Smooth Crabgrass and Goosegrass Control with Metamifop in Creeping Bentgrass

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SUMMARY. Smooth crabgrass (*Digitaria ischaemum*) and goosegrass (*Eleusine indica*) are problematic weeds in creeping bentgrass (*Agrostis stolonifera*) because of limited herbicide options for postemergence (POST) control and turfgrass injury potential. Metamifop is a herbicide currently being considered for release to markets in the United States but information is lacking on the most effective rates and application timings for smooth crabgrass and goosegrass control in creeping bentgrass. Field trials were conducted in Auburn, AL in 2009 and 2013 to evaluate metamifop rates (200 to 800 g·ha⁻¹) and single or sequential application timings compared with fenoxaprop (51 to 200 g·ha⁻¹) at two different mowing heights. Metamifop applied twice and three times sequentially at 200 g·ha⁻¹ provided the greatest smooth crabgrass (>97%) and goosegrass (>90%) control at rough (1½ inch) and green (1/8 inch) mowing heights without unacceptable creeping bentgrass injury at 56 days after initial treatment. All treatments caused <20% visible injury on creeping bentgrass at both mowing heights except the highest rate of metamifop. Smooth crabgrass control at the green mowing height was greater than at the rough mowing height, especially at lower metamifop rates with a single application.

Smooth crabgrass and goosegrass are problematic weeds in creeping bentgrass in the transition zone, an area that rests between the southern United States where warm-season grasses dominate, and the northern United States where cool-season grasses thrive. These weeds are able to survive low mowing heights, especially among cool-season grasses (Busey, 2003; Callahan, 1986). As herbicide-resistant populations of smooth crabgrass (e.g., quinclorac) and goosegrass (e.g., prodiamine and pendimethalin) increase and as cultural control methods can be ineffective in cool-season grasses, new herbicides will be needed to ensure future control (Busey, 2003; Callahan, 1986; Hart et al., 2004; Heap, 2015; Mudge et al., 1984).

Several herbicides have been registered for smooth crabgrass and goosegrass control in cool-season turfgrass (King, 1990; Parker et al., 1985). Fenoxaprop controls both crabgrass and goosegrass; however,

past research has shown fenoxaprop to cause stunting and stand reduction in seedling tall fescue (*Schedonorus arundinaceus*), perennial ryegrass (*Lolium perenne*), and creeping bentgrass (Cudney et al., 1997; Dernoeden, 1987; Neal et al., 1990). Herbicidal control options of smooth crabgrass and goosegrass in creeping bentgrass also include quinclorac, siduron, and bensulide. However, previous research has shown stunting, thinning, or foliar phytotoxicity to both mature and immature cool-season turfgrasses including creeping bentgrass with varying rates and application timings of many of these herbicides as well (Busey, 2003; Cudney et al., 1997; Dernoeden, 1987; Mueller-Warrant, 1990; Neal et al., 1990; Warren et al., 1989). Currently, only bensulide and oxadiazon are explicitly registered for preemergence (PRE) smooth crabgrass and goosegrass control on creeping bentgrass putting greens (PBI/Gordon Corp., 2009; Quali-Pro, 2013). Given these limited options

for controlling grass weeds in creeping bentgrass, new herbicidal control options would be beneficial for sustainable management.

Metamifop is an aryloxyphenoxypropionate (AOPP) herbicide that has reported herbicidal activity on smooth crabgrass and goosegrass with safety to creeping bentgrass. Metamifop is not currently registered in the United States, but is used for POST annual and perennial weed control in Asia and the Middle East. It is used in many turfgrass systems including parks, golf courses, and gardens (Flessner and McElroy, 2011; Hoyle et al., 2012; Kim et al., 2003a, 2003b; Post and Askew, 2010). It is also used in many cereal crops such as rice (*Oryza sativa*) for control of annual and perennial grass weeds at 100 to 200 g·ha⁻¹ (Moon et al., 2007, 2010). Along with smooth crabgrass and goosegrass, metamifop has also controls over annual grass weeds such as barnyardgrass (*Echinochloa crus-galli*), while remaining less injurious to cool-season grasses (Flessner and McElroy, 2011; Kim et al., 2003b; Post and Askew, 2010). Post and Askew (2010) observed that metamifop at 300 g·ha⁻¹ controlled smooth crabgrass while causing <10% creeping bentgrass injury whereas comparable smooth crabgrass control with fenoxaprop completely killed creeping bentgrass putting greens.

