Research Reports

Seedling Centipedegrass Response to Mesotrione Plus Simazine Mixtures

J. Scott McElroy[1], James D. McCurdy, and Michael L. Flessner

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SUMMARY. Centipedegrass (*Eremochloa ophiuroides*) is a low-maintenance, warm-season grass common throughout the southern United States. Slow establishment and growth rate of seeded centipedegrass often allows for increased weed competition, yet weed control options are limited. Tank-mixing simazine with mesotrione has been reported to improve weed control because of synergistic modes of action. A 2-year field trial was conducted to evaluate centipedegrass response to mesotrione and simazine applications applied 2 weeks after emergence. Mesotrione (0.25 lb/acre) did not reduce centipedegrass cover at any rating when applied alone. All rates of simazine, alone and tank-mixed with mesotrione, resulted in decreased centipedegrass cover 7 days after treatment (DAT). However, simazine alone at 0.25 lb/acre did not reduce turf cover 14, 28, and 49 DAT, and simazine at 0.25 lb/acre tank-mixed with mesotrione at 0.25 lb/acre did not reduce turf cover 28 and 49 DAT. Results indicate that newly established centipedegrass is vulnerable to cover reduction because of simazine and simazine plus mesotrione tank-mixture. Mesotrione and mesotrione tank-mixed with low rates of simazine is a viable option for newly seeded centipedegrass weed control; however, turf cover may be delayed.

Centipedegrass is a low-maintenance, warm-season grass used throughout the southern United States (Baird et al., 1989; Beard, 1973). Centipedegrass is established vegetatively and by seed; however, centipedegrass is slow to germinate and weed competition can delay turf coverage. Seeded centipedegrass requires 10 to 14 d to germinate, and large crabgrass (*Digitaria* sp.) populations can delay centipedegrass stolon development (Brede, 2000; Gannon et al., 2004). Slow establishment and growth rate often allows for increased weed competition (Gannon et al., 2004).

Weed control options for newly established centipedegrass are limited (Gannon et al., 2004; Porter 1996). Triazine herbicides such as atrazine and simazine are viable options for centipedegrass weed control. Gannon et al. (2004) demonstrated centipedegrass tolerance to atrazine (2.2 $kg \cdot ha^{-1}$) and simazine (3.4 $kg \cdot ha^{-1}$) at seeding stage; however, both provide limited residual weed control. McElroy and Walker (2009) found that atrazine reduced centipedegrass photosystem II (PS II) efficiency when applied postemergence and should only be applied preemergence to seedling centipedegrass. Triazine herbicides inhibit photosynthesis by competing with plastoquinone (PQ) for the quinone B binding domain of the D1 protein. As a result, electron flow between PS II and PS I is inhibited. The subsequent accumulation of reactive oxygen species (ROS) and singlet and triplet chlorophyll overwhelms the carotenoid quenching mechanism and degradation of thylakoid membranes occurs (Hess, 2000).

Previous research has shown mesotrione tank-mixture with atrazine improves weed control compared with either herbicide applied alone (Abendroth et al., 2006; Armel et al., 2003, 2005; Johnson and Young, 2002; Willis et al., 2007). Mesotrione, a carotenoid biosynthesis inhibitor, is an effective herbicide for turfgrass weed control. Mesotrione competitively inhibits 4-hydroxyphenylpyruvate dioxygenase, which prevents the biosynthesis of α-tocopherol and PQ (Prysbilla et al., 1993). α-Tocopherol scavenges ROS that are detrimental to the thylakoid membrane (Trebst et al., 2002). PQ transfers electrons from PS II to PS I reaction centers and is a cofactor in phytoene desaturase, a crucial enzyme of the carotenoid biosynthesis pathway (Norris et al., 1995). Carotenoids are components of light harvesting complexes where they transfer light energy to the photosynthetic reaction center and act in photoprotection by quenching free radicals, singlet oxygen, and other ROS (Siefermann-Harms, 1987). Thus, the combined effect of free radical and reactive oxygen generation by triazine herbicides and depletion of tocopherol and carotenoid antioxidants induces herbicidal synergism.

