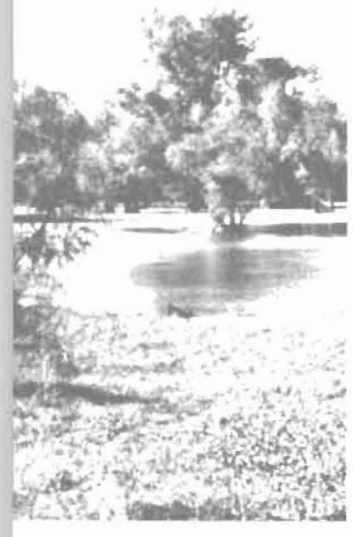
US Army Corps of Engineers



ENVIRONMENTAL LABORATORY

AQUATIC PLANT CONTROL RESEARCH PROGRAM

MISCELLANEOUS PAPER A-88-2

CHEMICAL CONTROL OF HYDRILLA IN FLOWING WATER: HERBICIDE UPTAKE CHARACTERISTICS AND CONCENTRATIONS VERSUS EXPOSURE

by

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March 1988
Final Report

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

and

US Army Engineer District, Baltimore
Baltimore, Maryland 21203-1715

Monitored by Environmental Laboratory
US Army Engineer Waterways Experiment Station
PO Box 631, Vicksburg, Mississippi 39180-0631

6a. PERFORMING ORGANIZATION (Continued).

US Department of Agriculture, Agricultural Research Service, Aquatic Plant Management Laboratory

8a. FUNDING/SPONSORING ORGANIZATION (Continued).

US Army Corps of Engineers;
USAE District, Baltimore

19. ABSTRACT (Continued).

Monoecious and dioecious hydrilla responded similarly to the aquatic herbicides currently registered for hydrilla control. Control of both biotypes was obtained with treatments of about 0.25 mg/ℓ diquat under the conditions prevailing during these studies. Copper (Koplex) was effective at about 1.0 mg/ℓ. Endothall controlled both biotypes at about 0.5 to 1.0 mg/ℓ.

The relationships between herbicide concentrations and contact time required for hydrilla control were investigated. For diquat, control of both hydrilla biotypes at 0.25 mg/ℓ required a minimum of 2 days contact time under laboratory conditions. Similarly, 2 to 4 days of contact were required to control hydrilla with 1.0 mg/ℓ endothall. When treatment rates were increased to 2.0 mg/ℓ diquat or 5.0 mg/ℓ endothall, the minimum required contact time was reduced to 6 to 12 hr depending on plant growth stage. Early growth emerging from sprouting tubers appeared to be more susceptible to herbicide treatments.

The lethal concentration of diquat in plant tissue was estimated to be about 80 µg/g dry weight when hydrilla was treated at 0.25 mg/ℓ diquat for 2 days of exposure. However, the lethal tissue concentration was found to vary with different herbicide lethal doses, probably because of the increasing amounts of adsorption to plant surfaces at higher treatment rates and shorter contact time. Similarly, a lethal endothall concentration of 75 µg/g was determined in hydrilla tissue after 72 hr contact to 1.0 mg/ℓ ambient endothall. The bioconcentration factor for endothall uptake (which indicates how efficiently the herbicide is taken up by the plant) increased to a maximum of 77 at 4 days after treatment, as compared to a factor of 550 observed for diquat uptake under similar conditions. The ability of diquat to be taken up much more easily than endothall provides one possible explanation why diquat is effective in hydrilla control at a lower rate than is endothall.

Uptake of fluridone by excised hydrilla tissue was linear with time when ambient fluridone levels were 0.1 to 0.5 mg/ℓ. However, a biphasic uptake curve was obtained at the high treatment rate of 1.0 mg/ℓ fluridone. At this high rate of fluridone, a bioconcentration factor of 35 was observed at the end of the first phase of uptake 4 days after treatment, followed by a sharp increase to 115 after 11 days. These biphasic uptake characteristics suggested that a split application of the herbicide may improve fluridone uptake.

Monoecious hydrilla appeared to be much more susceptible to fluridone than the dioecious biotype. Control of early growth from sprouting tubers of the monoecious biotype required 12 hr of contact to 1.0 mg/ℓ fluridone, whereas a 4-day exposure to this same treatment rate was required for similar control of dioecious hydrilla.

PREFACE

The study reported herein was performed under Agreement No. 6629-004-0930 between the US Department of Agriculture (USDA) and the US Army Engineer Waterways Experiment Station (WES). Funds for the study were provided by the US Army Engineer District, Baltimore, through the US Army Corps of Engineers Aquatic Plant Control Research Program (APCRP). The Technical Monitor was Mr. E. Carl Brown of the Office, Chief of Engineers.