Metamifop inhibits acetyl-CoA carboxylase (ACCase), the enzyme that catalyzes the first step in fatty acid synthesis for membranes and cell growth (Burton et al., 1987; Devine et al., 1993; Focke and Lichtenthaler, 1987; Senseman, 2007). Like other AOPP herbicides, metamifop does not affect eudicotyledonous plants because of limited activity against cytosolic, the prokaryotic ACCase (Burton et al., 1987; Senseman, 2007). It has been hypothesized that these differing activities of AOPP herbicides in cool-season grasses and the selectivity observed among grasses

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
70.0532	oz/acre	g·ha ⁻¹	0.0143

may be because of an altered binding site within the ACCase target enzyme (Senseman, 2007; Stoltenberg et al., 1989). Irrespective of the specific mechanism, metamifop appears to be safer to cool-season turfgrasses while offering comparable control to other herbicides currently marked for crabgrass and goosegrass control (Cox and Askew, 2014; Flessner and McElroy, 2011; Kim et al., 2003a; Post and Askew, 2010).

The most efficacious rates and sequential application timings to achieve smooth crabgrass and goosegrass control have not been established. In addition, creeping bentgrass tolerance to metamifop at different mowing heights must be assessed. Research was conducted to evaluate metamifop rates and sequential application timings for smooth crabgrass and goosegrass control compared with an industry standard, fenoxaprop. The second objective was to evaluate creeping bentgrass injury associated with varying rates and application timings of metamifop at two mowing heights.

Materials and methods

Field research was conducted at the Auburn University Turfgrass Research and Education Center in Auburn, AL (lat. 32.34°N, long. 85.29°W) in 'Crenshaw' creeping bentgrass that has been established for greater than 5 years. Soil type was Marvyn Sandy Loam (fine-loamy, kaolinitic, thermic Typic Kanhapludult) with a pH of 6.0 and 1.1% organic matter. All trials were irrigated as needed to prevent drought stress. Three studies were conducted. Studies 1 and 2 evaluated smooth crabgrass control and creeping bentgrass injury at two mowing heights—1/8 inch simulating a golf course putting green and 1½ inch simulating a golf course rough, respectively. Study 3 evaluated goosegrass control in creeping bentgrass at 1/8 inch height. All studies were conducted as randomized complete blocks with a minimum of three replications per treatment and all studies were repeated in-time in 2009 and 2013 as subsequently described.

TREATMENTS. Treatments evaluated for smooth crabgrass control were the same for both mowing heights and were metamifop (SAH-001; Summit Agro International, Tokyo, Japan) applied once at 200,

400, and 800 g·ha⁻¹, metamifop applied in two sequential applications on a 3-week interval at 200 or 400 g·ha⁻¹, metamifop applied in three sequential applications on 3-week intervals at 100 or 200 g·ha⁻¹. Fenoxaprop (Acclaim Extra®; Bayer Environmental Science, Research Triangle Park, NC) was included as a standard comparison and applied in three sequential applications on a 3-week interval at 17 g·ha⁻¹ (note that these rates are below label recommendations). Smooth crabgrass control studies were initiated on 17 July, 10 Aug., and 25 Aug. 2009 for the first experimental repetition and 19 June 2013 for the second experimental repetition. In both 2009 and 2013, smooth crabgrass growth stage was one to two tillers at the putting green height and three to five tillers at the rough height at the time of initial application. Smooth crabgrass control and creeping bentgrass injury data were collected 7, 14, 28, 42, and 56 d after initial treatment (DAIT). Twenty-eight DAIT corresponds to 7 d after second treatment, 42 DAIT corresponds to 21 d after second treatment, and 56 DAIT corresponds to 35 d after second treatment or 14 d after third treatment. All treatments were applied at 30 gal/acre with a handheld four-nozzle boom [nozzles on 25-cm spacing (TeeJet TJ8002VS; Spraying Systems, Wheaton, IL)] to 1.5 × 1.5-m plots.

