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Goosegrass Control and Turfgrass Injury Following Metribuzin and Topramezone Application with Immediate Irrigation

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***Abstract*. Goosegrass (*Eleusine indica* L. Gaertn.) is a problematic C_4 weedy grass species, occurring in the warmer regions of the world where it is difficult to selectively control without injuring the turfgrass. Furthermore, control efficacy is affected by plant maturity. End-user options for satisfactory goosegrass control has decreased; thus, the need for developing management techniques to improve the selectivity of POST goosegrass control options in turfgrass systems is ever increasing. One possible means of providing control, yet maintaining turf quality is immediately incorporating applied products via irrigation. Greenhouse and field trials were conducted in Pickens County, SC, with the objectives of 1) evaluating turfgrass injury following use of POST goosegrass control options; 2) assessing if irrigating (0.6 cm) immediately following the herbicide application reduces injury of 'Tifway 419' bermudagrass [*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* Burtt-Davy]; and 3) determining if immediate irrigation influences goosegrass control at one- to three-tiller and mature growth stage. Following the application of herbicide treatments, irrigation was applied (+) or not applied (−). Treatments included the following: control (+/− irrigation); topramezone at 12.3 g a.i./ha (+/− irrigation); metribuzin at 420 g a.i./ha (+/− irrigation); and topramezone plus metribuzin (+/− irrigation) at 12.3 and 420 g a.i./ha. Irrigation treatment had minimum effect on greenhouse-grown goosegrass biomass, all treatments provided >85% control of 1- to 3-tiller goosegrass plants. However, control for mature plants was <50% for topramezone- and 60% to 70% for metribuzin-containing treatments. In field studies, at 1 week after treatment (WAT), the irrigated metribuzin and topramezone plus metribuzin had ≈37% and ≈16%, respectively, less goosegrass control vs. nonirrigated treatments. At 2WAT, irrigated metribuzin and irrigated topramezone plus metribuzin–treated plots, had ≈50% less mature goosegrass control vs. nonirrigated treatments. Irrigated herbicide treatments, however, experienced ≈23% less turfgrass injury at this time. At 4 WAT, irrigated metribuzin- and irrigated topramezone plus metribuzin–treated plots experienced reduced mature goosegrass control by ≈65% and ≈59%, respectively. Overall, incorporating POST herbicide applications via 0.6 cm of irrigation reduced turfgrass injury by at least 20% for all herbicide treatments, while maintaining goosegrass control.**

Goosegrass (*Eleusine indica* L. Gaertn.) is a problematic C_4 weedy grass species throughout the warmer regions of the world (Lee and Ngim, 2000; McCullough et al., 2016; Mudge et al., 1984). Nishimoto and McCarty (1997) noted optimal (99%) germination with fluctuating temperatures; 20 °C for 16 h and 35 °C for 8 h with supplemental light. Kerr et al. (2018) noted goosegrass life cycle was complete 68 d after emergence in late-summer/early autumn in Clemson, SC. Typically, goosegrass plants are killed with the first frost; however, in the tropical regions of the world, plants continue to tiller year round and behave more like a perennial. Also, seeds germinate year round, resulting in varying aged goosegrass plants, and inconsistent PRE and POST control efficacy.

Goosegrass control efficacy is effected, among other variables by the maturity of the plant. Previous research noted a reduction in control at the one- to two-tiller and four- to six-tiller growth stage, compared with the two- to four-leaf growth stage (Burke et al., 2005). McCarty (1991) noted differences in goosegrass control with diclofop based on goosegrass mowing height. Greatest control was achieved on goosegrass maintained at 1.3 cm, compared with higher heights or unmown. The addition of metribuzin with diclofop improved control efficacy of mature goosegrass plants.

End-user options for goosegrass control efficacy while maintaining acceptable turfgrass quality has decreased over the past decade or so, due to reduced performance for certain herbicides (e.g., foramsulfuron), specific goosegrass herbicides (e.g., diclofop-methyl) being removed from the market, and the removal and/or severe use reductions of other herbicides (e.g., monosodium methanearsonate). Current goosegrass control options (e.g., topramezone, metribuzin) also have activity on warm-season turfgrass, often resulting in unacceptable injury. Developing management techniques to improve the selectivity of POST herbicides provides end-users more options for effective goosegrass control. Possible means of obtaining control, yet maintaining turf quality is immediately incorporating applied products via irrigation. Because metribuzin and topramezone have some or all root absorption, this strategy is hypothesized to provide desired goosegrass control, yet minimizing undesirable turfgrass injury (Abusteit et al., 1985; Elmore et al., 2011). The objectives of the trials were 1) evaluate turfgrass injury following use of POST goosegrass control options; 2) assess if irrigating immediately following the herbicide application reduces injury of 'Tifway 419' bermudagrass [*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* Burtt-Davy]; and 3) evaluate if immediate irrigation influences goosegrass control at one- to three-tiller and mature growth stage.

