Research Reports

Effects of Topramezone and Bispyribac-sodium in Irrigation Water on Warm-season Turfgrasses

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SUMMARY. Topramezone and bispyribac-sodium were registered for aquatic weed control in the last decade. A primary target for these products is fluridone-resistant hydrilla (*Hydrilla verticillata*), which is one of the most invasive submersed weeds in the southeastern United States. Both products have water use restrictions that prohibit irrigation of turfgrasses with treated waters until the herbicides have degraded to very low concentrations. The objective of these studies was to identify the concentrations of topramezone and bispyribac-sodium that are phytotoxic to turfgrasses that are commonly planted in Florida. Three species of turfgrass were irrigated twice weekly with 0.5 inch of treated water for 4 weeks (eight irrigations total). Cumulative EC₁₀ values (the herbicide concentration that caused a 10% reduction in biomass compared with untreated control plants) after eight irrigations with water containing topramezone were 3.5, 4.3, and 17 ppb for ‘Palmetto’ st. augustinegrass (*Stenotaphrum secundatum*), ‘Pensacola’ bahiagrass (*Paspalum notatum*), and ‘Tifway 419’ hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis*), respectively. Bispyribac-sodium was less toxic to all turfgrasses evaluated, with EC₁₀ values of 56, 16, and >800 ppb for ‘Palmetto’ st. augustinegrass, ‘Pensacola’ bahiagrass, and ‘Tifway 419’ hybrid bermudagrass, respectively. These results support label instructions and highlight the need to comply with irrigation restrictions because the typical use concentrations for submersed weed control with topramezone and bispyribac-sodium are in the 20–40-ppb range.

St. augustinegrass is the most widely used turfgrass in commercial and home landscapes in Florida, and also is commonly used in Alabama, LA, MS, and Texas. It grows throughout the year in southern Florida, but usually senesces during the winter in the northern range of its distribution. Bermudagrass (*Cynodon dactylon*) is a fine-textured high-maintenance turfgrass that is most often used on golf courses, athletic fields, and other high-profile areas. There are many bermudagrass varieties and hybrids grown throughout the southern portion of the

United States. Bahiagrass is grown as a pasture crop for forage and hay and is also used in low-maintenance landscapes, roadsides, and similar areas, but is much less common than st. augustinegrass and bermudagrass

in traditional urban landscapes. Bahiagrass is grown in the southeastern United States from Virginia to Texas, but is most frequently used in South Carolina, GA, FL, AL, MS, and Louisiana. These three species are considered warm-season grasses because they all undergo significant winter senescence in colder regions (Trenholm et al., 2011, 2014, 2015).

Topramezone is a carotenoid biosynthesis inhibitor that interferes with the production of the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD) in the carotenoid pigment synthesis pathway (Shaner, 2014). It is sold under a number of trade names, including Armezon, Pylex, and Frequency[®] (BASF, Research Triangle Park, NC). Armezon is labeled at application rates of up to 25 g·ha⁻¹ for postemergence control of grasses and broadleaf weeds in corn [*Zea mays* (BASF, 2012)], and Pylex is labeled for use in cool-season turfgrasses such as golf courses, sod farms, and residential landscapes (BASF, 2015). The Pylex label specifically states that applications will control or suppress st. augustinegrass, bahiagrass, and bermudagrass (BASF, 2015). The herbicide Frequency[®] allows applications of up to 50 g·ha⁻¹ topramezone in pine (*Pinus* sp.) plantations, rights of way, and other noncrop sites (BASF, 2013). Grasses listed as tolerant of topramezone include cool-season grasses such as bluestem (*Andropogon* sp.), fescue (*Festuca* sp.), bluegrass (*Poa* sp.), and centipedegrass (*Eremochloa* sp.).