Mesotrione has been reported to control creeping bentgrass (*Agrostis stolonifera*) as well as other common turfgrass weeds postemergence, including crabgrass, goosegrass (*Eleusine indica*), nimblewill (*Muhlenbergia schreberi*), ground ivy (*Glechoma hederacea*), common purslane (*Portulaca oleracea*), black medic (*Medicago*

Department of Agronomy and Soils, 201 Funchess Hall, Auburn University, Auburn, AL 36849

[1]Corresponding author. E-mail: jsm0010@auburn.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0929	ft^2	m^2	10.7639
9.3540	gal/acre	$L \cdot ha^{-1}$	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922

lupulina), and dandelion (*Taraxacum officinale*) (Beam et al., 2006; Giese et al., 2005; Johnson and Young, 2002; Reicher et al., 2006).

Previous research found tank-mixing low rates of atrazine with mesotrione improved weed control (Armel et al., 2005; Johnson and Young, 2002). Similarly, Willis et al. (2007) reported simazine plus mesotrione tank-mixture controlled white clover (*Trifolium repens*) greater than mesotrione alone. Mesotrione applied as an early postemergence herbicide on newly seeded centipedegrass does not reduce turf cover (McElroy and Walker, 2009). Improved weed control and centipedegrass injury because of tank-mixture of mesotrione and atrazine is well documented; however, tank-mixture of other PS II-inhibiting herbicides, such as simazine, with mesotrione is limited. Therefore, it is necessary to evaluate centipedegrass response to simazine plus mesotrione tank-mixture.

Materials and methods

A 2-year study was conducted in 2005 and 2006 at the University of Tennessee, East Tennessee Research and Education Center—Plant Science Unit, Knoxville, TN. Soil type was Sequatchie loam soil (Fine-loamy, siliceous, semiactive, thermic Humic Hapludult) with pH 6.2 and 2.1% organic matter. Soil fertility was not amended. 'TifBlair' centipedegrass was broadcast spread at a rate of 49 $kg \cdot ha^{-1}$. After broadcast spreading, soil was rolled with a cultipacker, covered with a white cotton seedbed cloth, and irrigated as need to maintain soil surface moisture for germination. Seeding dates were 13 June 2005 and 15 June 2006. Centipedegrass seedling emergence occurred on 24 June 2005 and 21 June 2006. Throughout the experiment, plots were mowed biweekly and maintained at 5-cm mowing height. Plots were overhead irrigated 4 min twice daily to maintain adequate soil moisture. Herbicide applications included mesotrione (0.25 lb/acre), varying rates of simazine (0.25, 0.50, 1.00, 2.00 lb/acre), and mesotrione (0.25 lb/acre) tank-mixed with varying rates of simazine (Table 1). All mesotrione applications included a 0.25% v/v nonionic surfactant. Herbicides were applied on 19 July 2005 and 10 July 2006 with a carbon dioxide (CO_2)-pressurized backpack sprayer at 30 gal/acre with 8002 flat fan nozzles (Spray Systems Co., Wheaton, IL). Herbicide applications were made when centipedegrass seedlings first started tillering—≈2 to 3 weeks after emergence.

Turfgrass injury was rated on a 0% to 100% scale where 0 equals no plant injury and 100 equals complete plant death. Visual symptoms signifying plant injury normally associated with carotenoid- and PS II-inhibiting herbicides are tissue whitening, chlorosis, and plant necrosis. Special attention was given to identifying these symptoms. Digital images (1.23 million pixels) were captured with a digital camera (G5; Canon U.S.A., Lake Success, NY) at 7, 14, 28, and 49 DAT. Images were downloaded to a personal computer for digital image analysis as previously published (Karcher 2007; Karcher and Richardson, 2003; Richardson et al., 2001). SigmaScan Pro (Systat Software, San Jose, CA) was used to estimate percent green cover by assessing hue and saturation and by comparing total green pixels (Richardson et al., 2001). Hue threshold levels were 31° to 120°. Saturation threshold levels were 18% to 98%. The software calculates the percentage pixels within this hue and saturation "green" range, and this percentage is analyzed as percent green cover. Goosegrass (*Eleusine indica*) and other minor weeds were removed by hand to prevent weed cover from confounding the research plots.

Experiments were conducted in a randomized complete block design with four replications. Experimental units were 4.5 m^2. All data were subject to analysis of variance ($P = 0.05$) and analyzed as a randomized complete block design with the two runs considered fixed effects. Herbicide application by run effects was evaluated to determine if there was a significant interaction because of year. Data were arcsine square root transformed; however, this did not change significant differences among treatments. Means were separated by Fisher's protected least significant difference at $P = 0.05$. Results were subjected to orthogonal contrast statements to evaluate the effects of increasing simazine rates with and without mesotrione ($P = 0.05$).

