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Native Forb Response to Aminocyclopyrachlor

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Abstract

Native forbs are an essential component in the functioning and diversity of prairie communities. Aminocyclopyrachlor (AMCP) will effectively control many noxious weeds that invade prairie communities; however, its efficacy on desirable broadleaf plants is relatively unknown. Few field studies have been reported, and locating adequate populations of native forbs for evaluation of tolerance to herbicides is difficult. The susceptibility of 10 prairie forb species to AMCP was evaluated in the greenhouse. Species were chosen to correlate with a field study of AMCP and a previous greenhouse experiment. AMCP was applied at 0, 35, 70, and 105 g ha^{-1} with a methylated seed oil (MSO) plus silicone-based non-ionic surfactant (NIS) blend at 0.25% v/v when plants reached the growth stage simulating a spring treatment for weed control. Blueflag iris (*Iris versicolor* L.) and harebell (*Campanula rotundifolia* L.) were relatively tolerant and would likely be unharmed following an application of AMCP in the field. Wild licorice (*Glycyrrhiza lepidota* Pursh), prairie wild rose (*Rosa arkansana* Porter), purple prairie clover (*Dalea purpurea* Vent.), and wild bergamot (*Monarda fistulosa* L.) were moderately susceptible to AMCP; however, plants might regrow in the field, since some survived at the highest AMCP application rate (105 g ha^{-1}) evaluated. Skyblue aster [*Symphyotrichum oolentangiense* (Riddell) G. L. Nesom], Canada goldenrod (*Solidago canadensis* L.), blue cardinal-flower (*Lobelia siphilitica* L.), and blacksamson echinacea (*Echinacea angustifolia* DC.) were susceptible to AMCP even when applied at 35 g ha^{-1}. The susceptibility of greenhouse-grown forbs to AMCP was the same or similar to species evaluated in the field and can be used to predict native forb tolerance in the field.

Introduction

Aminocyclopyrachlor (AMCP) controls many noxious and invasive broadleaf weeds such as Canada thistle [*Cirsium arvense* (L.) Scop.], field bindweed (*Convolvulus arvensis* L.) (Lindenmayer et al. 2012), Russian knapweed [*Rhaponticum repens* (L.) Hidalgo] (Lindenmayer et al. 2010), leafy spurge (*Euphorbia esula* L.), perennial sowthistle (*Sonchus arvensis* L.) (Lym 2010), prickly lettuce (*Lactuca serriola* L.) (Bell et al. 2011), houndstongue (*Cynoglossum officinale* L.), absinth wormwood (*Artemisia absinthium* L.), and yellow toadflax (*Linaria vulgaris* Mill.) (Conklin and Lym 2012). AMCP has moderate to long soil residual, which reduces reinfestation from targeted weeds. AMCP time to 50% dissipation (DT_{50}) averaged 20 d in four different soil types from the Northern Great Plains, with the longest DT_{50} of >112 d found in cool, dry, low organic matter soil (Conklin and Lym 2013).

The wide spectrum of weed control and soil residual from AMCP can have negative effects on non-target species (Hergert et al. 2015). AMCP reduced most of the 16 forbs observed in Colorado by Sebastian et al. (2012) in both density and richness. Smooth white aster [*Symphyotrichum porter* (A. Gray) G. L. Nesom] and heath aster [*Symphyotrichum ericoides* (L.) G. L. Nesom] were completely eliminated. Sagebrush (*Artemisia* spp.) and flax (*Linum* spp.) species density was reduced by 74% following AMCP application in Wyoming (Hergert et al. 2015). In a separate Wyoming study, forb cover was reduced but grass cover increased from 56% to 91% (Greet et al. 2016). In Colorado, shrub density was decreased by 45% to 76% and richness by 20% to 50%, depending on application rate (Sebastian et al. 2012).

AMCP decreased total foliar cover, species richness, evenness, and diversity in treated communities compared with nontreated in native prairie sites found in Minnesota and North Dakota (Thilmony and Lym 2017). High seral forb cover was reduced from 19.8% to 2.9% in North Dakota and 18.5% to 2% in Minnesota 14 mo after treatment (MAT) with AMCP at 140 g ha^{-1} (2 oz acre^{-1}).

