Does a Diflufenzopyr Plus Dicamba Premix Synergize Russian Knapweed (*Acroptilon repens*) Control with Auxinic Herbicides?

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Diflufenzopyr is a synergist that improves broadleaf weed control when mixed with certain auxinic herbicides. In nonagricultural settings, it is only available in a premix with dicamba, which is labeled for noncrop sites, pasture, hay, and rangeland. Our objectives were to determine the influence of diflufenzopyr + dicamba when applied with auxinic herbicides for Russian knapweed control. Studies were conducted near Ethete, WY, from 2005 to 2008 in a pasture heavily infested with Russian knapweed. Treatments were applied in the fall (September) and included aminopyralid, clopyralid, clopyralid + 2,4-D, clopyralid + triclopyr, and picloram at standard and reduced rates, with and without diflufenzopyr + dicamba. At 12 and at 24 mo after treatment (MAT), diflufenzopyr + dicamba did not influence Russian knapweed control when applied with standard rates of aminopyralid, clopyralid, clopyralid + 2,4-D, clopyralid + triclopyr, or picloram. All of these treatments except clopyralid + 2,4-D consistently provided ≥ 80% control 24 MAT. Reduced-rate herbicide interactions with diflufenzopyr + dicamba were also not significant at 12 MAT. However, at 24 MAT, aminopyralid applied with diflufenzopyr + dicamba controlled Russian knapweed 83% compared with 59% when aminopyralid was applied alone. Russian knapweed control with all other reduced-rate treatments, except picloram, fell below 80%. These results indicate that diflufenzopyr + dicamba does not generally improve Russian knapweed control at 12 or 24 MAT with either standard or reduced rates of typical fall, auxinic herbicide treatments.

Nomenclature: 2,4-D amine; aminopyralid; clopyralid; dicamba; diflufenzopyr; picloram; triclopyr; Russian knapweed, *Acroptilon repens* (L.) DC. ACRRE.

Key words: Auxin synergist, invasive forb, creeping perennial, pasture, wildland.

Long-term control or suppression of invasive plants is one of the main goals of land managers. However, many deeply rooted herbaceous perennials make this difficult because of regrowth from creeping lateral roots in years following control. Adaptive management using integrated techniques, such as reseeding, intensive grazing, and biological control, is difficult to implement for many land managers who have limited resources to deal with overwhelmingly large problems. For example, in Wyoming and other western states, many county weed supervisors are often responsible for weed control on hundreds of thousands of acres and are only able to visit most weed infestations 1 d/yr (L. Baker, personal communication). This is due to several factors, including limited budgets, prioritization of resources to other areas, remoteness of infestations, and large numbers of sites to manage. Given these limitations, many land managers apply components of the wildfire paradigm (Dewey et al. 1995) by containing remote infestations with annual or biennial herbicide treatments to prevent additional spread until new technologies allow for more integrated approaches. Improvements in current herbicide technologies or strategies, such as herbicide combinations that provide additive or synergistic weed control, would be beneficial in these situations.

Diflufenzopyr is a synergist initially developed for use with dicamba for control of many broadleaf weeds in corn (*Zea mays* L.)(Bowe et al. 1999; Franssen and Kells 2007). In turf, diflufenzopyr has also been shown to synergize fluroxypyr for control of Virginia buttonweed (*Diodia virginiana* L.)(Ni et al. 2006).

Few diflufenzopyr studies have been conducted on invasive plants in range and pasture settings. In a study evaluating the effect of diflufenzopyr on control of leafy spurge (*Euphorbia esula* L.) and Canada thistle [*Cirsium arvense* (L.) Scop.], Lym and Diebert (2005) found that the effect of diflufenzopyr was dependent on both the auxin

