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Aminocyclopyrachlor Efficacy for Controlling Virginia Buttonweed (*Diodia virginiana*) and Smooth Crabgrass (*Digitaria ischaemum*) in Tall Fescue

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Virginia buttonweed and smooth crabgrass are problematic weeds in tall fescue and may warrant control with herbicides at similar timings. The objectives of these field experiments were to evaluate (1) aminocyclopyrachlor rate and application regimens for controlling Virginia buttonweed and (2) the influence of growth stage on aminocyclopyrachlor efficacy for controlling smooth crabgrass. Single applications of aminocyclopyrachlor at 0.05 and 0.08 kg ai ha^{-1} provided poor (< 70%) and fair (70 to 79%) control of Virginia buttonweed, respectively, but sequential applications improved control to 83 to 99%. Single and sequential applications of aminocyclopyrachlor at 0.11 kg ai ha^{-1} provided good (80 to 89%) and excellent (> 90%) control of Virginia buttonweed, respectively. Aminocyclopyrachlor at 0.11 kg ha^{-1} provided fair control of smooth crabgrass at the multileaf growth stage prior to tillering but control was poor when applied at the multitiller stage. Aminocyclopyrachlor at 0.05 and 0.08 kg ha^{-1} provided poor control of crabgrass at both timings and were less effective than fenoxaprop at 0.10 kg ai ha^{-1}.

Nomenclature: Smooth crabgrass, *Digitaria ischaemum* (Schreb.) Schreb. ex Muhl.; Virginia buttonweed, *Diodia virginiana* L.; 'Titan' tall fescue, *Festuca arundinacea* Schreb.
Key words: Growth stage, herbicide, turfgrass.

Diodia virginiana y *Digitaria ischaemum* son malezas problemáticas en *Festuca arundinacea*, las cuales podrían requerir control con herbicidas en momentos similares. Los objetivos de estos experimentos de campo fueron evaluar (1) dosis y regímenes de aplicación de aminocyclopyrachlor para el control de *D. virginiana* y (2) la influencia del estado de desarrollo de *D. ischaemum* en la eficacia de aminocyclopyrachlor para el control de esta maleza. Aplicaciones simples de aminocyclopyrachlor a 0.05 y 0.08 kg ai ha^{-1} brindaron un control de *D. virginiana* pobre (<70%) y aceptable (70 a 79%), respectivamente, pero las aplicaciones secuenciales mejoraron el control hasta 83 y 99%. Aplicaciones simples y secuenciales de aminocyclopyrachlor a 0.11 kg ai ha^{-1} brindaron un control de *D. virginiana* bueno (80–89%) y excelente (>90%), respectivamente. Aminocyclopyrachlor a 0.11 kg ha^{-1} brindaron un control aceptable de *D. ischaemum* en el estado de desarrollo de múltiples hojas antes de la producción de hijuelos, pero el control fue pobre cuando se aplicó en el estado de múltiples hijuelos. Aminocyclopyrachlor a 0.05 y 0.08 kg ha^{-1} brindó un control pobre de *D. ischaemum* en ambos momentos de aplicación y fue menos efectivo que fenoxaprop a 0.10 kg ai ha^{-1}.

Virginia buttonweed is a problematic broadleaf weed in turfgrass, roadsides, and other grassy areas throughout the southeastern United States. Virginia buttonweed is a deep-rooted perennial with prostrate or spreading branches that usually proliferates in moist or wet soils (Radford et al. 1968). Cultural control is difficult in areas with significant infestations, and physical removal can be ineffective since creeping roots and rhizomes may reestablish viable plants (Baird et al. 1992).

PRE herbicides are generally ineffective for controlling Virginia buttonweed due to population emergence from vegetative stems rather than seed (Baird et al. 1992). Sulfonylureas, such as chlorsulfuron, metsulfuron, and trifloxysulfuron, have potential for POST Virginia buttonweed control, but applications may be injurious to tall fescue during summer months. Synthetic auxin herbicides are safe for use in tall fescue, but repeat applications are often required to control perennial broadleaf weeds such as Virginia buttonweed (Hutto et al. 2008; Kelly and Coats 2000a,b).

