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# Influence of Diflufenzopyr Addition to Picolinic Acid Herbicides for Russian Knapweed (*Acroptilon repens*) Control

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Diflufenzopyr is a synergist that has improved the efficacy of certain auxin-type herbicides such as dicamba on many broadleaf weed species. However, little is known regarding the activity of diflufenzopyr with other auxin-type herbicides. Russian knapweed is an invasive creeping perennial that is susceptible to certain pyridine carboxylic acids, which are auxin-type herbicides. The objective of this research was to determine if the addition of diflufenzopyr to three pyridine carboxylic acid herbicides enhances long-term control of Russian knapweed in Wyoming. All treatments were applied in the fall. Treatments included aminopyralid (0, 0.05, 0.09, and 0.12 kg ae/ha), clopyralid (0, 0.16, 0.21, 0.31, and 0.42 kg ae/ha) and picloram (0, 0.14, 0.28, 0.42, and 0.56 kg ae/ha), applied with and without diflufenzopyr (0.06 and 0.11 kg ae/ha). Twelve mo after treatment (MAT), diflufenzopyr had no significant impact on Russian knapweed control with either aminopyralid or picloram, and had significant but inconsistent impacts on knapweed control with clopyralid. At 24 MAT, diflufenzopyr did not enhance Russian knapweed control with either aminopyralid or clopyralid and was slightly antagonistic with picloram. These results indicate that the addition of diflufenzopyr does not improve Russian knapweed control with fall applications of either aminopyralid, clopyralid, or picloram.

**Nomenclature:** Aminopyralid; clopyralid; dicamba; diflufenzopyr; picloram; Russian knapweed, *Acroptilon repens* (L.) DC. ACRRE.

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

Diflufenzopyr is an auxin transport inhibitor that improves activity of certain auxin-type herbicides on many broadleaf weeds (Bowe et al. 1999; Grossman et al. 2002). Grossman et al. (2002) reported that diflufenzopyr enhanced picloram activity on redroot pigweed (*Amaranthus retroflexus* L.). Ni et al. (2006) reported that diflufenzopyr improved control of the creeping perennial Virginia buttonweed (*Diodia virginiana* L.) with fluroxypyr by nearly 40% compared to fluroxypyr alone. Wehtje (2008) reported synergistic control of purple cudweed [*Gnaphalium purpureum* L.; reclassified as *Gamochaeta purpurea* (L.) Cabrera] and common lespedeza [*Kummerowia striata* (Thunb.) Schindler] with dicamba plus diflufenzopyr. However, the synergism was only expressed within a narrow rate range that was below the registered use rate. In pasture, Boyles and Smith (2000) reported diflufenzopyr applied with dicamba synergized weed control of several pasture species compared to dicamba alone. Lym and Diebert (2005) reported that diflufenzopyr added to either dicamba or quinclorac increased both leafy spurge (*Euphorbia esula* L.) and Canada thistle [*Cirsiium arvense* (L.) Scop.] control. However, diflufenzopyr added to picloram increased activity on leafy spurge but not Canada thistle. These results suggest the response to diflufenzopyr may be both herbicide- and species-specific. Since the Lym and Diebert (2005) study, no other studies have been published on diflufenzopyr interactions with auxin-type herbicides besides dicamba in range and pasture. With regards to diflufenzopyr, a significant data gap exists for many species and auxin-type herbicides.

Aminopyralid, clopyralid, and picloram are widely used for control of invasive plant species in range and pasture. Clopyralid and picloram have been commercial standards for many years (Bussan and Dyer 1999). However, aminopyralid is a relatively new herbicide and has excellent activity on many invasive plant species such as Canada thistle (Enloe et al. 2007), Russian knapweed (Enloe et al. 2008) and tropical soda apple (*Solanum viarum* Dunal) (Ferrell et al. 2006). Given that Russian knapweed control is obtained almost exclusively with auxin-type herbicides, our objective was to determine if the addition of diflufenzopyr improved control of Russian knapweed relative to each herbicide alone. Based upon previous research, it was hypothesized that the addition of diflufenzopyr to aminopyralid, clopyralid, and picloram would improve control of Russian knapweed.

