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Efficacy of Diquat and Carfentrazone-ethyl on Variable-leaf Milfoil

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INTRODUCTION

Variable-leaf milfoil (*Myriophyllum heterophyllum* Michx.) is a native submersed plant historically ranging from southwestern Quebec and Ontario to North Dakota and southward to New Mexico and Florida (Godfrey and Wooten 1981). This species has recently been introduced to the Northeastern U.S., where it causes many of the same problems associated with Eurasian watermilfoil (*Myriophyllum spicatum* L.) infestations. Variable-leaf milfoil has become particularly problematic in low alkalinity water bodies characteristic of Connecticut, Maine, Massachusetts, and New Hampshire.

Despite ongoing management programs and continued expansion of this invasive species, there is limited information available regarding efficacy of the various registered herbicides for control of variable-leaf milfoil (Getsinger et al. 2003). Therefore a study was conducted to evaluate the efficacy of two contact herbicides registered for aquatic use. Diquat (6,7-dihydrodipyrido{1,2-α:2',1'-*c*]pyrazinediium ion) has been registered for aquatic use since 1961 and it is a rapid acting photosystem I inhibitor that is currently used for operational control of variable-leaf milfoil and numerous other submersed plants. Reports from resource managers indicate that diquat has been somewhat inconsistent regarding the duration of control of variable-leaf milfoil. While, diquat efficacy can be influenced by factors such as concentration and exposure time, turbidity, stage of plant growth, water temperature, and buildup of epiphytes and inorganic materials on leaf surfaces (Netherland et al. 2000, Hofstra et al. 2001, Poovey and Getsinger 2002), there is no information on the basic sensitivity of variable-leaf milfoil to this herbicide. Carfentrazone-ethyl (a,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]-4-fluorobenzene-propanoic acid, ethyl ester) was registered for aquatic use in 2005, and is a rapid-acting protoporphyrinogen oxidase (protox) inhibitor. Carfentrazone is used for broadleaf weed control in terrestrial systems and activity on various submersed species is still under investigation. Recent studies evaluating carfentrazone efficacy on Eurasian watermilfoil and parrotfeather (*Myriophyllum aquaticum* (Vell.) Verdc.) suggest that this compound is not highly active on these species at rates ranging from 50 to 200 µg ai L^{-1} (Gray et al. 2007, Glomski et al. 2006). The objective of this study was to evaluate the activity of two contact herbicides on variable-leaf milfoil, an emerging invasive plant problem in the Northeastern U.S.

MATERIALS AND METHODS

This study was conducted in a greenhouse at the Lewisville Aquatic Ecosystem Research Facility (LAERF) located in Lewisville, TX. Plastic pots (750 mL) were filled with LAERF pond sediment amended with 3 g L^{-1} osmocote (16-8-12). Each pot was planted with two 15 cm tips of variable-leaf milfoil and four pots were placed in each aquarium. Aquariums were filled with a 4:1 ratio of deionized water and alum treated water from nearby Lake Lewisville. Aquariums were situated in 1000-L fiberglass tanks that were filled with water and served to regulate water temperatures in the experimental aquaria. Water temperatures in the aquariums were maintained at 22 to 24°C by circulating water in the fiberglass tanks through a Pacific Coast Imports C-1000 1 HP chiller. Carbon dioxide was bubbled into each aquarium daily to lower the water pH to 6.5 to better simulate the soft water conditions that are characteristic in the Northeast where variable-leaf milfoil is problematic. Pretreatment biomass was collected and prior to treatment variable-leaf milfoil stems were either at the surface or just below the water surface.