This study was a portion of an overall effort to develop chemical control strategies for management of hydrilla in flowing water. The work was conducted by Dr. Thai K. Van, Principal Investigator, assisted by Mr. Richard D. Conant, Jr., Aquatic Plant Management Laboratory, USDA, Fort Lauderdale, Fla. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

Principal Investigator at WES was Dr. Howard E. Westerdahl; the point of content at the Baltimore District was Mr. Robert Pace, Planning Division. During the conduct of this study, Mr. J. Lewis Decell was APCRP Manager. Dr. John Harrison was Chief, Environmental Laboratory, WES.

Commander and Director of WES was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

Van, Thai K., and Conant, Richard D., Jr. 1988. "Chemical Control of Hydrilla in Flowing Water: Herbicide Uptake Characteristics and Concentrations Versus Exposure," Technical Report A-88-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

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PART I: INTRODUCTION

Background

1. The female dioecious biotype of hydrilla [*Hydrilla verticillata* (L.f.) Royle] was introduced into Florida in 1958 or 1959 (Blackburn et al. 1969). Since that time, it has spread to several states and become a multimillion-dollar problem when considering the costs of control and management and the losses from decreased use of the water resource due to the infestations.

2. Hydrilla is able to dominate a body of water rapidly through its photosynthetic characteristics (Van, Haller, and Bowes 1976; Bowes et al. 1977), combined with several very efficient methods of vegetative reproduction, i.e., through runners over the surface of the bottom muds and through fragments of the stems that break loose from established colonies. The plant also produces abundant axillary and subterranean propagules that enable it to survive hostile environments and to regrow after herbicide applications for control.

3. More recently, a monoecious biotype of hydrilla has been reported in Virginia, Maryland, the District of Columbia, Delaware, and North Carolina (Steward et al. 1984). The presence of this biotype is apparently the result of a separate introduction to this country, although the foreign source has not been identified. In comparative studies of the two biotypes, monoecious hydrilla has shown even greater efficiency in terms of reproductive and survival potential. Furthermore, sexual reproduction in the monoecious biotype greatly increases the potential for physiological diversity, which may have serious consequences for the management of the aquatic weed species (Conant, Van, and Steward 1984).

4. Herbicide use is presently the primary method for management of submersed aquatic vegetation (Ennis and Vandiver 1979). Diquat, endothall, and more recently, fluridone have been used successfully to control hydrilla in static and slow-moving water where contact with the chemical could be maintained for several days or weeks. However, the control of hydrilla in

flowing water is far more difficult because the herbicide rapidly disperses from the application sites.

5. For a chemical treatment to be effective, a minimum concentration of the applied herbicide must be maintained near the target plant, either in the sediment or water column, for some minimum contact time. Presently there is very little information on the minimum contact time required for effective hydrilla control. MacKenzie (1968) observed that control of dioecious hydrilla in drainage canals in Florida was obtained with diquat at 0.5 to 1.0 ppm only where the water was static and where rainfall did not dilute the treatment within 48 hr after application. Barrett (1981) stated that the recommended treatment rate of diquat for control of submersed vegetation in Britain is 1.0 ppm with a minimum contact time of 24 hr. Price (1969) applied the amine salt of endothall at 3 to 4 ppm for 3 hr in canals in western states and reported good control of several pondweed species for a distance of 30 km downstream. However, a similar treatment of 6 ppm acid equivalent (a.e.) of endothall amine for 3 hr provided only limited control of *Elodea canadensis* in flowing water in the Berriquin Irrigation District in Australia (Bowmer et al. 1979). Label recommendations for the use of endothall to control hydrilla in irrigation and drainage canals in Florida specify a minimum contact time of 2 hr at 3 to 5 ppm a.e.

6. The success of high-concentration, short-contact time treatments in flowing water depends on the relatively rapid uptake and retention of a lethal quantity of herbicide by the plant. However, information on herbicide uptake and lethal concentration in plant tissues is also extremely limited for aquatic macrophytes, especially submersed species. Generally, the slow-acting translocated herbicides appear to have much slower uptake rates and, thus, require longer contact time. For example, a minimum herbicide concentration must be maintained in the water for several days to ensure the effectiveness of fluridone for control of pondweeds (Anderson 1981) and hydrilla (Hall, Westerdahl, and Stewart 1984; Van and Steward 1986).

7. In contrast, contact herbicides are taken up rapidly and therefore appear more suitable for use in flowing water. Davies and Seaman (1968) reported that uptake of diquat by *E. canadensis* consisted of an initial rapid absorption phase followed by a constant, active uptake phase that continued over the 4.5-hr experiment. Sutton et al. (1972) observed a linear uptake in hydrilla shoots that continued for 9 days. Thomas and Seaman (1968), using

^{14}C-labeled endothall, observed uptake of the herbicide by both the foliage and root tissues in American pondweed (*Potamogeton nodosus*). These authors also recorded symplastic movement of the ^{14}C label from mature photosynthesizing leaves and accumulation of the herbicide in the apices and developing secondary shoots. However, there was no movement of the ^{14}C label from the treated roots to the foliage of the plant. Haller and Sutton (1973) observed a sigmoid-shaped uptake curve of endothall by hydrilla, with approximately 6 percent of the total ^{14}C-endothall incorporated being taken up after 2 days posttreatment, and about 23 percent after 4 days. These authors suggested that the slow initial uptake of endothall might present a problem in the control of hydrilla with this herbicide in flowing water.