## Materials and Methods

Three separate studies were conducted to assess the influence of diflufenzopyr with aminopyralid, clopyralid, and picloram for controlling Russian knapweed with fall treatments. All studies except one 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 Haplargids. Annual precipitation is 33 cm and the mean annual temperature is 7.1 C. The pasture had been heavily grazed for several years, and almost no desirable forage grasses were present. Treatments were broadcast-applied using a $CO_2$ pressurized backpack boom sprayer at 276 kPa delivering 187 L/ha. Plot size was 3 by 9 m. Treatments were applied in mid-September following the first frost. Russian knapweed plants had set seed but were still green and new rosettes were beginning to emerge. At the time of treatment, examination of several knapweed vertical roots revealed numerous new adventitious buds beginning to emerge from the top 15 cm below the crown. For the first study, treatments included aminopyralid[1] applied at 0, 0.05,

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Table 1. Model parameters and standard errors for the three parameter logistic function (provided in Equation 1) for Figures 1–4.

| | Model parameter | | |
|---|---|---|---|
| | *b* | *d* | *e* |
| Aminopyralid 12 months after treatment (MAT) (Figure 1A) | −9.9 (20.6) | 99 (1) | 0.03 (0.03) |
| Aminopyralid 24 MAT (Figure 1B) | −13.1 (9.0) | 95 (2) | 0.04 (0.01) |
| Clopyralid with diflufenzopyr 12 MAT (Figure 2) | −1.8 (1.7) | 102 (13) | 0.08 (0.03) |
| Clopyralid without diflufenzopyr 12 MAT (Figure 2) | −17.3 (22.4) | 95 (2) | 0.15 (0.01) |
| Clopyralid 24 MAT, 2005 (Figure 3) | −1.3 (1.1) | 109 (432) | 0.94 (4.2) |
| Clopyralid 24 MAT, 2006 (Figure 3) | −4.8 (1.8) | 87 (6) | 0.16 (0.01) |
| Picloram with diflufenzopyr 12 MAT (Figure 4A) | −0.8 (1.3) | 113 (49) | 0.04 (0.02) |
| Picloram without diflufenzopyr 12 MAT (Figure 4A) | −0.2 (0.2) | 176 (119) | 0.22 (1.3) |
| Picloram with diflufenzopyr 24 MAT (Figure 4B) | −0.6 (0.6) | 219 (457) | 1.16 (7.4) |
| Picloram without diflufenzopyr 24 MAT (Figure 4B) | −2 (1.1) | 99 (16) | 0.16 (0.03) |

0.09, and 0.12 kg ae/ha with and without diflufenzopyr[2] applied at 0.06 and 0.11 kg ae/ha. These aminopyralid treatments encompass the labeled rates for Russian knapweed control (0.09 to 0.12 kg/ha) (Anonymous 2008a). For the second study, treatments included clopyralid[3] applied at 0, 0.16, 0.21, 0.31, and 0.42 kg ae/ha with and without diflufenzopyr applied at 0.06 and 0.11 kg/ha. Labeled rates for Russian knapweed control with clopyralid are 0.42 to 0.56 kg/ha (Anonymous 2008b). For the third study, treatments included picloram[4] applied at 0, 0.14, 0.28, 0.42, and 0.56 kg ae/ha with and without diflufenzopyr applied at 0.06 and 0.11 kg/ha. Labeled rates for Russian knapweed control with picloram are 0.28 to 0.56 kg/ha (Anonymous 2009). For all three studies, the rates of diflufenzopyr used are within the labeled rate range of diflufenzopyr when premixed with dicamba (Anonymous 2004). Methylated seed oil[5] was added to all picloram and clopyralid treatments at 2.3 L/ha. Aminopyralid was applied with nonionic surfactant[6] at 0.25% v/v. All three studies were randomized complete block designs with three replicates per treatment. The picloram and clopyralid studies were initiated in 2005 and repeated in 2006 near Ethete, WY. The aminopyralid study was initiated at two locations in 2006: Ethete and Lost Cabin, WY.