Treatments evaluated for goosegrass control were metamifop applied once at 200, 300, and 400 g·ha⁻¹, and metamifop applied in two sequential applications on a 3-week interval at 200 or 300 g·ha⁻¹. Fenoxaprop was included as a standard comparison and applied once at 100 g·ha⁻¹ and in two sequential applications on a 3-week interval at 100 g·ha⁻¹. Goosegrass control studies were initiated on 29 June and 20 July 2009 for experimental run 1 and 24 July and 19 Aug. 2013 for experimental run 2. Goosegrass growth stage was mostly (≥75%) two to three tillers at the initial application for both experimental repetitions with the remaining plant at less mature growth stages. Goosegrass control was rated 7, 21, 42, and 56 DAIT.

MEASUREMENTS. Smooth crabgrass and goosegrass control were visually evaluated relative to the

nontreated control on a 0 (no control) to 100 (complete plant necrosis) scale. Creeping bentgrass injury was visually evaluated using a similar 0 to 100 scale, with a score of 20 representing the maximum level of creeping bentgrass injury considered acceptable, similar to previous studies (Johnson, 1995, 1996; Johnson and Murphy, 1995).

EXPERIMENTAL DESIGN AND ANALYSIS. Data analyses were performed using PROC GLM (SAS version 9.1; SAS Institute, Cary, NC). Data were subjected to analysis of variance and effects were considered significant when $P < 0.05$. Subsequently, data were subjected to means separation using Fisher's protected least significant difference ($P < 0.05$). All model assumptions were confirmed. In all studies, treatment and rating date were considered fixed effects whereas year was considered a random effect.

Results and discussion

SMOOTH CRABGRASS AT ROUGH HEIGHT. Smooth crabgrass control and creeping bentgrass injury data were pooled across years as the year by treatment interaction was not significant ($P > 0.05$). All metamifop treatments resulted in smooth crabgrass control greater than fenoxaprop at all rating dates (Table 1). Metamifop rates totaling 400 g·ha⁻¹ or greater resulted in ≥80% smooth crabgrass control 56 DAIT. These data were consistent with those of Cox and Askew (2014), who found that 400 g·ha⁻¹ resulted in 88% control at 8 weeks after treatment. Metamifop treatments applied sequentially at 3-week intervals offered greater and more prolonged control (at 56 DAIT) than those applied only once, with the exception of the highest rate of 800 g·ha⁻¹. Fenoxaprop applications resulted in <50% control of smooth crabgrass. All treatments resulted in <15% creeping bentgrass injury with applications of 800 g·ha⁻¹ (whether sequential or one time) resulting in the greatest injury (Table 2). Cox and Askew (2014) reported no injury to any cool-season turfgrasses (not including creeping bentgrass) in studies, but made no conclusions because of lack of replication. Overall, metamifop at 200 g·ha⁻¹ followed by 200 g·ha⁻¹ resulted in the most economical combination of smooth crabgrass control (>95% at 56 DAIT) and creeping

bentgrass injury (<15%) at the rough mowing height compared with fenoxaprop (<49% control at 56 DAIT).

SMOOTH CRABGRASS AT GREEN HEIGHT. At green mowing height, the year by treatment interaction was nonsignificant for smooth crabgrass control, so data were pooled across years. All metamifop treatments controlled smooth crabgrass greater than fenoxaprop at all rating dates (Table 3). All metamifop treatments resulted in >90% smooth crabgrass control 28 DAIT, >95% control 42 DAIT, and ≥94% control 56 DAIT. Fenoxaprop resulted in <75% smooth crabgrass control throughout the trial. A single application of metamifop at 800 g·ha⁻¹ resulted in ≥18% creeping bentgrass injury between 7 and 42 DAIT, with complete recovery by 56 DAIT (Table 4). The second application of 400 g·ha⁻¹ in the sequential treatment resulted in 17% creeping bentgrass injury. Therefore, there is risk of creeping bentgrass injury associated with higher rates of metamifop, especially at low mowing heights. Sequential metamifop applications resulted in similar smooth crabgrass control with less creeping bentgrass injury compared with single applications. Based on these results, an effective regimen for smooth crabgrass control in a creeping bentgrass putting green is three applications of 100 g·ha⁻¹ (98% control at 56 DAIT and 3% injury at 56 DAIT) or a single application of 200 g·ha⁻¹ (94% control at 56 DAIT and no injury at 56 DAIT). Similar to this research, Post and Askew (2010) reported that metamifop controlled smooth crabgrass with <10% creeping bentgrass injury, whereas comparable smooth crabgrass control with fenoxaprop completely killed creeping bentgrass putting greens. Comparing this with creeping bentgrass mowed at rough height, creeping bentgrass is more susceptible to metamifop injury at lower mowing heights.