8. One major problem with most of the herbicide uptake studies in submersed aquatic plants is the lack of information on lethal concentration in plant tissues and the minimum exposure time required to attain that concentration for effective weed control. This information is necessary for the development of a chemical management program to control submersed vegetation in flowing water.

Objectives

9. The objectives of this study were to: (a) determine the susceptibility of monoecious hydrilla to registered aquatic herbicides; (b) to provide information on the minimum contact time required for control of monoecious and dioecious hydrilla using diquat, endothall, and fluridone; and (c) to examine the time-course uptake characteristics of these herbicides by hydrilla.

PART II: METHODS

Comparative Responses of Monoecious and Dioecious Hydrilla to Selected Herbicides

10. Monoecious and dioecious biotypes of hydrilla were collected from Kenilworth Aquatic Gardens Lake, Washington, DC, and Lake Tiger Tail, Fort Lauderdale, Fla., respectively. Apical cuttings of both hydrilla biotypes (12 cm long) were planted in 5- by 5-cm plastic pots containing potting soil (60 percent sand, 26 percent silt, 14 percent clay) supplemented with 5 percent volume/volume (v/v) cattle manure. Two cuttings of a biotype were planted in a pot, and four of these pots (two for each biotype) were submersed in a 4-ℓ glass jar filled with pond water. Water quality was monitored monthly during the study from January to November 1985 (Table 1). The jars were placed in a growth chamber (photoperiod 14 hr, air temperature 27° ± 2° C, irradiance approximately 200 $\mu E/m^2/sec$).

11. The plants were established for 3 weeks before treatments were applied. Treatments were made by injecting the herbicide solution into the water with a hypodermic syringe. The plants were then evaluated biweekly for phytotoxic responses for a period of 10 weeks. Phytotoxicity ratings were made on a 0- to 100-percent scale with 0 percent representing no injury and 100 percent representing death of the entire plant.

Time Course of Uptake

12. The plants were cultured for 7 days in 5-percent Hoagland's nutrient solution (Hoagland and Arnon 1950) in a growth chamber (photoperiod 14 hr, air temperature 27° ± 2° C, irradiance approximately 200 $\mu E/m^2/sec$). After this initial growth period, the top 4-cm sections were excised underwater for use in the experiment.

13. One 4-cm plant section was placed in each test tube (2.5 cm in diameter, 15 cm long) to which 50 ml of nutrient solution was added 24 hr before the radioactive herbicide was injected. Diquat-^{14}C (specific activity (sp. act.) 1.67 μCi/mg) was applied at concentrations of 0.25, 0.5, 1.0, and 2.0 mg/ℓ; ^{14}C-endothall (sp. act. 0.97 μCi/mg), at 1.0, 2.0, 3.0, and 5.0 mg/ℓ; and ^{14}C-fluridone (sp. act. 3.49 μCi/mg), at 0.1, 0.25, 0.5, and

1.0 mg/ℓ. The specific activity was kept similar for all four test concentrations of each radioactive herbicide.

14. Treatments were replicated four times. Each of the four treatment concentrations of ^{14}C-diquat and ^{14}C-endothall was in contact with the plants for periods of 3, 6, 12, 24, 48, 96, and 168 hr. A longer exposure time to ^{14}C-fluridone (up to 10 days) was studied. All experiments with fluridone were conducted in a glass greenhouse with light intensity at midday of about 1,600 $\mu E/m^2/sec$ photosynthetic proton flux density.

15. After each exposure, the treated plant sections were removed from the test tubes and rinsed for 3 min in running tap water. The plant sections were then dried at 70° C for 72 hr, weighed, and combusted for radioassay of the released ^{14}C by liquid scintillation spectrometry. All counts were corrected for quench and for efficacy of combustion. The resulting counts were converted into micrograms of herbicide.

16. To evaluate the phytotoxic responses of hydrilla to the radioactive herbicide treatments, another set of four replicate plant sections were treated as above with similar herbicide rates and exposure time. After each exposure period, the plant sections were rinsed as above and planted individually in 5- by 5- by 5-cm plastic pots containing potting soil supplemented with 5-percent v/v cattle manure. The potted plants were kept in 4-ℓ glass jars containing pond water in the growth chamber for observation of phytotoxic responses. After 6 weeks, the plants were carefully removed from the pots, and the soil was washed from the roots. Plant dry weight was determined after oven-drying at 70° C for 72 hr, and percent control for each treatment was calculated based on the reduction of dry weight as compared to the control plant.

