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Response of Selected Foliage Plants to Four Herbicides in Irrigation Water

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SUMMARY. ‘Miami Beauty’ anthurium (*Anthurium andreanum*), ‘Frieda Hemple’ caladium (*Caladium x hortulanum*), ‘Debbie’ spathiphyllum (*Spathiphyllum*), and ‘Regina Red’ syngonium (*Syngonium podophyllum*) were irrigated with water treated with bispyribac-sodium, quinclorac, topramezone, and trifloxysulfuron to identify herbicide concentrations that cause phytotoxic effects. Plants were irrigated four times over a 11-day period with the equivalent of 0.5 inch of treated water during each irrigation and were then irrigated with well water until they were harvested 43 days after the first herbicide treatment. Visual quality and dry weight data revealed that caladium was the most sensitive of the foliage plants, regardless of herbicide mode of action. Noticeable reductions in visual quality and dry weight of caladium were evident after exposure to 182, 144, 186, and 1135 ppb of bispyribac-sodium, quinclorac, topramezone, and trifloxysulfuron, respectively. Of the four herbicides evaluated in these experiments, only quinclorac caused noticeable damage to plants when applied at a concentration similar to the proposed use rate.

Aquatic herbicides are used to ensure navigable waters, to improve human health by limiting mosquito habitat, and to provide an environment that is suitable for wildlife and human uses. There are a limited number of herbicides labeled for aquatic weed control, due in part to high registration costs relative to the

limited market size. The recent development of resistance in certain aquatic weeds to herbicides such as fluridone and diquat further limits the choices available for effective weed control in lakes, ponds, and other water bodies (Koschnick et al., 2006; Michel et al., 2004). Thus, the need for additional effective aquatic herbicides is great. The herbicides tested in these experiments—bispyribac-sodium, quinclorac, topramezone, and trifloxysulfuron—are not

currently registered for aquatic use. However, the efficacy, selectivity, and potential use rates of these herbicides are being evaluated under experimental use permits (EUPs) to determine whether they may be useful in aquatic systems.

Bispyribac-sodium is labeled for postemergence control of annual bluegrass (*Poa annua*), rough bluegrass (*Poa trivialis*), certain broadleaf weeds in certain turfgrasses, and for postemergence weed control in dry-seeded or water-seeded rice (*Oryza sativa*). Bispyribac-sodium is a pyrimidinylthio-benzoate and acts as an acetolactate synthase (ALS) inhibitor, which interferes with synthesis of the amino acids valine, leucine, and isoleucine (Senseman, 2007).

Quinclorac is currently labeled for postemergence weed control in rice and in grasses including tall fescue (*Festuca arundinacea*), kentucky bluegrass (*Poa pratensis*), and others. It is a substituted quinolinecarboxylic acid that acts as an auxin mimic and stimulates induction of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase activity. Increased ACC synthase activity promotes ethylene biosynthesis, which triggers accumulation of abscisic acid (ABA) and causes epinasty, growth inhibition, and senescence in susceptible plants (Grossmann, 1998).

Topramezone is labeled for postemergence weed control in field corn, sweet corn, and popcorn (*Zea mays*). Topramezone rapidly degrades in plants to [3-(4,5-dihydro-5-hydroxy-isoxazol-3-yl)-4-methanesulfonyl-2-methyl-phenyl]-(5-hydroxy-1-methyl-1H-pyrazol-4-yl)-methanone (M670H02), a metabolite that inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD) (U.S. Environmental Protection Agency, 2005). This disrupts photosynthesis and carotenoid formation and damages the structural integrity of membranes (Pest Management Regulatory Agency, 2006).

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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
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg-ha ⁻¹	0.8922
28.3495	oz	g	0.0353
1	ppb	µg-L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Fig. 1. Mean dry weight of three replicates each of ‘Miami Beauty’ anthurium, ‘Frieda Hemple’ caladium, ‘Debbie’ spathiphyllum, and ‘Regina Red’ syngonium treated with one of four herbicides: (A) bispyribac-sodium, (B) quinclorac, (C) topramezone, and (D) trifloxysulfuron. Plants were irrigated with herbicide solutions four times during a 10-d period and were then irrigated with well water for an additional 32 d before harvest. Herbicide rates were 0, 25, 100, 400, 1600, 4800, and 19,200 ppb. Each point represents the mean of three replicates and error bars represent one se. EC_{10} is the effective concentration of herbicide expected to cause a 10% reduction in dry weight compared with control plants; 1 ppb = 1 $\mu\text{g}\cdot\text{L}^{-1}$, 1 g = 0.0353 oz (Figure continued).

