

Turf and Ornamental Plant Tolerances to Endothall in Irrigation Water

II. Turf Species

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SUMMARY. Two formulations of the contact herbicide endothall are used to control submersed aquatic weeds. Waters treated with the amine or dipotassium salt formulations have irrigation restrictions varying from 7 to 25 days depending on the concentration of endothall applied. These water-use restrictions may be reduced for turfgrass if studies conclude there is no phytotoxicity to turf species irrigated with concentrations of endothall that may exist after an aquatic application. Two separate experiments were conducted to determine turfgrass tolerance to endothall in irrigation water on five species of grass: annual ryegrass (*Lolium multiflorum*), annual bluegrass (*Poa annua*), centipedegrass (*Eremochloa ophiuroides*), 'Floritam' st. augustinegrass (*Stenotaphrum secundatum*), and 'Tifton 419' bermudagrass (*Cynodon dactylon*). Expt. 1 used constant concentrations of endothall; Expt. 2 used decreasing concentrations of endothall over time. Annual turf species (bluegrass and ryegrass) were gener-

ally more susceptible than perennial turfgrasses. Concentrations resulting in a 10% reduction in total dry weight harvested compared to control plants [effective concentration (EC_{10})] for the amine and dipotassium salt formulations were 10 and 14 mg·L⁻¹ (ppm) a.i. on annual ryegrass, 10 and 16 mg·L⁻¹ a.i. on annual bluegrass, 50 and 54 mg·L⁻¹ a.i. on centipedegrass, 47 and 72 mg·L⁻¹ a.i. for st. augustinegrass, and for bermudagrass 1301 and 908 mg·L⁻¹ a.i. in Expt. 1. Expt. 2 resulted in EC_{10} values of 31 and 35 mg·L⁻¹ a.i. on annual ryegrass, 7 and 12 mg·L⁻¹ a.i. on annual bluegrass, 32 and 99 mg·L⁻¹ a.i. on centipedegrass, 27 and 20 mg·L⁻¹ a.i. on st. augustinegrass for the amine and dipotassium formulations of endothall respectively, and 958 mg·L⁻¹ a.i. for the dipotassium formulation on bermudagrass. There was no effect on bermudagrass dry weights when exposed to the amine formulation of endothall in Expt. 2 at concentrations up to 1600 mg·L⁻¹ a.i. There is a low risk of inhibiting growth of turf species at endothall concentrations used for aquatic weed control considering the maximum use concentrations, typical uses of the products, and decomposition rates.

Certain aquatic herbicides have restrictions on the use of treated water until the herbicide dissipates to concentrations that are determined to have no adverse effect on the intended use of the water including fishing, swimming, drinking and irrigation. Restriction time frames for aquatic herbicides generally range from 0 to 30 d. The interval depends on the intended use of the treated water and the amount of time it takes for the compound to be absorbed by plants, degraded or diluted in the aquatic environment. One of the most restricted uses on aquatic herbicide labels is the irrigation restriction. Irrigation water that contains an aquatic herbicide may be phytotoxic to certain terrestrial plant species.

First registered for aquatic use in 1960, endothall is currently formulated as the dipotassium salt and mono (*N,N*-dimethylalkylamine) salt of endothall. Both formulations of the contact herbicide are labeled for aquatic weed control. 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. The exception to these restrictions is bentgrass (*Agrostis* spp.); it can be irrigated immediately with water containing the dipotassium salt of endothall (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. Irrigation restrictions on the endothall label are partly due to a lack of data to demonstrate there is limited risk of phytotoxicity to irrigated plants.

There is a maximum amount of herbicide applied per hectare when using terrestrial herbicides. The amount of diluent can be varied. In contrast, aquatic herbicides are often added to a volume of lake or pond water to achieve a desired concentration for submersed plant control. The amount of herbicide applied per unit area will vary according to the depth of a lake or pond or total volume of water being treated. The differences between herbicide concentrations applied from a tank mix in terrestrial applications vs. concentrations of aquatic herbicides in irrigation water from a lake or pond must be considered when addressing the potential phytotoxicity to turf and ornamental plants. The actual concentration of herbicide applied to the foliage in terrestrial herbicide applications is generally much higher than when terrestrial plants are exposed to herbicides in irrigation water withdrawn from a water body treated with an aquatic herbicide.