Topramezone was studied for several years under an experimental use permit to evaluate its efficacy on the fluridone-resistant submersed aquatic weed hydrilla. Puri et al. (2009) found that topramezone provided effective control of fluridone-resistant hydrilla at concentrations of 25–40 ppb; it was highly selective at these rates and caused little damage to most native nontarget plants. It was registered for aquatic use by the U.S.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
1.0432	fl oz/oz	mL·g ⁻¹	0.9586
2.54	inch(es)	cm	0.3937
28.3495	oz	g	0.0353
2.8350 × 10 ⁷	oz	μg	3.5274 × 10 ⁻⁸
70.0532	oz/acre	g·ha ⁻¹	0.0143
1	ppb	μg·L ⁻¹	1

Environmental Protection Agency (USEPA) in 2013 under the trade name Oasis® (SePRO Corporation, 2014).

Bispyribac-sodium is an acetolactate synthase (ALS) inhibitor, which is used for pre- and postflood grass and broadleaf weed control in rice (*Oryza sativa*). It is sold under the trade name Regiment® for use in rice at rates of up to 32 g·ha⁻¹ (Valent U.S.A. Corporation, 2012). It is also labeled under the trade name Velocity® for weed control in creeping bentgrass (*Agrostis stolonifera*) and established perennial ryegrass turf (*Lolium perenne*) at application rates of up to 74 g·ha⁻¹ (Valent U.S.A. Corporation, 2010). Bispyribac-sodium was registered for aquatic use by the USEPA in 2011 under the trade name Tradewind (Valent U.S.A. Corporation, 2011).

The USEPA evaluates the impacts and risks associated with aquatic herbicides in water and may impose water use restrictions on treated water to protect human health and the environment. Water use restrictions typically prohibit the use of treated water for drinking and irrigation of food crops for a specified length of time or until concentrations of the herbicide are reduced to a particular level. Regulatory agencies are less concerned about the effects of using herbicide-treated water to irrigate turfgrasses and other ornamental species that are not destined for human consumption, but registrants must consider potential phytotoxic effects on these plants if treated water is used to irrigate landscape species.

Topramezone and bispyribac-sodium provide aquatic resource

managers with alternate modes of action to control fluridone-resistant hydrilla and are consequently expected to be used intensively in ponds and lakes in Florida. Many waterbodies are multiuse and are commonly used as a source of irrigation water by riparian owners. Therefore, these studies were designed to determine the effects of topramezone and bispyribac-sodium in water used to irrigate three warm-season grasses that are typically grown in the southeastern United States.

Materials and methods

‘Palmetto’ st. augustinegrass was purchased at a garden supply store near Gainesville, FL, whereas ‘Pensacola’ bahiagrass and ‘Tifway 419’ hybrid bermudagrass were obtained from a commercial grower in Polk County, FL. A hatchet was used to cut the sod into 7.5-inch-diameter rounds, which were placed in 7.5-inch-diameter nursery containers filled with washed builder’s sand (0% organic carbon) that was amended with 2 g of 15N–3.9P–9.9K controlled-release fertilizer (Osmocote Plus; ICL Specialty Fertilizers, Dublin, OH) per kilogram of sand. Plants were maintained in a greenhouse with an evaporative cooling system for 3–4 weeks to allow establishment; during this time, they were irrigated with tap water as needed and clipped with scissors to a height of 1 inch every 6–10 d. After establishment, plants were selected for uniformity and randomly assigned to herbicide treatments in a completely randomized block design with five replicates (pots) per herbicide concentration (treatment).

Herbicide concentrations were selected based on the activity of these products on hydrilla. Depending on the stage of growth, topramezone and bispyribac-sodium are phytotoxic to hydrilla at ≈20–40 ppb (Netherland, 2014). Topramezone (Oasis®; SePRO Corp., Carmel, IN) was tested at rates ranging from 0 to 240 ppb and bispyribac-sodium (Tradewind®; Valent U.S.A. Corp., Walnut Creek, CA) was evaluated at 0–800 ppb (Table 1). The concentrations of bispyribac-sodium were higher than those of topramezone because preliminary studies indicated that these warm-season turfgrasses were tolerant of higher concentrations of bispyribac-sodium than of topramezone in irrigation

water. These ranges of concentrations were designed to include low rates that were expected to be sublethal and high rates that were expected to result in complete mortality of treated plants. Treatments were applied by irrigating each container with water containing the test herbicide in a volume equivalent to 0.5 inch of irrigation water. Herbicide-treated water was applied to the foliage of plants twice per week, resulting in a total of eight herbicide applications (irrigations) over a 4-week period.