Concentration exposure times for diquat (Reward®, Syngenta Crop Protection, Inc., Greensboro, NC) included 180 and 370 µg ai L^{-1} for 6, 18, and 30 hours. The 370 µg ai L^{-1} rate of diquat represents the maximum use rate of 2 gallons per acre in 4 feet of water. Carfentrazone (Stingray®, FMC Corporation, Philadelphia, PA) treatments were 100 µg ai L^{-1}

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for 6, 18, and 30 hr and 200 μg ai L^{-1} for 2, 6 and 18 hours. The 200 μg ai L^{-1} rate of carfentrazone represents the maximum use rate of 1.1 gallons per acre in 4 feet of water. At the end of each exposure period, aquaria were flushed with untreated water for 10 minutes to exchange the volume of water in each aquarium three times. Continuous aeration with carbon dioxide was maintained during the treatment period. After that, carbon dioxide was added once a day between 10 am and 2 pm. The pH was monitored throughout the exposure period and ranged from 6.24 to 6.66. The pH was measured once daily following treatment.

At 42 days after treatment (DAT), all viable shoot biomass was harvested from three pots in each tank and plants were dried at 70°C for 48 hr. For statistical analysis, dry weight values were square root transformed in order to meet the assumptions of normality and equal variance. Transformed data was subjected to analysis of variance (ANOVA). Means were compared using the Student-Newman-Keuls Method (SNK; $P \leq 0.001$). Non-transformed data are presented in the figures comparing post-treatment plant biomass.

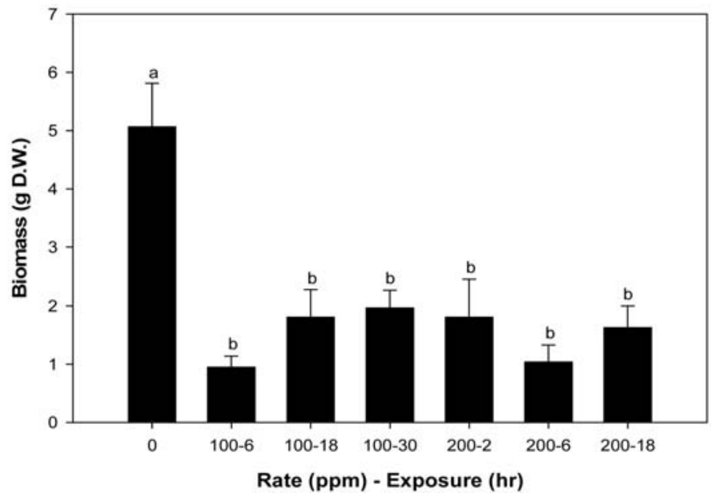

Figure 2. Mean (± SE) dry weight of variable-leaf biomass 42 days after treatment with carfentrazone-ethyl. Bars sharing the same letter do not significantly differ from each other.

RESULTS AND DISCUSSION

Variable-leaf milfoil grew well during the course of these studies as evidenced by the over 25-fold increase in the pretreatment biomass from 0.19 + 0.01 g to values exceeding 5 g per experimental container (Figures 1 and 2).

Diquat: At 15 DAT, plants treated with 370 μg ai L^{-1} diquat for 18 and 30 hours and 180 μg ai L^{-1} for 30 hours exhibited signs of browning. At 30 DAT, diquat treated plants still had green tissue present however, some apical tips had deteriorated. By 42 DAT most diquat treatments were not significantly different than the control and provided unacceptable control of variable-leaf milfoil with percent control ranging from 27 to 65 percent (Figure 1). Diquat treatments of 370 μg ai L^{-1} for 18 and 30 hours had significantly less biomass than the control however, only the 370 μg ai L^{-1} for 30 hour treatment provided good control (85%). Our studies allowed for static exposures in water of very high clarity (NTU < 1), however, a thirty-hour exposure period may be difficult to maintain following many treatment scenarios. Reported dissipation rates in reservoirs vary from 16 to 96 percent 0.5 h after treatment (Yeo 1967). Larger-scale applications of diquat in waters with low turbidity (NTU < 2) did result in maintenance of residues well past the 30 hours tested in this study (Parsons et al. 2007).

