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Immediate Irrigation Improves Turfgrass Safety to Postemergence Herbicides

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***Abstract*. Summer annual grassy weeds such as goosegrass (*Eleusine indica* L. Gaertn.) continue to be problematic to control selectively with postemergence (POST) herbicides within turfgrass stands. In recent years, reduced performance by certain herbicides (e.g., foramsulfuron), cancellation of goosegrass-specific herbicides (e.g., diclofop-methyl), and cancellation and/or severe use reductions of other herbicides [e.g., monosodium methanearsonate (MSMA)] have limited the options for satisfactory control and maintenance of an acceptable (≤30% visual turfgrass injury) turfgrass quality. Currently available herbicides (e.g., topramezone and metribuzin) with goosegrass activity typically injure warm-season turfgrass species. The objectives of this research were to evaluate both 'Tifway 419' bermudagrass [*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* Burtt-Davy] injury after treatment with POST herbicides, and to determine whether irrigating immediately after application reduces turfgrass injury. Treatments were control (± irrigation); topramezone (Pylex 2.8C; ± irrigation); carfentrazone + 2,4-D + dicamba + 2-(2-methyl-4-chlorophenoxy) propionic acid (MCPP) (Speedzone 2.2L; ± irrigation); carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone (± irrigation); metribuzin (Sencor 75DF; ± irrigation); mesotrione (Tenacity 4L; ± irrigation); simazine 4L (±irrigation); and mesotrione + simazine (± irrigation). Irrigated treatments were applied immediately with a hand hose precalibrated to apply 0.6 cm or 0.25 inch (≈6.3 L). Visual turfgrass injury for combined herbicide treatments for the irrigated plots was 6% 4 days after treatment (DAT), 12% 1 week after treatment (WAT), 17% 2 WAT, and 6% 4 WAT, whereas nonirrigated plots had turfgrass injury of 14% at 4 DAT, 31% 1 WAT, 35% 2 WAT, and 12% 4 WAT. Irrigated pots had normalized differences vegetative indices (NDVI) ratings of 0.769 at 4 DAT, 0.644 at 1 WAT, 0.612 at 2 WAT, and 0.621 at 4 WAT, whereas nonirrigated plots had the lowest (least green) turfgrass NDVI ratings of 0.734 at 4 DAT, 0.599 at 1 WAT, 0.528 at 2 WAT, and 0.596 at 4 WAT. These experiments suggest turfgrass injury could be alleviated by immediately incorporating herbicides through irrigation.**

Goosegrass (*Eleusine indica* L. Gaertn.), a weedy C_4 grass species throughout much of the world, is problematic to control selectively with POST herbicides within 'Tifway 419' bermudagrass [*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* Burtt-Davy] stands (Lee and Ngim, 2000; McCullough et al., 2016; Mudge et al., 1984). Classified botanically as a summer annual, goosegrass plants are eradicated by the first killing frost. However, in tropical regions, goosegrass behaves like a perennial, continuing to tiller year-round as a result of the lack of frost. Also in tropical regions, year-round seed germination leads to plants with varying maturity, resulting in inconsistent preemergence (PRE) and POST control efficacy.

In recent years, reduced performance by certain herbicides (e.g., foramsulfuron), cancellation of goosegrass-specific herbicides (e.g., diclofop-methyl), and cancellation and/or severe use reductions of other herbicides (e.g., MSMA) have limited the options end users have for satisfactory control and maintenance of acceptable turfgrass quality. Currently available herbicides (e.g., topramezone, metribuzin) with activity on goosegrass also often result in unacceptable injury (bleaching) to the desirable turfgrass species. Developing management techniques to reduce turfgrass injury while maintaining herbicide efficacy is imperative for effective POST control of goosegrass within turfgrass stands. Immediately incorporating products via irrigation, or tank-mixing products such as chelated iron (Fe), could reduce turf injury while maintaining control efficacy. The current study focused on turfgrass injury only. Kerr and McCarty (2017) noted little reduction in goosegrass control efficacy of topramezone and carfentrazone + 2,4-D + dicamba + MCPP when irrigated immediately at the same rates used in the current study.