Plants were grown out for 4 weeks after the final herbicide application to allow manifestation of delayed responses to treatments. Scissors were used to clip the plants every 7–10 d, depending on plant growth; clippings were collected, dried in a forced-air oven and weighed. Dry weight data were subjected to analysis of variance and nonlinear regression using SAS (version 9.1; SAS Institute, Cary, NC). Regression models were used to calculate EC₁₀, EC₅₀, and EC₉₀ values—the concentrations that reduce biomass by 10%, 50%, and 90% compared with untreated control plants—for each herbicide-species combination. The EC₁₀ value is conservative and was selected to represent the level at which herbicide damage might become noticeable to a homeowner (Koschnick et al., 2005).

Results and discussion

TOPRAMEZONE. Topramezone did not reduce growth of ‘Palmetto’ st. augustinegrass during the first two harvests after treatment, but a dramatic effect was evident in later harvests (Fig. 1; Table 2). Growth was reduced at concentrations of ≥15 ppb by the third harvest (20 d after the initial topramezone application), and this trend continued for the remainder of the experiment at topramezone concentrations of 7.5 ppb and higher. Plants irrigated with topramezone at 120 ppb or higher were dead after the fourth harvest. In addition, very few plants irrigated with 60 ppb of topramezone had living, green tissue at the conclusion of the study. Cumulative EC₁₀, EC₅₀, and EC₉₀ values were 3.5, 23, and 76 ppb, respectively (Table 2).

‘Pensacola’ bahiagrass irrigated with topramezone-treated water was more tolerant than ‘Palmetto’ st. augustinegrass at concentrations of 7.5 ppb (Fig. 2), but similar to the st. augustinegrass response, reduced

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Table 1. Concentration of herbicide applied to turfgrasses during these experiments, total grams applied to each 7.5-inch-diameter (19.05 cm) container and calculated total grams per hectare application rate. The highest single labeled application rate in turf is also listed in bold type.

Topramezone concentration ^z			Bispyribac-sodium concentration		
(ppb)	($\mu\text{g}/\text{container}$)	($\text{g}\cdot\text{ha}^{-1}$)	(ppb)	($\mu\text{g}/\text{container}$)	($\text{g}\cdot\text{ha}^{-1}$)
7.5	21.7	7.7	25	72	26
15	43.4	15.4	50	145	51
30	86.9	30.7	72	210	74^y
48	139.3	49.1^x	100	290	102
60	173.8	61.3	200	579	204
120	347.5	122.6	400	1,158	409
			800	2,317	818

^z1 ppb = 1 $\mu\text{g}\cdot\text{L}^{-1}$, 1 μg = 3.5274×10^{-8} oz, 1 $\text{g}\cdot\text{ha}^{-1}$ = 0.0143 oz/acre.

^yBispyribac-sodium [Velocity® (BASF)] labeled single application rate for turf use back-calculated to determine concentration (parts per billion) required to equal field application rates.

^xTopramezone [Pylex (BASF)] labeled single application rate for turf use back-calculated for this study.