Herbicide Concentrations Versus Exposure

17. Apical cuttings of hydrilla 12 cm long were planted in 5- by 5- by 5-cm plastic pots containing the standard potting soil. Four of these pots (two for each herbicide) were submersed in each 4-ℓ glass jar filled with pond water and placed in a growth room under controlled environment conditions as described above. The plants were allowed to grow for 4 weeks and fill the jars, to simulate conditions of a relatively dense and more mature hydrilla mat.

18. The response of young hydrilla shoots just emerging from sprouting tubers was also investigated. The tubers were pregerminated in pond water; then, uniform 5-cm-long sprouting tubers were planted as described above. After 4 to 5 days, chemical treatments were applied when the young hydrilla shoots were 10 to 12 cm long.

19. Commercial formulations of diquat (Diquat), endothall dipotassium (Aquathol K), and fluridone (Sonar 4AS) were applied to the jars at various concentrations with exposure periods similar to those described for the herbicide uptake studies. All treatments were replicated three times. Individual jars were replicates. After each exposure period, the planted pots were removed from the treatment jars and placed in a running bath of pond water for 30 min to remove any adhering herbicide. The pots were then transferred to new 4-ℓ jars containing fresh pond water for observation of phytotoxic responses to the chemical treatment. All plants were harvested after 6 weeks exposure and weighed after drying to constant mass in a 70° C forced-air oven.

PART III: RESULTS AND DISCUSSION

20. When the monoecious biotype of hydrilla was first identified in the Washington, DC, metropolitan area, it was suggested that this biotype might be easier to control because of its "less robust" growth habit as compared to the more southerly populations. Our laboratory results have proved this not to be true. Figures 1-4 show that both monoecious (labeled "KG" for its source, Kenilworth Gardens, Washington, DC) and dioecious (labeled "FL," for Fort Lauderdale, Fla.) hydrilla responded similarly to the aquatic herbicides currently registered for hydrilla control.

21. Similar field observations were made by Langeland and Pesacreta (1985). These authors reported that control of monoecious hydrilla in North Carolina was as difficult and as variable as control of the dioecious biotypes in other southeastern states. Under our laboratory conditions, control of both biotypes was obtained with treatments of about 0.25 mg/ℓ diquat (Figure 1). Organic copper (Koplex) was effective at about 1.0 mg/ℓ against both

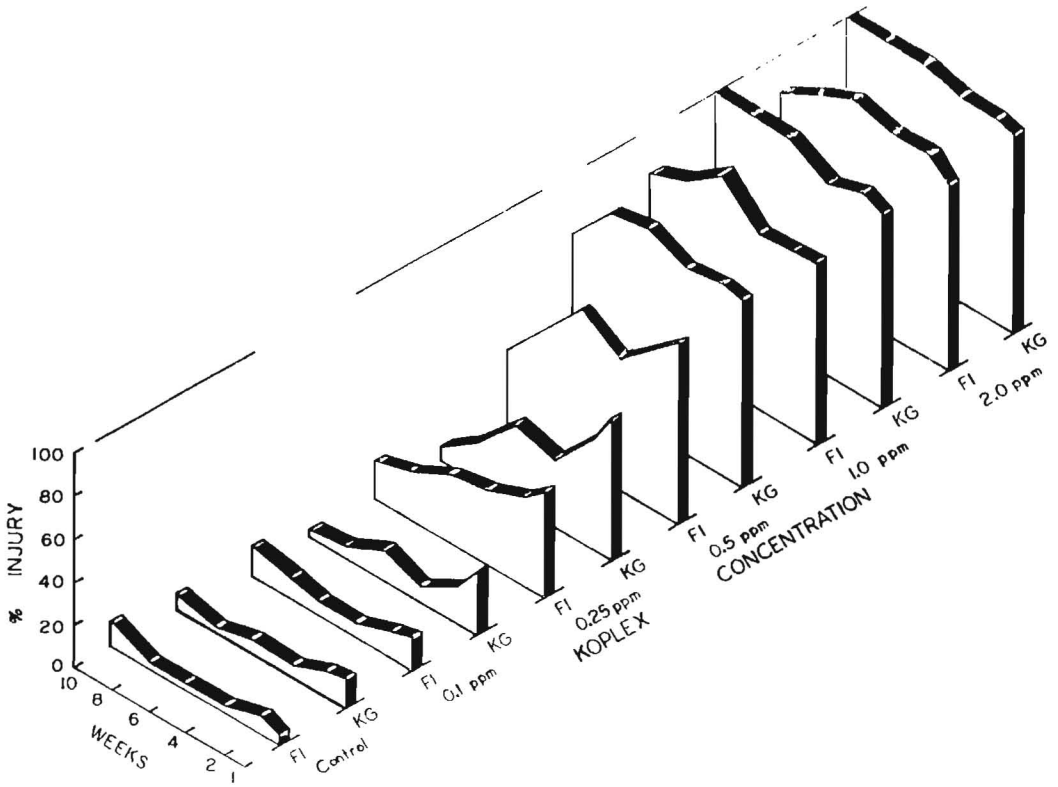


Figure 1. Laboratory evaluation of copper (Koplex) for phytotoxicity toward monoecious (KG) and dioecious (FL) hydrilla biotypes