Trifloxysulfuron-sodium is labeled for postemergence control of broadleaf, sedge, and grass weeds in warm season turfgrasses such as bermudagrass (*Cynodon dactylon* $\times$ *C. transvaalensis*) and zoysiagrass (*Zoysia japonica*). It is also used to control the shoreline weed torpedograss (*Panicum repens*) in bermudagrass turf (Stephenson et al., 2006). Trifloxysulfuron-sodium is a sulfonylurea derivative of trifloxysulfuron in the pyrimidinylsulfonylurea class of herbicides (Wood, 2009). Similar to bispyribac-sodium, trifloxysulfuron is an ALS inhibitor and interferes with biosynthesis of the essential amino acids valine, leucine, and isoleucine (Senseman, 2007).

Terrestrial use rates for bispyribac-sodium, topramezone, and trifloxysulfuron are relatively low (e.g.,

measured in ounces per acre) and aquatic use rates for these herbicides would likely be less than 100 ppb. On the other hand, terrestrial use rates for quinclorac are higher (e.g., up to 0.75 lb/acre a.i.), and this herbicide is being evaluated for aquatic use at concentrations of up to 300 ppb.

The U.S. Environmental Protection Agency (USEPA) regulates the level of herbicide allowable in irrigation water if that water will be applied to food crops (U.S. Environmental Protection Agency, 2003). However, no regulations are in place if this same water is used to irrigate ornamental plants. This is important because many ornamentals are high-value crops and accidental injury of these valuable plants with herbicide-treated irrigation water is highly undesirable. Previous research has reported the effects

of other aquatic herbicides on turfgrasses, crops, and ornamental species (Andrew et al., 2003; Gettys and Haller, 2009; Koschnick et al., 2005a, 2005b; Mudge et al., 2007; Mudge and Haller, 2009), but little is known regarding the effects of bispyribac-sodium, quinclorac, topramezone, and trifloxysulfuron on foliage plants. Homeowners living adjacent to canals and lakes often use water from these sources to irrigate turf, bedding plants, foliage species, and other ornamental plants. Therefore, a study of the possible phytotoxicity of these herbicides is important to determine appropriate irrigation restrictions on turf, ornamentals, and foliage plants. The objective of these experiments was to evaluate the effects of these herbicides on selected foliage plants to provide further information

Fig. 1. Continued.

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for potential irrigation restrictions that will limit damage to foliage plants in landscapes that are irrigated with herbicide-treated water.

Materials and methods

Anthurium, caladium, spathiphyllum, and syngonium were purchased in Apr. and May 2009 from Agri-Starts IV, Inc. in Apopka, FL. All plants were purchased as liners in 72-cell 612 flats and were transplanted into 4-inch-diameter traditional round pots filled with Jungle Growth Grower's Mix Professional (composed of Canadian long-fiber sphagnum peatmoss, composted aged-processed pine bark, vermiculite, perlite, horticulture-grade charcoal ash, time-release fertilizer, and trace elements and minerals; Jungle Growth, Statham, GA). Plants were kept under mist (a 2-min duration every 2 h from 8:00 am to 6:00 pm) in an unlit greenhouse (temperature range 20–35 °C) at the University of Florida Center for Aquatic and Invasive Plants in Gainesville for 4 weeks before treatment. Experimental plants were healthy, actively growing, “garden-ready,” and

selected for uniform growth and height to minimize variation.

Six concentrations of each herbicide (25–19,200 ppb) and a well-water control were compared for all four foliage plants. These treatment concentrations were chosen to include the highest proposed aquatic use rates on EUP labels (45 ppb for bispyribac-sodium; 500 ppb for quinclorac; 50 ppb for topramezone; and 90 ppb for trifloxysulfuron) and increased to encompass much higher concentrations. These ranges were selected to ensure that the maximum treatment rate of each herbicide in these experiments caused near-total mortality of the foliage plants tested, which results in more accurate computation of the effective concentration of herbicide expected to cause a 10% reduction in dry weight compared with control plants (EC_{10}) derived from regression analysis. All experiments were conducted once in an unlit greenhouse (temperature range 20–35 °C) at the University of Florida Center for Aquatic and Invasive Plants. Treatments were applied in a completely

