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Comparative Efficacy of Diquat for Control of Two Members of the Hydrocharitaceae: Elodea and Hydrilla

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INTRODUCTION

The submersed plants hydrilla (*Hydrilla verticillata* (L.f.) Royle) and elodea (*Elodea canadensis* Rich.) are both members of the Hydrocharitaceae family and cause problems in waterways throughout the world. Hydrilla is a serious nuisance weed in the southeast, and parts of the mid-Atlantic and western U.S. Although elodea is native to the U.S. in northern and western states, it can grow to nuisance levels in irrigation canals, swimming areas, and boat marinas. Elodea has also invaded many European waterways (Sculthorpe 1967) and is considered to be an invasive weed in areas of Africa, Asia, Australia and New Zealand (Bowmer et al. 1995).

Diquat (6,7-dihydrodipyrido[1,2-α:2',1'-*c*]pyrazinediium dibromide) is a contact herbicide used to control nuisance submersed and floating aquatic macrophytes. As a bipyridylium herbicide, it disrupts electron flow in photosystem I of the photosynthetic reaction (Hess 2000) and ultimately causes the destruction of cell membranes (WSSA 2002). Within several hours after diquat application, plant tissues become desiccated and within one to three days tissue becomes necrotic (Hess 2000; WSSA 2002). Diquat has been a particularly valuable tool in aquatic plant management situations when rapid removal of standing vegetation is desired, or when rapid dispersion via water exchange patterns limits herbicide exposure time to the target submersed species.

Studies have shown that elodea can be successfully controlled with diquat. Yeo (1967) found that elodea was killed within two weeks when exposed to 500 ug L^{-1} (ppb) of diquat however, Hiltebran (1965) reported that a rate of 1 mg L^{-1} (ppm) diquat was required to control elodea. For hydrilla, exposure for two days to 0.25 mg/L (ppm) diquat provided 80 percent control (Van et al. 1987), and Langeland et al. (2002) observed a 91 percent reduction in hydrilla biomass three weeks after plants were treated at the same rate.

There is no readily available information in the literature on the control of elodea under various diquat concentration and exposure times (CET) and other than the study of Van (above), little on hydrilla. Since CET relationships are critical in controlling submersed plants in areas influenced by water exchange, this study was designed to evaluate the efficacy of diquat on hydrilla and elodea under various CET scenarios.

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MATERIALS AND METHODS

This experiment was conducted in a greenhouse facility at the U.S. Army Engineer Research and Development Center's Lewisville Aquatic Ecosystem Research Facility (LAERF) located in Lewisville, TX in March 2003. Sediment was collected from LAERF ponds, amended with 3 g L^{-1} ammonium sulfate and placed into 1 L plastic pots to serve as plant growth media. Three healthy 6-inch apical tips were planted into each pot. Two pots of each species were placed into 50 L glass aquariums, which were filled with alum-treated water supplied from nearby Lake Lewisville. Eight aquariums were placed inside each of six 1000 L temperature controlled (25°C) water baths. Natural light was supplemented with Hamilton 400W metal halide lights which were set at a 14:10 h light:dark photoperiod. Plants were allowed to grow for three weeks. Shoots were healthy and near the water surface prior to treatment, and roots were well established in the sediment.

Diquat as Reward[4] (Syngenta Crop Protection, Inc., Greensboro, NC) was applied at 0.09 mg L^{-1} for 10 and 12 hours, 0.185 and 0.37 mg L^{-1} for 6, 8, 10, and 12 hours, and 0.37 mg L^{-1} for 4, 6, 8, 10, and 12 hours. Aquariums containing plants not treated with diquat were included as controls (untreated references). At the end of each exposure period, treated water was flushed from each aquarium using untreated water applied for a period determined to replace the entire volume of water in the aquarium twice and remove aqueous herbicide residues. Treatments were replicated three times.

Prior to treatment, water samples were collected from six aquariums and analyzed for pH, alkalinity (Standard Method #2320, APHA 1989), and hardness (Standard Method #2340, APHA 1989). Turbidity readings were taken on every aquarium using a Hach 2100P portable turbidimeter (Loveland, CO). Water residue samples were also collected from one set of replicates treated at 0.09, 0.185, and 0.37 mg L^{-1} ai with an exposure time of 12 h. Samples were collected 15 min after treatment (MAT), 6 hours after treatment (HAT) and 12 HAT, and sent to Kappa Laboratories (Miami, FL) for analy-

[4]Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

sis using liquid-solid extraction and high performance liquid chromatography (EPA Method 549.2, USEPA 1997).

At 3 weeks after treatment (WAT), all living shoot biomass was collected and placed into an oven and dried (65°C) to a constant weight. Comparisons of biomass data were made using one-way analysis of variance (ANOVA) least significant difference comparison procedure with a significance value of 0.05.