Fig. 1. Dry weight of each harvest and cumulative dry weight of st. augustinegrass irrigated eight times over a 4-week period with topramezone, followed by a 4-week grow-out period to evaluate delayed effects. Grass was clipped every 7–10 d during the 8-week study beginning the week of the first herbicide treatment. Bars represent the mean of five replicates per treatment, and treatments coded with the same letter are not different at $P = 0.05$ least significant difference; lowercase letters = differences within an individual harvest, uppercase letters = differences in cumulative effects, NSD = no significant difference, 1 ppb = 1 $\mu\text{g}\cdot\text{L}^{-1}$, 1 g = 0.0353 oz.

growth was evident at concentrations of ≥ 15 ppb by the third harvest (Fig. 2; Table 2). ‘Pensacola’ bahiagrass receiving 120 and 240 ppb of topramezone in irrigation water were completely necrotic by the end of these studies. Cumulative EC_{10} , EC_{50} , and EC_{90} values were 4.3, 28, and 94 ppb, respectively; which are similar to the values calculated for ‘Palmetto’ st. augustinegrass (Table 2).

‘Tifway 419’ hybrid bermudagrass was unaffected by receiving eight irrigations with water containing up to

15 ppb topramezone (Fig. 3), but growth was reduced at concentrations of ≥ 30 ppb. Similar to ‘Palmetto’ st. augustinegrass and ‘Pensacola’ bahiagrass, reduced growth of ‘Tifway 419’ hybrid bermudagrass was evident by the third harvest (Table 2). Also, no new growth was collected during harvests 6 or 7 from plants treated with 120 or 240 ppb of topramezone as all tissue was necrotic and no live biomass remained.

EC values were calculated at the beginning, midpoint, and end

of these turfgrass studies (Table 2). As noted above, EC_{10} values are thought to represent the level at which herbicide damage might become noticeable to a homeowner (Koschnick et al., 2005). Although this is an arbitrary figure, it is useful for comparisons among data. For example, EC_{10} values for the third and later harvests of ‘Palmetto’ st. augustinegrass and ‘Pensacola’ bahiagrass and the sixth harvest of ‘Tifway 419’ hybrid bermudagrass were <10 ppb. Cumulative EC_{10} values for ‘Palmetto’ st. augustinegrass and ‘Pensacola’ bahiagrass were similar. ‘Tifway 419’ hybrid bermudagrass, with a cumulative EC_{10} of 17 ppb, was the most tolerant of these species. However, EC_{50} values for all three turfgrasses tested fell within the range of rates listed on the topramezone label for aquatic weed control (i.e., 20–40 ppb).

BISPYRIBAC-SODIUM. Growth of ‘Palmetto’ st. augustinegrass decreased as the concentration of the ALS-inhibiting herbicide bispyribac-sodium increased (Fig. 4). There was no difference in EC_{10} , EC_{50} , and EC_{90} values calculated from the first harvest, but values were significantly different from one another by the third harvest (Table 3). ‘Palmetto’ st. augustinegrass continued to grow throughout all six harvests in these experiments, even when plants were irrigated with water containing 400 and 800 ppb of topramezone (Fig. 4). Although growth was reduced by applications of irrigation water containing bispyribac-sodium, reductions occurred at much higher herbicide concentrations than those recorded for topramezone. For example, cumulative

Table 2. Effect of topramezone on dry weight of warm-season turfgrasses irrigated eight times over a 4-week period with topamezone, followed by a 4-week grow-out period to evaluate delayed effects.

Harvest no.	Topramezone concentration (ppb) ^a		
	EC ₁₀ (CI)	EC ₅₀ (CI)	EC ₉₀ (CI)
'Palmetto' st. augustinegrass			
1	80 (33–240)	>240 (218–>240)	>240 (>240–>240)
3	3.7 (2.7–5.5)	24 (18–36)	80 (60–121)
6	1.2 (0.9–1.8)	8 (6–12)	27 (21–39)
Cumulative	3.5 (2.7–4.8)	23 (18–32)	76 (59–105)
'Pensacola' bahiagrass			
1	214 (45–>240)	>240 (>240–>240)	>240 (>240–>240)
3	5.5 (3.9–9.3)	36 (25–61)	120 (85–204)
6	2.8 (2.1–4.5)	18 (14–29)	61 (45–97)
9	4.5 (2.8–11.4)	29 (18–75)	98 (61–250)
Cumulative	4.3 (3.5–5.6)	28 (23–37)	94 (76–122)
'Tifway 419' hybrid bermudagrass			
1	>240 (123–>240)	>240 (>240–>240)	>240 (>240–>240)
3	20 (13–38)	130 (88–250)	>240 (>240–>240)
6	7 (5–9)	44 (34–61)	146 (114–202)
Cumulative	17 (15–21)	115 (97–141)	>240 (>240–>240)

