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Ornamental Plant Susceptibility to Diquat in Overhead Irrigation Water

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ABSTRACT

The effects of the aquatic herbicide diquat (6,7-dihydrodipyrido[1,2-a:2',1'-c]pyrazinediium ion) in irrigation water were evaluated on five ornamental plant species (begonia, *Begonia* × *Semperflorens-Cultorum* 'Senator'; dianthus, *Dianthus hybrida* 'Ideal Rose'; impatiens, *Impatiens wallerana*; petunia, *Petunia* × *hybrida* 'Dreams'; and snapdragon, *Antirrhinum majus* 'LaBella Pink') to determine whether irrigation restrictions for non-food crop use may be reduced to less than the current labeled three day restriction. Plants were overhead irrigated one time with diquat containing water equivalent to 1.27 cm (0.5 inches). Visual injury was noted, and diquat effects on plant height and weight were determined. All species were relatively susceptible to diquat in irrigation water, but at concentrations above the maximum labeled use rate of 0.37 mg/L a.i. Ornamental plant tolerances in order of increasing tolerance and associated concentrations (mg/L) causing a 10% reduction in dry weight (EC_{10}) were: dianthus (1.0), snapdragon (2.5), impatiens (2.8), petunias (3.1), and begonias (5.1). Diquat concentrations exceeding 2.8 mg/L would be required to reduce plant height by 10% for each species. No visual plant injury (e.g., leaf speckling, necrotic spots, chlorosis) was noted at diquat concentrations of 5.0 mg/L or less, except on dianthus, and concentrations exceeding 50 mg/L were necessary to cause plant death. The results from these studies suggest that the risks associated with damaging these popular ornamental plants irrigated with water treated with diquat up to 0.37 mg/L is minimal.

Key words: EC_{10}, Effective Concentration 10, phytotoxicity.

INTRODUCTION

Diquat[3] is a highly water soluble, nonselective contact herbicide that, when applied to susceptible plants, interferes with electron flow in photosynthesis and results in rapid desiccation of plant tissue (Brian et al. 1958, Dodge 1971, Cassidy and Rogers 1989). Bipyridilium herbicides such as diquat interfere with photosystem I and may develop symptoms within a few hours after treatment (Hess 2000). This particular group of herbicides cause plasma membrane disruption resulting in cell contents to leak into the intercellular spaces (Vencill et al. 2002). Affected areas become necrotic within 1 or 2 d after membrane disruption. Diquat has been reported to have herbicidal properties since the 1950s and is used primarily in aquatic weed control management for control of floating and submersed aquatic weeds (Brian et al. 1958, Simsiman et al. 1976). The maximum concentration of diquat that can be applied to water is 0.37 mg/L and a three-day ornamental and turf irrigation restriction is required when the maximum-labeled rates are applied (Anonymous 2003). The half-life of diquat in water generally ranges from a few hours to two days depending on water quality and other environmental conditions (Langeland et al. 1994). Diquat is rapidly absorbed and inactivated by organic matter and clay particles (Vencill 2002), and both photolysis and microbial degradation are thought to play minor roles in degradation (Smith and Grove 1969). Therefore, the three-day waiting period allows herbicide concentrations to dissipate below concentrations that could be phytotoxic to irrigated plants.

The Environmental Protection Agency has set tolerances on the maximum amount of pesticide residue that can remain in or on a treated food commodity to ensure food safety (EPA 2003). However, no such tolerances are required for ornamental plants (non-food crops). Therefore, the major concern with diquat residues in irrigation water used for non-food crop irrigation is plant phytotoxicity. Previous research has been conducted on the response of turf and ornamental plant species to irrigation water containing the aquatic herbicides fluridone and endothall (Andrew et al. 2003, Koschnick et al. 2005a, Koschnick et al. 2005b). Despite the use of diquat since the 1950s, little research has been published on its phytotoxic effects in irrigation water. Therefore, the objective of this research was to evaluate the effects of diquat-treated irrigation water on five commonly used ornamental species. Additionally, this research may be a basis to assist in reducing homeowner irrigation restrictions (3 d) on current use labels for ornamental plants. This research was intended to address reducing the restrictions for waterfront homeowners who frequently irrigate established plants with water from ponds, lakes, or canals which may be treated with diquat for submersed or emergent aquatic weed control.

