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Utility of Aminocyclopyrachlor for Control of Horsenettle (*Solanum carolinense*) and Tall Ironweed (*Vernonia gigantea*) in Cool-Season Grass Pastures

William P. Phillips, Trevor D. Israel, Thomas C. Mueller, Gregory R. Armel, Dennis R. West, Jonathan D. Green, and G. Neil Rhodes, Jr.*

Because horsenettle and tall ironweed are difficult to control in cool-season grass pastures, research was conducted in Tennessee and Kentucky in 2010 and 2011 to examine the efficacy of aminocyclopyrachlor on these weeds. Aminocyclopyrachlor was evaluated at 49 and 98 g ai ha^{-1} alone and in mixtures with 2,4-D amine at 371 and 742 g ae ha^{-1}. Aminopyralid was also included as a comparison treatment at 88 g ai ha^{-1}. Treatments were applied at three POST timings to horsenettle and two POST timings to tall ironweed. By 1 yr after treatment (YAT) horsenettle was controlled 74% with aminocyclopyrachlor plus 2,4-D applied late POST (LPOST) at 98 + 742 g ha^{-1}. By 1 YAT, tall ironweed was controlled ≥ 93% by aminocyclopyrachlor applied early POST (EPOST) or LPOST, at rates as low as 49 g ha^{-1}. Similar control was achieved with aminopyralid applied LPOST. Both aminocyclopyrachlor and aminopyralid were found to reduce horsenettle and tall ironweed biomass the following year. Moreover, all LPOST applications of aminocyclopyrachlor alone or in mixtures with 2,4-D prevented regrowth of tall ironweed at 1 YAT. Based on these studies, a LPOST herbicide application in August or September when soil moisture is adequate is recommended for control of horsenettle and tall ironweed in cool-season grass pastures.

Nomenclature: 2,4-D; aminocyclopyrachlor; aminopyralid; horsenettle, *Solanum carolinense* L.; tall ironweed, *Vernonia gigantea* (Walt.) Trel.

Key words: Auxin-mimic herbicides, bullnettle, hay fields, tall fescue.

Porque *Solanum carolinense* y *Vernonia gigantea* son difíciles de control en pastos de clima frío, se realizó una investigación en Tennessee y Kentucky, en 2010 y 2011, para examinar la eficacia de aminocyclopyrachlor para el control de estas malezas. Aminocyclopyrachlor fue evaluado a 49 y 98 g ai ha^{-1} solo y en mezclas con 2,4-D amine a 371 y 742 g ae ha^{-1}. Aminopyralid a 88 g ai ha^{-1} fue también incluido como tratamiento de comparación. Los tratamientos fueron aplicados en tres momentos POST a *S. carolinense* y dos momentos POST a *V. gigantea*. A 1 año después del tratamiento (YAT), *S. carolinense* fue controlada 74% con aminocyclopyrachlor más 2,4-D aplicados en POST tardío (LPOST) a 98 + 742 g ha^{-1}. A 1 YAT, *V. gigantea* fue controlada ≥ 93% con aminocyclopyrachlor aplicado en POST temprano (EPOST) o LPOST, a dosis tan bajas como 49 g ha^{-1}. Un control similar fue alcanzado con aminopyralid aplicado LPOST. Se encontró que tanto aminocyclopyrachlor como aminopyralid redujeron la biomasa de *S. carolinense* y *V. gigantea* el siguiente año. Además, todas las aplicaciones LPOST de aminocyclopyrachlor solo o en mezclas con 2,4-D previnieron el rebrote de *V. gigantea* a 1 YAT. Con base en estos estudios, se recomienda una aplicación de herbicida LPOST en Agosto o Septiembre cuando la humedad del suelo es adecuada para el control de *S. carolinense* y *V. gigantea* en pastos de clima frío.

In order to remain economically viable, cattle producers have turned their attention to increased efficiency of their grazing and hay operations. Rotationally grazing a group of small paddocks has gained popularity over the traditional method of continuously grazing cattle in a large single area. Rotational grazing allows the cattle to more efficiently utilize the available forage, and therefore can increase the carrying capacity of an area (Ball et al. 2007). Likewise, greater emphasis has been given to properly timed hay harvest and dry hay storage to minimize losses due to decreased nutritive value and storage losses (Ball et al. 2007). With emphasis on maximizing the production of every acre, a field with significant weed pressure is no longer acceptable. Weeds compete with forage grasses for limited resources, thereby decreasing forage yield and

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* First, second, third, fourth, fifth, and seventh authors: Former Graduate Research Assistant, Former Extension Assistant, Professor, Former Assistant Professor and Extension Specialist, Professor, Professor and Extension Specialist, Department of Plant Sciences, University of Tennessee, Knoxville, TN 37996; sixth author: Extension Professor, Department of Plant and Soil Sciences, University of Kentucky, Lexington, KY 40546. Corresponding author's E-mail: nrhodes@utk.edu

quality (Beeler et al. 2004; Bradley and Kallenbach 2005; Mann et al. 1983). Producers must be able to effectively control weeds in their hay fields and pastures to maximize production.