^aEC₁₀, EC₅₀, and EC₉₀ are the effective concentrations of topamezone required to reduce plant growth by 10%, 50%, and 90%, respectively, compared with untreated control plants. EC values were calculated using nonlinear regression components generated during analysis of variance of five replicates per treatment; CI = 95% confidence interval, 1 ppb = 1 µg·L⁻¹.

Fig. 2. Dry weight of each harvest and cumulative dry weight of bahiagrass irrigated eight times over a 4-week period with topamezone, followed by a 4-week grow-out period to evaluate delayed effects. Grass was clipped every 7–10 d during the 8-week study beginning the week of the first herbicide treatment. Bars represent the mean of five replicates per treatment, and treatments coded with the same letter are not different at $P = 0.05$ least significant difference; lowercase letters = differences within an individual harvest, uppercase letters = differences in cumulative effects, NSD = no significant difference, 1 ppb = 1 µg·L⁻¹, 1 g = 0.0353 oz.

EC₁₀ values for 'Palmetto' st. augustinegrass treated with bispyribac-sodium or topamezone were 56 and 3.5 ppb, respectively (Tables 1 and 2).

The response of 'Pensacola' bahiagrass to increasing concentrations of bispyribac-sodium in irrigation water was a stepwise decrease in growth,

which is in contrast to the gradual decrease exhibited by 'Palmetto' st. augustinegrass (Fig. 5). Cumulative growth of 'Pensacola' bahiagrass treated with 25 ppb bispyribac-sodium was about 15% less than the biomass produced by plants irrigated with plain water; growth was reduced by 50% after

irrigation with water containing 50 or 100 ppb bispyribac-sodium and by 75% in plants treated with 200 or 400 ppb bispyribac-sodium. Irrigation with 25 ppb bispyribac-sodium did not reduce growth until the sixth harvest, whereas reductions in growth after irrigation with 50 or ≥100 ppb became evident in the fourth and second harvests, respectively (Fig. 5). Despite this, the calculated EC₁₀ value at the third harvest was 35 ppb and cumulative EC₁₀, EC₅₀, and EC₉₀ values were 16, 103, and 347 ppb, respectively (Table 3). Calculated EC₁₀ values for bispyribac-sodium on 'Palmetto' st. augustinegrass and 'Pensacola' bahiagrass also fell within the suggested application concentrations for this herbicide. By contrast, growth of 'Tifway 419' hybrid bermudagrass was unaffected by bispyribac-sodium at all tested treatment concentrations in irrigation water in this study (Fig. 6).

Bispyribac-sodium is registered for control of broadleaf and grass weed species in hybrid or common bermudagrass, perennial ryegrass, and creeping bentgrass at up to 74 g·ha⁻¹ (Valent U.S.A. Corporation, 2010). With the exception of harvest 6 of 'Pensacola' bahiagrass, all EC₅₀ and EC₉₀ values were above 45 ppb, the maximum concentration allowed for aquatic use (Valent U.S.A. Corporation, 2011). The EC₁₀ values for 'Palmetto' st. augustinegrass and 'Pensacola' bahiagrass fell within the range of rates

Fig. 3. Dry weight of each harvest and cumulative dry weight of hybrid bermudagrass irrigated eight times over a 4-week period with topramezone, followed by a 4-week grow-out period to evaluate delayed effects. Grass was clipped every 7–10 d during the 8-week study beginning the week of the first herbicide treatment. Bars represent the mean of five replicates per treatment, and treatments coded with the same letter are not different at $P = 0.05$ least significant difference; lowercase letters = differences within an individual harvest, uppercase letters = differences in cumulative effects, NSD = no significant difference, 1 ppb = 1 $\mu\text{g}\cdot\text{L}^{-1}$, 1 g = 0.0353 oz.