Native forbs are an essential component of prairie communities. Floristically diverse plant communities, including more than 200 species of plants, with a majority being forbs, were once commonly found in the tallgrass prairie ecosystems of the Northern Great Plains (Beran et al. 1999; Jordan et al. 1988; Weaver 1954). Native forbs increase diversity

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Management Implications

Native forbs are an essential component of prairie communities. Floristically diverse plant communities, including more than 200 species of plants, with a majority being forbs, were once commonly found in the tallgrass prairie ecosystems of the Northern Great Plains. Invasion by noxious weeds has become a major threat to the biodiversity and ecosystem sustainability in remnant and restored prairies. Aminocyclopyrachlor (AMCP) will control many noxious and invasive broadleaf weeds and has moderate to long soil residual. The wide spectrum of weed control and soil residual from aminocyclopyrachlor can have negative effects on non-target species. Data from field evaluations are important to determine which forbs may be damaged by AMCP. However, locating adequate populations of native forbs to evaluate tolerance to herbicide applications is often difficult. A greenhouse study evaluated tolerance of 10 native prairie forbs to spring-applied AMCP. Blueflag iris (*Iris versicolor* L.) and harebell (*Campanula rotundifolia* L.) were relatively tolerant and would likely be unharmed following an application of AMCP in the field. Wild licorice (*Glycyrrhiza lepidota* Pursh), prairie wild rose (*Rosa arkansana* Porter), purple prairie clover (*Dalea purpurea* Vent.), and wild bergamot (*Monarda fistulosa* L.) were moderately susceptible to AMCP; however, plants might regrow in the field, since some survived at the highest AMCP application rate (105 g ha^{-1}) evaluated. Skyblue aster [*Symphyotrichum oolentangiense* (Riddell) G. L. Nesom], Canada goldenrod (*Solidago canadensis* L.), blue cardinal-flower (*Lobelia siphilitica* L.), and blacksamson echinacea (*Echinacea angustifolia* DC.) were susceptible to AMCP even when applied at 35 g ha^{-1}. The susceptibility of greenhouse-grown forbs to AMCP was the same or similar to species evaluated in the field with no instance of contradictory findings. Thus, these data could be used to estimate tolerance to AMCP of forb species that have not been tested in the field. Land managers need to consider both the susceptibility of the target weed and the potential of injury to desirable plant species when choosing which herbicide to apply and at what rate and timing of application to maximize weed control and minimize non-target plant injury.

(Hooper et al. 2005), provide cover and seed for wildlife, require low maintenance, and increase aesthetic attributes.

Data from field evaluations are important to determine which forbs may be damaged by AMCP application to control weeds. However, locating adequate populations of native forbs in close proximity to evaluate herbicide tolerance is often difficult. The purpose of this research was to determine the susceptibility of native prairie forb species to AMCP under greenhouse conditions. Forb species selected in this study were from families that are difficult to evaluate in the field because of their rarity or tendency to grow singularly in the wild. Representatives of commonly found native prairie plants were also included so results could be compared with field trials. Greenhouse trials are often a more rapid and cost-effective alternative to field trials, especially for evaluation of relatively rare or low-abundance forbs.

Materials and Methods

Ten native forb species were evaluated for susceptibility to AMCP in greenhouse trials. Species included were wild licorice (*Glycyrrhiza lepidota* Pursh), skyblue aster [*Symphyotrichum oolentangiense* (Riddell) G.L. Nesom], blueflag iris (*Iris versicolor* L.), Canada goldenrod (*Solidago canadensis* L.), blue cardinal-flower (*Lobelia siphilitica* L.), harebell (*Campanula rotundifolia* L.), prairie rose (*Rosa arkansana* Porter), blacksamson echinacea (*Echinacea angustifolia* DC.), purple prairie clover (*Dalea purpurea* Vent.), and wild bergamot (*Monarda fistulosa* L.). These species were chosen either because populations were too sparse to adequately evaluate in the field or so that results could be compared with a field study of AMCP applied to forbs (Thilmony and Lym 2017).