Management of many perennial pasture weeds has been a challenge with traditional pasture herbicides, clipping, or grazing. This is due to their tolerance of herbicides, their capacity to store ample carbohydrates in rhizomes and roots, and the fact that most grazing animals avoid them (Albert 1960; Gorrell et al. 1981; Ilnicki and Fertig 1962; Marshall et al. 2006; McCarty and Linscott 1963; Peters and Lowance 1978; Tolson et al. 2012). Another study found that clipping reduced tall ironweed biomass, but had no positive long-term effect on weed population (Tolson et al. 2012). These weeds can accumulate in pastures and hay fields that are otherwise weed-free and properly managed. Tall ironweed and horsenettle are two of the most common and troublesome pasture weeds in the southeastern United States (Webster 2012).

Horsenettle is a perennial herbaceous plant native to the United States. It is a member of the Solanaceae family and spreads by both seeds and rhizomes. Horsenettle creeping roots spread as much as 6 m laterally and taproots can reach depths of 3 m (Ilnicki and Fertig 1962). Cultivation is not a practical option for control and can even exacerbate the weed problem by spreading viable root fragments across fields (Beeler et al. 2004; Ilnicki and Fertig 1962; Wehtje et al. 1987). Mowing also provides unsatisfactory control. Ilnicki and Fertig (1962) demonstrated that horsenettle mowed frequently at very low heights eventually forms a rosette growth pattern and thus keeps the root system sufficiently supplied with carbohydrates. In one herbicide study, two annual applications of 2.2 kg ha^{-1} 2,4-D reduced a pasture horsenettle population by about 50% (Albert 1960). When Gorrell et al. (1981) evaluated horsenettle control in pastures, they found that three annual applications of 2,4-D at 1.1 kg ha^{-1} reduced shoot density about 75%, compared to $>$ 95% with three annual applications of picloram. Recent strategies have shifted toward herbicides that provide selective horsenettle control in a single application. Picloram plus 2,4-D controlled horsenettle as much as 66% when evaluated the following year (Beeler et al. 2004). Other studies have reported acceptable levels of horsenettle control with aminopyralid plus 2,4-D (Enloe et al. 2010; Langston et al. 2010; Tolson et al. 2009).

Tall ironweed is a native perennial found throughout the eastern United States. It is a member of the Asteraceae family and propagates by seeds and rhizomes. The plant is frequently found in pastures and grows across a range of habitats, from moist bottoms to upland sites. Because most livestock avoid it, tall ironweed can spread easily in pastures (Marshall et al. 2006; Payne et al. 2010). Previous studies have indicated that 2,4-D and dicamba initially provide control of top growth, but regrowth occurs the following year (Mann et al. 1983; Peters and Lowance 1979). Triclopyr, picloram, and aminopyralid have been shown to control tall ironweed the year following treatment (Fryman and Witt 2007; Mann et al. 1983; Peters and Lowance 1979). Research is needed for new active ingredients in pasture herbicides that control troublesome perennial weeds such as horsenettle and tall ironweed, control a broad spectrum of other weeds, and have low risk for runoff to sensitive areas.

Aminocyclopyrachlor is an auxin-mimic herbicide that is registered for use in noncropland applications (Anonymous 2014). The herbicide is a member of the substituted pyrimidine family of chemicals, controls several annual and perennial broadleaf weeds, and has a favorable environmental profile (Finkelstein et al. 2008). Aminocyclopyrachlor shows promise for control of horsenettle and tall ironweed in cool-season grass pastures (Rhodes 2010). The objective of this research was to identify the optimum application rate and timing of aminocyclopyrachlor for control of horsenettle and tall ironweed in cool-season grass pastures and to compare its efficacy with that of aminopyralid.