Materials and Methods

Greenhouse experiments. Goosegrass seeds were collected from a low turf maintenance site, The Cherry Farm at Clemson University, Clemson, SC (lat. 34.65°N, long. 82.84°W) on 25 Oct. 2016 and stored at 4 °C. Seeds were sown in 1020 NCR trays (Landmark Plastic Corporation, Akron, OH) filled with a sterile growing medium (Farfard Growing Mix 3B; Sun Gro Horticulture, Agawam, MA). Trays were placed on a misting bench for 10 d to promote germination. Once plants emerged and matured to a two-leaf stage, seedlings were transplanted (one plant per pot) to 10 cm × 9 cm greenhouse pots (Landmark Plastic

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Corporation) filled with a sterile growing medium (Farfard Growing Mix 3B; Sun Gro Horticulture). Plants were grown until the 1- to 3-tiller growth stage or mature with seedheads growth stage; thereafter, treatments were applied (Table 1).

The experiment was arranged as a randomized complete block design with four replications, each block consisted of eight goosegrass plants (one plant per pot), for a total of 32 plants. Blocking was used to eliminate any spatial effect within the greenhouse. Two experimental runs were conducted, Oct. to Mar. 2016–17 and 2017–18. For both experimental runs, maximum and minimum temperatures were 30 °C and 23 °C, respectively. Light intensity was at 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ with a 14-h photoperiod, via supplemental lighting. Plants were subirrigated to prevent moisture stress. Plants were not clipped and no supplemental fertility was added for the duration of the study.

Treatments included the following: control (± irrigation); topramezone (Pylex Herbicide 2.8C; BASF Corporation, Research Triangle, NC) at 12.3 g a.i./ha (± irrigation); metribuzin (Sencor 75DF; Bayer Crop Science, St. Louis, MO) at 420 g a.i./ha (± irrigation); and topramezone plus metribuzin (± irrigation) at 12.3 and 420 g a.i./ha (Table 1). All treatments were mixed with a nonionic surfactant (NIS) (Induce; Helena Chemical, Collierville, TN; at 0.25% v/v). Herbicides were applied using a pressurized CO_2 backpack boom sprayer with a water carrier volume of 187 $L \cdot ha^{-1}$ through 8003 flat-fan nozzles (Tee jet; Spraying Systems Co., Roswell, GA). Irrigated treatments were applied immediately with a volume of water in a beaker precalibrated to apply 0.6 cm. Additional irrigation was withheld from the treated pots for 48 h.

At 4 WAT, aboveground biomass was destructively harvested and plant material placed into paper bags and oven dried at 80 °C for 72 h. At the completion of the drying period, plant material was weighed to determine biomass.

Field experiments. Two field studies were conducted during Aug. 2017 and Aug. 2018 in Pickens County, SC on 'Tifway 419' bermudagrass golf course fairways infested with goosegrass plants (>80%). Fairways were mown three times weekly at 13 mm and soil type was a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) with a pH of 5.6 and organic matter of 1.2%.

The experiment was arranged as a randomized complete block design with four replications, plots were 1.5 m × 2.0 m. Treatments included control (± irrigation); topramezone (Pylex 2.8C) at 12.3 g a.i./ha (± irrigation); metribuzin (Sencor 75DF) at 420 g a.i./ha (± irrigation); and topramezone plus metribuzin at 12.3 and 420 g a.i./ha (± irrigation) (Table 1). All treatments were mixed with an NIS (Induce; at 0.25% v/v). Herbicides were applied using a pressurized CO_2 backpack boom sprayer with a water carrier volume of 187 $L \cdot ha^{-1}$ through 8003 flat-fan nozzles (Tee jet; Spraying Systems Co.). Irrigated treatments were applied immediately with a hand hose precalibrated to apply 0.6 cm. Additional irrigation was withheld from the treated plots for 48 h. No supplemental fertility was added for the duration of the study. Ratings occurred 3 d after treatment (DAT), 1 WAT, 2 WAT, and 4 WAT. Plots were rated visually for turfgrass injury (scale of 0% to 100%, with 100 = dark green dense turfgrass, 0 = dead/brown turfgrass, and 30 = minimally acceptable turfgrass) and goosegrass control (0 = no control, 100 = complete control).