Endothall was once labeled as a turf herbicide [19.2% disodium salt containing 175.74 g·L⁻¹ a.i. (1.5 lb/gal a.i.)] used for the selective removal of certain species of grass (annual bluegrass and annual ryegrass) and broad-leaf weeds in bentgrass (*Agrostis* spp.) and bluegrass (*Poa pratensis*) turf. The concentrations of endothall applied to turf were higher than those used for aquatic weed control. Application rates on turf ranged from 857 to 2139

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mg·L⁻¹ a.i. depending on spray volume (Endothall Turf Herbicide; Atochem North America, Philadelphia). Endothall may be phytotoxic to some turf species at concentrations that exceed the maximum aquatic herbicide use rate (Hiltibrand and Turgeon, 1977; Turgeon et al., 1972a). However, no studies have been conducted to define concentrations causing phytotoxic effects. Most of the data generated on endothall in turf was completed on species in the northern tier of the U.S., not perennial species in the southern U.S. Therefore, studies were initiated to evaluate the potential phytotoxic effects of irrigating with endothall-treated water on selected turf species to determine tolerance levels associated with endothall residues on turfgrass. Turfgrasses used in this study were selected based on their widespread use in the southeastern U.S. These species represent a majority of the \$300 million sod production business in Florida (Hodges and Haydu, 2002). The hypothesis was endothall concentrations used to control aquatic weeds would not be phytotoxic to common southern U.S. turfgrass species.

Two experiments were conducted to assess the risks associated with irrigating turf with endothall in irrigation water. Expt. 1 was conducted by irrigating turfgrass four times with constant concentrations of endothall. Expt. 2 was conducted by irrigating turfgrass eight times with decreasing concentrations of endothall to mimic irrigation from a lake or pond treated with endothall where the herbicide would degrade over time. Endothall concentrations were decreased over time on the basis of a 9-d half-life to mimic irrigation from a lake or pond treated with endothall. Half-life was chosen based on dissipation data in static water studies (Langeland and Warner, 1986; Reinert et al., 1985), and under laboratory conditions (Reinert et al., 1986).

Materials and methods

Species included three stoloniferous, perennial species, st. augustinegrass, centipedegrass, and bermudagrass; and two annual species, annual bluegrass and annual ryegrass. Plants were grown in either a greenhouse or outdoors at the University of Florida, Center for Aquatic and Invasive Plants, in 3-L (0.8 gal) pots [17.1-cm diameter × 13.3 cm deep (6³/₄ × 5¹/₄ inches)] with

holes for drainage. Each pot was filled with builder's sand, amended with 4 g (0.14 oz) of 15N-3.9P-10.0K slow release (12 to 14 months) Osmocote fertilizer (Scotts-Sierra Horticultural Products Co., Marysville, Ohio) to within 5.1 cm (2 inches) of the top of each pot to leave space for sod or seed establishment. Greenhouse grown st. augustinegrass and centipedegrass were 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). All other species were grown outdoors under ambient conditions.

St. augustinegrass, centipedegrass, and bermudagrass were established from commercially available sod that was approximately 3 to 4 cm (1.2 to 1.6 inches) in thickness. Circular pieces of sod 15.2 cm (6 inches) in diameter were cut and placed into the pots containing sand. Annual grass species (bluegrass and ryegrass) were established from seed according to manufacturers recommendations, with bluegrass seeded at a rate of 392.3 kg·ha⁻¹ (350 lb/acre) and ryegrass at a rate of 488.7 kg·ha⁻¹ (436 lb/acre). Approximately 4 cm (1.6 inches) of commercial topsoil was added to the top of each pot over the sand base and seeds were placed uniformly on top and lightly compacted. Additional nutrients were added as required to maintain healthy growth [Hoaglands solution, Peters fertilizer 20N-8.7P-16.6K (Spectrum Group, St. Louis) or micronutrients]. Grass was clipped back to approximately 2 cm (0.8 inch) in height twice before irrigation with endothall-treated water.