GOOSEGRASS. Year by treatment interactions were not significant for goosegrass control studies; accordingly, data were pooled. Metamifop at 200 followed by 200 g·ha⁻¹ and 300 followed by 300 g·ha⁻¹ resulted in >89% goosegrass control 42 DAIT and 56 DAIT, respectively (Table 5). Fenoxaprop treatments resulted in similar to significantly less goosegrass control at 56 DAIT (<74%) relative to

Table 1. Smooth crabgrass control comparing metamifop treatments and fenoxaprop at simulated roughs mowing height of 1½ inch (3.81 cm) pooled over experiments in 2009 and 2013 in Auburn, AL.

Herbicide	Rate (g·ha ⁻¹) ^z	14 DAIT ^y	28 DAIT	42 DAIT	56 DAIT
		% control			
Metamifop	200	65	65	59	64
Metamifop	400	75	83	82	80
Metamifop	800	94	95	95	93
Metamifop	200 fb 200	68	90	96	98
Metamifop	400 fb 400	92	96	100	100
Metamifop	200 fb 200 fb 200	81	92	97	98
Metamifop	100 fb 100 fb 100	60	67	72	91
Fenoxaprop	17 fb 17 fb 17	23	25	39	49
LSD(0.05) ^x		28	16	11	5

LSD = least significant difference.

^zSequential treatments were applied on 3-week intervals; 1 g·ha⁻¹ = 0.0143 oz/acre, fb = followed by.

^yDays after initial treatment.

^xLSD with a 95% confidence interval.

Table 2. Creeping bentgrass injury from metamifop at various rates and application regimes at simulated roughs mowing height of 1½ inch (3.81 cm) in 2009 and 2013 in Auburn, AL.

Herbicide	Rate (g·ha ⁻¹) ^z	7 DAIT ^y	14 DAIT	28 DAIT	42 DAIT
		% injury			
Metamifop	200	0	0	2	0
Metamifop	400	1	0	4	3
Metamifop	800	13	13	12	10
Metamifop	200 fb 200	0	0	6	7
Metamifop	400 fb 400	4	0	10	9
Metamifop	200 fb 200 fb 200	3	0	4	2
Metamifop	100 fb 100 fb 100	0	0	3	0
Fenoxaprop	17 fb 17 fb 17	1	0	0	0
LSD(0.05) ^x		5	NS	5	7

LSD = least significant difference.

^zSequential treatments were applied on 3-week intervals; 1 g·ha⁻¹ = 0.0143 oz/acre, fb = followed by.

^yDays after initial treatment.

^xLSD with a 95% confidence interval; NS = not significant.

Table 3. Smooth crabgrass control comparing metamifop and fenoxaprop at simulated greens mowing height of 1/8 inch (3.18 mm) pooled over experiments in 2009 and 2013 in Auburn, AL.

Herbicide	Rate (g·ha ⁻¹) ^z	14 DAIT ^y	28 DAIT	42 DAIT	56 DAIT
		% control			
Metamifop	200	93	96	96	94
Metamifop	400	99	100	99	96
Metamifop	800	99	100	99	96
Metamifop	200 fb 200	92	96	98	99
Metamifop	400 fb 400	97	99	99	100
Metamifop	200 fb 200 fb 200	95	98	99	98
Metamifop	100 fb 100 fb 100	86	91	99	98
Fenoxaprop	17 fb 17 fb 17	52	62	69	74
LSD(0.05) ^x		8	6	7	10

LSD = least significant difference.