Materials and Methods

Research was conducted on naturally occurring infestations of horsenettle and tall ironweed in pastures with predominately Kentucky 31 tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] as the desirable forage grass. Horsenettle studies were conducted in 2010 at Alcoa (35.84°N, 83.96°W), Fork Creek (35.66°N, 84.31°W), and Greenback, TN (35.66°N, 84.16°W). The studies were repeated in 2011 at Maynardville, TN (36.30°N, 83.78°W), and Fork Creek, on an

Table 1. Application dates of horsenettle and tall ironweed studies in 2010 and 2011.[a]

		2010			2011		
Target weed	Location	EPOST	MPOST	LPOST	EPOST	MPOST	LPOST
Horsenettle	Alcoa, TN	June 30	July 14	September 14			
	Greenback, TN	June 17	July 16	September 9			
	Fork Creek, TN	June 3	July 15	September 9	May 31	July 8	September 8
	Maynardville, TN				June 29	July 15	September 9
Tall ironweed	London, KY	June 15		August 23	June 20		August 30
	Pulaski, TN	June 7		August 25	May 25		August 31

[a] Abbreviations: EPOST, early POST; MPOST, mid-POST; LPOST, late POST.

adjacent, previously nontreated area. Tall ironweed studies were conducted at Pulaski, TN (35.17°N, 87.02°W), and London, KY (37.10°N, 84.00°W) in 2010 and in 2011 on adjacent, previously nontreated areas.

Five herbicide treatments with three application timings [designated as early-POST (EPOST), mid-POST (MPOST) and late-POST (LPOST)] were evaluated in the horsenettle trials. The same five herbicide treatments were evaluated in the tall ironweed trials with two application timings, EPOST and LPOST. The herbicides were aminocyclopyrachlor (DPX-MAT28, E. I. du Pont de Nemours and Co., 1007 Market St., Wilmington, DE 19898) at 49 and 98 g ai ha^{-1}, aminocyclopyrachlor plus 2,4-D amine (2,4-D Amine, E. I. du Pont de Nemours and Co.) at 49 g ai ha^{-1} + 371 g ae ha^{-1} and 98 g ai ha^{-1} + 742 g ae ha^{-1}, and aminopyralid (Milestone®, Dow AgroSciences LLC, 9330 Zionsville Rd., Indianapolis, IN 46268) at 88 g ai ha^{-1}. The application dates for the herbicide treatments at each location are shown in Table 1. Rainfall data for all locations are presented in Table 2.

A randomized complete block design with four replications was utilized in all studies. Blocking was based on field parameters to minimize errors due to changes in weed populations across the site. Experimental units were 3.0 m wide by 9.1 m long. Treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 168 L ha^{-1} of spray solution and fitted with six flat-fan nozzle tips (Teejet® XR8002, Spraying Systems Co., PO Box 7900, Wheaton, IL 60189). Due to the size of the experiments, two nontreated check plots were included in each replication. A nonionic

Table 2. Precipitation data for horsenettle and tall ironweed locations.

	Knoxville, TN[a]		London, KY		Huntsville, AL[b]		Tazewell, TN[c]	
Month	Precip[d]	Departure from avg[d]	Precip	Departure from avg	Precip	Departure from avg	Precip	Departure from avg
	cm							
May 2010	10.7	−1.2	13.9	2.0	12.4	−0.9		
June 2010	3.2	−7.1	9.8	−1.0	7.0	−3.7		
July 2010	15.0	3.0	11.7	0.5	5.1	−6.1		
August 2010	7.1	−0.2	15.3	6.8	8.8	0.4		
September 2010	11.0	3.3	7.1	−1.5	6.4	−4.5		
May 2011	4.2	−7.7	14.1	2.2	4.9	−8.5	8.2	−5.2
June 2011	7.6	−2.7	16.3	5.6	9.5	−1.2	24.6	14.0
July 2011	6.3	−5.6	10.2	−1.0	8.4	−2.8	12.8	1.2
August 2011	2.7	−5.6	7.8	−1.6	9.7	0.5	7.6	−2.2
September 2011	22.2	14.0	12.5	3.9	15.5	6.1	26.3	18.1

[a] Knoxville, TN is the closest National Weather Service (NWS) Recording Station to Alcoa, Fork Creek, and Greenback, TN.
[b] Huntsville, AL is the closest NWS Recording Station to Pulaski, TN.
[c] Tazewell, TN is the closest NWS Recording Station to Maynardville, TN.
[d] Abbreviations: Precip, precipitation; avg, average.

Table 3. Influence of herbicides and application timing on horsenettle visual control, density, height, and dry weight biomass at 1 yr after treatment across 5 site–years in Tennessee.