In both experiments, nine endothall concentrations were compared for each species. Treatments were arranged in a completely randomized design with five replications (pots) for st. augustinegrass and centipedegrass, and six replications for all other species in each experiment. Concentrations were predetermined by non-replicated trials since differential responses were expected between species. For Expt. 1, st. augustinegrass was irrigated with 0, 5, 50, 100, 200, 400, 800, 1600, and 3200 mg·L⁻¹ a.i. endothall, centipedegrass irrigated with 0, 5, 25, 50, 100, 200, 400, 800 and 1600 mg·L⁻¹ a.i. endothall, and bermudagrass with 0, 5, 10, 50, 100, 200, 400, 800, and 1600 mg·L⁻¹ a.i. Annual bluegrass was

irrigated with endothall concentrations of 0, 2.5, 5, 10, 20, 40, 80, 160, and 320 mg·L⁻¹ a.i., whereas annual ryegrass was irrigated with 0, 5, 10, 25, 50, 100, 200, 400, and 800 mg·L⁻¹ a.i. endothall. For Expt. 2, st. augustinegrass, centipedegrass, annual bluegrass and annual ryegrass were irrigated with 0, 2.5, 5, 10, 15, 20, 40, 80, and 160 mg·L⁻¹ a.i. endothall, and bermudagrass was irrigated with endothall concentrations of 0, 5, 10, 50, 100, 200, 400, 800, and 1600 mg·L⁻¹ a.i. Grass was irrigated with approximately 378.55 mL (12.8 fl oz) water per pot twice a week (generally every Sunday and Wednesday) with water containing endothall. This resulted in an irrigation event equivalent to 1.27 cm (0.5 inch) water. Overhead irrigation water was applied to each pot via a sprinkle can to ensure complete coverage of all foliage. The pots were completely saturated in a short period of time. Irrigation water did not overflow the pots. Three to four days after the final irrigation with herbicide containing water, well water (1.27 cm/pot) containing no herbicide was applied to each pot approximately two times per week for the remainder of the experiment. During this time grass was harvested to monitor recovery from any initial injury.

The grass was clipped with scissors every 7 to 20 d after initial treatment, depending on growth rates of each species. Each harvest consisted of clipping growth back in each pot to 1.8 cm (0.71 inch) in height for annual ryegrass, annual bluegrass, and bermudagrass, and to 2.5 cm (0.98 inch) for centipedegrass and st. augustinegrass. The intervals between harvests were determined by monitoring growth in the control plants. Harvests were conducted when the growth of the control plants reached the approximate height of the plants at the time when irrigations containing endothall-treated water were initiated. Grass cuttings for each pot were collected during the harvest and placed in a drying oven for 5 to 7 d at 90 °C (194.0 °F) to determine dry weights. The weight of the first turf cutting after irrigation with endothall-treated water was not included in the data analysis because it was not possible to separate live from necrotic leaf blades on plants treated with the higher concentrations of endothall. After the first cutting, the harvest consisted of green leaf tissue, and dry weights of live plants were eas-

ily measured. The dry weights from all harvests were combined for each species to get a total dry weight harvested after exposure to endothall.

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. Regression models were used to determine the EC_{10} , which is the concentration of endothall expected to cause a 10% reduction in dry weight compared to control plants. The EC_{10} reporting value was determined to be near the threshold where a homeowner might detect adverse affects on plant growth.

Results and discussion

Irrigation with endothall containing water resulted in similar dose responses on st. augustinegrass for both

the amine salt and dipotassium salt of endothall in both experiments. However, the total dry weight harvested in Expt. 2 was greater than Expt. 1 (Fig. 1). St. augustinegrass had EC_{10} values for amine endothall of $47 \text{ mg}\cdot\text{L}^{-1}$ a.i. in Expt. 1 and $27 \text{ mg}\cdot\text{L}^{-1}$ a.i. in Expt. 2. Irrigation with dipotassium endothall resulted in EC_{10} values of $72 \text{ mg}\cdot\text{L}^{-1}$ a.i. in Expt. 1 and $20 \text{ mg}\cdot\text{L}^{-1}$ a.i. in Expt. 2.

Centipedegrass dose responses to endothall were similar for both formulations in Expt. 1, and with the dipotassium salt of endothall in Expt. 2 (Fig. 2). EC_{10} values for Expt. 1 were calculated as $54 \text{ mg}\cdot\text{L}^{-1}$ a.i. for dipotassium endothall and $50 \text{ mg}\cdot\text{L}^{-1}$ a.i. for amine endothall. Expt. 2 resulted in EC_{10} values of $99 \text{ mg}\cdot\text{L}^{-1}$ a.i. for dipotassium endothall and $32 \text{ mg}\cdot\text{L}^{-1}$ a.i. for amine endothall. Total dry weight harvested in Expt. 2 was approximately 60% greater than in Expt. 1.