Aminocyclopyrachlor is a pyridine carboxylic acid herbicide for POST broadleaf weed control and is currently available for use on roadside grasses with pending registration in pastures. Aminocyclopyrachlor has a mode of action similar to synthetic auxins and effectively controls annual and perennial broadleaf weeds (Minogue et al. 2011; Reed and McCullough 2012; Strachan et al. 2010). Although aminocyclopyrachlor is primarily used for controlling broadleaf species, applications alone and in combination with POST herbicides controlled smooth crabgrass in tall fescue in preliminary studies suggesting other uses warrant investigation with this chemistry (McCullough et al. 2011).

Smooth crabgrass is a problematic summer annual weed that is often present at similar timings as Virginia buttonweed in turf, pastures, and roadsides. Herbicides such as quinclorac, fenoxaprop, and mesotrione are available for use in tall fescue turf, but applications may be limited based on crabgrass growth stage, turf maturity, or potential resistance to these chemistries (Derr 2002; Hart et al. 2004; Patton et al. 2007; Willis et al. 2006). Practitioners may use imazapic in tall fescue pastures and roadsides but reduced application rates of ≤ 0.07 kg ai ha^{-1} are necessary to minimize injury that compromise potential for controlling smooth crabgrass

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(Anonymous 2011). Recent restrictions on MSMA use in turf and grassy roadsides have further limited options for POST crabgrass control and new herbicides, such as aminocyclopyrachlor, could provide an alternative mode of action to practitioners. The objectives of these field experiments were to evaluate (1) aminocyclopyrachlor rate and application regimens for controlling Virginia buttonweed and (2) the influence of growth stage on aminocyclopyrachlor efficacy for controlling smooth crabgrass in tall fescue.

Materials and Methods

Virginia Buttonweed Experiment. Field experiments were conducted at the University of Georgia in Griffin, GA, from May to August in 2011 and 2012. Soil was a Cecil sandy clay loam (fine, kaolinitic, thermic Typic Kanhapludult) with a 6.0 pH and 2.2% organic matter. In April of both years, existing vegetation was killed with glyphosate, scalped with a rotary mower, and debris was removed. 'Titan' tall fescue (Seed Research of Oregon, Inc. Corvallis, OR 97339) was seeded with a drop spreader at 392 kg ha^{-1} and irrigated as needed to promote establishment. After establishment, tall fescue was irrigated to prevent wilt and mowed weekly with a rotary mower at 7.5-cm height and clippings were returned. Virginia buttonweed emerged in late April of both years and was at the multileaf stage, without flowers present, on the day of applications.

Experimental design was a randomized complete block with four and three replications in 2011 and 2012, respectively. Plots used in 2012 were adjacent to plots in 2011 and measured 0.9 $\times$ 2.5 m. Treatments included aminocyclopyrachlor (Imprelis 2SL, E. I. du Pont de Nemours and Co., 1007 Market St., Wilmington, DE 19898) at 0, 0.05, 0.08, or 0.11 kg ai ha^{-1} and a prepackaged formulated mixture of 2,4-D + dicamba + MCPP (Trimec Classic 2.7SL, PBI Gordon Corp., 1217 W. 12th St., Kansas City, MO 64101) at 1.11 + 0.12 + 0.3 kg ai ha^{-1}. Treatments were applied once or twice with the second application made 3 wk after initial treatment (WAIT) and a nontreated check was included. Applications were made with CO_2-pressured sprayers calibrated to deliver 374 L ha^{-1} with a single 9504E flat-fan nozzle (Teejet Spraying Systems Co., Roswell, GA 30075). Application dates were May 12 and June 2 in 2011 and May 7 and May 28 in 2012. Weather conditions for May 12, 2011, application were 35 C air temperature, 65% relative humidity, and 1.6 km h^{-1} wind, and the next rainfall of 0.07 cm occurred on May 13, 2011. For the June 2, 2011, application, conditions were 29 C air temperature, 53% relative humidity, and 6.4 km h^{-1} wind, and the next rainfall of 0.66 cm occurred on June 15, 2011. The weather conditions on May 7, 2012, were 29 C air temperature, 61% relative humidity, and 3.2 km h^{-1} wind, and the next rainfall of 1.19 cm occurred on May 8, 2012. The conditions for the May 29, 2012, application were 26 C air temperature, 71% relative humidity, and 9.6 km h^{-1} wind, and the next rainfall of 1.07 cm occurred on May 30, 2012.

Virginia buttonweed control was rated visually 2, 4, 6, 8, and 12 WAIT on a percent scale where 0 equaled on control and 100 equaled complete control. Virginia buttonweed shoots were counted in a 929-cm^2 grid at 12 WAIT in 2011 and are presented as percent reductions from the untreated. Tall fescue injury was visually rated where 0 equaled no injury and 100 equaled completely dead turf. Data were subjected to analysis of variance. Means were separated with Fisher's protected LSD test at $\alpha = 0.05$. Year by treatment interactions were not detected and thus years were combined.