Russian knapweed control was visually evaluated 12 and 24 MAT in all studies except the 2006 aminopyralid study conducted at Lost Cabin, WY. At this location, the ranch manager inadvertently hayed the test area just prior to the 24 MAT evaluation timing. However, Russian knapweed stems were still green below the cutting height. To determine treatment impacts, a 0.5 by 4 m quadrat was randomly placed in each plot and all Russian knapweed stems were counted. This data was converted to a percent reduction compared to the non-treated controls in each block. Visual evaluations were made by comparing treated plots to non-treated controls using a rating scale of 0% (no control) to 100% (no living Russian knapweed shoots).

**Statistical Analyses.** Visual assessments of control data were arcsine square-root transformed and subject to ANOVA using the "aov()" function in R[7] (R Development Core Team 2008). Fixed effects for all studies included the experimental run, block within experimental run, herbicide rate, diflufenzopyr rate, and all interactions. Interactions including the block within experimental run effect were used as error terms in the model. Where the main effect of herbicide rate or an interaction with herbicide rate was significant, nonlinear regression was carried out to further evaluate the response. No differences were observed between the 0.06 and 0.11 kg/ha rate of diflufenzopyr, and thus these rates were combined for regression analysis. A three-parameter logistic model of the form

$$f(x) = \frac{d}{1 + \exp\{b[\log(rate) - \log(e)]\}} \qquad [1]$$

was fit to the data where $f(x)$ is the visual control at 12 or 24 MAT, *rate* is the herbicide rate in kg/ha, *b* is the slope around the inflection point, *d* is the horizontal asymptote on the right side, and *e* is the inflection point of the fitted curve. The drc package in R was used to conduct all dose-response analyses (R Development Core Team 2008; Ritz and Streibig 2005). Standard errors of the predicted response for each variable were extracted from the fitted models and plotted. Model parameters and their standard errors are provided in Table 1.

## Results and Discussion

**Aminopyralid.** Experimental run was not significant nor were any interactions with experimental run, so experiments were pooled for analysis. At 12 MAT, diflufenzopyr rate was not significant ($P = 0.62$), nor were any interaction terms containing diflufenzopyr. Aminopyralid rate was significant 12 MAT for Russian knapweed control ($P < 0.0001$) and all rates tested provided greater than 90% control (Figure 1A). The $ED_{90}$ (the dose required for 90% efficiency) calculated for aminopyralid was 0.047 kg/ha. This is substantiated by Enloe et al. 2008, who reported that aminopyralid applied alone at 0.05 kg/ha controlled 90% of Russian knapweed 12 MAT. At 24 MAT, the effect of diflufenzopyr was not significant ($P = 0.61$), nor were any of the interaction terms. Aminopyralid rate was again significant ($P < 0.0001$) as all rates tested provided greater than 90% control (Figure 1B). An $ED_{90}$ of 0.05 kg/ha was calculated for 24 MAT and was similar to Enloe et al. (2007), who reported that 0.05 kg/ha provided 83% control of Russian knapweed. The high level of control at the lowest aminopyralid rate tested left little room for potential positive interaction with diflufenzopyr, so it is not surprising that diflufenzopyr was not significant in the model. When this research was initiated in 2005, aminopyralid data for Russian knapweed control 24 MAT was not

