Turf and Ornamental Plant Tolerances to Endothall in Irrigation Water I. Ornamental Species

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SUMMARY. Restrictions on the endothall aquatic herbicide label include the use of endothall treated water for irrigating plants from 7 to 25 days after application. This interval was established to allow sufficient time for endothall to dissipate to levels that were considered safe for irrigation to prevent phytotoxicity to desirable plants. The effects of endothall on begonias (*Begonia semperflorens* 'Vodka Cocktail'), pansies (*Viola xwittrockiana* 'Atlas Purple'), petunias (*Petunia hybrida*), and impatiens (*Impatiens wallerana* 'Lipstick') were determined by comparing aboveground dry weight to control plants after exposure to endothall in irrigation water. The objective was to determine if endothall concentrations used for aquatic weed control were phytotoxic to ornamental plants. Plants were irrigated every other day for 6 days in Expt. 1 with constant concentrations of endothall, and for 8 days in Expt. 2 with decreasing concentrations of endothall. Concentrations causing a 10% reduction in dry weight (effec-

tive concentration: EC₁₀) compared to control plants showed there was a wide range of tolerance among plants exposed to endothall in irrigation water in the two experiments. Begonias, pansies, and impatiens had the lowest tolerance to two formulations of endothall in irrigation water with EC₁₀ values ranging from 2 to 4 mg·L⁻¹ (ppm) a.i. (a.i. based on acid equivalence) in both experiments. Petunias, which were more tolerant to endothall, had EC₁₀ values of 15 and 34 mg·L⁻¹ a.i. in Expt. 1 and 11 and 20 mg·L⁻¹ a.i. in Expt. 2 for the amine and dipotassium formulations of endothall, respectively. Endothall did abscise flowers on impatiens after irrigation with endothall at concentrations of 10 mg·L⁻¹ a.i. and higher. Effects of endothall on begonias at concentrations close to the EC₁₀ values (2 to 3 mg·L⁻¹ a.i.) were limited to growth inhibition with no apparent desiccation or necrosis of plant tissue.

The dipotassium salt and mono (*N,N*-dimethylalkylamine) salt of endothall are contact herbicides used to control submersed aquatic weeds and algae. The dipotassium salt of endothall has a 7-d restriction on irrigation when concentrations of ≤0.35 mg·L⁻¹ a.i. are applied, a 14-d restriction for concentrations of 0.36 to 3.00 mg·L⁻¹ a.i., and a 25-d restriction when concentrations are 3.01 to 3.50 mg·L⁻¹ a.i. (Aquathol K Aquatic Herbicide; Cerexagri, King of Prussia, Pa.). The amine salt of endothall has a 7-d restriction when concentrations of ≤0.30 mg·L⁻¹ a.i. are applied, a 14-d restriction at concentrations of 0.31 to 3.00 mg·L⁻¹ a.i., and a 25 d restriction from 3.01 to 5.00 mg·L⁻¹ a.i. (Hydrothol 191 Aquatic Algicide and Herbicide; Cerexagri).

The maximum concentration of endothall that can be applied to water is 3.5 mg·L⁻¹ a.i. for the dipotassium salt and 5.0 mg·L⁻¹ a.i. for the amine salt. Typically, the amine salt is used at concentrations less than 1.0 mg·L⁻¹ a.i. due to potential fish toxicity, and the dipotassium salt is used at concentrations between 0.7 and 2.8 mg·L⁻¹ a.i.

The irrigation restriction on the endothall label is because food-crop residue tolerances have not been established. Therefore, the irrigation restriction allows sufficient time for endothall to dissipate to concentrations considered safe for application to food crops. In addition, concerns

about possible phytotoxicity to susceptible ornamental plants have been raised when irrigating with endothall treated water. Currently, the water-use restrictions for food-crop irrigation have limited the use of endothall because there have been limited studies to document phytotoxicity occurring from endothall in irrigation water.