RESULTS AND DISCUSSION

Water residue data (Table 1) indicated a 25 to 28 percent decrease in diquat concentrations between 0 and 6 h, and a 16 to 25 percent decrease between 6 and 12 h. The decrease in residues could be attributed to diquat adsorbing to suspended particulates in the water or to the glass aquariums. Water quality analyses showed mean (±SE) average turbidity was 0.33 ± 0.03 NTU, pH was 8.82 ± 0.08, alkalinity was 39.3 ± 4.09 mg $CaCO_3$ L^{-1}, and hardness was 125 ± 7.07 mg $CaCO_3$ L^{-1}. Hydrilla was less sensitive than elodea to the suite of diquat CETs evaluated. No application rate resulted in significantly reduced hydrilla biomass compared to the untreated reference (Figure 1A). The current maximum allowable use rate of 0.37 ppm was evaluated in this study, therefore results indicate that in order to achieve improved control hydrilla may require longer exposure periods than were obtained in this study. Results of Van et al. (1987) reported that at rates of 2 mg L^{-1} diquat (over 5 times the current maximum label rate), a 12-h exposure period only provided 81 percent control. In a separate study at the LAERF, 100 percent control of hydrilla at 0.37 mg L^{-1} under static conditions was achieved, but only 15 to 30 percent control at 0.37 mg L^{-1} with half-lives of 3 and 6 h, respectively (authors unpublished data). Due to the tendency of diquat to be rapidly adsorbed by suspended clays and particulates, long exposure periods are not always possible in the field. Yeo (1967) observed diquat dissipation rates of 16 to 96 percent in reservoirs 0.5 h after treatment. Several researchers have reported improved efficacy on hydrilla when diquat was used in combination with copper compounds (Frank et al. 1979), a standard practice in operational control of hydrilla. Also, Pennington et al. 2001 reported improved control of hydrilla when low doses of endothall (mono(N,N-dimethylalkylamine salt) were combined with diquat.

Elodea rapidly takes up diquat from solution (Davies and Seaman 1968) and was extremely sensitive to diquat in this study. A CET relationship could not be determine for elodea

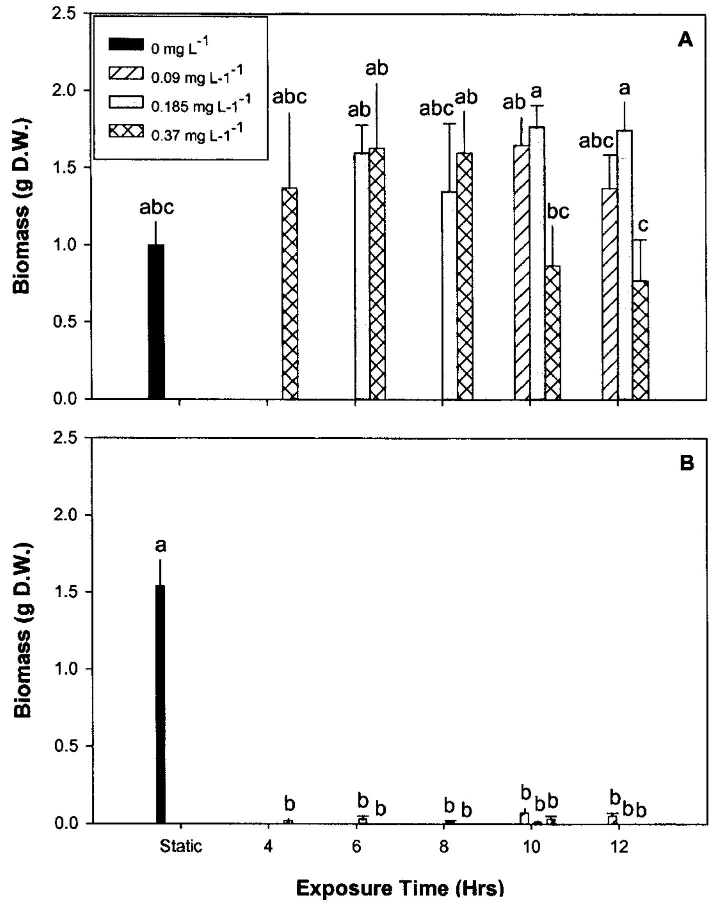

Figure 1. A) Dry weight (±SE) of hydrilla biomass 3 weeks after treatment (WAT) at diquat application rates of 0, 0.09, 0.185, and 0.37 mg L^{-1}. Diquat exposure times varied from four to twelve hours and treatments were replicated three times. B) Dry weight (±SE) of elodea biomass 3 WAT at diquat rates of 0, 0.09, 0.185, and 0.37 mg L^{-1}. Exposure times varied from four to twelve hours and treatments were replicated three times.

in this study because all application rates and exposure times were significantly less than the untreated reference (Figure 1B) and no differences occurred between application rates and exposure times. Control ranged from 96 to 100 percent indicating that diquat is an excellent herbicide for controlling elodea. However, this also indicates that diquat treatments, even those that result in concentrations as low as 0.09 mg L^{-1}, could impact elodea populations in the field, where that plant is considered a non-target species.

Results of this study indicate that diquat under the CETs evaluated, provides excellent control of elodea, but poor control of hydrilla. Even though both hydrilla and elodea belong to the same plant family (Hydrocharitaceae), there was a distinct difference in their response to diquat. This may suggest that the sensitivity of a plant species to diquat may be more important than CET relationships and would make diquat somewhat unique among contact herbicides in aquatics. These results also suggest diquat would control elodea at labeled use rates in areas where water exchange patterns may dilute aqeuous residues, whereas control of hydrilla in these same circumstances would not be expected.

TABLE 1. DIQUAT RESIDUE DATA COLLECTED 0.25, 6, AND 12 HOURS AFTER TREATMENT (HAT). WATER RESIDUES WERE COLLECTED FROM ONE REPLICATE FOR EACH APPLICATION RATE AND EXPOSURE TIME COMBINATION. THE DETECTION LIMIT WAS 0.00144 MG L^{-1} AND SPIKE RECOVERY WAS 72%. NA = NOT APPLICABLE; U = UNDETECTABLE.

Application rate (mg L^{-1}ai)	Exposure time (hours)	Hours after treatment 0.25	6	12
0	NA	NA	U	NA
0.09	12	0.06535	0.04889	0.03681
0.185	12	0.15115	0.11212	0.09200
0.37	12	0.30473	0.22082	0.18548

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