Smooth Crabgrass Experiment. Field experiments were conducted on the aforementioned tall fescue field established in April of 2011 and 2012 in Griffin, GA. Experimental design was a randomized complete block with four replications of 0.9 $\times$ 2.5-m plots. Treatments were the factorial combination of five herbicides at two application timings. Herbicides evaluated included aminocyclopyrachlor at 0, 0.05, 0.8, or 0.11 kg ai ha^{-1} and fenoxaprop (Acclaim Extra 0.57EC, Bayer Environmental Sciences, 2 T. W. Alexander Drive, Research Triangle Park, NC 27709) at 0.10 kg ai ha^{-1}. Applications were made when smooth crabgrass was at a multileaf stage or multitiller. Herbicides were applied with the aforementioned CO_2-pressured sprayers at 374 L ha^{-1}. Application dates were May 12 and June 2 in 2011 and May 7 and May 28 in 2012. Temperatures on the day of treatments were similar to aforementioned experiments with Virginia buttonweed.

Smooth crabgrass control was rated visually on a percent scale where 0 equaled no control and 100 equaled complete control. Tall fescue injury was visually rated on the aforementioned dates on a percent scale where 0 equals no injury and 100 equals completely dead turf. Evaluations were made 3, 6, and 9 wk after treatment (WAT). Data were subjected to analysis of variance and means were separated with Fisher's Protected LSD test at $\alpha = 0.05$. Year by treatment interactions were not detected and thus years were combined.

Results and Discussion

Virginia Buttonweed Control. Tall fescue injury was not detected on any evaluation date (data not shown). Herbicide by application interactions were detected on every date, and thus, results are presented across all possible treatments (Table 1). Single applications of aminocyclopyrachlor at 0.05 and 0.08 kg ha^{-1} controlled Virginia buttonweed 67 and 75% at 4 WAIT, respectively, but control declined to 27 and 71% at 12 WAIT in all likelihood from injured plant regrowth. Sequential applications of these rates improved control to $\geq$ 88% at 6 WAIT and control measured 83% at 12 WAIT. Shoot count reductions from the untreated had similar trends to control measurements at 12 WAIT as single applications of aminocyclopyrachlor at 0.05 and 0.08 kg ha^{-1} had $<$ 65% reductions from the untreated but sequential applications had 94% reductions at both rates.

Single applications of aminocyclopyrachlor at 0.11 kg ha^{-1} controlled Virginia buttonweed 85% after 4 WAIT and control measured 80% at 12 WAIT (Table 1). Sequential applications of aminocyclopyrachlor at 0.11 kg ha^{-1} controlled Virginia buttonweed $\geq$ 98% while single and sequential applications reduced plant counts 92 and 100%

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Table 1. Virginia buttonweed control in 'Titan' tall fescue treated with herbicides in two combined field experiments, 2011 to 2012, Griffin, GA.

Applications[a]	Herbicide[b]	Rate	Control (WAIT)[c]					Count reduction (WAIT)[d]
			2	4	6	8	12	12
		kg ai ha^{-1}	%					
1	Aminocyclopyrachlor	0.05	36	67	59	56	27	20
		0.08	47	75	75	64	71	64
		0.11	53	85	81	81	80	92
	2,4-D + dicamba + MCPP	1.11 + 0.12 + 0.3	63	89	81	77	60	75
2	Aminocyclopyrachlor	0.05		81	88	88	83	94
		0.08		88	95	92	83	94
		0.11		98	99	99	98	100
	2,4-D + dicamba + MCPP	1.11 + 0.12 + 0.3		86	93	88	74	72
		$LSD_{0.05}$	18	19	19	21	31	41

[a] WAIT = weeks after initial treatments.

[b] Shoots were counted in a 929-cm^2 sampling area at 12 WAIT in 2012 and presented as percent reductions from the untreated.

[c] Application dates were May 12 and June 2 in 2011 for single and sequential applications, respectively, and May 7 and May 28 in 2012, respectively.