Prairie forbs were either purchased from a nursery (Prairie Restorations, Princeton, MN) in August 2014 or 2015 or grown from seed or root from local collections. The forbs were then transplanted into cone-tainers (6.3-cm diameter by 25-cm deep [2.5 by 9.8 in]; Deepots^{TM}, Stuewe & Sons, Tangent, OR) with a blend of commercial mix (Sunshine Mix No. 1, patented formulation with wetting agents; Sun Gro Horticulture, Agawam, MA) and sandy loam soil (4:1 by volume). Plants were grown for 4 to 8 wk in a greenhouse at a maintained temperature of ~24 C (75 F) with a 16-h photoperiod of natural and supplemental light using metal-halide lamps with an intensity of 450 $\mu E\ m^{-2}\ s^{-1}$. Plants were watered as needed and fertilized with a diluted 20-20-20 nutrient solution (Jack's All Purpose Water Soluble Plant Food, JR Peters, Allentown, PA) one to two times before treatment. Imidacloprid was applied at 5 mg ai (0.00017 oz) per cone-tainer to *G. lepidota*, *S. oolentangiense*, *L. siphilitica*, *C. rotundifolia*, and *R. arkansana* to control mealybugs [*Pseudococcus longispinus* (Targioni Tozzetti)], aphids [*Myzus persicae* (Sulzer)], and spider mites (*Tetranychus urticae* Koch).

AMCP was applied when plants reached the late-spring growth stage to simulate a spring treatment for weed control (Table 1). Plants were spaced apart for treatment to maximize spray coverage. AMCP at 0, 35, 70, and 105 g ha^{-1} (0, 0.5, 1, and 1.5 oz $acre^{-1}$) was applied with an air-pressurized cabinet-type sprayer equipped with an 80015 nozzle, delivering 160 L ha^{-1} (17 gal $acre^{-1}$) at 240 kPa (35 psi). All herbicide treatments were applied with an MSO plus silicone-based NIS blend (Dyne-Amic®, Helena Chemical, Collierville, TN) at 0.25% v/v to maximize potential injury.

Visual evaluations for plant response, such as epinasty, leaf cupping, and reduced height compared with untreated plants, were recorded 2 wk after treatment (WAT) on a scale of 0% to 100% (0 = no effect; 100 = all visible material dead). The top growth was then removed 3 cm above the soil surface and discarded. Plants were then allowed to regrow for 8 to 12 wk, dependent on species, in the same greenhouse conditions as previously described. After the regrowth period, injury was visually estimated, and plant material was harvested, dried at 50 C for 96 h, and weighed to estimate the effect of AMCP on plant production.

The experiment was a randomized complete-block design with four replicates and was repeated. Each species was analyzed as an individual experiment. Plant injury ratings and regrowth weights were assessed using the PROC GLM procedure of SAS to determine differences in injury among application rates. Mean separations were tested using F-protected LSD ($P = 0.05$), and homogeneity of variance was assessed using error mean squares from each run. A combined analysis was performed when error mean squares differed by less than a factor of 10. Plant susceptibility to AMCP was categorized as tolerant (<20% injury), moderately tolerant (21% to 50% injury), moderately susceptible

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Table 1. Species, family, growth stage, and plant height of forbs when treated with aminocyclopyrachlor in a greenhouse to simulate exposure received during a spring weed control application.

Common name	Scientific name	Family	Growth stage[a]	Height
				–cm–
Wild licorice	*Glycyrrhiza lepidota* Pursh	Fabaceae	VEG	10–25
Skyblue aster	*Symphyotrichum oolentangiense* (Riddell) G. L. Nesom	Asteraceae	VEG	10–15
Blueflag iris	*Iris versicolor* L.	Iridaceae	VEG to FLW	45–55
Canada goldenrod	*Solidago canadensis* L.	Asteraceae	VEG	15–35
Blue cardinal-flower	*Lobelia siphilitica* L.	Campanulaceae	VEG to FLW	10–25
Harebell	*Campanula rotundifolia* L.	Campanulaceae	FLW	15–30
Prairie wild rose	*Rosa arkansana* Porter	Rosaceae	VEG	15–40
Blacksamson echinacea	*Echinacea angustifolia* DC.	Asteraceae	VEG	10–15
Purple prairie clover	*Dalea purpurea* Vent.	Fabaceae	VEG	10–20
Wild bergamot	*Monarda fistulosa* L.	Lamiaceae	VEG	10–15

[a]Abbreviations: FLW, flowering; VEG, vegetative.