^zSequential treatments were applied on 3-week intervals; 1 g·ha⁻¹ = 0.0143 oz/acre, fb = followed by.

^yDays after initial treatment.

^xLSD with a 95% confidence interval.

the best metamifop treatments (>90%). These data indicate that metamifop at 300 followed by 300 g·ha⁻¹ was the best treatment for goosegrass control.

Metamifop applied sequentially at 300 followed by 300 g·ha⁻¹ does pose injury risk to creeping bentgrass greens, therefore timing is important

Table 4. Creeping bentgrass injury from metamifop at various rates and application regimes at simulated greens mowing height of 1/8 inch (3.18 mm) in 2009 and 2013 in Auburn, AL.

Herbicide	Rate (g·ha ⁻¹) ^z	7 DAIT ^y	14 DAIT	28 DAIT	42 DAIT	56 DAIT
		% injury				
Metamifop	200	1	0	1	0	0
Metamifop	400	9	3	6	1	0
Metamifop	800	22	23	18	19	1
Metamifop	200 fb 200	0	0	0	5	3
Metamifop	400 fb 400	9	4	7	17	8
Metamifop	200 fb 200 fb 200	4	1	2	6	4
Metamifop	100 fb 100 fb 100	2	0	1	0	3
Fenoxaprop	17 fb 17 fb 17	5	0	0	1	0
LSD _(0.05) ^x		6	3	6	4	NS

LSD = least significant difference.

^zSequential treatments were applied on 3-week intervals; 1 g·ha⁻¹ = 0.0143 oz/acre, fb = followed by.

^yDays after initial treatment.

^xLSD with a 95% confidence interval; NS = not significant.

Table 5. Goosegrass control from metamifop at various rates and application regimes in 2009 and 2013 in Auburn, AL.

Herbicide	Rate (g·ha ⁻¹) ^z	7 DAIT ^y	21 DAIT	42 DAIT	56 DAIT
		% control			
Metamifop	200	33	63	50	57
Metamifop	300	42	72	68	73
Metamifop	400	45	76	75	81
Metamifop	200 fb 200	34	58	89	91
Metamifop	300 fb 300	31	81	99	100
Fenoxaprop	100	39	60	52	40
Fenoxaprop	100 fb 100	38	58	87	74
LSD _(0.05) ^x		8	17	10	14

LSD = least significant difference.

^zSequential treatments were applied on 3-week intervals; 1 g·ha⁻¹ = 0.0143 oz/acre, fb = followed by.

^yDays after initial treatment.

^xLSD with a 95% confidence interval.

when choosing a second application date. An alternative is to apply 200 followed by 200 g·ha⁻¹, which provides good goosegrass control with less injury potential to creeping bentgrass than fenoxaprop, as well as decreased cost in amount of product used.

Summary

Compared with current herbicide options for smooth crabgrass and goosegrass control, metamifop offers comparable control with less threat of cool-season grass injury (Derr et al., 1985; Neal et al., 1990; Warren et al., 1989). Metamifop can effectively control smooth crabgrass POST at both rough and putting green mowing heights without injury to creeping bentgrass. In addition, goosegrass can be effectively controlled POST in a creeping bentgrass putting green, although higher rates are required compared with smooth

crabgrass. Generally, metamifop applied sequentially resulted in greater smooth crabgrass and goosegrass control and creeping bentgrass safety relative to single applications. POST metamifop applications along with currently used PRE options such as bensulide and siduron will allow for greater smooth crabgrass and goosegrass control with the added benefit of multiple modes of action to decrease the likelihood of herbicide resistance in creeping bentgrass systems. Multiple applications of metamifop totaling 300 to 600 g·ha⁻¹ will provide good control of smooth crabgrass and goosegrass, especially after late flushes of these troublesome weeds, with limited risk of creeping bentgrass injury. Future research may focus on further refining metamifop rates and timings or possible differences in creeping bentgrass tolerance by variety.

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