Bermudagrass was the most tolerant grass species to endothall in irrigation water evaluated (Fig. 3). EC_{10} s for dipotassium endothall were

908 in Expt. 1 and $958 \text{ mg}\cdot\text{L}^{-1}$ a.i. for Expt. 2. The EC_{10} for amine endothall in irrigation water was $1301 \text{ mg}\cdot\text{L}^{-1}$ a.i. in Expt. 1. The amine formulation of endothall had no effect on cumulative dry weights of bermudagrass in Expt. 2 at concentrations up to $1600 \text{ mg}\cdot\text{L}^{-1}$ a.i.

Endothall in irrigation water caused similar responses in annual bluegrass in Expts. 1 and 2. The total dry weights harvested in Expt. 2 were greater than in Expt. 1 (Fig. 4). Irrigation with dipotassium endothall resulted in an EC_{10} of $16 \text{ mg}\cdot\text{L}^{-1}$ a.i. in Expt. 1, and $12 \text{ mg}\cdot\text{L}^{-1}$ a.i. in Expt. 2. EC_{10} s were $10 \text{ mg}\cdot\text{L}^{-1}$ a.i. and $7 \text{ mg}\cdot\text{L}^{-1}$ a.i. for irrigation with amine endothall in Expts. 1 and 2, respectively.

Annual ryegrass was also more susceptible to endothall than the perennial species (Fig. 5). EC_{10} s for Expt. 1 were calculated $14 \text{ mg}\cdot\text{L}^{-1}$ a.i. and $10 \text{ mg}\cdot\text{L}^{-1}$ a.i. for the dipotassium and amine salts of endothall respectively. Concentrations causing a 10% reduction in cumulative dry weight increased during Expt. 2, with the