Herbicide treatments	Rate[a]	Application timing[b]	Control[c]	Density	Height	Dry wt
	$g\ ha^{-1} + g\ ae\ ha^{-1}$		%	plants m^{-1}	cm	$g\ m^{-2}$
Aminocyclopyrachlor	49	EPOST	60 cde	3.8 bcd	10 bc	2.3 bc
Aminocyclopyrachlor	98	EPOST	65 abcd	2.5 d	10 bc	2.0 bc
Aminocyclopyrachlor + 2,4-D	49 + 371	EPOST	63 bcde	4.6 bcd	10 bc	2.2 bc
Aminocyclopyrachlor + 2,4-D	98 + 742	EPOST	67 abcd	2.4 d	7 c	1.0 c
Aminopyralid	88	EPOST	67 abcd	4.0 bcd	8 bc	2.4 bc
Aminocyclopyrachlor	49	MPOST	58 de	3.9 bcd	8 bc	1.9 bc
Aminocyclopyrachlor	98	MPOST	60 cde	4.7 bcd	12 b	3.8 b
Aminocyclopyrachlor + 2,4-D	49 + 371	MPOST	67 abcd	5.6 bc	9 bc	4.0 b
Aminocyclopyrachlor + 2,4-D	98 + 742	MPOST	67 abcd	2.6 d	9 bc	1.4 c
Aminopyralid	88	MPOST	63 bcde	6.5 b	9 bc	2.8 bc
Aminocyclopyrachlor	49	LPOST	63 bcde	4.0 bcd	8 bc	1.8 bc
Aminocyclopyrachlor	98	LPOST	72 ab	2.6 d	11 b	1.3 c
Aminocyclopyrachlor + 2,4-D	49 + 371	LPOST	69 abc	2.7 d	9 bc	1.2 c
Aminocyclopyrachlor + 2,4-D	98 + 742	LPOST	74 a	2.3 d	6 c	1.1 c
Aminopyralid	88	LPOST	55 e	3.6 cd	9 bc	1.9 bc
Nontreated Check			0 f	9.3 a	16 a	6.8 a

[a] Rates for aminocyclopyrachlor and aminopyralid are g ai ha^{-1}. Rates for 2,4-D are g ae ha^{-1}.

[b] Abbreviations: EPOST, early POST; MPOST, mid-POST; LPOST, late POST application.

[c] Means followed by same letter do not significantly differ ($P \leq 0.05$).

surfactant (Induce®, Helena Chemical Company, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017) at 0.25% v/v was included with each herbicide treatment.

Herbicide efficacy was measured with visual estimates of weed control, weed stem counts, heights, and dry weights of weed biomass taken 1 yr after the EPOST application (YAT). All visual evaluations were based on a 0 to 100% scale when compared to the nontreated checks, with 0 being no control and 100 being complete control. Tall fescue injury was not observed in any treatment. Weed stem counts, average heights, and biomass were determined by randomly placing a 1 m^2 PVC square within each plot. All living weed stems were counted, measured for height, and cut at the soil surface. Weed biomass samples were dried in a 54 C oven for 30 h and weighed to determine dry weight.

The data were analyzed using ANOVA in SAS (SAS 9.2, SAS Institute Inc., SAS Circle, Box 8000, Cary, NC 27512). Each site–year combination was considered an environment sampled at random, as suggested by Carmer et al. (1989) and Blouin et al. (2011). Considering environment as a random effect allowed for estimation of treatment effects over a variety of environments (Blouin et al. 2011). Herbicide and application timing were considered fixed effects, whereas environment and replication (nested within environment) were considered random effects. Means were separated using Fisher's protected LSD ($P < 0.05$).

Results and Discussion

Horsenettle. A timing-by-herbicide interaction occurred for visual estimates of weed control, weed stem counts, heights, and dry weights. Although > 90% control of horsenettle was observed with all treatments during the year of application (data not shown), by 1 YAT visual control means ranged from 55 to 74% (Table 3). All herbicide treatments reduced horsenettle stem density, average height, and dry biomass compared to the nontreated checks 1 YAT. MPOST applications of aminopyralid at 88 g ha^{-1} and aminocyclopyrachlor plus 2,4-D at 49 + 371 g ha^{-1} did not reduce horsenettle stem density as much as other treatments. MPOST applications of aminocyclopyrachlor at 98 g ha^{-1} and aminocyclopyrachlor plus 2,4-D at 49 + 371 g ha^{-1} did not reduce dry weight biomass as much as other treatments. One possible explanation for reduced horsenettle control at the MPOST timing

Table 4. Influence of herbicides and application timing on tall ironweed visual control, density, height, and dry weight biomass at 1 yr after treatment across 4 site–years in Tennessee and Kentucky.