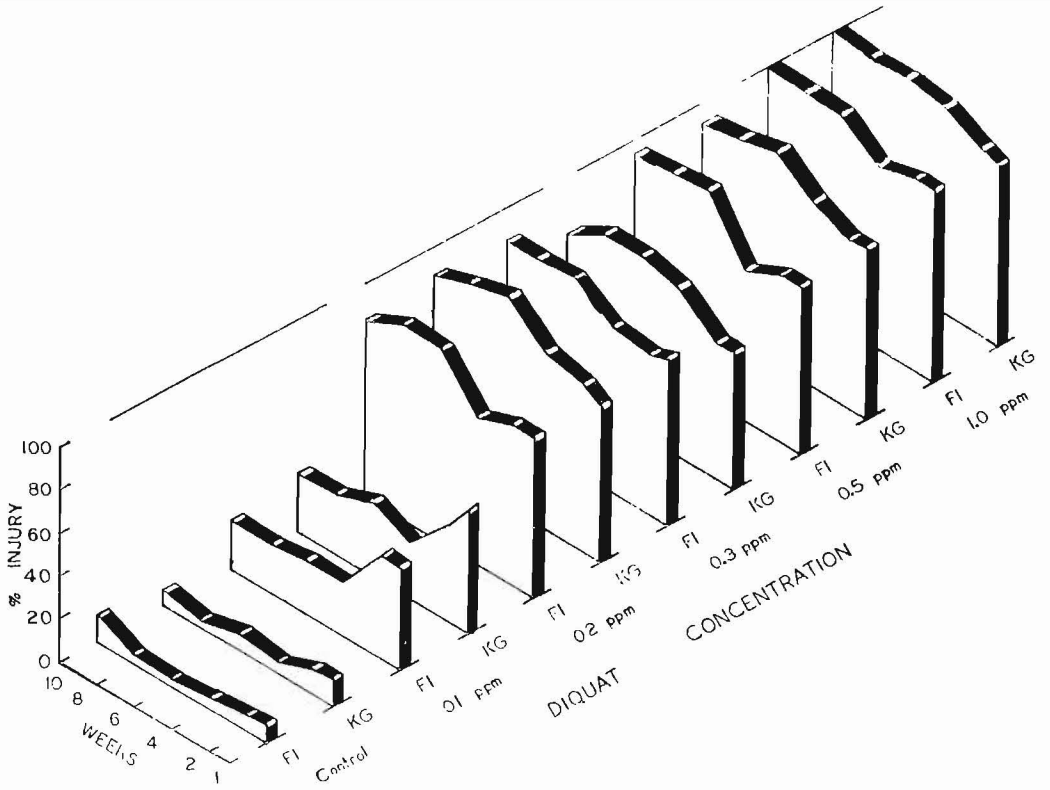


Figure 2. Laboratory evaluation of diquat for phytotoxicity toward monoecious (KG) and dioecious (FL) hydrilla biotypes

biotypes (Figure 2). Endothall (Aquathol K, Figure 3; and Hydrothol 191, Figure 4) controlled both hydrilla biotypes at about 0.5 to 1.0 mg/ℓ.

Diquat

22. Figure 5 illustrates the time-course uptake of ^{14}C from ^{14}C-diquat by excised hydrilla tissue during a 4-day period. At treatment rates up to 1.0 mg/ℓ diquat, uptake was linear with time. When the ambient diquat level was 2.0 mg/ℓ, however, uptake data fitted best to a quadratic equation. At this high treatment rate, the plants harvested after 3 and 4 days began to show some visible damages, which probably explains the decrease in uptake rate observed at these sampling times.

23. Also, at a given sampling time, the tissue concentration of diquat appeared to increase proportionally with increases in diquat treatment rates in water (Figure 5). Consequently, within a given exposure period, the bioconcentration factors of diquat (determined as ratios of concentration of