Topramezone (Pylex Herbicide 2.8C; BASF Corporation, Research Triangle Park, NC) and mesotrione (Tenacity 4L; Syngenta Professional Products, Greensboro, NC) are 4-hydroxyphenylpyruvate dioxygenase inhibitors absorbed through roots and shoots (Brosnan et al., 2014; Elmore et al., 2011a). Simazine (Princep 4L; Syngenta Professional Products, Greensboro, NC) and metribuzin (Sencor 75DF; Bayer Crop Science, Research Triangle Park, NC) are photosynthetic (PSII) inhibitors (Nimbal et al., 1996). Simazine is absorbed through the roots; metribuzin is absorbed mostly through the roots (Abusteit et al., 1985; Sheets, 1961). Carfentrazone-ethyl (shoot-absorbed) plus 2,4-D (root-absorbed) plus dicamba (root- and shoot-absorbed) plus mecoprop (mostly root-absorbed) (Speedzone 2.2L; PBI Gordon, KS City, MO) is effective for the control of many broadleaf weeds and goosegrass—the only grassy weed listed on the label (http://www.cdms.net/ldat/ld61R001.pdf) (Beck et al., 2014). The site of herbicide uptake is an important factor to consider when developing techniques to reduce turfgrass injury. If an herbicide is shoot-absorbed, immediate irrigation will most likely remove a certain amount of product, thus possibly reducing efficacy. If an herbicide is fully or partly root-absorbed, immediate irrigation could potentially reduce turfgrass injury while maintaining desirable weed control efficacy.

The objectives of the trials were 1) to evaluate turfgrass injury after the use of POST goosegrass control options and 2) to assess whether irrigating immediately after herbicide application reduces turfgrass injury on mature stands of 'Tifway 419' bermudagrass [*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* Burtt-Davy].

Materials and Methods

Two field sites were used in these experiments: the Walker Golf Course, Clemson University, Clemson, SC; and the Auburn Sports Surface Field Laboratory, Auburn University, Auburn, AL. In 2017, the Clemson University trial site received 25 kg N/ha in May and 12.5 kg N/ha in August. The site was mowed weekly at 25 mm with no other herbicides, fungicides, or plant growth regulators applied. In 2017, the Auburn University trial site received 25 kg N/ha on 4 Apr., 20 kg N/ha on 24 Apr., and 2.5 kg N/ha and 0.59 L/ha trinexapac-ethyl (Primo Maxx, Syngenta Professional Products, Greensboro, NC) on 13 and 27 June, 11 and 25 July, 7 and 22 Aug. Fertilizer was applied at both trial sites using the nitrate source N20–4.4P–16.6K (Harrell's Turf Specialty, Inc., Lakeland, FL). The trial area was mowed three times weekly at 13 mm. No other herbicides or fungicides were applied during the 2017

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Table 1. Irrigation, herbicides, formulations, and rates used in two experiments: one in Clemson, SC, and one in Auburn, AL, 2017.

Irrigation[z]	Trade name[y]	Common name	Rate (kg a.i./ha)
Yes	Untreated control	—	—
Yes	Pylex 2.8C	Topramezone	0.0123
Yes	Speedzone	Carfentrazone + 2,4-D + dicamba + MCPP	0.5
Yes	Speedzone 2.2 L + Pylex 2.8C	Carfentrazone + 2,4-D + dicamba + MCPP + topramezone	0.5 + 0.0123
Yes	Sencor 75DF	Metribuzin	0.42
Yes	Tenacity 4L	Mesotrione	0.28
Yes	Princep 4L	Simazine	0.87
Yes	Tenacity + Princep 4L	Mesotrione + simazine	0.28 + 0.87
No	Untreated control	—	—
No	Pylex 2.8C	Topramezone	0.0123
No	Speedzone	Carfentrazone + 2,4-D + dicamba + MCPP	0.5
No	Speedzone 2.2 L + Pylex 2.8C	Carfentrazone + 2,4-D + dicamba + MCPP + topramezone	0.5 + 0.0123
No	Sencor 75DF	Metribuzin	0.42
No	Tenacity 4L	Mesotrione	0.28
No	Princep 4L	Simazine	0.87
No	Tenacity + Princep 4L	Mesotrione + simazine	0.28 + 0.87

[z]Irrigation applied to a depth of 0.66 cm (0.25 inch) immediately after treatment.
[y]All treatments were mixed with a nonionic surfactant (Induce®; Helena Chemical, Collierville, TN) at 0.25% v/v in 2-L bottles.
MCPP = 2-(2-methyl-4-chlorophenoxy) propionic acid.