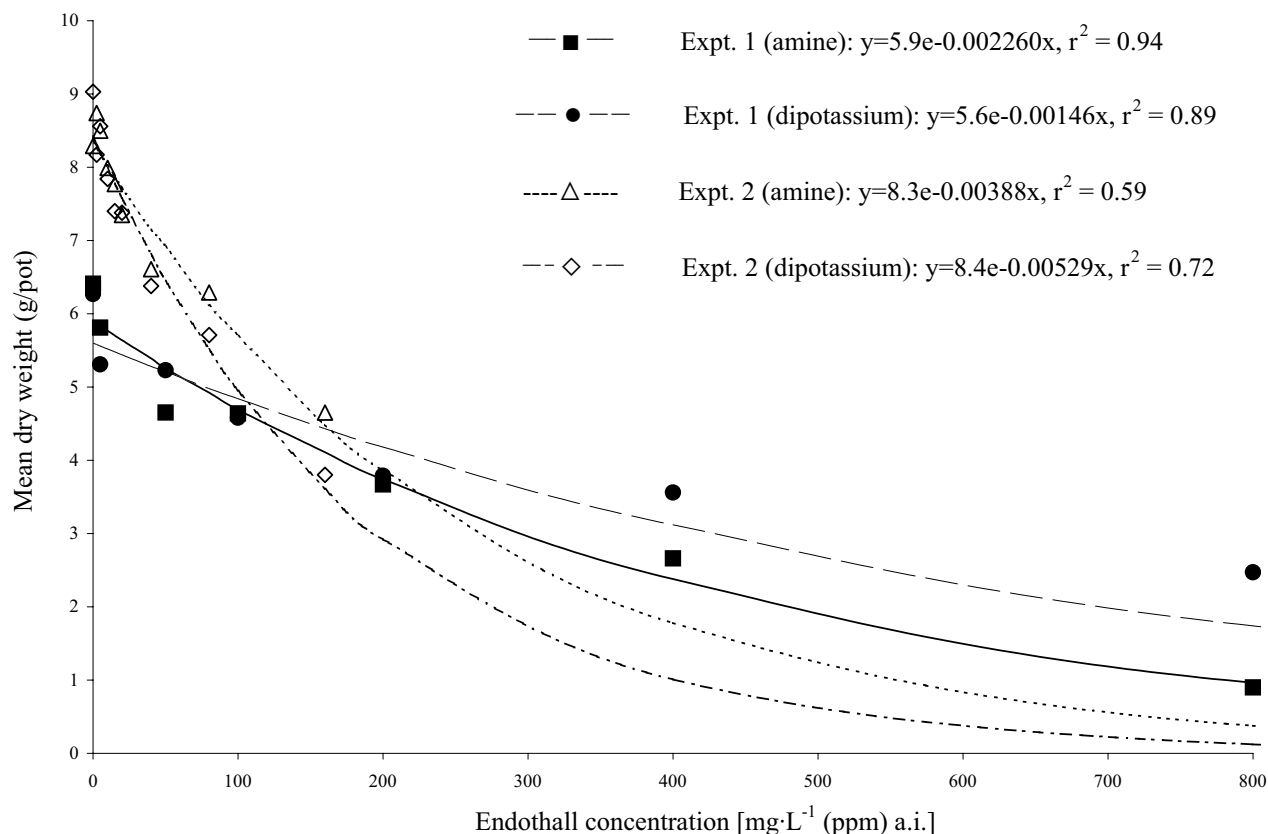


Fig. 1. Relationships between st. augustinegrass dry weight ($1.0 \text{ g} = 0.035 \text{ oz}$) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments (Expts. 1 and 2). During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied eight times with decreasing concentrations.

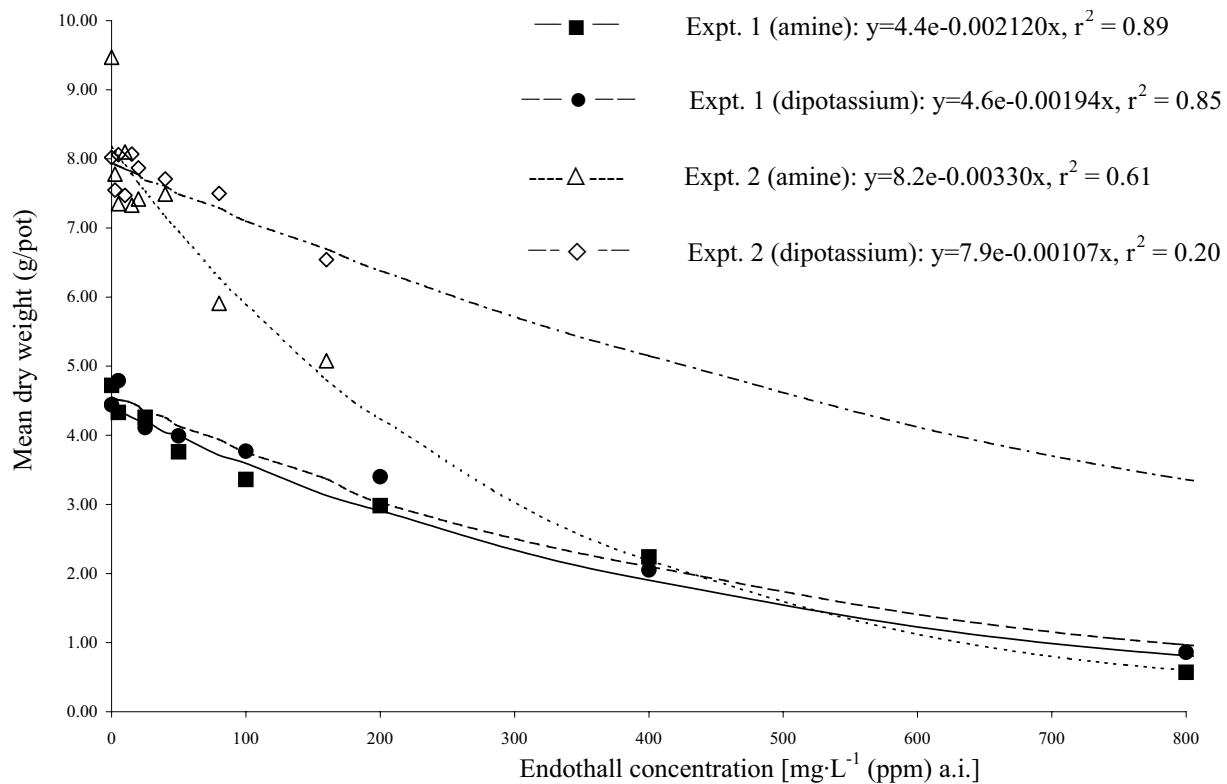


Fig. 2. Relationships between centipede grass dry weight (1.0 g = 0.035 oz) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments (Expts. 1 and 2). During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied eight times with decreasing concentrations.