MATERIALS AND METHODS

A greenhouse study was conducted and repeated at the University of Florida, Center for Aquatic and Invasive Plants in Gainesville, FL. Plant species evaluated for diquat sensitivity were begonia, dianthus, impatiens, petunia, and snapdragon. All plants were purchased from local nurseries in Gainesville, FL and grown in 8.8 by 8.8 by 9.0 cm pots as

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[3]Reward herbicide label. Syngenta Crop Protection, Inc., Greensboro, NC 27409.

purchased from the growers. The pots contained an organic commercial potting media. Plants were subjected to 10 h photoperiod with maximum daytime temperatures of 29 ± 2°C and minimum nighttime temperatures of 15 ± 2°C. Experimental plants were selected based on uniform height to minimize variation in initial height and weight. At treatment, plant height (cm ± standard error) for each of the species was as follows: begonia 21.2 ± 0.5, dianthus 15.7 ± 0.5, impatiens 16.7 ± 0.7, petunia 7.1 ± 0.3, and snapdragon 16.5 ± 0.5. All plants except snapdragon were flowering at the time of treatment.

The experiment was a completely randomized design with five replications (five pots per treatment). Both the initial and repeated studies were conducted in the spring of 2005. Pots containing ornamental plants were placed in dishpans (25 by 31 by 14 cm) and overhead irrigated one time with a sprinkle can containing herbicide treated water equivalent to 1.27 cm of irrigation water (tap water). This volume of water was sufficient to cover plants and saturate the soil. Diquat concentrations of 0, 0.1, 1.0, 5.0, 10.0, 50.0, 100.0, and 200.0 mg/L were applied to all ornamental plant species. Excess herbicide treated water was removed from the dishpans after the pots were allowed to drain for 24 h. Every other day for 15 days, 1.27 cm of water containing no herbicide was applied overhead via a sprinkle can to each dishpan. Begonias and impatiens were treated during the course of the studies with azoxystrobin fungicide[4] when fungal pathogens were first noted. Plant height was recorded from the soil surface to the tip of the tallest leaf, 15 days after treatment (DAT). Visual estimates of ornamental plant injury were determined at the same time on a scale of 0 to 100%, where 0 = no chlorosis/necrosis and 100 = plant death. Visual injury ratings were based on controls of each species. At 15 DAT, all plants were harvested by collecting all aboveground biomass excluding dead tissue. Aboveground tissue was placed in a drying oven at 90°C for approximately 1 week and weighed.

Plant height and injury was subjected to the Mixed Procedure of SAS (SAS Institute 2002) with experiment used as a random factor. Experiment, replication (nested experiment), and all interactions containing either of these effects were considered random effects; diquat concentration was considered a fixed effect. Considering experiment or the combination of experiment and location as environments or random effects permits inferences about diquat concentration to be made over a range of environments (Carmer et al. 1989, Hager et al. 2003). Type III statistics were used to test all possible effects of fixed factors. Least square means were used for mean separation at $p \leq 0.05$. Plant dry weight and height data were also subjected to the NLIN Procedure of SAS (SAS Institute 2002). Regression models were used to determine the effective concentration 10 (EC_{10}), which is the concentration of diquat in irrigation water to cause a 10% reduction in dry weight compared to control plants. Koschnick et al. (2005a) reported this value to be conservative but near the threshold where an observant homeowner might detect adverse effects on plant growth.

[4]Heritage fungicide label. Syngenta Crop Protection, Inc., Greensboro, NC 27409.

RESULTS AND DISCUSSION

Begonias were more tolerant to diquat in irrigation water than dianthus, impatiens, petunias, or snapdragons with respect to the EC_{10} values (Table 1). The EC_{10} value calculated from non-linear regression (Figure 1) was 5.1 and 10.8 mg/L for begonia dry weight and height, respectively. Petunia dry weight and impatiens height was not different from begonia when the slopes of the plant dry weights (Figure 1) and heights were compared. Previous research has shown begonia and impatiens dry weight to be reduced by 10% with concentrations of the dipotassium and dimethylalkylamine salts of endothall at 2 to 4 mg a.i./L (Koschnick et al. 2005b). Average initial begonia dry weight was 2.9 g/pot with the control plants increasing in growth by 24% from the onset of the experiment until the plants were harvested 15 DAT. This growth may indicate that diquat can cause growth inhibition with no visual injury.