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Interpretive Summary

Russian knapweed is a Eurasian creeping forb that has invaded more than 485,000 ha (1 million acres) in the western United States. Diflufenzopyr is an auxin synergist that is available for use in a premix with dicamba. We tested the diflufenzopyr + dicamba premix with aminopyralid, clopyralid, clopyralid + 2,4-D, clopyralid + triclopyr, and picloram for Russian knapweed control with fall (September) treatments. At 12 and 24 mo after treatment (MAT), diflufenzopyr + dicamba did not improve Russian knapweed control with any of the herbicides tested when they were applied at standard rates. All herbicides tested at standard rates controlled ≥ 96% Russian knapweed at 12 MAT, and all herbicides, except clopyralid + 2,4-D, controlled ≥ 80% Russian knapweed at 24 MAT. Additionally, diflufenzopyr + dicamba did not improve Russian knapweed control at 12 MAT with any herbicides tested at reduced rates because all herbicides controlled ≥ 80% Russian knapweed at 12 MAT. At 24 MAT, Russian knapweed control was improved with the reduced rate of aminopyralid from 58 to 83% with the addition of diflufenzopyr + dicamba. However, diflufenzopyr + dicamba did not increase Russian knapweed control with any of the other reduced rate herbicides. These studies indicate that the addition of diflufenzopyr + dicamba to auxinic herbicides does not improve Russian knapweed control at either 12 or 24 MAT, with the exception of the reduced rate of aminopyralid.

herbicide and the plant species. This work established the need for additional research on other species and herbicides to determine specifically where diflufenzopyr might be useful. To our knowledge, no additional peer-reviewed studies have been published testing diflufenzopyr combinations on other invasive plants. Currently, diflufenzopyr is not labeled as a stand-alone product and is only available for use in corn and in noncrop sites, pasture, hay, and rangeland in a premix with dicamba. However, this premix is labeled as a viable tank-mix partner with several auxin-type herbicides without specific rates for those herbicides (Anonymous 2004). As a stand-alone material, the diflufenzopyr + dicamba premix is not effective on creeping perennials, such as Canada thistle, when applied at 0.08 + 0.2 kg ai/ha (Enloe et al. 2007) or Carolina horsenettle (*Solanum carolinense* L.) when applied at 0.06 + 0.16 kg ai/ha (Whaley and VanGessel 2002).

Among deep-rooted, creeping, perennial, invasive plants, Russian knapweed [*Acroptilon repens* (L.) DC.] is one of the most problematic species that many land managers face, having invaded more than 485,633 ha (1.2 million ac) in the western United States (Duncan and Jachetta 2005). Because the herbicides used for Russian knapweed control are almost exclusively auxin-type herbicides, it is useful to determine whether diflufenzopyr + dicamba can improve long-term control of Russian knapweed. Therefore, our objective was to determine the influence of diflufenzopyr + dicamba when tank-mixed with standard and reduced rates of commonly used auxin-type herbicides for Russian knapweed control. Based on previous research, we hypothesized that the addition of diflufenzopyr + dicamba to auxinic herbicides at standard and reduced rates would improve long-term control of Russian knapweed.

Materials and Methods

Studies were conducted near Ethete, WY, from 2005 to 2008, in a pasture heavily infested with Russian knapweed. The soil is a Forkwood fine-loamy mixed, superactive, mesic Ustic Haplargid. Annual precipitation is 334 mm, and the mean annual temperature is 7.1 C. The pasture had been heavily grazed for several years. Other species found in the understory of the knapweed pasture included hoary cress [*Cardaria draba* (L.) Desv.], quackgrass [*Elymus repens* (L.) Gould], and field bindweed (*Convolvulus arvensis* L.). Almost no desirable forage grasses were present. Treatments were broadcast-applied with a CO_2-pressurized backpack-boom sprayer, delivering a total application volume of 187 L/ha (20 gal/ac) at 276 kPa. Plot size was 3 by 9 m (10 by 30 ft). Treatments were applied in early to mid-September following the first frost. At that time, Russian knapweed had set seed, plants were still green, and new rosettes were beginning to emerge. Additionally, knapweed vertical roots had numerous new adventitious buds beginning to emerge from the top 15 cm below the crown. Treatments included difluzenzopyr[1] + dicamba (0.056 + 0.14 kg ai/ha [4 oz/ac]) alone, standard rates of aminopyralid[2] (0.12 kg/ha [7 fl oz/ac]), picloram[3] (0.56 kg/ha [32 fl oz/ac]), clopyralid[4] (0.55 kg/ha [21 fl oz/ac]), clopyralid + 2,4-D[5] (0.32 + 1.68 kg/ha [96 fl oz/ac]), and clopyralid + triclopyr[6] (0.42 + 1.26 kg/ha [64 fl oz/ac]), and reduced (one-half standard) rates of each herbicide alone and mixed with diflufenzopyr + dicamba. Only the reduced rate of aminopyralid was slightly less (0.05 kg/ha) than one-half of the standard rate (0.12 kg/ha). The first experiment was initiated in 2005 and the second in 2006. Russian knapweed control was visually evaluated 12 and 24 mo after treatment (MAT). Visual evaluations were made by comparing treated plots to nontreated controls using a rating scale of 0% (no control) to 100% (complete absence of living Russian knapweed shoots).