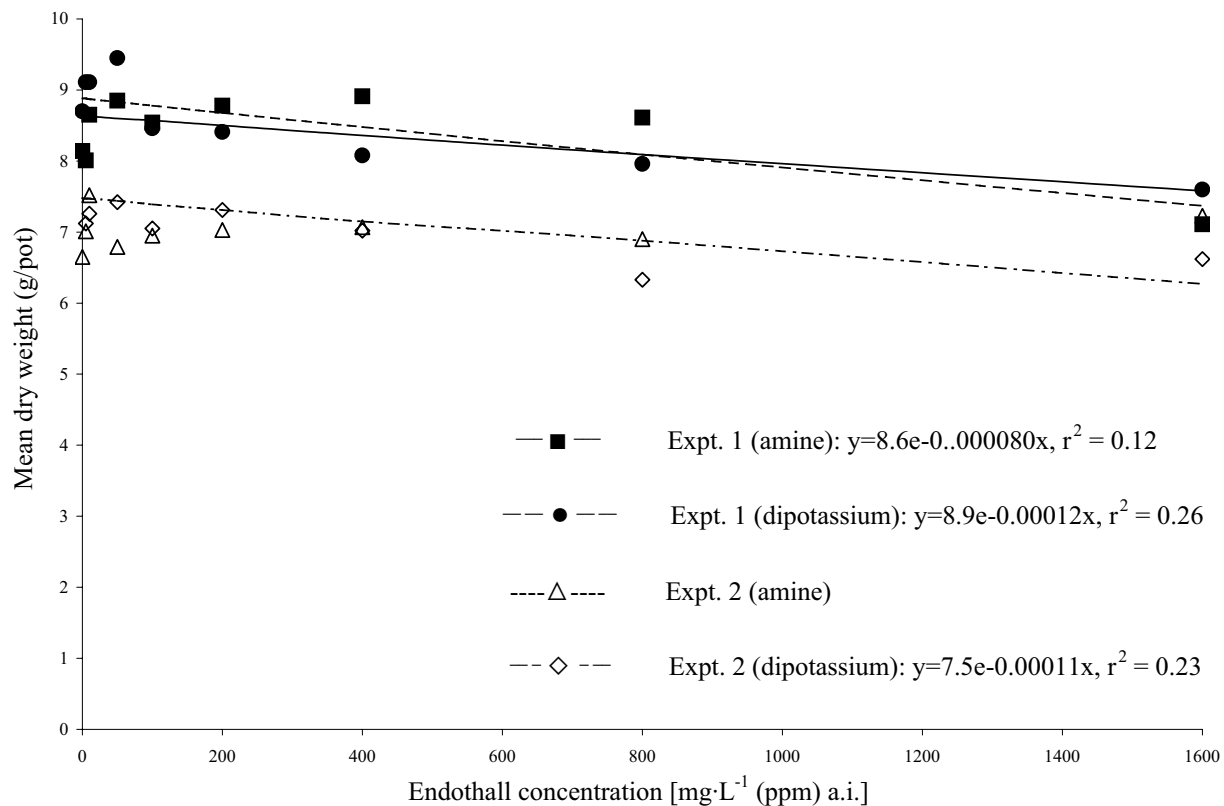


Fig. 3. Relationships between bermudagrass dry weight (1.0 g = 0.035 oz) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments (Expts. 1 and 2). During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied eight times with decreasing concentrations.