Table 2. Visual turfgrass injury on a percentage basis in response to herbicide treatments (treatment effect) and immediate irrigation (irrigation effect) in Clemson, SC, and Auburn, AL, 2017.

		Turfgrass injury (%)[z]			
	kg a.i./ha	4 DAT	1 WAT	2 WAT	4 WAT
Treatment[y]					
Control	—	0 c	0 e	0 e	0 b
Topramezone	0.0123	9 b	48 a	81 a	28 a
Carfentrazone + 2,4-D + dicamba + MCPP	0.5	13 ab	13 cd	13 d	5 b
Carfentrazone + 2,4-D + dicamba + MCPP + topramezone	0.5 + 0.0123	17 a	40 a	60 b	19 a
Metribuzin	0.42	18 a	21 bc	8 de	6 b
Mesotrione	0.28	8 b	16 cd	11 d	3 b
Simazine	0.87	8 b	10 d	12 d	7 b
Mesotrione + simazine	0.28 + 0.87	9 b	25 b	27 c	8 b
P value		<0.0001	<0.0001	<0.0001	<0.0001
Irrigation					
Yes		6 b	12 b	17 b	6 b
No		14 a	31 a	35 a	12 a
P value		<0.0001	<0.0001	<0.0001	<0.0001

[z]Means with the same letter within the same column are not statistically different based on Tukey's honestly significant difference test ($\alpha = 0.005$).
[y]All treatments were mixed with a nonionic surfactant (Induce®; Helena Chemical, Collierville, TN) at 0.25% v/v in 2-L bottles.
DAT = days after treatment; WAT = weeks after treatment; MCPP = 2-(2-methyl-4-chlorophenoxy) propionic acid.

growing season. Except for specific irrigation timing treatments, both sites were irrigated normally to prevent moisture stress.

Four replications of 1-m × 1-m plots were used in a randomized complete block design. Treatments were control (± irrigation); topramezone (Pylex 2.8C, ± irrigation); carfentrazone + 2,4-D + dicamba + MCPP (Speedzone 2.2L, ± irrigation); carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone (± irrigation); metribuzin (Sencor 75DF, ± irrigation); mesotrione (Tenacity 4L, ± irrigation); simazine (Princep 4L, ± irrigation); and mesotrione + simazine (± irrigation) (Table 1). All treatments were mixed with a nonionic surfactant (Induce®; Helena Chemical, Collierville, TN) at 0.25% v/v in 2-L bottles. Herbicides were applied 14 Aug. 2017 using a pressurized carbon dioxide backpack boom sprayer with a water carrier volume of 187 L/ha through 8003 flat-fan nozzles (Tee jet; Spraying Systems Co., Roswell, GA). Irrigated treatments were applied immediately with a hand hose pre-calibrated to apply 0.6 cm or 0.25 inch (≈6.3 L).

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 NDVI. The measurement of NDVI was calculated as

$$\mathrm{NDVI} = \frac{R_{935} - R_{661}}{R_{935} + R_{661}},$$

where R_{935} is the reflectance of near-infrared radiation at 935 nm and R_{661} is the reflectance of visible red radiation at 661 nm (Bremer et al., 2011; Trenholm et al., 1999) (Greenseeker Handheld Crop Sensor; Trimble Navigation Limited, Westminster, CO). Plots were rated at 4 DAT, 1 WAT, 2 WAT, and 4 WAT.

Analysis of variance and means separation were performed on all data sets using the SAS statistical software package JMP Pro 13.2 (SAS Institute Inc., Cary NC). Data were analyzed individually for each evaluation date. Significant means were separated using Tukey's honestly significant difference test ($P = 0.05$).

Results and Discussion

Location was analyzed statistically and visually for effects. No significant effect was detected and the data were combined. Location was not part of the statistical model for data analysis of the visual turfgrass injury or NDVI ratings. The main irrigation effect for visual turfgrass injury across all herbicide treatments was significant ($P < 0.0001$) at 4 DAT, 1 WAT, 2 WAT, and 4 WAT (Table 2). At 4 DAT, nonirrigated plots experienced the greatest injury (14%), followed by irrigated plots (6%) (Table 2). At 1 WAT, nonirrigated plots experienced the greatest injury (31%), followed by irrigated plots (12%) (Table 2). At 2 WAT, nonirrigated plots experienced the greatest injury (35%), followed by irrigated plots (17%) (Table 2). At 4 WAT, nonirrigated plots experienced the greatest injury (12%), followed by irrigated plots (6%) (Table 2).