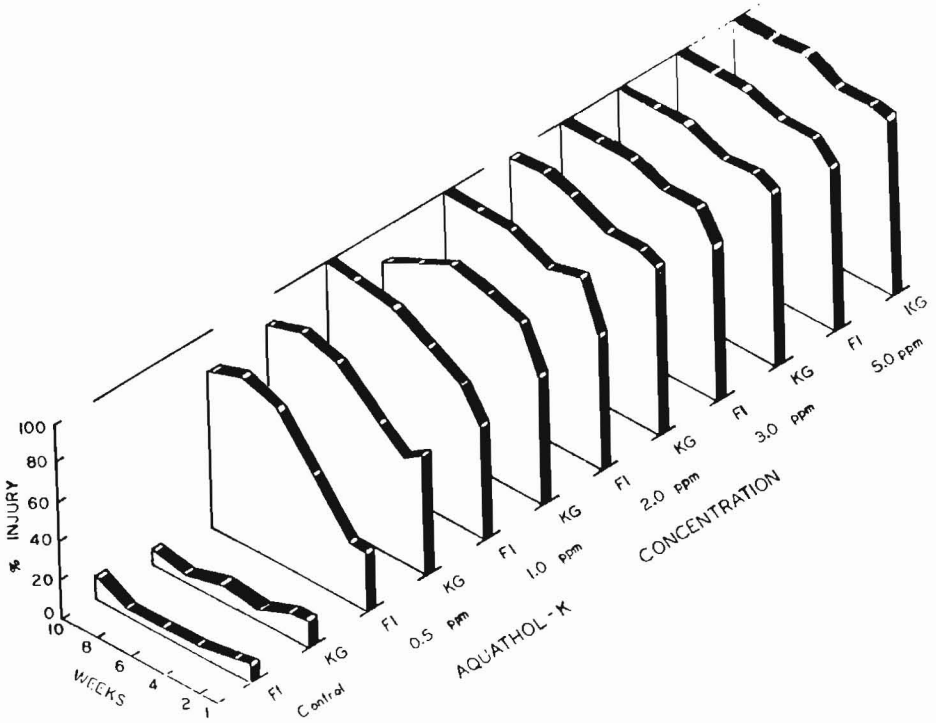


Figure 3. Laboratory evaluation of endothall (Aquathol K) for phytotoxicity toward monoecious (KG) and dioecious (FL) hydrilla biotypes

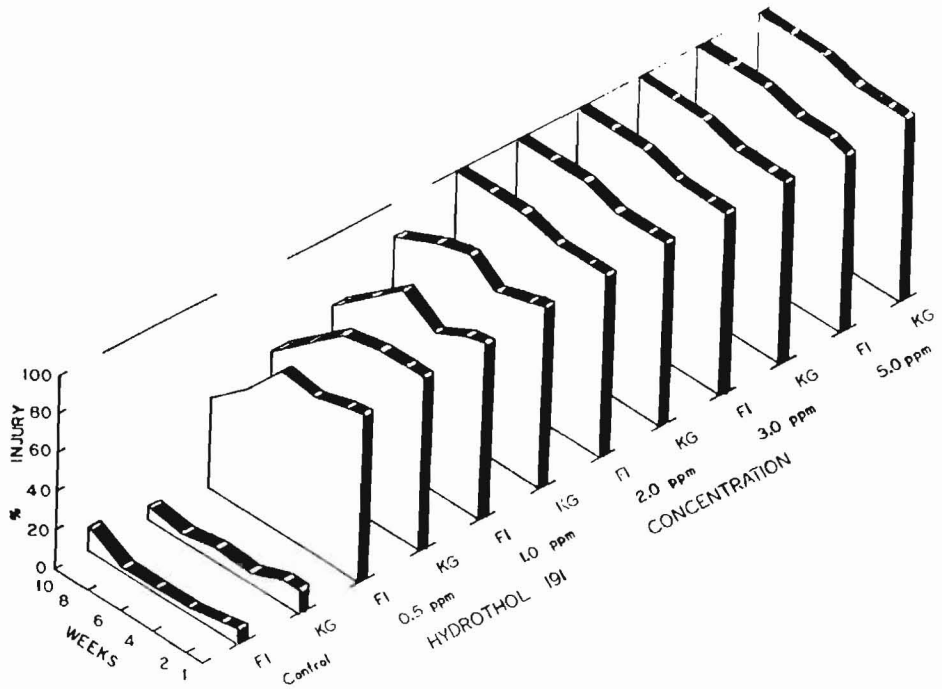


Figure 4. Laboratory evaluation of endothall (Hydrothol 191) for phytotoxicity toward monoecious (KG) and dioecious (FL) hydrilla biotypes