(51% to 80% injury), and susceptible (>80% injury) based on plant regrowth response and injury evaluations.

Results and Discussion

Prairie forb susceptibility to AMCP varied among species (Tables 2 and 3). *Iris versicolor* and *C. rotundifolia* were the most tolerant to AMCP of the 10 species evaluated, whereas *S. oolentangiense*, *S. canadensis*, *L. siphilitica*, and *E. angustifolia* were the most susceptible.

Iris versicolor was tolerant to AMCP at all application rates (Table 2). Plant injury at 2 and 10 WAT was minimal and difficult to visually discern from control plants. Regrowth weight was similar among treated and control *I. versicolor* plants and averaged 1.4 g (Table 3). All plants quickly regrew shortly after top growth was removed at 2 WAT. Based on these results, *I. versicolor* likely will not be affected by AMCP in the field, as the herbicide was applied with an MSO plus silicone-based NIS blend surfactant to maximize potential injury in the greenhouse.

Campanula rotundifolia was moderately tolerant to AMCP (Tables 2 and 3). Injury averaged approximately 32% at 2 and 10 wk after AMCP was applied at 35 to 105 g ha^{-1}. Regrowth of treated plants was similar to the control except when AMCP was applied at the highest rate of 105 g ha^{-1}. Short-term cupping of *C. rotundifolia* basal leaves was observed following an AMCP application in the greenhouse, which would likely be short-lived in the field as well. Conversely, *C. rotundifolia* was extremely susceptible to aminopyralid, as all treated plants died, even when the herbicide was applied at 30 g ha^{-1} in a similar greenhouse study (Mikkelson and Lym 2013).

Glycyrrhiza lepidota, *R. arkansana*, *D. purpurea*, and *M. fistulosa* were all considered moderately susceptible to AMCP, which was similar to the results from field trials conducted by Thilmony and Lym (2017) (Table 3). *Glycyrrhiza lepidota* regrowth averaged 0.4 g when AMCP was applied at 70 g ha^{-1}, compared with 1.6 g for the control, a 75% reduction in regrowth, even though plants were grown an additional 4 wk (14 wk total) to allow maximum regrowth. These findings were consistent with a field study using AMCP at 170 g ha^{-1}, in which *G. lepidota* was reduced from 1.8% to 0.1% foliar cover at 10 MAT (Thilmony and Lym 2017). However, by 14 MAT, *G. lepidota* cover increased to 1.5%, and plants exhibited minimal signs of injury.

Rosa arkansana regrowth declined as AMCP application rate increased, and injury ranged from 9% to 37% at 10 WAT (Tables 2 and 3). *Rosa arkansana* foliar cover was reduced but not eliminated at 14 MAT when AMCP was applied at 170 g ha^{-1} in the field (Thilmony and Lym 2017). Other plants in the Rosaceae family such as Woods' rose (*Rosa woodsii* Lindl.) and wild strawberry (*Fragaria virginiana* Duchesne) were also moderately susceptible to AMCP (Thilmony and Lym 2017; Wallace and Prather 2012). *Rosa woodsii* cover decreased slightly at 13 MAT but recovered by 25 MAT in Idaho, while *F. virginiana* was reduced 55% at 14 MAT in Minnesota.

Dalea purpurea dry weight at 10 WAT was 1.2 g when AMCP was applied at 35 g ha^{-1} compared with the control at 1.9 g, but weight decreased to 0.4 g or less when the herbicide was applied at 70 and 105 g ha^{-1} (Table 3). The reduced regrowth observed in the greenhouse following AMCP application was consistent with field trials that included *D. purpurea*. *Dalea purpurea* was not present at 10 MAT, but plants recovered slightly by 14 MAT in MN (Thilmony and Lym 2017). In Idaho, legume biomass was reduced by more than 71% for 3 yr following a single AMCP application (Miller et al. 2015).