Statistical Analyses. The experimental design was a randomized complete block with four replications in each experiment (2005 and 2006). Visual control evaluations were arcsine square root–transformed before analysis. Data from standard and reduced rate herbicide treatments were analyzed separately using ANOVA because of a significant rate by diflufenzopyr + dicamba interaction. Fixed effects for the analysis included experimental run, block within experimental run, herbicide treatment, presence of diflufenzopyr + dicamba, and interactions between fixed effects. Interaction terms that included block within experimental

Table 1. Partial ANOVA and significant treatment means for control of Russian knapweed 12 and 24 mo after treatment with commercial herbicide rates.[a]

Effect	df	P value 12 MAT	P value 24 MAT
Experiment	1	0.0132	0.3248
Block	3	0.2092	0.6268
Herbicide	4	0.0078	< 0.0001
Experiment × herbicide	4	0.0274	0.0011
Diflu + dicamba	1	0.1223	0.7642
Experiment × diflu + dicamba	1	0.2554	0.5359
Herbicide × diflu + dicamba	4	0.4447	0.4963
Experiment × herbicide × diflu + dicamba	4	0.1862	0.8643

Experiment	Herbicide	Rate	Control[b,c] 12 MAT	Control[b,c] 24 MAT
		kg/ha	%	%
2005	Aminopyralid	0.12	98 a	91 a
	Clopyralid	0.55	99 a	95 a
	Clopyralid + 2,4-D	0.32 + 1.68	96 b	42 b
	Clopyralid + triclopyr	0.42 + 1.26	96 b	88 a
	Picloram	0.56	96 b	95 a
2006	Aminopyralid	0.12	100 a*	95 a
	Clopyralid	0.55	99 a	88 a
	Clopyralid + 2,4-D	0.32 + 1.68	99 a*	82 b*
	Clopyralid + triclopyr	0.42 + 1.26	100 a*	92 a
	Picloram	0.56	99 a*	80 b

[a] Abbreviations: df, degrees of freedom; diflu, diflufenzopyr; MAT, months after treatment.

[b] Means within an experiment and evaluation timing followed by the same letter are not significantly different ($\alpha = 0.05$).

[c] Means in the 2006 experiment followed by an asterisk (*) denote a significant difference ($\alpha = 0.05$) compared with the same herbicide treatment in the 2005 experiment.

run were used as error terms in the model. Fisher's Protected LSD ($P < 0.05$) was used to separate transformed means, where appropriate; however, untransformed means are presented for clarity.

Results and Discussion

Standard Herbicide Rates. Diflufenzopyr + dicamba did not influence Russian knapweed control 12 MAT (Table 1). However, there was a significant experiment by herbicide interaction ($P = 0.0274$). In the 2005 experiment, control ranged from 96 to 99%, with aminopyralid and clopyralid providing slightly better control than the other treatments (Table 1). In the 2006 experiment, all herbicides were equally efficacious, providing 99 to 100% control 12 MAT (Table 1). Although these differences were significant, they were operationally negligible, given that all treatments provided excellent control. Additionally, the high levels of control precluded any detectable influence of diflufenzopyr + dicamba, which could explain why its effect was not significant in the analysis.