Snapdragons and impatiens were more sensitive to diquat in irrigation water than begonias or petunias. Impatiens tolerance to diquat in irrigation water was intermediate to begonia and dianthus with an EC_{10} value of 2.8 mg/L (Table 1). The impatiens control plants increased in growth (dry weight) by as much as 155% from the onset of the study to the conclusion for both experiments. The most sensitive species to diquat in this study was dianthus with a concentration of 1.0 mg/L resulting in a 10% reduction in dry weight.

Although plant dry weight more accurately reflects the effect of herbicides on plants, plant height can be used as a secondary means to detect herbicide phytotoxicity. The order of increased susceptibility of these plants to irrigation water containing diquat with respect to height was as follows: begonia, impatiens, petunia, dianthus, and snapdragon (Table 1).

A safety factor of 2.7 to 13.8 and 7.6 to 29.2 times the maximum diquat labeled rate was calculated for all the ornamental plants for plant dry weight and plant height, respectively

Table 1. The effect of single overhead irrigation with 1.27 cm water containing diquat (mg/L a.i.) on begonia, petunia, snapdragon, impatiens, and dianthus dry weight and height 15 d after treatment.

Dry weight	EC_{10}[a] (95% CI[b])	Regression equation	r^2	Safety factor[c]
Begonia	5.1 (4.4-6.1)	y = 3.9879e-0.0208x	0.98	13.8
Petunia	3.1 (1.9-7.6)	y = 4.5666e-0.0344x	0.79	8.4
Impatiens	2.8 (2.2-3.7)	y = 3.4630e-0.0382x	0.96	7.6
Snapdragon	2.5 (1.9-3.6)	y = 2.9153e-0.0422x	0.94	6.8
Dianthus	1.0 (0.9-1.2)	y = 3.7755e-0.1065x	0.97	2.7
Height				
Begonia	10.8 (9.2-12.9)	y = 22.5340e-0.0098x	0.97	29.2
Petunia	6.4 (5.3-8.1)	y = 20.0364e-0.0164x	0.96	17.3
Impatiens	7.5 (6.1-9.8)	y = 20.1900e-0.0141x	0.95	7.6
Snapdragon	2.8 (2.4-3.5)	y = 19.3793e-0.0375x	0.98	20.3
Dianthus	4.7 (3.8-6.0)	y = 17.2375e-0.0226x	0.96	12.7

[a]Effective concentration 10: EC_{10} = concentration of diquat (mg/L a.i.) in irrigation water to reduce plant dry weight or height by 10%. Each value is a mean of two experiments with a total of 10 replications (pots).
[b]95% CI = 95% Confidence Interval.
[c]Safety Factor = EC_{10}/0.37 mg/L a.i. (maximum labeled rate).