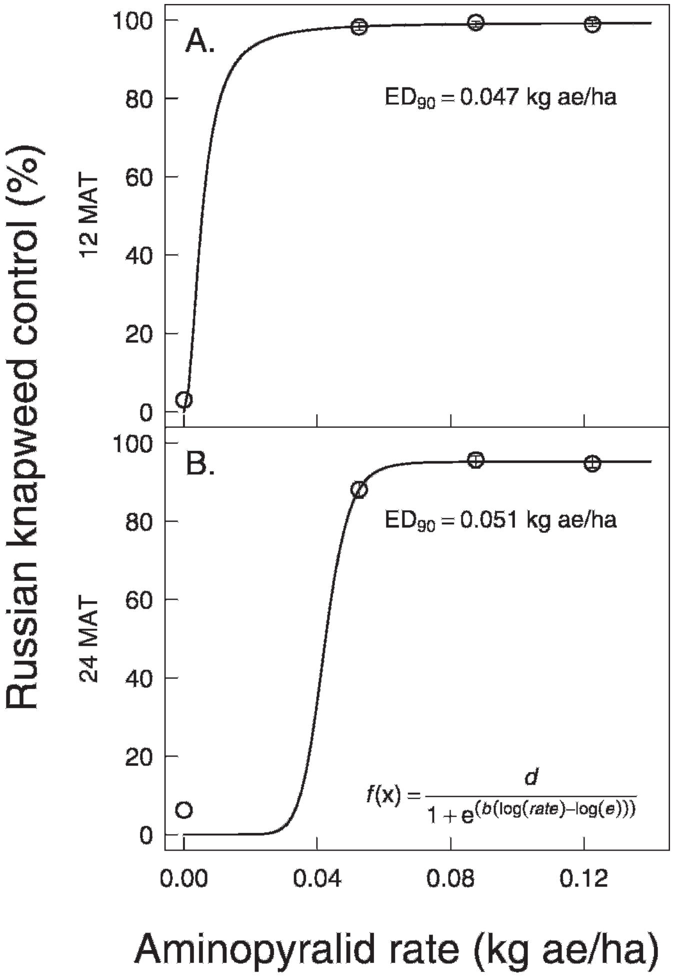

Figure 1. (A) Response of Russian knapweed to aminopyralid 12 mo after treatment (MAT). (B) Response of Russian knapweed to aminopyralid 24 MAT. For A and B, data were pooled across diflufenzopyr rates and experimental runs. Model parameters are reported in Table 1.

available and the low rates used in this study were not expected to be this effective long-term. Further aminopyralid + diflufenzopyr studies should focus on rates well below 0.05 kg/ha, where long-term Russian knapweed control with aminopyralid is now known to be poor. Enloe et al. (2008) found that aminopyralid applied at 0.02 and 0.04 kg/ha controlled 41 and 66% of Russian knapweed, respectively, at 21 MAT. However, it is clear that diflufenzopyr does not improve fall Russian knapweed control up to 24 MAT with aminopyralid rates ≥ 0.05 kg/ha.

**Clopyralid.** No effect of experimental run was observed 12 MAT, so data were pooled for analysis. The clopyralid-by-diflufenzopyr interaction was significant at 12 MAT ($P = 0.001$). The interaction was driven by a slight increase in control when clopyralid was applied alone; at 0.21 kg/ha it provided better control than clopyralid + diflufenzopyr (Figure 2). For all other clopyralid rates, the addition of diflufenzopyr had little impact on Russian knapweed control. At 24 MAT, the clopyralid by diflufenzopyr rate was no longer significant ($P = 0.5960$). However, the experimental run by clopyralid interaction was highly significant ($P = 0.0009$). In the 2005 study, all levels of clopyralid failed, and control was less than 40% even at the highest rate (Figure 3). In the 2006 study, clopyralid at the two highest rates (0.31 and 0.42 kg/ha) controlled Russian knapweed > 80% at 24 MAT. Clopyralid applied at 0.16 and 0.21 kg/ha controlled Russian knapweed at approximately 40 and 70%, respectively (Figure 3). The inconsistency of clopyralid at 24 MAT across both studies is not easily explained. Neither precipitation patterns across study years (data not shown) nor knapweed condition at the time of treatment appeared responsible for the differences in the two studies. At 12 MAT the two studies were similar in Russian knapweed control (study by herbicide interaction effect, $P = 0.719$) and better than previously published work. Clopyralid efficacy at 24 MAT in these two studies bracket the results of Enloe et al. (2007), who reported clopyralid applied at 0.42 kg/ha controlled 67% of Russian knapweed 21 MAT. Despite the differences, difluzenzopyr did not provide any consistent positive response when added to clopyralid in either study at either 12 or 24 MAT.