Similarly, at 24 MAT, diflufenzopyr + dicamba did not influence Russian knapweed control with any other herbicide tested (Table 1), and the experiment by herbicide interaction was again significant ($P = 0.0011$). In the 2005 experiment, aminopyralid, clopyralid, clopyralid + triclopyr, and picloram provided 88 to 95% control at 24 MAT, whereas clopyralid + 2,4-D controlled only 42% of the Russian knapweed (Table 1). In the 2006 experiment, aminopyralid, clopyralid, and clopyralid + triclopyr controlled 88 to 95% of Russian knapweed, whereas picloram and clopyralid + 2,4-D controlled the weed 80 to 82% (Table 1). The experiment by herbicide interaction was likely caused by the large difference in clopyralid + 2,4-D efficacy between the 2005 and 2006 experiments. This variability in long-term control is not unexpected because

Table 2. Partial ANOVA and significant treatment means for control of Russian knapweed 12 mo after treatment with reduced herbicide rates.[a]

Effect		df	P value
Experiment		1	0.0133
Block		3	0.7274
Herbicide		4	0.0005
Experiment × herbicide		4	0.2206
Diflu + dicamba		1	0.2077
Experiment × diflu + dicamba		1	0.5042
Herbicide × diflu + dicamba		4	0.1698
Experiment × herbicide × diflu + dicamba		4	0.4013
Experiment		Control[b]	
		%	
2005		82 a	
2006		96 b	
Herbicide	Rate	Control[b]	
	kg/ha	%	
Aminopyralid	0.05	93 a	
Clopyralid	0.28	96 a	
Clopyralid + 2,4-D	0.16 + 0.84	80 b	
Clopyralid + triclopyr	0.21 + 0.63	83 b	
Picloram	0.28	94 a	

[a] Abbreviations: df, degrees of freedom; diflu, diflufenzopyr.

[b] Means followed by the same letter are not significantly different (α = 0.05).

clopyralid + 2,4-D has provided inconsistent control of Russian knapweed (Anonymous 2008). These results demonstrate that the addition of diflufenzopyr + dicamba at 0.056 + 0.14 kg/ha to standard rates of several auxinic herbicides did not improve Russian knapweed control at either 12 or 24 MAT with fall (September) applications.

Reduced Herbicide Rates. Diflufenzopyr + dicamba with reduced rates of any of the herbicides tested did not affect Russian knapweed control 12 MAT (Table 2). However, there were differences among experiment (P = 0.0133) and herbicide (P = 0.0005) main effects. Averaged across herbicides, at 12 MAT, Russian knapweed control was significantly better in the 2006 experiment (96%) than the 2005 experiment (82%). Across both experiments at 12 MAT, aminopyralid, clopyralid, and picloram controlled 93 to 96% of Russian knapweed and were significantly better than clopyralid + 2,4-D and clopyralid + triclopyr, which controlled 80 and 83% of Russian knapweed, respectively (Table 2).

At 24 MAT, the interaction between herbicide treatment and diflufenzopyr + dicamba was significant (P = 0.0373; Table 3). Aminopyralid applied at 0.05 kg/ha controlled Russian knapweed 83% when applied with diflufenzopyr + dicamba and only 58% when applied alone (Table 3). Russian knapweed control with all other herbicides, except picloram, ranged from 40 to 70% and was not improved when diflufenzopyr + dicamba was added (Table 3). Picloram at the reduced rate of 0.28 kg/ha controlled 85 and 84% of Russian knapweed with and without diflufenzopyr + dicamba, respectively.