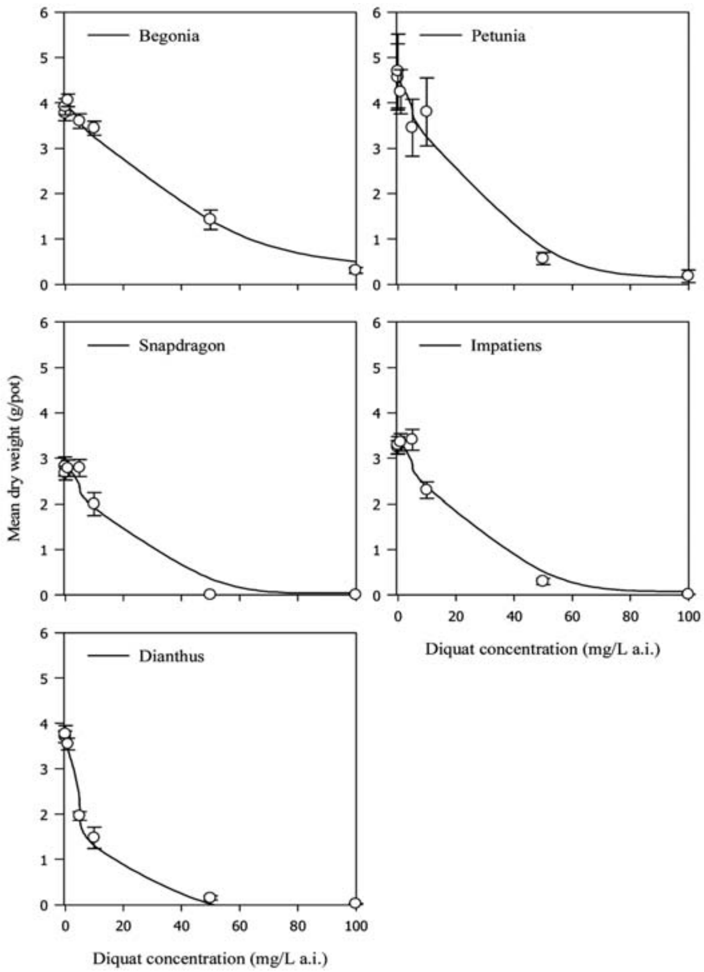

Figure 1. Relationship between begonia, petunia, snapdragon, impatiens, and dianthus dry weight and the concentration of diquat in irrigation water applied one time. Actual dry weight means ± standard error (n = 5). Data for 200 mg/L treatments were not included on the graphs as these treatments resulted in total mortality of all plants.

(Table 1). The safety factor from the maximum label use rate (0.37 mg/L) in water to the EC_{10} for dianthus dry weight is only 2.7×. The short half-life of diquat in water and the rare event of homeowners irrigating immediately after diquat application suggests that even such a low safety margin is acceptable, but close to the EC_{10} arbitrary level of concern.

Concentrations of diquat at 1.0 mg/L or less did not result in visual injury to any of the ornamental species (Table 2). All species displayed visual injury symptoms of isolated leaf speckling at 10 mg/L, except dianthus (5 mg/L). Diquat applied at 10 mg/L caused moderate leaf speckling 2 to 5 DAT on all species, and a concentration of 50 mg/L and greater killed snapdragons by 3 DAT (data not shown). Unlike the other species treated with irrigation water containing diquat at 50 mg/L, snapdragons had no regrowth from desiccated tissue through 15 DAT. Though severely damaged, begonia was the only plant not killed at diquat concentrations of 200 mg/L.

The results from these studies indicate that begonia was the most tolerant plant to diquat in irrigation water; while dianthus was the most sensitive. Begonia, dianthus, and impatiens height was not affected until diquat was applied at rates greater than 10 mg/L. If ornamental plants are irrigated with water containing diquat uniformly applied at the labeled rate of 0.37 mg/L or less, the above ground biomass of these ornamental plants will not be reduced.

TABLE 2. BEGONIA, DIANTHUS, IMPATIENS, PETUNIA AND SNAPDRAGON INJURY[a] (%) 15 D AFTER 1.27 CM OVERHEAD IRRIGATION WITH WATER CONTAINING DIQUAT (MG/L A.I.) TREATMENT.

Diquat	Begonia[b]	Dianthus	Impatiens	Petunia	Snapdragon
0	0 a	0 a	0 a	0 a	0 a
0.1	0 a	0 a	0 a	0 a	0 a
1.0	0 a	0 a	0 a	0 a	0 a
5.0	2 a	25 b	1 a	11 a	3 a
10.0	11 b	42 c	14 b	8 a	27 b
50.0	73 c	93 d	85 c	68 b	100 c
100.0	93 d	99 e	99 d	89 c	100 c
200.0	96 d	100 e	100 d	100 c	100 c

[a]% Injury represented on a scale of 0 to 100%, where 0 = no chlorosis/necrosis and 100 = plant death.
[b]Means within a column followed by the same lowercase letter were not significant according to the least square means for effect of concentration at p ≤ 0.05.

Concentrations resulting in a 10% reduction in dry weight compared to control plants were approximately 2.7 to 13.8 times the maximum label concentration of 0.37 mg/L. Immediate use of diquat treated water following application could result in minor injury to these species if the herbicide were not diluted or applied uniformly to the water. However, due to the short half-life, rapid dilution, and the findings of this study, it is suggested the three-day irrigation restriction should be removed or at least reduced for homeowner ornamental plants and possibly replaced with a set-back distance from irrigation intakes. By placing a minimum distance between the irrigation intake and the application site, an avoidance of uptake of lethal or visually damaging doses of herbicides could be easily achieved allowing dissipation and dilution following application. Based upon these data, the likelihood of damaging these ornamental annual plants following diquat application is minimal. These suggestions for changes to the current diquat label are strictly intended for homeowner use and not for commercial nursery use. The authors do not support removing or decreasing the current restriction for nursery production due to the wide variety of plants (trees, shrubs, perennials, etc.) and ages (seedling, immature, mature) which could be exposed to this herbicide. Until further testing has been done to determine phytotoxicity, a great deal of uncertainty remains with irrigating nursery stock.

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