[d] Herbicides applied were Imprelis 2SL (aminocyclopyrachlor) and Trimec Classic 2.7SL (2,4-D + dicamba + MCPP).

from the untreated, respectively. Aminocyclopyrachlor at 0.08 or 0.11 kg ha^{-1} applied once provided comparable Virginia buttonweed control to single and sequential treatments of 2,4-D + dicamba + MCPP. Single applications of aminocyclopyrachlor at 0.05 kg ha^{-1} were less effective than 2,4-D + dicamba + MCPP, but sequential applications provided similar control.

Aminocyclopyrachlor appears safe and effective for Virginia buttonweed control in tall fescue but sequential applications may be needed with low rates to achieve good control ($>$ 80%). Although repeat applications were generally more effective, single applications of aminocyclopyrachlor at 0.08 and 0.11 kg ha^{-1} provided comparable Virginia buttonweed control to applications of 2,4-D + dicamba + MCPP. Results are consistent with previous reports that sequential applications of auxin herbicides were most effective for controlling Virginia buttonweed (Hutto et al. 2008; Kelly and Coats 2000a,b). Aminocyclopyrachlor has potential for controlling Virginia buttonweed and other perennial species in tall fescue but residual effects of POST treatments on populations in subsequent growing seasons warrant further investigation in turf, pastures, and roadsides grasses.

Table 2. Smooth crabgrass control in 'Titan' tall fescue treated with herbicides applied at multileaf and multitiller timings in two combined field experiments, 2011 to 2012, Griffin, GA.

Growth stage	Herbicide[a]	Rate	Smooth crabgrass control (WAT)[b]		
			3	6	9
		kg ai ha^{-1}	%		
Multileaf	Aminocyclopyrachlor	0.05	33	58	54
		0.08	33	60	46
		0.11	69	78	76
	Fenoxaprop	0.10	100	97	94
Multitiller	Aminocyclopyrachlor	0.05	17	13	18
		0.08	31	26	25
		0.11	55	59	50
	Fenoxaprop	0.10	84	72	66
		$LSD_{0.05}$	20	24	29

[a] WAT = weeks after treatment.

[b] Herbicides applied were Imprelis 2SL (aminocyclopyrachlor) and Acclaim Extra 0.57EC (fenoxaprop).

Smooth Crabgrass Control. Tall fescue injury was not detected on any evaluation date (data not shown). Smooth crabgrass cover in untreated control plots 9 WAT ranged from 50 to 75% in 2011 and 75 to 85% in 2012. Herbicide by application interactions were detected on every date, and thus, results are presented across all possible treatments (Table 2). Single applications of aminocyclopyrachlor at 0.05 and 0.08 kg ha^{-1} provided $\leq$ 60% control of multileaf smooth crabgrass from 3 to 9 WAT, but 0.11 kg ha^{-1} provided 76% control at 9 WAT. Fenoxaprop provided $>$ 90% control of multileaf smooth crabgrass on all dates and provided better control at 3 WAT than all aminocyclopyrachlor rates. However, control from fenoxaprop was similar to the high rate of aminocyclopyrachlor at 6 and 9 WAT.

Fenoxaprop provided better control of multitiller smooth crabgrass than aminocyclopyrachlor at 3 WAT but all treatments were generally less effective than the multileaf timing (Table 2). Multitiller smooth crabgrass control increased with aminocyclopyrachlor rate but was $<$ 60% from 3 to 9 WAT. Fenoxaprop initially provided 84% control of multitiller crabgrass at 3 WAT but control declined seemingly due to regrowth from injured plants and was similar to the high rate of aminocyclopyrachlor at 9 WAT.

Aminocyclopyrachlor has potential to control smooth crabgrass prior to tillering but applications are less effective on mature populations. The influence of growth stage is consistent with previous research with other herbicides for smooth crabgrass control including dithiopyr, fenoxaprop, and quinclorac (Brosnan et al. 2010; Neal et al. 1990). However, aminocyclopyrachlor was less effective than fenoxaprop at standard use rates (0.05 to 0.08 kg ha^{-1}) and will likely require tank mixing with other herbicides for grassy weed control in roadsides or other managed areas.

Since aminocyclopyrachlor has safety on immature tall fescue, applications may have potential to control seedling crabgrass and warrant further investigation for use during establishment of grassy roadsides, turf, and pastures. Aminocyclopyrachlor is compatible with most herbicides and improves smooth crabgrass control in tank-mixtures with fenoxaprop (McCullough et al. 2011). Further research should investigate tank-mixtures with other grassy herbicides used in pastures and roadsides, such as nicosulfuron or imazapic, for controlling multitiller smooth crabgrass, perennial broadleaves, and other problematic weeds.

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