 94%, respectively. No treatment controlled henbit more than 75%. Depending on weed species, 3% to 31% higher weed control was achieved with fall herbicide applications compared to spring applications. Herbicide injury was observed in only two instances and the injury was ≤13% with no difference between treatments. This injury did not adversely affect grain yields.

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