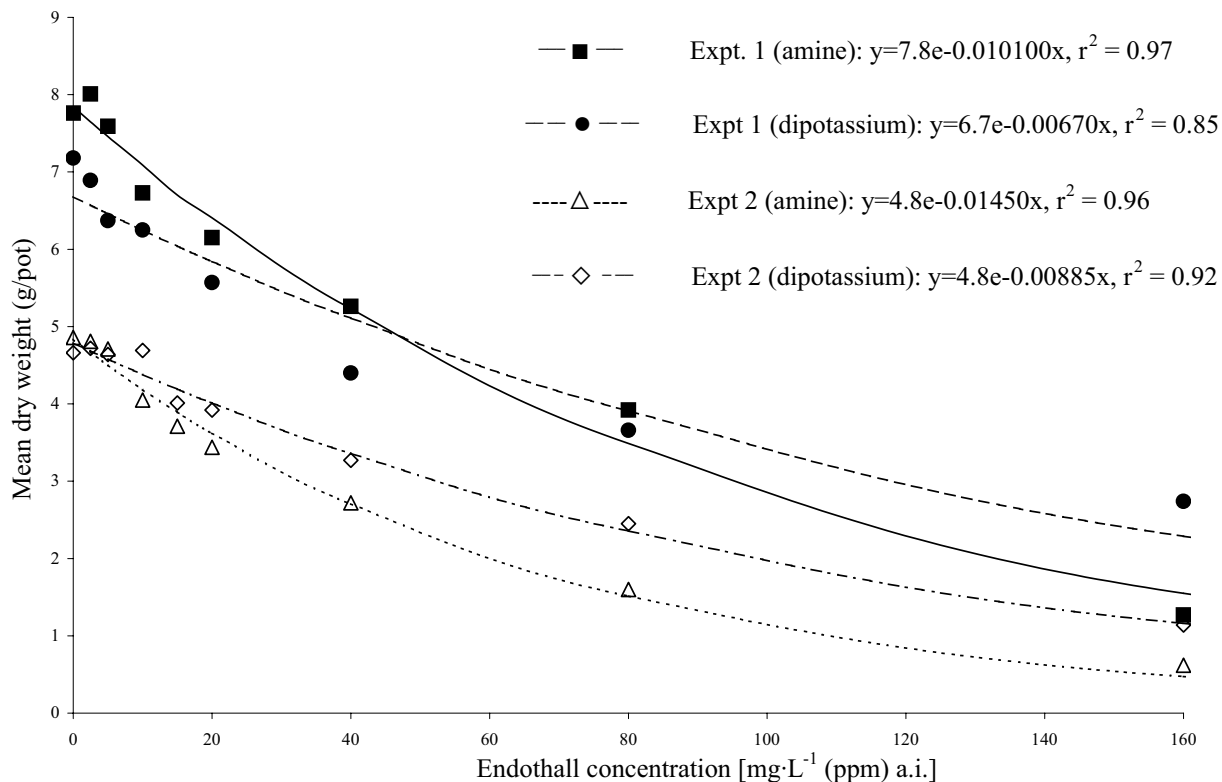


Fig. 4. Relationships between annual bluegrass dry weight (1.0 g = 0.035 oz) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments (Expts. 1 and 2). During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied eight times with decreasing concentrations.