Statistical analysis. The SAS statistical software package JMP Pro 13 (SAS Institute Inc., Cary, NC) was used for analysis of variance (ANOVA) and means separation on all data sets. The ANOVA was used to evaluate the main effects of herbicide, irrigation, and growth stage, as well as the interactions. When the main effects or interactions were significant, Tukey's honestly significant difference test ($\alpha = 0.05$) was used to separate means. Data were analyzed individually for each evaluation date.

Table 1. Irrigation, herbicides, formulations, and rates used in two field experiments and two greenhouse experiments in Pickens County, SC, from Oct. 2016 to Aug. 2018.

Irrigation[z]	Trade name[y]	Common name	Rate (g a.i./ha)
Yes	Nontreated control	—	—
Yes	Pylex 2.8C	Topramezone	12.3
Yes	Sencor 75DF	Metribuzin	420
Yes	Pylex 2.8C + Sencor 75DF	Topramezone + metribuzin	12.3 + 420
No	Nontreated control	—	—
No	Pylex 2.8C	Topramezone	12.3
No	Sencor 75DF	Metribuzin	420
No	Pylex 2.8C + Sencor 75DF	Topramezone + metribuzin	12.3 + 420

[z]Irrigation applied to a depth of 0.6 cm immediately following treatment.
[y]All treatments were mixed with a nonionic surfactant (Induce; Helena Chemical, Collierville, TN) at 0.25% v/v.

Table 2. Goosegrass control in the greenhouse based on aboveground biomass at 4 weeks after treatment (4 WAT), data combined as irrigation were not significant. Herbicide applications made at two growth stages: 1 to 3 tiller and mature with seedheads.

		Aboveground biomass[z]	
	Rate	1 to 3 Tiller	Mature
Treatment	g a.i./ha	g	
Control	—	1.6 c	4.6 a
Topramezone	12.3	0.2 d	2.6 b
Metribuzin	420	0 d	1.6 c
Topramezone + metribuzin	12.3 + 420	0 d	1.4 c

[z]Means with the same letter within the same column are not statistically different based on Tukey's honestly significant difference test ($\alpha = 0.05$).

Table 3. Goosegrass control in the field on a percentage basis in response to herbicide (treatment effect) and irrigation (yes or no) at 0.6 cm immediately following herbicide application. Ratings occurred 3 d after treatment (3 DAT) and 1 week after treatment (1 WAT).

		Goosegrass control[z]			
		3 DAT		1 WAT	
	Rate	Yes	No	Yes	No
Treatment	g a.i./ha	%			
Topramezone	12.3	2 b	2 b	31 d	39 cd
Metribuzin	420	0 b	5 b	49 c	86 ab
Topramezone + metribuzin	12.3 + 420	0 b	12 a	72 b	88 a

[z]Means with the same letter within the same rating date are not statistically different based on Tukey's honestly significant difference test ($\alpha = 0.05$).

Table 4. Goosegrass control in the field on a percent basis at two growth stages (1 to 3 tiller and mature with seedheads) and the effect of irrigation (yes or no), data combined across herbicide treatments. Ratings occurred 1 week after treatment.

	Goosegrass control[z]	
	1 to 3 tiller	Mature
Irrigation	%	
Yes	39 bc	37 c
No	48 b	59 a

[z]Means with the same letter are not statistically different based on Tukey's honestly significant difference test ($\alpha = 0.05$).

Results and Discussion

Experimental run per year was analyzed statistically and visually for effects, and no significant effect was detected. Experimental run per year by treatment was analyzed statistically and visually for effects, and no significant interaction was detected; thus, data were combined. Experimental run per year was not part of the statistical model for data analysis of the greenhouse or field studies. Each sampling date was analyzed separately for effects.

Greenhouse experiments. Immediate irrigation had no effect on goosegrass aboveground biomass at 4 WAT. However, based on aboveground biomass, the interaction of treatment by plant growth stage was significant at 4 WAT. Compared with nontreated plants, for the mature growth stage, metribuzin alone and topramezone plus metribuzin reduced biomass ≈67%, topramezone alone reduced biomass ≈43% (Table 2). Compared with nontreated plants, for the 1- to 3-tiller growth stage, metribuzin alone and topramezone plus metribuzin reduced biomass ≈100%, topramezone alone reduced biomass ≈89% (Table 2). Cox et al. (2017) noted topramezone alone at 12.3 g a.i./ha reduced goosegrass biomass 40%.