Herbicide treatments	Rate[a]	Application timing[b]	Control[c]	Density	Height	Dry wt
	g ha^{-1} + g ae ha^{-1}		%	stems m^{-2}	cm	g m^{-2}
Aminocyclopyrachlor	49	EPOST	93 bc	0.9 c	17 bc	4 b
Aminocyclopyrachlor	98	EPOST	97 ab	0.7 c	7 cd	1 b
Aminocyclopyrachlor + 2,4-D	49 + 371	EPOST	90 c	3.8 bc	28 b	7 b
Aminocyclopyrachlor + 2,4-D	98 + 742	EPOST	97 ab	0.4 c	4 cd	1 b
Aminopyralid	88	EPOST	79 d	5.8 b	28 b	13 b
Aminocyclopyrachlor	49	LPOST	99 a	0 c	0 d	0 b
Aminocyclopyrachlor	98	LPOST	98 ab	0 c	0 d	0 b
Aminocyclopyrachlor + 2,4-D	49 + 371	LPOST	97 ab	0 c	0 d	0 b
Aminocyclopyrachlor + 2,4-D	98 + 742	LPOST	99 a	0 c	0 d	0 b
Aminopyralid	88	LPOST	90 c	2.8 bc	24 b	16 b
Nontreated Check			0 e	18 a	64 a	151 a

[a] Rates for aminocyclopyrachlor and aminopyralid are g ai ha^{-1}. Rates for 2,4-D are g ae ha^{-1}.

[b] Abbreviations: EPOST, early POST; LPOST, late POST application.

[c] Means followed by same letter do not significantly differ ($P \leq 0.05$).

is because rainfall was well below average leading up to the application and plants were drought-stressed.

Aminocyclopyrachlor applied alone or in combination with 2,4-D controls horsenettle during the season of application, but not all plants might be eliminated the following year. Enloe et al. (2010) reported 70 g ha^{-1} aminocyclopyrachlor and 110 + 970 g ha^{-1} aminopyralid plus 2,4-D applied at fruit set controlled horsenettle $\geq$ 90% the season of treatment. In another study, picloram plus 2,4-D controlled horsenettle 81 to 99% the season of treatment, but control was only 47 to 66% the following spring (Beeler et al. 2004). Also, all treatments reduced stem density the following year, but did not eliminate horsenettle.

Tall Ironweed. A timing-by-herbicide interaction occurred for all measures of efficacy. Tall ironweed was better controlled than horsenettle with aminocyclopyrachlor and aminopyralid at the rates used in these studies (Table 4). Furthermore, although the tall ironweed locations varied greatly in temperature and summer rainfall, results were more consistent than in the horsenettle study. This suggests efficacy of aminopyralid, and especially aminocyclopyrachlor, on tall ironweed is not as weather-dependent as their efficacy on horsenettle. Visual control evaluations 1 YAT revealed that aminocyclopyrachlor at any rate applied LPOST or at the higher rate applied EPOST provided $\geq$ 97% control of tall ironweed, which was greater than the control provided by aminopyralid. All herbicide treatments reduced tall ironweed stem density, average height, and dry weight biomass 1 YAT when compared to the nontreated check.

In a previous study, aminopyralid at 70 to 88 g ha^{-1} provided 83 to 86% control of tall ironweed, respectively (Fryman and Witt 2007). In a Missouri study, 70 g ha^{-1} aminopyralid applied in May or August reduced stem density 73 to 75% the following season (Payne et al. 2010). Tolson et al. (2012) reported 66 to 89% reduction in tall ironweed stems at 1 yr after August application of aminopyralid plus 2,4-D at 115 + 1,000 g ha^{-1}.

This research suggests that tall ironweed might be effectively controlled (99%) with aminocyclopyrachlor at rates as low as 49 g ha^{-1} applied LPOST, when ironweed is flowering. Good control (> 95%) might also be obtained with an EPOST application, but the higher rate would be recommended for consistent results. The addition of 2,4-D at the rates used in this study typically did not improve tall ironweed control over aminocyclopyrachlor alone; no antagonism was observed. Applications of aminocyclopyrachlor might also provide fair control (70 to 80%) of horsenettle in the following year. A LPOST application of 98 g ha^{-1} (with or without 2,4-D) or 49 g ha^{-1} with 2,4-D would be expected to provide the best control. To maximize efficacy, it is important that the horsenettle plants not be drought-stressed. An evaluation of aminocyclopyrachlor efficacy on these two weeds 2 to 3 yr after treatment was not included in this study, but would be useful in making management decisions concerning the use of this herbicide in pastures and hay fields.

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