The potential of injury to container-grown ornamental species by endothall-treated water is a concern where irrigation water may be used for non-food crop uses, such as by a homeowner, golf course, or in other landscaped areas. Therefore, studies were conducted to determine concentrations of endothall in irrigation water that cause phytotoxicity on four widely used annual ornamental species. Impatiens are the most widely sold bedding plant in the United States, followed by petunias (Perry, 1998). Begonias are also widely distributed, with more than 1200 different species and hybrids, many in commercial trade (Tija and Black, 1990). Pansies were selected as an additional test species. These species were used to determine concentrations of endothall in irrigation water that cause growth reduction or phytotoxicity. The hypothesis was that endothall concentrations used to control aquatic weeds would not be phytotoxic to container-grown ornamental plant species.

Two experiments were conducted to assess the risks associated with irrigating ornamental plant species with endothall in irrigation water. The first experiment (Expt. 1) used constant concentrations of endothall, whereas the second experiment (Expt. 2) used decreasing endothall concentrations that mimic herbicide degradation over time based on a 9-d half-life. This half-life of endothall was based on results from static water studies (Langeland and Warner, 1986; Reinert et al., 1985) and laboratory degradation studies (Reinert et al., 1986). The hypothesis was that irrigating with decreasing concentrations of endothall would have less affect on plant dry weight than irrigating with constant concentrations. A third study (Expt. 3) was designed to determine if endothall application would cause flower abscission on impatiens.

Materials and methods

Begonias, petunias, pansies, and impatiens were maintained in a green-

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house at the University of Florida, Center for Aquatic and Invasive Plants, in Gainesville. All plants were grown in potting media (one-third peat, one-third sand, one-third organic soils) in 20-cm² (3.1 inch²) pots and subjected to 16 h photoperiod with maximum daytime temperatures of 32.2 ± 2.8 °C (90 ± 5 °F) and minimum nighttime temperatures of 18.3 ± 2.8 °C (65 ± 5 °F). Experimental plants were selected based on uniform growth and visual height estimates to minimize variation. Begonias, pansies, and impatiens were approximately 20 cm (7.9 inches) in height at the start of the experiments and petunias approximately 45 cm (17.7 inches). Additional nutrients were applied as needed to maintain healthy growth [Peters 20-20-20 fertilizer (20N-8.7P-16.6K; Spectrum Group, St. Louis)], and plants were treated with azoxystrobin fungicide when pathogens were first noted during the course of the studies.

Nine endothall concentrations (0 to 320 mg·L⁻¹ a.i.) were compared for begonias, pansies, and impatiens and 10 concentrations (0 to 640 mg·L⁻¹ a.i.) were applied to petunias in a completely randomized design with at least five replications during Expt. 1 (Table 1). Concentrations were predetermined by non-replicated trials since differential responses were expected between species. Pots were irrigated every other day over a 6-d period (Day 0, 2, 4, and 6) for a total of four irrigations so that an effective concentration could be calculated after irrigations with constant concentra-

tions of endothall. Replicate begonia plants were harvested to determine initial dry weights.

For Expt. 2, ornamental species were irrigated five times every other day over a period of 8 d to take into consideration approximately one theoretical half-life of endothall. Succeeding irrigations were made with decreasing concentrations of herbicide. Seven endothall concentrations (0 to 25 mg·L⁻¹ a.i.) were compared on begonias and pansies, and 9 for petunias and impatiens [0 to 100 mg·L⁻¹ a.i. (Table 1)] in a similar design as Expt. 1. All concentrations reported for Expt. 2 are expressed as the initial concentration during the first irrigation.

Pots of each species of ornamental plants were overhead irrigated manually with a sprinkle can with a volume of herbicide containing water equivalent to 1.27 cm (0.5 inch) per irrigation, which was enough water to completely wet the foliage and saturate the soil in the pots. Fresh solutions were prepared prior to each irrigation event. Four plants were placed into dishpans that were used to collect and dispose of any excess irrigation water. Excess irrigation water was disposed of from the bottom of the dishpans every 12 to 24 h.