Field experiments. The interaction of treatment by irrigation for goosegrass control in the field was significant at 3 DAT and 1 WAT (Table 3). At 3 DAT, nonirrigated topramezone plus metribuzin treatment had the highest goosegrass control (≈12%) (Table 3). At 1 WAT, nonirrigated topramezone plus metribuzin–treated plots had highest control (≈88%), followed by nonirrigated metribuzin (≈86%), irrigated topramezone plus metribuzin (≈72%), irrigated metribuzin (≈49%), nonirrigated topramezone (≈39%), and irrigated topramezone (≈31%) (Table 3). For metribuzin- and topramezone plus metribuzin–treated plots, irrigation reduced goosegrass control by ≈37% and ≈16%, respectively (Table 3).

The interaction of growth stage by irrigation for goosegrass control in the field was significant at 1 WAT (Table 4). The mature nonirrigated plots had highest control (≈59%), followed by 1- to 3-tiller nonirrigated (≈48%), 1- to 3-tiller irrigated (≈39%), and mature irrigated (≈37%) (Table 4).

The interaction of treatment by growth stage for goosegrass control in the field was significant at 1 WAT (Table 5). The mature topramezone plus metribuzin–treated plots (≈88%) and 1- to 3-tiller topramezone plus metribuzin–treated plots (≈79%) had highest control; followed by 1- to 3-tiller metribuzin (≈74%), mature metribuzin (≈62%), mature topramezone (≈49%), and 1- to 3-tiller topramezone (≈21%) (Table 5). Nishimoto and Murdoch (1999) noted metribuzin applied at 280 and 560 g a.i./ha controlled mature goosegrass 7 WAT 30% and 53%, respectively. In the present study, nonirrigated metribuzin applied at 420 g a.i./ha controlled mature goosegrass ≈62% 1 WAT (Table 5), ≈86% 2 WAT (Table 4), and ≈73% 4 WAT (Table 4).

The interaction of treatment by irrigation by growth stage was significant at 2 WAT and 4 WAT (Table 6). At 2 WAT, the nonirrigated mature topramezone plus metribuzin (≈100%), the nonirrigated 1-to 3-tiller topramezone plus metribuzin (≈100%), the nonirrigated 1- to 3-tiller metribuzin (≈100%), the irrigated 1- to 3-tiller topramezone plus metribuzin (≈100%), the irrigated 1- to 3-tiller metribuzin (≈99%), and the nonirrigated 1- to 3-tiller topramezone–treated plots (≈81%) had highest control (Table 6). At 4 WAT, goosegrass control trends were similar as 2 WAT; however, 1- to 3-tiller topramezone alone nonirrigated improved to complete control (≈100%) (Table 6).

Turfgrass injury. The main effects of treatment and irrigation for turfgrass injury were significant at 2 WAT. The main effect of treatment for turfgrass injury at 2WAT was highest for topramezone plus metribuzin (≈61%) and topramezone alone (≈51%), followed by metribuzin alone (≈7%) (Table 7). The main effect of irrigation for turfgrass injury at 2 WAT was highest for nonirrigated plots (≈41%), followed by irrigated plots (≈18%) (Table 8). By irrigating the herbicides immediately after application, visual turfgrass injury was reduced by ≈23%.

The interaction of treatment by irrigation for turfgrass injury was significant at 3 DAT, 1 WAT, and 4 WAT. At 3 DAT, the nonirrigated topramezone plus metribuzin–treated plots had highest injury (≈14%) followed by nonirrigated metribuzin-treated plots (≈10%) (Table 9). At 1 WAT, the nonirrigated topramezone plus metribuzin–treated plots had the highest injury (≈82%), followed by nonirrigated topramezone alone (≈53%), nonirrigated metribuzin alone (≈38), and irrigated topramezone plus metribuzin (≈22%) (Table 9) (Armel et al., 2007). At 4 WAT, nonirrigated topramezone alone–treated plots had highest injury (≈21%) (Table 9). The injury by topramezone alone noted in the present study is supported by previous research. Breeden et al. (2017) noted turfgrass injury for nonirrigated topramezone alone of 34% (1 WAT), 43% (2 WAT), and 1% (4 WAT). In

Table 5. Goosegrass control in the field on a percent basis in response to herbicide (treatment effect) and growth stage (1 to 3 tiller and mature with seedheads), data combined for irrigation treatments. Ratings occurred 1 week after treatment.