Monarda fistulosa regrowth decreased as AMCP application rate increased and ranged from 0.1 to 0.4 g compared with 0.7 g for the control (Table 3). Although *M. fistulosa* top growth was reduced in the greenhouse, especially at high application rates, most plants survived at 10 WAT (Table 2). AMCP effect on other plants in the genus *Monarda* has not been reported, but healall (*Prunella vulgaris* L.), another member of the Lamiaceae family, was completely eliminated when AMCP was applied at 170 g ha^{-1} (Thilmony and Lym 2017).

Symphyotrichum oolentangiense, *S. canadensis*, *L. siphilitica*, and *E. angustifolia* were all susceptible to AMCP at 70 g ha^{-1} or more with 0 to 0.1 g of regrowth at 10 WAT (Table 3). *Symphyotrichum oolentangiense*, *S. canadensis*, and *E. angustifolia* are in the Asteraceae family. All three species had >80% injury at

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Table 2. Effect of aminocyclopyrachlor (AMCP) on various greenhouse-grown forbs 2 and 10 to 14 wk after treatment (WAT).

Scientific name	AMCP rate[a] (g ha^{-1})							
	35	70	105	LSD	35	70	105	LSD
	—% injury[b] 2 WAT—			(0.05)	—% injury[b] 10–14 WAT—			(0.05)
Glycyrrhiza lepidota Pursh	56	75	88	9	58	57	93	35
Symphyotrichum oolentangiense (Riddell) G. L. Nesom	23	15	34	9	100	100	100	NS
Iris versicolor L.	2	2	2	NS	0.5	0.5	0.5	NS
Solidago canadensis L.	20	26	33	5	32	89	100	23
Lobelia siphilitica L.	24	34	40	10	16	69	74	32
Campanula rotundifolia L.	21	29	40	14	22	31	46	25
Rosa arkansana Porter	8	11	16	8	9	32	37	NS
Echinacea angustifolia DC.	7	20	36	9	100	81	100	NS
Dalea purpurea Vent.	14	14	22	5	22	38	83	32
Monarda fistulosa L.	8	29	26	10	4	29	47	39

[a]AMCP applied with an MSO plus silicone-based NIS blend at 0.25% v/v (Dyne-Amic®, Helena Chemical, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017) at 0.25% v/v.
[b]Injury ratings were based on a scale of 0% to 100% (0 = no effect; 100 = all visible material dead).

10 WAT following AMCP applied at 70 g ha^{-1}, and no plants regrew when the herbicide was applied at 105 g ha^{-1} (Table 2). In field studies, *S. canadensis* cover was reduced an average of 97% at two sites (Thilmony and Lym 2017), which closely compares to the results of this study. Many members of the Asteraceae family were sensitive to AMCP in field trials, including *S. ericoides*, *S. porter* (Sebastian et al. 2012), Maximilian sunflower (*Helianthus maximiliani* Schrad.), and stiff goldenrod [*Oligoneuron rigidum* (L.) Small var. rigidum] (Thilmony and Lym 2017). However, some Asteraceae members were much less sensitive to AMCP, including three Artemisia spp. (Hergert et al. 2015) and common sunflower (*Helianthus annuus* L.). The variation in results was expected, since Asteraceae is a large family, and similar work with aminopyralid found plant sensitivity varied from tolerant to

Table 3. Effect of aminocyclopyrachlor (AMCP) on regrowth of various greenhouse-grown forbs 10 to 14 wks after treatment.