After the final irrigation with endothall, 1.27 cm tap water containing no herbicide was applied overhead via a sprinkle can to each pot approximately every other day to allow decay of necrotic tissue or recovery until the plants were harvested. Each species was allowed to grow for 5 to 9 d (Table

1), and then harvested by collecting all aboveground biomass excluding dead tissue. Aboveground plant tissue was placed in a drying oven at 90 °C (194.0 °F) for approximately 2 weeks to determine plant dry weights, and percent reductions in dry weight were compared to control plants.

For Expt. 3, impatiens plants with 10 flowers/pot were selected for uniformity and irrigated two times with endothall containing irrigation water at constant concentrations. Irrigations were conducted in a manner similar to Expts. 1 and 2. A total of seven concentrations of endothall (0, 5, 10, 15, 20, 25, and 30 mg·L⁻¹ a.i.) were evaluated to determine the concentration at which flower abscission occurs, with four replications per treatment. Flower counts were made prior to treatment and 24 h after each of the two irrigations that occurred 48 h apart.

Analysis of variance using percent reductions in dry weight compared to control plants and nonlinear regression were conducted using the SAS statistical package (SAS Institute, Cary, N.C.) for the first two experiments. To satisfy the assumptions of normality and equal variance in a linear model, the data were transformed prior to statistical analysis using arcsin for all general linear model procedures. In both experiments, regression models were used to determine the effective concentration 10 (EC₁₀), which is the concentration of endothall expected to cause a 10% reduction in dry weight compared to control plants. The EC₁₀ reporting value was determined to

Table 1. Concentrations of endothall applied to four ornamental plants in irrigation water in two experiments (Expts. 1 and 2), and the time elapsed (days) before plants were harvested after the final irrigation with herbicide containing water.

Endothall concn [mg·L ⁻¹ (ppm) a.i.]			
Species	Formulation		Harvest (d)
	Amine	Dipotassium	
<i>Begonia</i>			
Expt. 1	2.5, 5, 10, 20, 40, 80, 160, 320	2.5, 5, 10, 20, 40, 80, 160, 320	7
Expt. 2	2.5, 5, 10, 15, 20, 25	2.5, 5, 10, 15, 20, 25	9
<i>Pansy</i>			
Expt. 1	2.5, 5, 10, 20, 40, 80, 160, 320	2.5, 5, 10, 20, 40, 80, 160, 320	7
Expt. 2	2.5, 5, 10, 15, 20, 25	2.5, 5, 10, 15, 20, 25	7
<i>Petunia</i>			
Expt. 1	2.5, 5, 10, 20, 40, 80, 160, 320, 640	2.5, 5, 10, 20, 40, 80, 160, 320, 640	8
Expt. 2	2.5, 5, 10, 15, 20, 25, 50, 100	2.5, 5, 10, 15, 20, 25, 50, 100	8
<i>Impatiens</i>			
Expt. 1	2.5, 5, 10, 20, 40, 80, 160, 320	2, 4, 7, 14, 28, 57, 114, 227	8
Expt. 2	2.5, 5, 10, 15, 20, 25, 30, 60	2, 4, 7, 11, 14, 18, 21, 42	5

Fig. 1. Relationship between begonia dry weight (1 g = 0.035 oz) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments. During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied five times with decreasing concentrations.

be a conservative value and near the threshold where a homeowner might detect adverse affects on plant growth. A repeated measures analysis was used to determine the effect of endothall on flower abscission (Expt. 3).

Results and discussion

Begonias responded similarly to endothall in both Expts. 1 and 2, as dry weights decreased with increasing concentrations of endothall (Fig. 1). EC_{10} values were calculated at 2 mg·L⁻¹ a.i. in Expt. 1, and 3 mg·L⁻¹ a.i. in Expt. 2. No differences between endothall formulations were observed. Initial dry weights of begonias used for the dipotassium endothall study were 1.22 ± 0.15 g/pot (0.043 ± 0.005 oz/pot). Dry weights of plants 7 d after four irrigations with endothall concentrations ranging from 5 to 25 mg·L⁻¹ a.i. were similar to control plants with dry weights of 1.25 to 1.98 g/pot [0.044 to 0.070 oz/pot (Fig. 1)]. Pre-treatment weights of begonias irrigated with the amine formulation of endothall were 1.30 ± 0.16 g/pot (0.046 ± 0.006 oz/pot). Plant dry weights exposed to 10, 15, 20, and 25 mg·L⁻¹