Treatment	Rate (g a.i./ha)	Goosegrass Control[z] 1 to 3 Tiller (%)	Goosegrass Control[z] Mature (%)
Topramezone	12.3	21 d	49 c
Metribuzin	420	74 ab	62 bc
Topramezone + metribuzin	12.3 + 420	79 a	81 a

[z]Means with the same letter are not statistically different based on Tukey's honestly significant difference test (α = 0.05).

Table 6. Goosegrass control in the field on a percent basis in response to herbicide (treatment effect), irrigation (yes or no), and growth stage (1 to 3 tiller and mature with seedheads). Ratings occurred 2 weeks after treatment (2 WAT) and 4 weeks after treatment (4 WAT).

			Goosegrass control[z]			
			2 WAT		4 WAT	
Treatment	Rate (g a.i./ha)	Irrigation	1 to 3 Tiller (%)	Mature (%)	1 to 3 Tiller (%)	Mature (%)
Topramezone	12.3	Yes	43 c	43 c	54 bc	20 de
Metribuzin	420	Yes	99 ab	33 c	100 a	8 e
Topramezone + metribuzin	12.3 + 420	Yes	100 a	51 c	100 a	41 cd
Topramezone	12.3	No	81 ab	78 b	100 a	66 bc
Metribuzin	420	No	100 a	86 ab	100 a	73 ab
Topramezone + metribuzin	12.3 + 420	No	100 a	100 a	100 a	100 a

[z]Means with the same letter within the same column are not statistically different based on Tukey's honestly significant difference test (α = 0.05).

Table 7. Turfgrass injury in the field on a percent basis in response to herbicide (treatment effect), data combined across irrigation treatment. Ratings occurred 2 weeks after treatment.

Treatment	Rate (g a.i./ha)	Turf injury[z] (%)
Topramezone	12.3	51 a
Metribuzin	420	7 b
Topramezone + metribuzin	12.3 + 420	61 a

[z]Means with the same letter are not statistically different based on Tukey's honestly significant difference test (α = 0.05).

Table 8. Turfgrass injury in the field on a percent basis in response to irrigation (yes or no), data combined across herbicide treatments. Ratings occurred 2 weeks after treatment.

Irrigation	Turf injury[z] (%)
Yes	18 b
No	41 a

[z]Means with the same letter are not statistically different based on Tukey's honestly significant difference test (α = 0.05).

Table 9. Turfgrass injury in the field on a percent basis in response to herbicide (treatment effect) and irrigation (yes or no). Ratings occurred 3 d after treatment (3 DAT), 1 week after treatment (1 WAT), and 4 weeks after treatment (4 WAT).

			Turfgrass injury[z]		
	Rate		3 DAT	1 WAT	4 WAT
Treatment	g a.i./ha	Irrigation		%	
Topramezone	12.3	Yes	1 c	11 d	1 b
Metribuzin	420	Yes	0 c	0 d	0 b
Topramezone + metribuzin	12.3 + 420	Yes	1 c	22 cd	4 ab
Topramezone	12.3	No	4 bc	53 b	21 a
Metribuzin	420	No	10 ab	38 bc	0 b
Topramezone + metribuzin	12.3 + 420	No	14 a	82 a	8 ab

[z]Means with the same letter within the same column are not statistically different based on Tukey's honestly significant difference test ($\alpha = 0.05$).

the present study, nonirrigated topramezone alone–treated plots had higher turfgrass injury at 4 WAT (21%); however, this is deemed acceptable turfgrass injury (≤30%). Cox et al. (2017) noted similar turfgrass injury as the present study at 1 WAT and 4 WAT for nonirrigated topramezone-alone treatments.

In conclusion, no reduction in goosegrass control based on biomass reduction occurred in greenhouse studies. In field studies, a reduction in goosegrass control for irrigated herbicide treatments occurred, although reasonable (>50%) control efficacy was achieved. Goosegrass growth stage in the present studies affected results, as mature goosegrass plants were more difficult to control. Good to complete control for all irrigated herbicide treatments occurred when goosegrass was at the 1- to 3-tiller growth stage. Incorporating POST herbicide applications via 0.6 cm of irrigation reduced turfgrass injury by at least 20% for all herbicide treatments. End-users should irrigate POST herbicide applications to reduce turfgrass injury. If goosegrass plants are mature, a second application 2 to 3 weeks after the initial application will improve control efficacy.

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