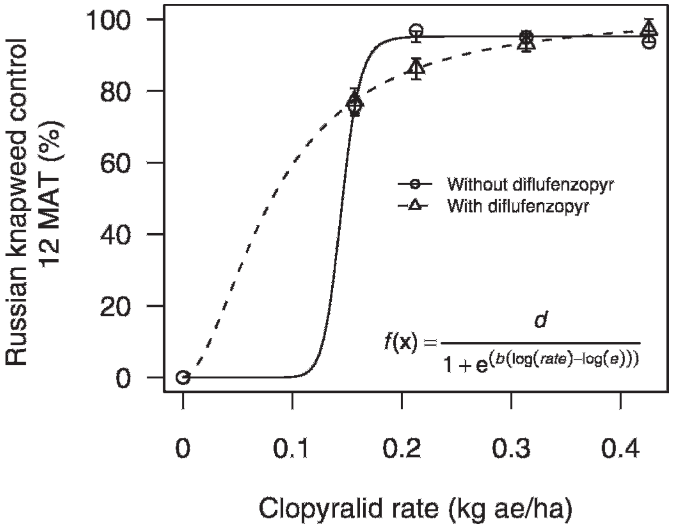

Figure 2. Response of Russian knapweed to clopyralid 12 mo after treatment (MAT) with and without diflufenzopyr. Data were pooled across experimental runs. Model parameters are reported in Table 1.

**Picloram.** Experimental run was not significant, nor were any interactions with experimental run, so data were pooled for further analysis. The picloram-by-diflufenzopyr interaction was significant ($P = 0.0005$) at 12 MAT. This interaction was likely driven by a slight reduction in control when picloram was applied at 0.28 kg/ha without diflufenzopyr (Figure 4A). However, a concomitant increase in control with diflufenzopyr was not observed at either the lower (0.14) or higher (0.42 kg/ha) rate, which made the interaction somewhat questionable. Picloram applied at 0.42 and 0.56 kg/ha, with and without diflufenzopyr, controlled Russian knapweed greater than 95% 12 MAT. Picloram applied alone at 0.14 kg/ha controlled Russian knapweed 80 to 85% at 12 MAT.

The picloram-by-diflufenzopyr interaction was significant ($P = 0.0001$) at 24 MAT. However, control was slightly

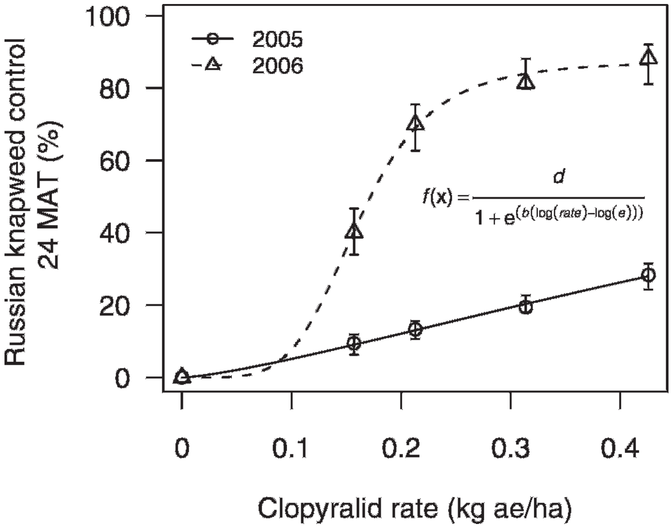

Figure 3. Response of Russian knapweed to clopyralid 24 mo after treatment (MAT) in two field trials initiated in 2005 and 2006, respectively. Data were pooled across diflufenzopyr rates. Model parameters are reported in Table 1.