a.i. showed no differences and ranged from 1.38 to 1.65 g/pot [0.049 to 0.058 oz/pot (Fig. 1)]. Control plants increased growth by greater than 130% from the onset of the study until the plants were harvested. Without control plants as a reference for comparison to plants exposed to herbicide, it is unlikely differences in growth would be noticeable at concentrations less than 25 mg·L⁻¹ a.i. The visual effect of endothall treatment was due to growth inhibition rather than toxicity and desiccation of plant tissue.

Pansies had a similar response to endothall in irrigation water as begonias (Fig. 2). A concentration of 4 mg·L⁻¹ a.i. caused a 10% reduction in dry weights compared to control plants for the amine salt in Expt. 1 and dipotassium salt in Expt. 2, while a concentration of 3 mg·L⁻¹ a.i. caused a 10% reduction in dry weights for the dipotassium salt in Expt. 1 and amine salt in Expt. 2.

Petunias were more tolerant to endothall in irrigation water than begonias, impatiens, and pansies (Fig. 3.) EC_{10} values were 15 mg·L⁻¹ a.i. and 11 mg·L⁻¹ a.i. for the amine salt

in Expts. 1 and 2, respectively. Concentrations causing a 10% reduction in dry weights compared to control plants for the dipotassium salt were 34 mg·L⁻¹ a.i. in Expt. 1 and 20 mg·L⁻¹ a.i. in Expt. 2.

Impatiens dry weights exhibited similar responses to endothall in irrigation water for the two experiments even though plants were initially smaller in Expt. 1 than those used in Expt. 2 (Fig. 4). Calculated EC_{10} values were 4 mg·L⁻¹ a.i. for both formulations and experiments. During Expt. 1, endothall appeared to affect the total number of flowers on impatiens. While not an original study objective, flowers were counted to determine if endothall was causing flower abscission during Expt. 2, but variation in the total number of flowers counted per plant was high. Endothall concentrations of ≥10 mg·L⁻¹ a.i. for the amine formulation and ≥11 mg·L⁻¹ a.i. for the dipotassium formulation decreased the total number of flowers/pot to less than three, while control plants had approximately 15 to 18 flowers/pot (Fig. 5). A concentration greater than 15 mg·L⁻¹ a.i. nearly abscised all flow-

Fig. 2. Relationship between pansy dry weight (1 g = 0.035 oz) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments. During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied five times with decreasing concentrations.

Fig. 3. Relationship between petunia dry weight (1 g = 0.035 oz) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments. During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied five times with decreasing concentrations.

Fig. 5. Flower abscission on impatiens after five irrigations with decreasing concentrations of endothall treated water. Total number of flowers were counted after the final irrigation. Values represented as the means of five replications $\pm$ SE. Concentrations are listed for amine salt, followed by dipotassium salt.

ers from impatiens plants, but these concentrations also caused reductions in plant dry weights (Fig. 4).

An experiment (Expt. 3) was initiated to determine the effects of endothall on impatiens flower abscission, and endothall reduced the number of flowers present on impatiens compared to control plants; with both concentration ($P < 0.0001$) and time ($P = 0.0010$) having a significant effect, and the concentration–time interaction also having a significant effect ($P = 0.0114$). There was no effect due to formulation ($P = 0.3478$) and no other significant interactions. This study was completed over a short period of time, as there was some concern that irrigating over a long period of time would possibly cause injury to plants, obscuring the effects of endothall on flower abscission. Twenty-four hours after the first and second irrigations, the number of flowers on impatiens was reduced at a concentration of 10 mg·L⁻¹ a.i. for both formulations of endothall, with the exception of the amine formulation 24 h after the first irrigation. Additional flowers were abscised as concentrations increased (Table 2). The results from this study are comparable to and confirm the results when impatiens flowers were counted during Expt. 2 (Fig. 4).