Fig. 4. Dry weight of each harvest and cumulative dry weight of st. augustinegrass irrigated eight times over a 4-week period with bispyribac-sodium, followed by a 4-week grow-out period to evaluate delayed effects. Grass was clipped every 7–10 d during the 8-week study beginning the week of the first herbicide treatment. Bars represent the mean of five replicates per treatment, and treatments coded with the same letter are not different at $P = 0.05$ least significant difference; lowercase letters = differences within an individual harvest, uppercase letters = differences in cumulative effects, NSD = no significant difference, 1 ppb = 1 $\mu\text{g}\cdot\text{L}^{-1}$, 1 g = 0.0353 oz.

follow label directions or risk significant injury to these grasses (particularly st. augustinegrass and bahiagrass) and possibly to other ornamental species as well.

Because topramezone and bispyribac-sodium are registered for weed control in selected turfgrass species, it is useful to compare the total loading of active ingredient applied to the turfgrasses in these experiments with recommended rates for weed control in tolerant turfgrass species (Table 1). The total amount of active ingredient (grams) applied for each herbicide concentration was calculated by summing the active ingredient (grams) applied to the 7.5-inch-diameter pots during the eight irrigation events and calculating the total active ingredient (grams) applied on an area basis [i.e., active ingredient (grams) per hectare]. Both herbicides have half-lives of 10–14 d in soil (Shaner, 2014), so the comparison of total loading of pots in our experiments may not accurately reflect field situations where single applications are recommended for weed control in turfgrasses. However, a comparison of these data (Table 1) clearly reveals why topramezone is not used to control weeds in warm-season turfgrasses. The maximum rate for a single application of topramezone on cool-season turfgrasses correlates to ≈ 48 ppb in our experiments, which is higher than the EC_{50} values for ‘Palmetto’ st. augustinegrass and ‘Pensacola’ bahiagrass and is similar to the sixth harvest EC_{50} for ‘Tifway 419’ hybrid bermudagrass (Table 2). The calculated experiment-wide (eight irrigation events) active ingredient loading of bispyribac-sodium in our studies is 72 ppb (Table 1). EC_{10} values for bispyribac-sodium (Table 3) clearly show that ‘Tifway 419’ hybrid bermudagrass is very tolerant of this herbicide, which is labeled for single applications at 74 $\text{g}\cdot\text{ha}^{-1}$. However, the 72 ppb calculated load for bispyribac-sodium is similar to (or exceeds) the EC_{50} values for harvests 6 and 9 of ‘Pensacola’ bahiagrass and harvest 6 of ‘Palmetto’ st. augustinegrass. The total amount of herbicide applied in eight irrigations over a 28-d period would seemingly have a lesser effect on plants than a single application of the same amount of herbicide, particularly when using herbicides with short (e.g., 10–14 d) soil half-lives. However, as indicated in

listed on the bispyribac-sodium label for aquatic weed control (i.e., 20–40 ppb), but bispyribac-sodium is less

phytotoxic to these turfgrasses than is topramezone (Table 2). However, homeowners and other irrigators must

Table 3. Effect of bispyribac-sodium on dry weight of warm-season turfgrasses irrigated six ('Palmetto' st. augustinegrass) or nine ('Pensacola' bahiagrass and 'Tifway 419' bermudagrass) times over a 4-week period with bispyribac-sodium, followed by a 4-week grow-out period to evaluate delayed effects.