Scientific name	AMCP rate[a] (g ha^{-1})					Susceptibility rating			
						Greenhouse trial[b]	Finding in field trials[c]		
	0	35	70	105	LSD		Same species	Same genus	Same family
	— dry wt (g) —				(0.05)			— Number of species[d] —	
Glycyrrhiza lepidota Pursh	1.6	0.6	0.4	0.1	0.5	MS	MS	—	MS/2 S/1
Symphyotrichum oolentangiense (Riddell) G. L. Nesom	1.5	0	0	0	0.2	S	—	S/2	MS/5 S/9
Iris versicolor L.	1.4	1.3	1.3	1.4	NS	T	—	—	—
Solidago canadensis L.	2.6	0.9	0.1	0	0.2	S	S	—	MS/5 S/9
Lobelia siphilitica L.	1.1	0.4	0.02	0.03	0.2	S	—	S/1	S/1
Campanula rotundifolia L.	1.6	1.1	1	0.6	0.7	MT	—	—	S/1
Rosa arkansana Porter	2.1	1.5	0.5	0.6	0.5	MS	MS	MS/1	MS/2 S/1
Echinacea angustifolia DC.	0.7	0	0.1	0	0.3	S	—	—	MS/5 S/9
Dalea purpurea Vent.	1.9	1.2	0.4	0.07	0.2	MS	MS	—	MS/2 S/1
Monarda fistulosa L.	0.7	0.4	0.2	0.1	0.2	MS	—	—	S/1

[a]AMCP applied with an MSO plus silicone-based NIS blend at 0.25% v/v (Dyne-Amic®, Helena Chemical, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017).
[b]Abbreviations: MS, moderately susceptible; MT, moderately tolerant; S, susceptible; T, tolerant.
[c]Field trial results are combined from reports from Hergert et al. (2015), Sebastian et al. (2012), Thilmony and Lym (2017), and/or Wallace and Prather (2012).
[d]Susceptibility rating from field trial followed by "/number" indicates number of plants from the same species, genus, or family evaluated in the field that received that rating.

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moderately susceptible to susceptible even within the same genus of Asteraceae (Halstvedt 2015).

Lobelia siphilitica was susceptible to AMCP at all application rates evaluated, and regrowth was minimal (<0.1 g) at 10 WAT when treated with AMCP at 70 or 105 g ha^{-1} (Tables 2 and 3). Epinasty and leaf cupping was observed in the greenhouse and may occur shortly after a field application. Similarly, palespike lobelia (*Lobelia spicata* Lam.) was reduced but not eliminated by AMCP in the field (Thilmony and Lym 2017). *Lobelia siphilitica* susceptibility to AMCP contrasts with *C. rotundifolia*, which was moderately tolerant and further illustrates the variance in sensitivity to this herbicide from plants in the same family (Campanulaceae).

Forbs in this and previous studies were generally more sensitive to AMCP than aminopyralid at commonly used application rates (Almquist and Lym 2010; Halstvedt 2015; Samuel and Lym 2008; Thilmony and Lym 2017). However, land managers need to consider the weed to be controlled, application timing, herbicide rate, and forbs present when choosing the most effective treatment program. For instance, *Rosa* spp. were considered susceptible to aminopyralid but only moderately susceptible to AMCP (Tables 2 and 3) and regrew the year following application in the field (Thilmony and Lym 2017). In contrast, *D. purpurea* and *M. fistulosa* were susceptible to AMCP in this study, but tolerant of aminopyralid (Halstvedt 2015). Both herbicides will control *C. arvense*, so a land manger could choose between AMCP and aminopyralid based on the forbs present and/or desired at the site following treatment. Timing of application should also be considered. For instance, slender cinquefoil (*Potentilla gracilis* Douglas ex Hook.) was susceptible to aminopyralid when fall applied but tolerant of spring treatments, while subalpine buckwheat (*Eriogonum umbellatum* Torrey var. majus Hooker) tolerated fall but not summer application (Halstvedt 2015).

The susceptibility of greenhouse-grown forbs to AMCP was the same or similar to species evaluated in the field with no instance of contradictory findings. Thus, these data can be used to estimate tolerance to AMCP of forb species that have not been tested in the field. Many forb species could be evaluated in greenhouse trials fairly rapidly, and this would likely be more cost-effective than similar trials in the field, especially if the forb species is rare or difficult to find in numbers high enough to conduct susceptibility trials. This information will be beneficial to land managers, who must balance the benefits of a herbicide application to control invasive weeds with the potential of unintended injury to desirable plant species.