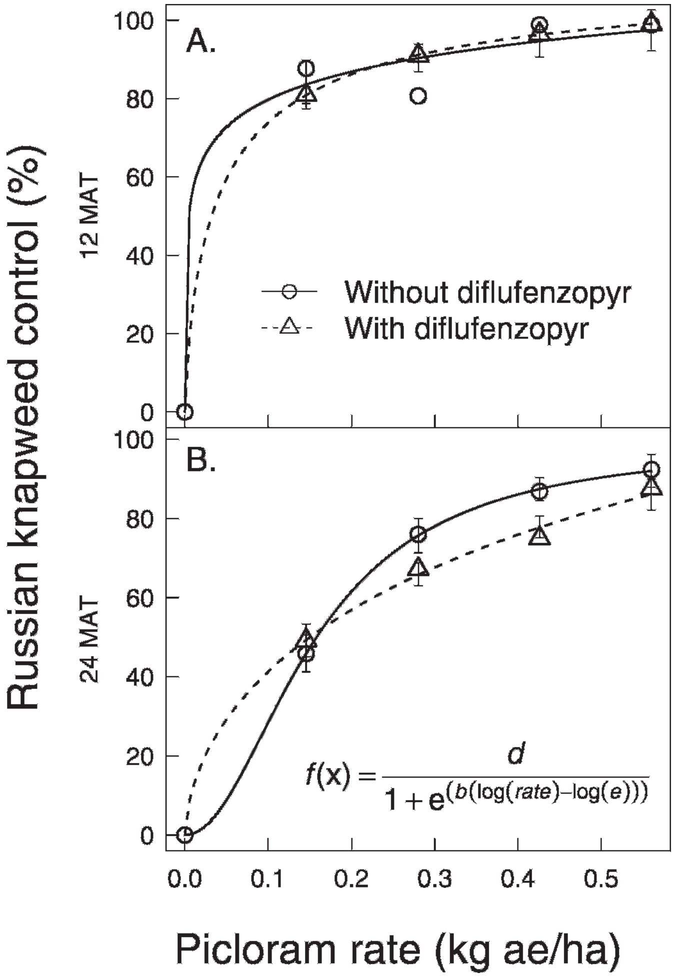

Figure 4. (A) Response of Russian knapweed to picloram 12 mo after treatment (MAT) with and without diflufenzopyr. (B) Response of Russian knapweed to picloram 24 MAT with and without diflufenzopyr. For A and B, data are pooled across experimental runs. Model parameters are reported in Table 1.

lower with diflufenzopyr than without at the three highest picloram rates (i.e., 0.28, 0.42, and 0.56 kg/ha), and was similar at the low rate (0.14 kg/ha, Figure 4B). Russian knapweed control in this study at 0.56 kg/ha was comparable to Enloe et al. (2007) at both 12 and 24 MAT. For an auxin synergist, this is the first known report of an antagonistic interaction with any auxin-type herbicide. However, Lym and Deibert (2005) reported that diflufenzopyr added to glyphosate resulted in antagonism of leafy spurge control compared to glyphosate alone.

These field studies indicate that diflufenzopyr does not improve Russian knapweed control when added to fall treatments of commercial standards. These studies are also similar to recent research that determined that dicamba + diflufenzopyr applied at 0.14 + 0.06 kg/ha did not improve Russian knapweed control 12 and 24 MAT when tank mixed with commercial rates of aminopyralid, clopyralid, picloram, clopyralid + 2,4-D, or clopyralid + triclopyr (S. F. Enloe and A. R. Kniss, unpublished data). Research presented in this paper is also the first reported study of diflufenzopyr applied without dicamba for weed control for both semiarid conditions and fall applications. These results warrant further investigation to determine if diflufenzopyr function is affected either by environmental conditions or timing of application.

## Sources of Materials

[1] Aminopyralid, Milestone®, Dow AgroSciences, Indianapolis, IN 46268.

[2] Diflufenzopyr, BASF Corp., Research Triangle Park, NC 27709.

[3] Clopyralid, Transline®, Dow AgroSciences, Indianapolis, IN 46268.

[4] Picloram, Tordon® 22K, Dow AgroSciences, Indianapolis, IN 46268.

[5] Methylated seed oil, Helena Chemical Company, Collierville, TN 38017.

[6] Activator 90, Loveland Products Inc. Greeley, CO 80631.

[7] R Development Core Team. 2008. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. URL: http://www.R-project.org.

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