The main herbicide treatment effect for irrigated and nonirrigated visual turfgrass injury was significant ($P < 0.0001$) at 4 DAT, 1 WAT, 2 WAT, and 4 WAT (Table 2). At 4 DAT, metribuzin and carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone-treated plots experienced the greatest injury (≈18%), followed by carfentrazone + 2,4-D + dicamba + MCPP alone (13%) (Table 2). At 1 WAT, topramezone-treated plots experienced the greatest injury (48%), followed by carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone (40%), and mesotrione plus simazine (25%) (Table 2). At 2 WAT, topramezone-treated plots experienced the greatest injury (81%), followed by carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone (60%) and mesotrione plus simazine (27%) (Table 2). At 4 WAT, topramezone-treated plots again experienced the greatest injury (28%), followed by carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone (19%) (Table 2).

Table 3. Visual turfgrass injury on a percentage basis in response to herbicide treatments (treatment effect) and immediate irrigation (irrigation effect) in Clemson, SC, and Auburn, AL, 2017.

		Turfgrass injury (%)[y]							
		4 DAT		1 WAT		2 WAT		4 WAT	
Treatment[z]	kg a.i./ha	Irrigated	Nonirrigated	Irrigated	Nonirrigated	Irrigated	Nonirrigated	Irrigated	Nonirrigated
Control	—	0 d	0 d	0 g	0 g	0 f	0 f	0 c	0 c
Topramezone	0.0123	8 cd	11 bcd	44 abc	51 a	74 a	88 a	14 bc	41 a
Carfentrazone + 2,4-D + dicamba + MCPP	0.5	5 cd	21 ab	3 g	23 ef	4 ef	21 cd	8 c	3 c
Carfentrazone + 2,4-D + dicamba + MCPP + topramezone	0.5 + 0.0123	7 cd	26 a	26 e	55 a	33 bc	87 a	12 c	27 ab
Metribuzin	0.42	9 cd	26 a	6 g	35 cde	1 ef	14 def	7 c	4 c
Mesotrione	0.28	2 cd	13 bc	2 g	29 de	4 ef	18 cde	3 c	3 c
Simazine	0.87	9 cd	7 cd	8 g	13 fg	14 def	11 def	6 c	8 c
Mesotrione + simazine	0.28 + 0.87	7 cd	11 bcd	8 g	42 bcd	9 def	45 b	3 c	13 bc
P value		<0.0001		<0.0001		<0.0001		<0.0001	

[z]All treatments were mixed with a nonionic surfactant (Induce®; Helena Chemical, Collierville, TN) at 0.25% v/v in 2-L bottles.
[y]Means with the same letter within the same column are not statistically different based on Tukey's honestly significant difference test (α = 0.005).DAT = days after treatment; WAT = weeks after treatment; MCPP = 2-(2-methyl-4-chlorophenoxy) propionic acid.

Table 4. Turfgrass injury ratings based on normalized differences vegetative indices (NDVI) in response to herbicide treatments (treatment effect) and immediate irrigation (irrigation effect) in Clemson, SC, and Auburn, AL, 2017.

		Turfgrass injury (NDVI)[z]			
	kg a.i./ha	4 DAT	1 WAT	2 WAT	4 WAT
Treatment[y]					
Control	—	0.781 a	0.681 ab	0.669 a	0.625 a
Topramezone	0.0123	0.735 ab	0.606 abc	0.442 d	0.546 b
Carfentrazone + 2,4-D + dicamba + MCPP	0.5	0.735 ab	0.620 abc	0.604 ab	0.611 ab
Carfentrazone + 2,4-D + dicamba + MCPP + topramezone	0.5 + 0.0123	0.716 b	0.582 c	0.484 cd	0.598 ab
Metribuzin	0.42	0.745 ab	0.576 c	0.590 abc	0.630 a
Mesotrione	0.28	0.758 ab	0.614 abc	0.590 abc	0.624 a
Simazine	0.87	0.774 a	0.690 a	0.662 a	0.625 a
Mesotrione + simazine	0.28 + 0.87	0.765 ab	0.602 bc	0.519 bcd	0.610 ab
P value		0.0108	0.0001	<0.0001	0.0257
Irrigation					
Yes		0.769 a	0.644 a	0.612 a	0.621 a
No		0.734 b	0.599 b	0.528 b	0.596 b
P value		0.0003	0.0017	<0.0001	0.0446

[z]Means with the same letter within the same column are not statistically different based on Tukey's honestly significant difference test (α = 0.005).
[y]All treatments were mixed with a nonionic surfactant (Induce®; Helena Chemical, Collierville, TN) at 0.25% v/v in 2-L bottles.
DAT = days after treatment; WAT = weeks after treatment; MCPP = 2-(2-methyl-4-chlorophenoxy) propionic acid.