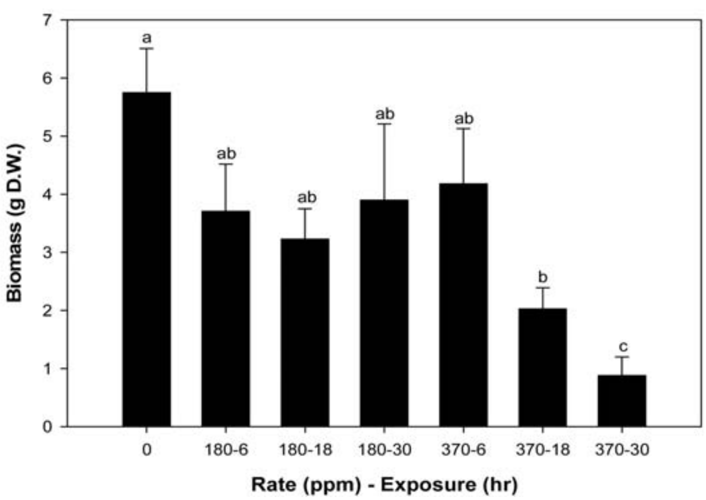

Figure 1. Mean (± SE) dry weight of variable-leaf milfoil biomass 42 days after treatment with diquat. Bars sharing the same letter do not significantly differ from each other.

Unlike Eurasian watermilfoil, which is highly susceptible to diquat, variable-leaf milfoil was only moderately susceptible to diquat at the maximum label rate following extended exposure periods. Skogerboe et al. (2006) reported 97 to 99 percent control of Eurasian watermilfoil at 185 and 370 μg ai L^{-1} with half-lives of just 2.5 and 4.5 h. Therefore, diquat treatments that would provide near complete control of Eurasian watermilfoil would have limited impact on variable-leaf milfoil. Even though Eurasian watermilfoil and variable-leaf milfoil are in the same plant family (Halogoraceae) and genus (*Myriophyllum*) they responded quite differently to diquat. This differing response to diquat among plants in the same plant family has also been reported for members of the Hydrocharitaceae (Glomski et al. 2005).

Carfentrazone: Within four days of treatment, all carfentrazone treated plants exhibited bleached or brown apical tips. By 15 DAT, most carfentrazone treated plants were starting to deteriorate however all treatments had shoot regrowth from the root crown present at the time of harvest. Despite this regrowth, all carfentrazone treated plants had significantly less biomass than the untreated control at the harvest period (Figure 2). Regrowth from plant tissue not initially killed is a common response when treating with contact herbicides due to limited translocation throughout plant tissues (Lembi and Ross 1985). Rates of 100 μg ai L^{-1} for 6 to 30 hours provided 61 to 81 percent control and 200 μg ai L^{-1} for 2 to 18 hours provided 64 to 79 percent control. There were no significant differences between concentration-exposure times. Doubling the rate from 100 to 200 μg ai L^{-1} and extending exposures did not improve efficacy. This lack of a rate response to carfentrazone was also seen in Eurasian watermilfoil under static conditions (Glomski et al. 2006). These data suggest that carfentrazone is a very rapid acting herbicide and that traditional concentration and exposure relationships may not best explain the activity of this protox inhibitor on variable-leaf milfoil. The lack of both a concentration and exposure effect for carfentrazone suggests that lower rates and shorter exposures could be efficacious and need to be tested. The results of this study would suggest that carfentrazone should be evaluated in the field for control of variable-leaf milfoil.

In conclusion, only diquat at 370 µg ai L^{-1} for 30 hours provided good control (85%) of variable-leaf milfoil. Due to the potential for rapid binding to particulates or dissipation of diquat in the field, a 30 hour exposure may not be possible. The strong difference in response between variable-leaf and Eurasian watermilfoil to diquat suggests that variable-leaf milfoil has a higher tolerance to diquat. The combination of a plant that is not highly sensitive and a molecule that would require an extended exposure in order to provide control, may ultimately limit the use of diquat for variable-leaf milfoil control. All rates and exposures of carfentrazone significantly reduced variable-leaf milfoil biomass, however, shoot regrowth from root crowns will require follow-up applications. In contrast to diquat, carfentrazone is much weaker against Eurasian watermilfoil when compared to variable-leaf milfoil.

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