Harvest no.	Bispyribac-sodium concn (ppb) ^z		
	EC ₁₀ (CI)	EC ₅₀ (95% CI)	EC ₉₀ (95% CI)
'Palmetto' st. augustinegrass			
1	246 (144->800)	>800 (>800->800)	>800 (>800->800)
3	47 (34-73)	307 (225-481)	>800 (748->800)
6	11 (7-25)	73 (47-165)	242 (155-550)
Cumulative	56 (44-78)	369 (290-510)	>800 (>800->800)
'Pensacola' bahiagrass			
1	176 (86->800)	>800 (568->800)	>800 (>800->800)
3	35 (21-99)	227 (138-654)	755 (457->800)
6	7 (5-12)	48 (35-76)	160 (117-254)
9	12 (8-25)	77 (51-162)	255 (168-538)
Cumulative	16 (11-26)	103 (74-168)	343 (247-559)
'Tifway 419' hybrid bermudagrass			
1	319 (179->800)	>800 (>800->800)	>800 (>800->800)
3	>800 (321->800)	>800 (>800->800)	>800 (>800->800)
6	>800 (497->800)	>800 (>800->800)	>800 (>800->800)
9	>800 (>800->800)	>800 (>800->800)	>800 (>800->800)
Cumulative	>800 (742->800)	>800 (>800->800)	>800 (>800->800)

^zEC₁₀, EC₅₀, and EC₉₀ are the effective concentrations of bispyribac-sodium required to reduce plant growth by 10%, 50%, and 90%, respectively, compared with untreated control plants. EC values were calculated using nonlinear regression components generated during analysis of variance of five replicates per treatment; CI = 95% confidence interval, 1 ppb = 1 µg·L⁻¹.

Fig. 5. Dry weight of each harvest and cumulative dry weight of bahiagrass irrigated eight times over a 4-week period with bispyribac-sodium, followed by a 4-week grow-out period to evaluate delayed effects. Grass was clipped every 7–10 d during the 8-week study beginning the week of the first herbicide treatment. Bars represent the mean of five replicates per treatment, and treatments coded with the same letter are not different at $P = 0.05$ least significant difference; lowercase letters = differences within an individual harvest, uppercase letters = differences in cumulative effects, NSD = no significant difference, 1 ppb = 1 µg·L⁻¹, 1 g = 0.0353 oz.

Table 1, the comparisons in this study generally agree with the labeled rates for weed control in turf. The limitation of this comparison is that impacts were determined on the turfgrasses themselves as opposed to

the weeds that are the target of herbicide applications.

Elmore et al. (2011) compared several photosynthetic characteristics of common bermudagrass after application of HPPD inhibitors.

Topramezone applied at 18 g·ha⁻¹ reduced chlorophyll content 14 d after treatment (DAT), but plants had recovered by 21 and 28 DAT. Also, chlorophyll concentrations were significantly reduced 14, 21, and 28 DAT by topramezone applied at 38 g·ha⁻¹. Our results provide additional support to these findings because 18 g·ha⁻¹ of topramezone had little long-term effect on 'Tifway 419' hybrid bermudagrass (Fig. 3). Significant injury of bermudagrass could occur after a single application of 38 g·ha⁻¹, but because eight applications of 60 ppb of topramezone failed to kill plants in our study, it seems likely that plants would recover from herbicide damage.

Although 'Tifway 419' hybrid bermudagrass was slightly more tolerant of topramezone in irrigation water in this study, the EC values for turfgrasses were generally similar at 100 µg·L⁻¹ or less. Other irrigation studies with methods similar to those used in this study have shown much greater variation in tolerance to topramezone and bispyribac-sodium in irrigation water. For example, Gettys and Haller (2009) studied the effects of topramezone in irrigation water on four species of bedding plants and reported that the EC₁₀ values of topramezone on vinca (*Catharanthus roseus*) and impatiens (*Impatiens walleriana*) were 109 and >4000 µg·L⁻¹,

Fig. 6. Dry weight of each harvest and cumulative dry weight of hybrid bermudagrass irrigated eight times over a 4-week period with bispyribac-sodium, followed by a 4-week grow-out period to evaluate delayed effects. Grass was clipped every 7–10 d during the 8-week study beginning the week of the first herbicide treatment. Bars represent the mean of five replicates per treatment, and treatments coded with the same letter are not different at $P = 0.05$ least significant difference; lowercase letters = differences within an individual harvest, uppercase letters = differences in cumulative effects, NSD = no significant difference, 1 ppb = $1 \mu\text{g}\cdot\text{L}^{-1}$, 1 g = 0.0353 oz.