The treatment-by-irrigation interaction was also significant ($P < 0.0001$) at 4 DAT, 1 WAT, 2 WAT, and 4 WAT (Table 3). At 4 DAT, carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone and metribuzin alone nonirrigated experienced the greatest injury (26%), followed by carfentrazone + 2,4-D + dicamba + MCPP nonirrigated (21%) (Table 3). At 1 WAT, plots with the greatest injury were carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone nonirrigated (55%) and topramezone alone nonirrigated (51%); followed by topramezone alone irrigated (44%), mesotrione plus simazine nonirrigated (41%), metribuzin nonirrigated (35%), and mesotrione nonirrigated (29%) (Table 3). At 2 WAT, plots with the greatest (≈88%) injury were topramezone nonirrigated and carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone nonirrigated, followed by topramezone irrigated (74%), mesotrione plus simazine nonirrigated (45%), and carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone irrigated (33%) (Table 3). At 4 WAT, plots with the greatest injury were topramezone nonirrigated (41%) and carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone nonirrigated (27%) (Table 3).

The main herbicide treatment effect for irrigated and nonirrigated NDVI turfgrass injury ratings was significant at 4 DAT, 1 WAT, 2 WAT, and 4 WAT (Table 4). At 4 DAT, plots treated with carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone had the lowest (least-green) NDVI rating (0.716) (Table 4). At 1 WAT, the lowest NDVI ratings were for carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone (0.582) and metribuzin (0.576). At 2 WAT, the lowest NDVI ratings were for topramezone alone (0.442); carfentrazone + 2,4-D + dicamba + MCPP in combination with topramezone (0.484); and mesotrione plus simazine (0.519). At 4 WAT, the lowest NDVI rating was for topramezone (0.546).

The main irrigation effect for NDVI turfgrass injury ratings was significant at 4 DAT, 1 WAT, 2 WAT, and 4 WAT (Table 4). At 4 DAT, nonirrigated plots experienced the lowest NDVI ratings (0.734), followed by irrigated plots (0.769) (Table 4). At 1 WAT, nonirrigated plots had the lowest NDVI ratings (0.599), followed by irrigated plots (0.644) (Table 4). At 2 WAT, nonirrigated plots had the lowest NDVI ratings (0.582), followed by irrigated plots (0.612) (Table 4). At 4 WAT nonirrigated plots had the lowest NDVI ratings (0.596), followed by irrigated plots (0.621) (Table 4).

Overall, without irrigation, turfgrass injury from topramezone was greatest (up to 88%) at 2 WAT, and from metribuzin (≈29%) at 1 WAT. Of the two treatments, injury from metribuzin was least damaging throughout the study. Cox et al. (2017) noted similar turfgrass injury 2 WAT with topramezone. Elmore et al. (2011b) reported turfgrass injury from topramezone was greatest 2 WAT (≈47%), although in our study the turfgrass injury was greater (up to 81%). Simazine and mesotrione treatments alone maintained acceptable turfgrass injury (≈13%); however, when applied in combination, considerable (up to 27%) turfgrass injury occurred. Elmore et al. (2011b) noted acceptable mesotrione turfgrass injury throughout a 5-week study. Simazine alone provided acceptable turfgrass injury (≤30%), consistent with previous research (Sharpe et al., 1989).

Turfgrass injury was reduced by irrigation for all herbicides used alone and in combination in these trials. Topramezone alone nonirrigated had the greatest turfgrass injury (≈81% at 2 WAT) (Table 2); however, combining topramezone with carfentrazone + 2,4-D + dicamba + MCPP reduced turfgrass injury (≈60% at 2 WAT) (Table 2). When the combination was irrigated, turfgrass injury was reduced further (≈33% at 2 WAT) (Table 3).

In conclusion, immediate incorporation of POST herbicide treatments by irrigating with 0.66 cm reduces turfgrass injury to mostly acceptable levels.

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