Currently, endothall is being evaluated as a blossom thinner in apple (*Malus domestica*) and peach (*Prunus persica*) trees to increase fruit size, reduce biennial bearing of fruit, and to reduce the amount of hand thinning (Greene et al., 2001; Stover et al., 2002). Therefore, endothall might cause flower abscission or affect blooming in other plants due to its activity as a plant desiccant. When used as a blossom thinner, endothall desiccates flower parts preventing pollination of

open blooms (Williams et al., 1995), but endothall is possibly affecting ethylene or abscisic acid production (Abeles and Abeles, 1972; Rikin and Rubin, 1983). Although, the exact mechanism that causes flower abscission is not known, endothall did not have the same effect on begonias, pansies or petunias unless severe reductions in dry weights were evident. Flower abscission occurred in impatiens before any direct impact on plant growth was observed, with flower abscission being the first noticeable indication of irrigation with endothall.

The results from these studies indicate that endothall has some potential to cause growth inhibition, but not phytotoxicity, to ornamental plants irrigated with endothall at concentrations that may be used for aquatic weed control. Effective concentrations resulting in a 10% reduction in dry weight compared to control plants were approximately 0.6 to 1.1 times the maximum-label concentration of endothall in water (3.5 mg·L⁻¹ a.i. dipotassium and 5.0 mg·L⁻¹ a.i. amine salt formulation) on begonias, impatiens and pansies. Petunia EC₁₀ values were 2.2 to 9.7 times greater. Additional studies should be completed on more ornamental plant species since it is not clear whether begonias, impatiens and pansies are the most sensitive plants. Risks of phytotoxicity after irrigating ornamental plants with endothall treated water may be reduced in the field considering the typical uses of the herbicide (spot treatments and concentrations). Few differences should be expected for the two formulations. Additional stresses on plants, such as nutrient deficiency, drought, and disease, may change the tolerance of species to endothall as well.

While these data suggest 10%

growth inhibition can occur at concentrations in the upper range of the labeled rates, endothall is only applied once or twice annually for aquatic weed control and phytotoxicity did not occur until higher concentrations were applied. There is some risk that ornamental plantings of homeowners could be affected, but this risk is relatively small. However, endothall treated water should not be used in commercial nurseries where irrigation water may be applied daily or more frequently. Significant flower abscission is unlikely at normal use rates. To investigate whether irrigation restrictions may be reduced on the endothall labels for non-crop purposes, such as irrigation by a homeowner or golf course, a companion paper (Koschnick et al., 2005) reports the effects of endothall in irrigation water on five turf species.

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Table 2. Mean number of impatiens flowers 24 h after each of two irrigations with water containing endothall, reported as 24 and 72 h after the first irrigation. All plants were selected to have 10 flowers/pot at the start of irrigation.

Endothall concn [mg·L ⁻¹ (ppm) a.i.]	No. of flowers [no./pot (mean ± SD)] ²			
	Amine		Dipotassium	
	24 h	72 h	24 h	72 h
0	10.9 ± 1.6 a ²	13.1 ± 3.6 a	10.9 ± 1.6 a	13.1 ± 3.6 a
5	9.3 ± 3.0 a	8.5 ± 4.0 ab	11.8 ± 1.3 a	9.5 ± 3.3 a
10	7.3 ± 2.1 ab	5.3 ± 3.1 bc	5.5 ± 1.3 bc	5.5 ± 2.1 b
15	7.3 ± 3.0 ab	7.3 ± 1.0 b	6.3 ± 1.9 b	5.0 ± 3.3 b
20	5.3 ± 2.1 bc	3.5 ± 1.0 c	4.5 ± 2.1 bc	3.0 ± 1.8 bc
25	3.0 ± 1.8 c	2.0 ± 2.2 c	3.5 ± 0.6 c	1.8 ± 1.0 cd
30	2.3 ± 1.7 c	2.0 ± 2.3 c	1.0 ± 0.8 d	0.3 ± 0.5 d

²Means within a column followed by different letters are significantly different according to least square means for effect of concentration ($P < 0.005$).