respectively. Gettys and Haller (2010) conducted other research to evaluate the effects of herbicides in irrigation water on foliage plants and found great variation in those studies as well. For example, EC_{10} values of topramezone on caladium (*Caladium x hortulanum*) and syngonium (*Syngonium podophyllum*) were 186 and $>6000 \mu\text{g}\cdot\text{L}^{-1}$, respectively, and EC_{10} values of bispyribac-sodium on caladium and anthurium (*Anthurium andraeanum*) were 180 and $>5000 \mu\text{g}\cdot\text{L}^{-1}$, respectively.

The tolerance of bedding and foliage plants to topramezone and bispyribac-sodium in irrigation water is higher than the concentrations typically used for aquatic weed control. By contrast, “transplant-ready” vegetable plants were much more sensitive to these herbicides in irrigation water. Gettys and Haller (2012) irrigated 4-week-old plants of bush bean (*Phaseolus vulgaris*), tomato (*Solanum lycopersicum*), sweet pepper (*Capsicum annuum*), and zucchini (*Cucurbita pepo*) four times over an 11-d period with water containing herbicides and reported that topramezone EC_{10} values for bush bean, tomato, sweet pepper, and zucchini

were 7.1, 34.5, 51.7, and $257.1 \mu\text{g}\cdot\text{L}^{-1}$, respectively. In the same study, Gettys and Haller (2012) calculated bispyribac-sodium EC_{10} values of 1.2, 12.0, 8.9, and $59.5 \mu\text{g}\cdot\text{L}^{-1}$ for bush bean, tomato, sweet pepper, and zucchini, respectively. The reason for the vegetable plants’ greater sensitivity to herbicides in irrigation water is unknown; however, it is likely related to the immaturity and faster growth rate of the vegetable plants compared with the more mature, slower-growing bedding, and foliage plants used in previous studies.

The susceptibility of turfgrasses to these two herbicides could be considered a worst-case scenario because the substrate used in these experiments was pure sand and contained no measurable organic matter. The K_{oc} or soil adsorption coefficient (a measure of the tendency of a chemical to bind to soils) for topramezone reportedly ranges from 22 to $172 \text{ mL}\cdot\text{g}^{-1}$, whereas the K_{oc} of bispyribac-sodium ranges from 852 to $1793 \text{ mL}\cdot\text{g}^{-1}$ (Shaner, 2014). Andrew et al. (2003) compared the effects of fluridone (K_{oc} 350 to $>2000 \text{ mL}\cdot\text{g}^{-1}$) in irrigation water on st. augustinegrass grown in soils containing 1.5% organic matter to the same species grown in pure sand with no organic matter. They

reported that $15 \mu\text{g}\cdot\text{L}^{-1}$ of fluridone reduced growth of st. augustinegrass planted in pure sand, but that plants grown in soils containing organic matter were unaffected by up to $120 \mu\text{g}\cdot\text{L}^{-1}$ of fluridone. Similarly, C.J. Della Torre III, W.T. Haller, and L.A. Gettys (unpublished data) found that soil carbon content significantly affected the phytotoxic response of st. augustinegrass to topramezone in irrigation water and that EC_{10} values increased as soil carbon increased.

Irrigation of food crops with water containing topramezone or bispyribac-sodium is not allowed unless the herbicide is specifically labeled for use on that crop (e.g., bispyribac-sodium products that are labeled for use in rice, topramezone products that are labeled for use in corn). There appears to be a margin of safety when irrigating ornamental plants with these herbicides, but the susceptibility of warm-season turfgrasses (and quite likely other ornamental species that have not been studied) clearly shows that applicators must strictly adhere to irrigation restrictions outlined on product labels, particularly when these turf species are established in sandy soils containing little organic matter.

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