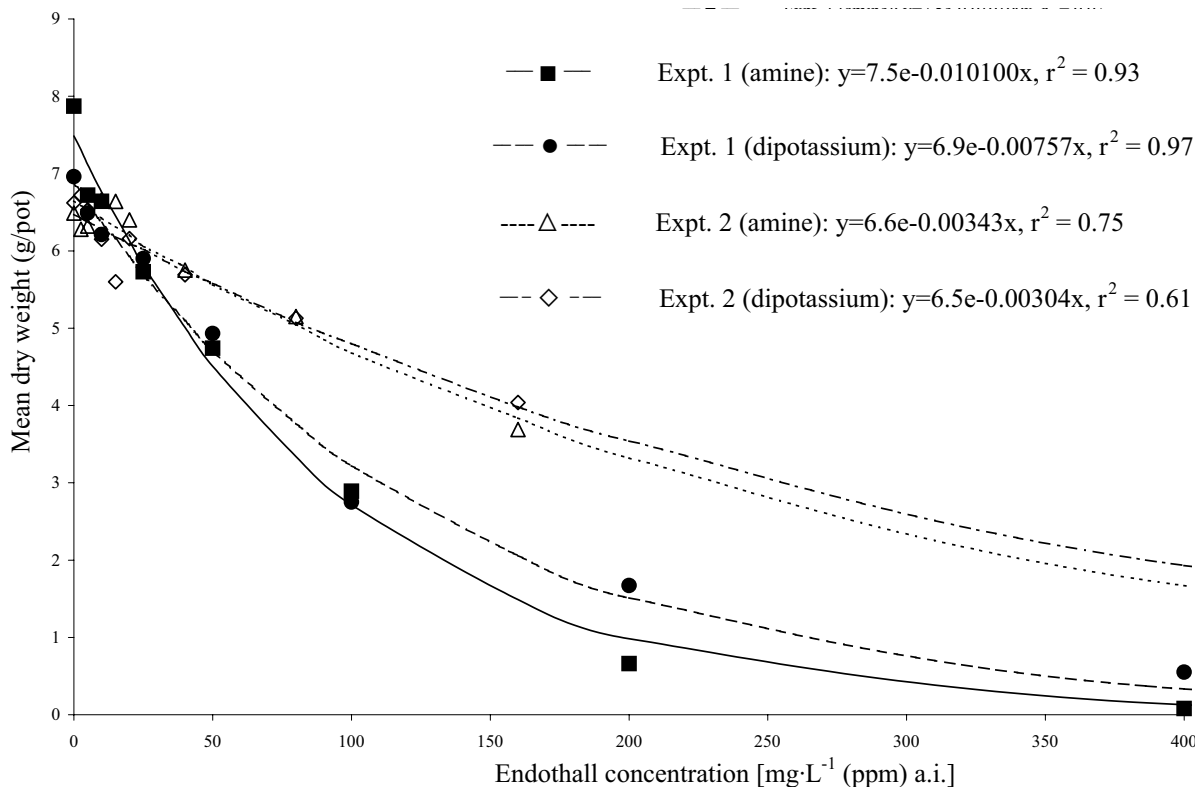


Fig. 5. Relationships between annual ryegrass dry weight (1.0 g = 0.035 oz) and the concentration of two formulations of endothall (amine and dipotassium) in irrigation water for two different experiments (Expts. 1 and 2). During Expt. 1, irrigation water was applied four times with constant concentrations of endothall, and in Expt. 2 it was applied eight times with decreasing concentrations.

dipotassium formulation having and EC_{10} of $35 \text{ mg}\cdot\text{L}^{-1}$ a.i. and the amine salt $31 \text{ mg}\cdot\text{L}^{-1}$ a.i.

Annual species were more sensitive than perennial species. Perennial species possessed a thick stolon or rhizome system that likely contributed to greater regeneration capacity (Turgeon et al., 1972b). When endothall was used as a turf herbicide, low rate, multiple treatments were more toxic than high rate single treatments (Watschke et al., 1979). Irrigation over a longer duration in these studies (Expt. 2) did not necessarily support this conclusion. An additional four irrigations (8 total) were applied to plants in Expt. 2. This comparison is slightly confounded due to irrigating with decreasing concentrations. Additionally, the total amount of herbicide applied to each pot was similar in both experiments.

Endothall did not act as a severe desiccant at concentrations used for aquatic weed control. It appeared to act primarily as a growth inhibitor. Only the highest concentrations caused discoloration of leaf tissue and necrosis immediately following the first irrigation. Recovery is likely from injury from endothall exposure for these species evaluated. Endothall is a contact herbicide and plant dry weights were not reduced to zero by maximum labeled concentrations of endothall used for submersed weed control ($\leq 5.0 \text{ mg}\cdot\text{L}^{-1}$ a.i.).

Turf species were grown in sand media with only a 4-cm layer of topsoil. Plants were irrigated in a short period of time saturating all foliage and rooting media. Addition of organic material (Turgeon et al., 1972a) and an irrigation method that does not

flood the vegetation may reduce the risks of injury to irrigated plants. The frequency of irrigation by a homeowner is important, and this was not evaluated in our trials. Plants would be exposed to more endothall over a shorter period of time if a homeowner irrigated more frequently (e.g., daily or twice daily). Actual phytotoxicity will depend not only on the concentration that is in the water, but also the accumulation of herbicide based on the volume of irrigation water and frequency of irrigation (Murphy and Johnson, 1992). For example, 2.5 cm (1 inch) of water vs. 1.27 cm of water results in twice the amount of active ingredient deposited on the plant/soil.

Turf species are unlikely to be injured if endothall residues used for aquatic weed control ($\leq 5.0 \text{ mg}\cdot\text{L}^{-1}$ a.i.) were contained in irrigation water. Any factor that may increase the field dissipation or degradation of endothall would further reduce the risk associated with irrigating with endothall containing water. Additional stresses on the plants might alter their susceptibilities to endothall. 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 on the effects of endothall in irrigation water on four ornamental species.

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