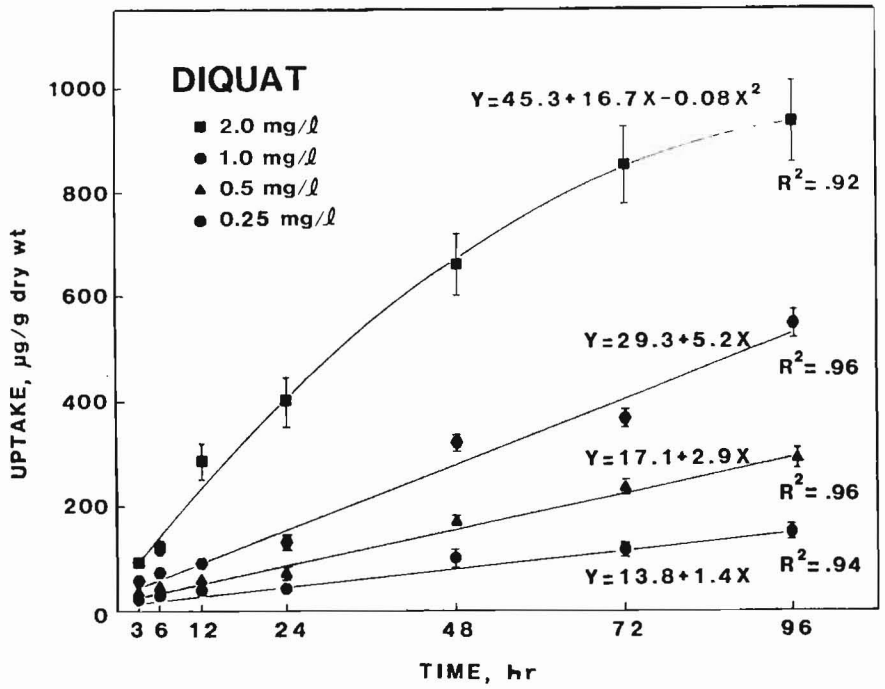


Figure 5. Time course of ^{14}C uptake by excised hydrilla tissue from various combinations of ambient ^{14}C-diquat concentrations and exposure periods. Vertical bars indicate ± standard error for each time interval

diquat in plant tissue divided by concentration in water) remained unchanged with the different ambient diquat levels (Figure 6).

24. Over the 4-day experiment, regression analysis indicated that the bioconcentration factors (which indicate how efficiently a herbicide is taken up by a plant) increased in a linear fashion with increasing exposure time. A bioconcentration factor as high as 550 was obtained after 4 days (Figure 6).

25. The equation for this linear relationship is $Y = 45.3 + 5.3(X)$, with a correlation coefficient $R^2 = 0.93$ significant at the 1-percent level. Extrapolation of the line for $X = 0$ will not extend the line through zero, and the Y intercept may be explained partially by the presence of an initial passive diffusion and/or adsorption of ^{14}C-diquat into intercellular free space (Figure 6). This initial adsorption phase of diquat was previously observed in *E. canadensis* (Davies and Seaman 1968) and in hydrilla (Sutton et al. 1972).

26. Our data indicated that this initial adsorption phase increased with increasing ambient diquat concentrations in water (Figure 5). Since this

adsorption was indistinguishable from the absorbed diquat in plant tissue by the ^{14}C techniques, caution must be exercised during comparison of herbicide uptake across different diquat treatment rates in water (Table 2).

27. Phytotoxicity responses to the ^{14}C-diquat treatments are presented in Figure 7. The low treatment (0.25 mg/ℓ) represents a field rate of about 4 kg/ha diquat in a body water 6 ft (1.8 m) deep, assuming uniform distribution throughout the water column. At 0.25 mg/ℓ diquat, a contact time of 2 days was required to obtain about 80-percent control under our experimental conditions. More importantly, the data appear to indicate that as the treatment rate of diquat was doubled to 0.5 mg/ℓ, the required contact time was reduced to one-half, i.e., 1 day. Similarly, at 1.0 mg/ℓ diquat, the required contact time was about 12 hr. A 6-hr contact time to 2.0 mg/ℓ diquat was required to obtain about 80-percent control.

28. Table 2 correlates the herbicide lethal doses (Figure 7) with corresponding diquat concentrations in hydrilla tissue (Figure 5). At the 0.25-mg/ℓ treatment rate and 48-hr contact time, the lethal tissue concentration of diquat was 81 µg/g dry weight of hydrilla. Higher tissue concentrations were observed, however, when the lethal doses were achieved using higher diquat treatment levels and shorter contact time (Table 2). A diquat concentration as high as 151 µg/g was found in hydrilla tissue after a 6-hr contact to the 2.0-mg/ℓ treatment level. These differences in lethal tissue concentration were due in part to the increased initial adsorption in the presence of higher ambient diquat levels in water (Table 2).

29. Table 3 gives the results of tissue concentration and initial adsorption calculated from the regression equation for bioconcentration factors of diquat in Figure 6. The tissue concentration of diquat adjusted for initial adsorption was 64 µg/g dry weight for all lethal doses obtained with different combinations of herbicide rates and contact time.

30. The response of hydrilla to various diquat concentrations and exposure times was then confirmed in "whole-plant" studies with both hydrilla biotypes grown from germinating tubers and from plant cuttings. Data were collected for percent injury ratings after 2, 4, and 6 weeks and for plant dry weight at the end of the 6-week experiment.