randomized design and each herbicide/rate/species combination was replicated three times with three single-plant pots per replicate. Each replicate was maintained in an aluminum pan (12.75 × 10.5 × 3.25 inches deep) to allow collection of excess treatment solutions. All plants within a single pan were overhead irrigated with 1.084 L of treatment solution (equivalent to 0.5 inch per pan per irrigation), which completely wet all foliage and saturated the potting medium. Excess treatment solutions were collected in pans and were poured off 12 to 24 h after treatment. Plants were treated four times over a 11-d period (on days 1, 4, 8, and 11) to simulate a twice-weekly irrigation regime, with fresh treatment solutions prepared before each irrigation event.

Plants were maintained until day 43 (32 d after application of the final treatment) to allow manifestation of treatment effects, and were destructively harvested before significant regrowth from apical or adventitious buds could occur. Plants were irrigated

Fig. 2. Mean visual rating of three replicates each of ‘Miami Beauty’ anthurium, ‘Frieda Hemple’ caladium, ‘Debbie’ spathiphyllum, and ‘Regina Red’ syngonium treated with one of four herbicides: (A) bispyribac-sodium, (B) quinclorac, (C) topramezone, and (D) trifloxysulfuron. Plants were irrigated with herbicide solutions four times during a 10-d period and were then irrigated with well water for an additional 32 d before harvest. Herbicide rates were 0, 25, 100, 400, 1600, 4800, and 19,200 ppb. Visual quality was rated on a scale of 0 to 10, with a score of 0 signifying plant death and a score of 10 signifying no visible damage. Each point represents the mean of three replicates and error bars represent one se. EC₁₀ is the effective concentration of herbicide expected to cause a 10% reduction in visual quality compared with control plants; 1 ppb = 1 µg·L⁻¹, 1 g = 0.0353 oz (Figure continued).

with about 360 mL of well water per container as needed during the grow-out period. On day 43, each replicate was assigned a visual quality rating on a scale of 0 to 10 by the lead investigator, with a score of 0 signifying plant death and a score of 10 signifying no visible damage. All necrotic and chlorotic tissue was removed from plants and a destructive harvest was used to collect all remaining aboveground live plant tissue, which was dried in a forced-air oven at 90 °C for 2 weeks until a constant mass was achieved.

Data were subjected to analysis of variance and non-linear regression using SAS (version 9.1; SAS Institute, Cary, NC). Plant size and weight differed among the foliage plants tested, thus each species was analyzed

separately. Regression models were used to determine the EC₁₀. 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., 2005b).

Results and discussion

Caladium was the most sensitive foliage plant exposed to bispyribac-sodium (Figs. 1A and 2A), with EC₁₀ values of 303 ppb for visual quality and 182 ppb for dry weight. The visual quality of syngonium was reduced at 1584 ppb, but dry weight was less affected by bispyribac-sodium, with an EC₁₀ value of 2050 ppb. Bispyribac-sodium reduced visual quality and dry weight of spathiphyllum by 10% at 2405 and 3572 ppb,

respectively, while these parameters in anthurium were reduced by 10% at 2951 and 5575 ppb, respectively. These data show a wide variance in tolerance to bispyribac-sodium in irrigation water, but average dry weight and visual quality of all foliage plants declined as the concentration of bispyribac-sodium increased. Visual EC₁₀ values varied from 303 to 2951 ppb, whereas dry weight EC₁₀ values ranged from 182 to 5575 ppb across the four species. The current proposed aquatic use label for bispyribac-sodium allows the use of this herbicide at concentrations up to 45 ppb, with a maximum of two applications per year. If bispyribac is applied at the maximum label rate, it is unlikely that water use restrictions will be needed to avoid damage to these foliage species. In addition, the

Fig. 2. Continued.

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half-life of bispyribac-sodium in water is thought to be between 21 and 42 d (W.T. Haller, unpublished data), thus it is unlikely that concentrations would remain high enough to damage these foliage plants, even with repeated irrigations.