Variation in herbicide efficacy increased with the reduced herbicide rates at 24 MAT (Table 3). For example, aminopyralid at 0.05 kg/ha controlled Russian knapweed 84% at 24 MAT in the 2005 experiment but only controlled it 58% in the 2006 experiment. The 2006 experiment is comparable to findings by Enloe et al. (2008) in which aminopyralid applied at 0.05 kg/ha controlled 63% Russian knapweed 24 MAT at multiple locations across the western United States. Clopyralid + 2,4-D was also highly variable controlling 30 and 60% of Russian knapweed in the 2005 and 2006 experiments, respectively. With the exception of picloram, the other herbicide treatments were also quite variable. Picloram at 0.28 kg/ha controlled 88 and 81% Russian knapweed in the 2005 and 2006 experiments, respectively.

Contrary to our hypothesis, these experiments demonstrated that diflufenzopyr + dicamba applied at the rate of 0.056 +0.14 kg/ha did not strongly influence auxinic herbicides for Russian knapweed control at 12 and 24 MAT. The only exception was aminopyralid at the reduced rate of 0.05 kg/ha at 24 MAT. Although the increase in control with diflufenzopyr + dicamba added to aminopyralid is significant, the economics of reducing the aminopyralid rate and adding dicamba + diflufenzopyr need to be evaluated. However, an economic analysis was not performed for these experiments. Additional research with a broader range of rates of aminopyralid, with and without diflufenzopyr + dicamba, would help to further elucidate the interaction between those herbicides.

Sources of Materials

[1] Diflufenzopyr + dicamba, Overdrive, BASF, Research Triangle Park, NC 27709.

[2] Aminopyralid, Milestone, Dow AgroSciences, Indianapolis, IN 46268.

[3] Picloram, Tordon, Dow AgroSciences, Indianapolis, IN 46268.

[4] Clopyralid, Transline, Dow AgroSciences, Indianapolis, IN 46268.

[5] Clopyralid + 2,4-D, Curtail, Dow AgroSciences, Indianapolis, IN 46268.

[6] Clopyralid + triclopyr, Redeem, Dow AgroSciences, Indianapolis, IN 46268.

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Table 3. Partial ANOVA and significant treatment means for control of Russian knapweed 24 mo after treatment with reduced herbicide rates.[a]

Effect	df	P value
Experiment	1	0.5526
Block	3	0.9822
Herbicide	4	0.0009
Experiment × herbicide	4	0.0232
Diflu + dicamba	1	0.7076
Experiment × diflu + dicamba	1	0.2146
Herbicide × diflu + dicamba	4	0.0373
Experiment × herbicide × diflu + dicamba	4	0.0823

Experiment	Herbicide	Rate	Control[b]
		kg/ha	%
2005	Aminopyralid	0.05	84 a
	Clopyralid	0.28	76 a
	Clopyralid + 2,4-D	0.16 + 0.84	30 b
	Clopyralid + triclopyr	0.21 + 0.63	66 a
	Picloram	0.28	88 a
2006	Aminopyralid	0.05	58 ab
	Clopyralid	0.28	57 ab
	Clopyralid + 2,4-D	0.16 + 0.84	60 ab
	Clopyralid + triclopyr	0.21 + 0.63	49 b
	Picloram	0.28	81 a

Herbicide	Rate	Diflufenzopyr + dicamba rate	Control[c]
	kg/ha	kg/ha	%
Aminopyralid	0.05	0 + 0	58
		0.14 + 0.056	83*
Clopyralid	0.28	0 + 0	64
		0.14 + 0.056	70
Clopyralid + 2,4-D	0.16 + 0.84	0 + 0	50
		0.14 + 0.056	40
Clopyralid + triclopyr	0.21 + 0.63	0 + 0	65
		0.14 + 0.056	51
Picloram	0.28	0 + 0	84
		0.14 + 0.056	85

[a] Abbreviations: df, degrees of freedom; diflu, diflufenzopyr.

[b] Means within an experiment followed by the same letter are not significantly different ($\alpha = 0.05$).

[c] Means followed by an asterisk (*) denote a significant difference ($\alpha = 0.05$) compared with the same herbicide treatment without diflufenzopyr + dicamba.

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