Table 1. Mesotrione, simazine, and mesotrione plus simazine effects on centipedegrass percent green cover rated 7, 14, 28, and 49 d after treatment (DAT).

		Cover compared with non-treated control (%)[x]			
Herbicide treatment[z]	**Rate (lb/acre)[y]**	**7 DAT**	**14 DAT**	**28 DAT**	**49 DAT**
Mesotrione	0.25	38	46	77	90
Simazine	0.25	24	32	67	88
Simazine	0.50	14	21	59	86
Simazine	1.00	11	12	44	82
Simazine	2.00	10	12	42	77
Mesotrione + simazine	0.25 + 0.25	19	24	66	89
Mesotrione + simazine	0.25 + 0.50	10	16	53	82
Mesotrione + simazine	0.25 + 1.00	12	12	50	79
Mesotrione + simazine	0.25 + 2.00	9	9	40	73
Nontreated	—	37	40	75	92
LSD ($P = 0.05$)[w]		8	10	13	8

[z]All treatments contained a nonionic surfactant (0.25% v/v). Herbicides were applied on 19 July 2005 and 10 July 2006. Herbicide treatment by run interaction was not significant; therefore, runs were pooled over years.
[y]1 lb/acre = 1.1209 $kg \cdot ha^{-1}$.
[x]Percent green cover was determined using digital image analysis. Green cover response because of herbicide applications were compared with nontreated checks.
[w]Fisher's protected least significant difference at $P = 0.05$.

Results and discussion

At no time was visual plant injury of tissue whitening, chlorosis, or necrosis observed on centipedegrass seedlings; therefore, no injury data were recorded for any treatment (data not shown). Delayed seedling development hindered turfgrass green cover development, which was observed in simazine-treated plots. Herbicide treatment by run interaction was not significant; therefore, runs were pooled over years. Green cover response from herbicide applications was compared with nontreated checks. Mesotrione did not reduce green cover 7, 14, 28, or 49 DAT when applied alone (Table 1). Nontreated centipedegrass green cover

Table 2. Orthogonal contrast statements for simazine alone and simazine plus mesotrione comparing regression response of centipedegrass to increasing simazine rates.

	Orthogonal contrasts			
	7 DAT[y]	14 DAT	28 DAT	49 DAT
Herbicide treatment[z]	*P* value			
Simazine alone				
Linear	<0.001	<0.001	<0.001	<0.01
Quadratic	NS[z]	NS	NS	NS
Lack-of-fit	NS	NS	NS	NS
Simazine plus mesotrione				
Linear	NS	<0.01	<0.01	<0.01
Quadratic	NS	NS	NS	NS
Lack-of-fit	NS	NS	NS	NS

[z]Simazine rates were 0.25, 0.50, 1.00, and 2.00 lb/acre (1 lb/acre = 1.1209 kg·ha^{-1}). Mesotrione rate was 0.25 lb/acre. All treatments contained a nonionic surfactant (0.25% v/v). Herbicides were applied on 19 July 2005 and 10 July 2006. Herbicide treatment by run interaction was not significant (NS); therefore, runs were pooled over years.
[y]Days after treatment.

was 37% 7 DAT. Mesotrione-alone treated centipedegrass green cover was not reduced when compared with the nontreated 7 DAT and was greater than green cover from all other treatments (38%). Similarly, McElroy and Walker (2009) reported mesotrione (0.25 lb/acre) applied to newly seeded centipedegrass did not injure centipedegrass; however, rates exceeding 0.25 lb/acre resulted in minimal centipedegrass green cover. All simazine applications alone or tank-mixed with mesotrione reduced centipedegrass green cover 7 DAT when compared with the nontreated. Simazine at 0.25 lb/acre resulted in 24% green cover 7 DAT, whereas simazine rates greater than 0.25 lb/acre resulted in less than 15% centipedegrass green cover. Gannon et al. (2004) reported that newly seeded centipedegrass cover was not reduced when simazine was applied at 1.1 to 2.2 kg·ha^{-1} (0.98 to 1.96 lb/acre) at seeding. Established centipedegrass cover was not reduced by rates of simazine as high as 3.0 lb/acre when sprayed postemergence (Turner et al., 1990). Our study differs from Gannon et al. (2004) and Turner et al. (1990) in that we treated seedling centipedegrass, not before seedling emergence or to established centipedegrass. Mesotrione tank-mixed with 0.25 lb/acre simazine resulted in similar percent green cover (19%) as simazine 0.25 lb/acre applied alone (24%) 7 DAT. Mesotrione tank-mixed with rates of simazine greater than 0.25 lb/acre resulted in less than 13% green cover.