References

Almquist TL, Lym RG (2010) Effect of aminopyralid on Canada thistle (*Cirsium arvense*) and the native plant community in a restored tallgrass prairie. Invasive Plant Sci Manag 3:155–168

Bell JL, Burke IC, Prather TS (2011) Uptake, translocation and metabolism of aminocyclopyrachlor in prickly lettuce, rush skeletonweed and yellow starthistle. Pest Manage Sci 67:1338–1348

Beran DD, Gaussoin RE, Masters RA (1999) Native wildflower establishment with imidazolinone herbicides. HortSci 34:283–286

Conklin KL, Lym RG (2012) Absinth wormwood (*Artemisia absinthium* L.), houndstongue (*Cynoglossum officinale* L.), and yellow toadflax (*Linaria vulgaris* Mill.) control with aminocyclopyrachlor. Abstract 77 *in* Proceedings of the 2012 Weed Science Society of America Annual Meeting. Waikoloa, HI: Weed Science Society of America

Conklin KL, Lym RG (2013) Effect of temperature and moisture on aminocyclopyrachlor soil half-life. Weed Technol 27:552–556

Greet BJ, Mealor BA, Kniss AR (2016) Response of *Delphinium occidentale* and associated vegetation to aminocyclopyrachlor. Range Ecol Manage 69:474–480

Halstvedt M (2015) Native Forb and Shrub Tolerance to Milestone® Herbicide. https://update-techline.squarespace.com/s/ForbShrubTolerancetoMilestone.pdf. Accessed: July 28, 2016

Hergert HJ, Mealor BA, Kniss AR (2015) Inter- and intraspecific variation in native restoration plants for herbicide tolerance. Ecol Restor 33: 1543–4079

Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol Monogr 75:3–35

Jordan WR, Peters RL, Allen EB (1988) Ecological restorations as a strategy for conserving biological diversity. Environ Manage 12:55–72

Lindenmayer B, Nissen S, Westra P, Shaner D, Brunk G (2012) Aminocyclopyrachlor absorption, translocation, and metabolism in field bindweed (*Convolvulus arvensis*). Weed Sci 61:63–67

Lindenmayer B, Westra P, Brunk G, Nissen S, Shaner D (2010) Field and laboratory studies with aminocyclopyrachlor (DPX-MAT28). Abstract O-281 *in* Proceedings of the Weed Science Society of America. Denver, CO: Weed Science Society of America

Lym RG (2010) Control of invasive and troublesome weeds with aminocyclopyrachlor in North Dakota. Pages 41–42 *in*, Proceedings of the Western Society of Weed Science Volume 63. Waikoloa, HI: Western Society of Weed Science

Mikkelson JR, Lym RG (2013) Effect of aminopyralid on desirable forb species. Invasive Plant Sci Manag 6: 30–35

Miller AJ, Bork EW, Hall LM, Summers B (2015) Long-term forage dynamics in pastures sprayed with residual broadleaf herbicides: a test of legume recovery. Can J Plant Sci. 95:43–53

Samuel LW, Lym RG (2008) Aminopyralid effects on Canada thistle (*Cirsium arvense*) and native plant species. Invasive Plant Sci Manag 1:265–278

Sebastian JR, Beck G, Sebastian D, Rodgers S (2012) Using aminocyclopyrachlor to control Dalmatian toadflax and promote native plant community recovery and diversity. Pages 51–52 *in* Proceedings of the Western Society of Weed Science Volume 65. Reno, NV: Western Society of Weed Science

Thilmony BM, Lym RG (2017) Effect of aminocyclopyrachlor on native forb species in the Northern Great Plains. Invasive Plant Sci Manag 10:201–209

Wallace J, Prather T (2012) Response of native grassland forbs and shrubs to various rates of aminocyclopyrachlor. Pages 15–16 *in* 2012 Research Progress Report. Las Cruces, NM: Western Society of Weed Science

Weaver JE (1954) Studies in central and western prairies. Pages 194–220 *in* North American Prairie. Lincoln, NE: Johnsen Publishing