Caladium was the most sensitive foliage plant exposed to quinclorac in irrigation water (Figs. 1B and 2B), with EC_{10} values of 144 ppb for visual quality and 367 ppb for dry weight. The visual quality of syngonium was reduced at 785 ppb, but dry weight was less affected by quinclorac, with an EC_{10} value of 871 ppb. Quinclorac reduced visual quality and dry weight of spathiphyllum by 10% at 1457 and 6309 ppb, respectively, while these parameters in anthurium were reduced by 10% at 2046 and 18,916 ppb, respectively. These data show a wide variance in tolerance to quinclorac in irrigation water, but average dry weight and visual quality of all foliage plants declined as the concentration of quinclorac increased. Visual EC_{10} values varied from 144 to 2046 ppb, whereas dry weight EC_{10} values

ranged from 367 to 18,916 ppb across the four species. The current EUP label for quinclorac allows the use of this herbicide at concentrations up to 500 ppb. If quinclorac is eventually labeled for aquatic use, its use rate for control of aquatic weeds should be reduced or irrigation restrictions should be developed to avoid damage to some sensitive non-target plants such as caladium.

Visual quality and dry weight of caladium were reduced by exposure to 455 and 186 ppb, respectively, of topramezone (Figs. 1C and 2C). Topramezone reduced visual quality and dry weight of syngonium at 6932 and 6271 ppb, respectively, while these parameters in spathiphyllum were reduced at 280 and 2545 ppb, respectively. Anthurium was relatively tolerant of topramezone, with EC_{10} values of 15,891 and 4248 ppb for visual quality and dry weight, respectively. The current EUP label for topramezone allows the use of this product at concentrations up to 50 ppb for control of submersed weeds. Spathiphyllum was the most sensitive

species evaluated against topramezone based on visual quality ratings, with an EC_{10} value of 280, whereas caladium was the most sensitive foliage plant species based on dry weight and showed reductions in dry weight at 186 ppb. These data suggest that water use restrictions may not be necessary if topramezone is applied at or below the recommended label rate for aquatic weed control.

Caladium was the most sensitive foliage plant exposed to trifloxysulfuron (Figs. 1D and 2D), with EC_{10} values of 1135 ppb for visual quality and 1727 ppb for dry weight. The visual quality of spathiphyllum was reduced at 1641 ppb, but dry weight was less affected by trifloxysulfuron, with an EC_{10} value of 1951 ppb. Trifloxysulfuron reduced visual quality and dry weight of syngonium by 10% at 1958 and 3559 ppb, respectively, while these parameters in anthurium were reduced by 10% at 2589 and 6797 ppb, respectively. These data show a wide variance in tolerance to trifloxysulfuron in irrigation water, but average dry weight

and visual quality of all foliage plants declined as the concentration of trifloxysulfuron increased. Visual EC_{10} values varied from 1135 to 2589 ppb, whereas dry weight EC_{10} values ranged from 1727 to 6797 ppb across the four species. The current EUP label for trifloxysulfuron allows the use of this herbicide at concentrations up to 90 ppb, with a maximum of two applications per year. If trifloxysulfuron is ultimately registered for aquatic use and applied at or below this concentration, it is unlikely that these foliage species will be damaged if irrigated with herbicide-treated water.

Conclusions

The four herbicides tested in these experiments included one auxin mimic (quinclorac), one photosynthetic disrupter/HPPD inhibitor (topramezone), and two ALS inhibitors (bispyribac-sodium and trifloxysulfuron), and a range of susceptibilities to these herbicides was anticipated. Caladium was clearly the most sensitive of the foliage plants to these herbicides, regardless of mode of action. Visual ratings, though subjective, were in close agreement with dry weight data and may be useful in establishing possible irrigation restrictions on water treated for aquatic weed control. It is possible that plants tested in these experiments may have grown out of herbicide damage symptoms given enough time, but homeowners might assume that plants were destroyed and demand replacement of plants damaged after irrigation with herbicide-treated water. In addition, repeated irrigations with the same treated water would likely cause damage over an extended length of time because the half-lives of these herbicides range from 20 d to greater than 60 d. Finally, herbicides such as topramezone remain

active in the soil for long periods of time, thus foliage plants irrigated with water containing these types of herbicides may be challenged in the long term as well.

None of the herbicides tested in these experiments is currently labeled for use in aquatic systems. The studies outlined in this article show that anthurium, caladium, spathiphyllum, and syngonium are relatively tolerant of bispyribac-sodium, topramezone, and trifloxysulfuron in irrigation water, but quinclorac may cause damage to sensitive species when applied at rates below the maximum EUP label rate. A number of factors—including final use rates, half-lives in water, and soil activity—influence phytotoxicity of herbicides to irrigated plants, but these parameters have not yet been determined for the herbicides examined in these experiments.

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