Nontreated centipedegrass green cover was 40% 14 DAT (Table 1). Simazine at 0.25 lb/acre and mesotrione plus simazine at 0.25 lb/acre resulted in similar centipedegrass green cover (32% and 24%, respectively) 14 DAT. Simazine at 0.50 lb/acre or higher, with and without mesotrione, reduced green cover to between 9% and 21% 14 DAT. Tank-mixture of mesotrione and simazine did not affect green cover greater than simazine alone at comparable rates; thus, simazine appears to have been the main factor contributing to green cover reduction.

Nontreated centipedegrass green cover was 75% 28 DAT. Unlike 7 and 14 DAT, mesotrione (0.25 lb/acre) and simazine (0.25 lb/acre) applied alone and tank-mixed resulted in similar green cover (66% to 77%) to the nontreated. Similar green cover of simazine-treated centipedegrass is likely due to recovery from PS II inhibition. Simazine is readily metabolized in corn (*Zea mays*) seedlings (Cherifi et al., 2001). The ability to metabolize atrazine and reduce the concentration at the active site is necessary for a plant's survival from atrazine exposure (Shimabukuro and Swanson, 1969). McElroy and Walker (2009) reported centipedegrass photochemical efficiency suppression by atrazine at 28 DAT, potentially indicating that centipedegrass seedlings do not metabolize atrazine as readily as corn seedlings. Further, simazine applied alone and tank-mixed at rates greater than 0.50 lb/acre continued to reduce centipedegrass green cover relative to the nontreated control. When applied alone and tank-mixed with mesotrione, simazine (1.00 and 2.00 lb/acre) resulted in less than 51% green cover 28 DAT. Few studies have directly compared simazine and atrazine metabolism in plants. One such study (Thompson, 1972) reported faster metabolism of atrazine in sweet sorghum (*Sorghum bicolor*) than simazine. Such differences in metabolism may explain the observed injury from simazine.

Nontreated centipedegrass green cover was 92% 49 DAT. Centipedegrass green cover was similar for mesotrione-alone (0.25 lb/acre), simazine-alone (0.25, 0.50, and 1.00 lb/acre), and mesotrione plus simazine (0.25 and 0.25 lb/acre), providing 82% to 90% green cover. Simazine applied alone and tank-mixed with mesotrione at rates greater than 1.00 lb/acre continued to reduce centipedegrass to less than 80% green cover 49 DAT. Although a decrease in cover was observed with these treatments, the potential increase in weed control from synergistic mixtures of triazines and mesotrione may be tolerable under high weed pressure scenarios.

Orthogonal contrast statements demonstrate a strong linear relationship between increasing rates of simazine and lower green cover values at each rating date ($P < 0.001$) (Table 2). Likewise, tank-mixing simazine and mesotrione demonstrated a strong linear relationship between increasing rates of simazine and decreased green cover 14, 28, and 49 DAT ($P < 0.001$). Willis et al. (2007) found that tank-mixing mesotrione (0.25 lb/acre) and simazine (2.00 lb/acre) provided excellent control of white clover on established bermudagrass (*Cynodon dactylon*). Tank-mixing mesotrione and simazine controlled weeds better than spraying two separate applications for each herbicide in bermudagrass and corn (Johnson and Young, 2002; Stephenson et al., 2004; Willis et al., 2007).

Tank-mixing simazine (0.50, 1.00, and 2.00 lb/acre) and mesotrione (0.25 lb/acre) reduced turf green cover compared with nontreated centipedegrass but was comparable to equal rates of simazine alone. These results demonstrate that simazine tank-mixture was the main factor in green cover reduction. Gannon et al. (2004) reported simazine applied at 1.1 to 2.2 kg·ha^{-1} (0.98 to 1.96 lb/acre) did not reduce established seeded centipedegrass cover; however, our results indicate that newly established centipedegrass is more vulnerable to green cover reduction because of simazine. Mesotrione tank-mixed with low rates of simazine is a viable option for newly seeded centipedegrass weed control; however, green cover of turf may be delayed, thus potentially delaying sod harvest and decreasing the wear tolerance of the juvenile turfgrass stand.

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