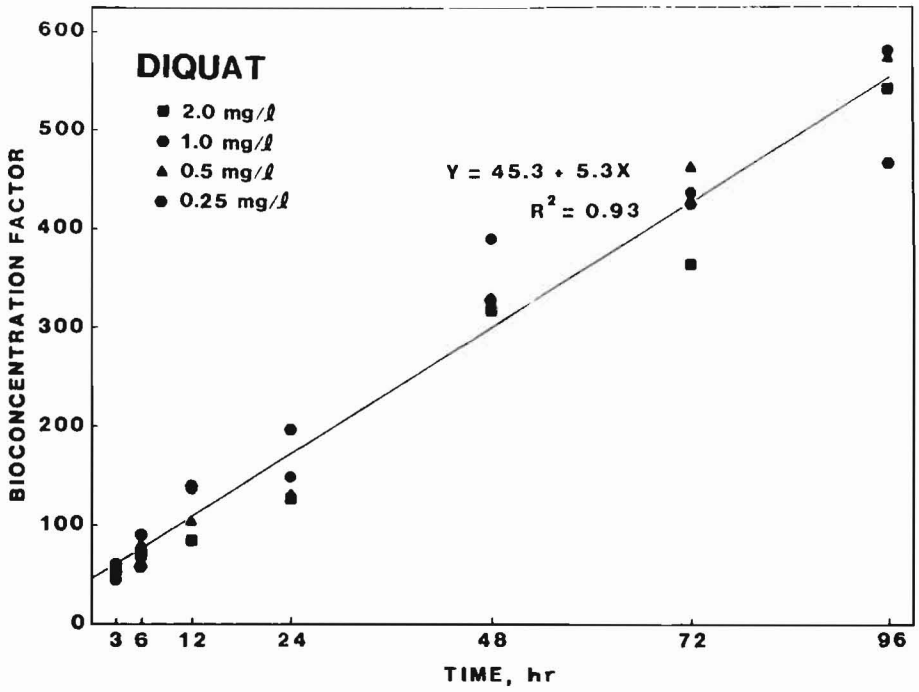


Figure 6. Bioconcentration factors, ^{14}C-diquat uptake by excised hydrilla tissue treated with various herbicide concentrations and exposure periods

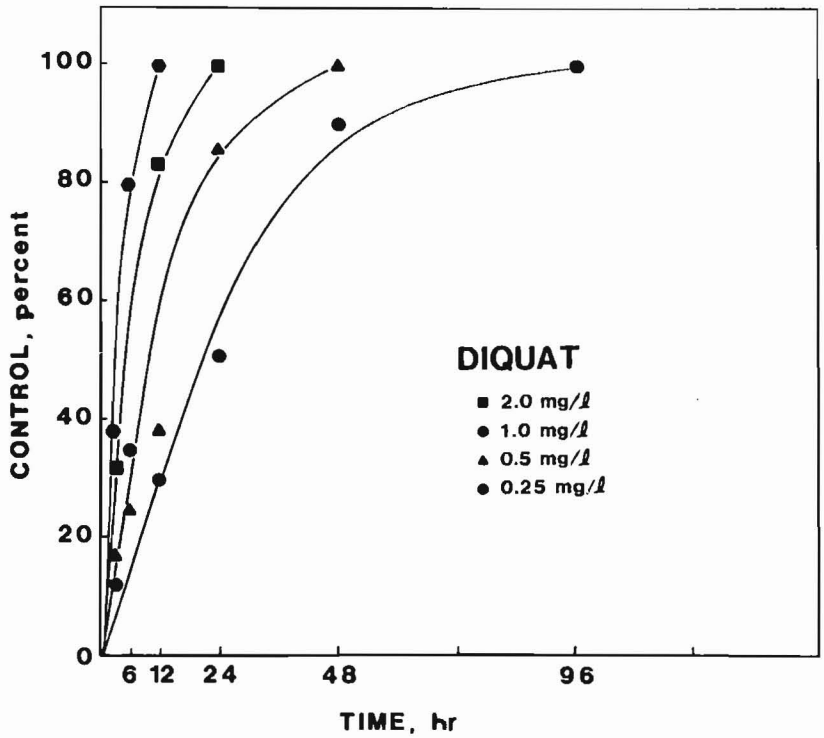


Figure 7. Phytotoxic response of excised hydrilla tissue to various ^{14}C-diquat concentrations and exposure periods

31. Young hydrilla shoots just emerging from tubers appeared to be about as equally susceptible to diquat treatments as excised apical tissues. For the monoecious biotype, a 6-hr exposure to an ambient diquat concentration of 2.0 mg/ℓ was sufficient to provide more than 80-percent reduction of plant biomass when treatment was made 2 to 3 weeks after tuber sprouting (Table 4).

32. Also, similar responses to diquat treatments were obtained with young shoots just emerging from sprouting tubers of the dioecious biotype (Table 5). Analysis of variance of the dry weight data indicated no significant differences between the two hydrilla biotypes in their responses to the diquat treatments, confirming our earlier results (Figure 1).

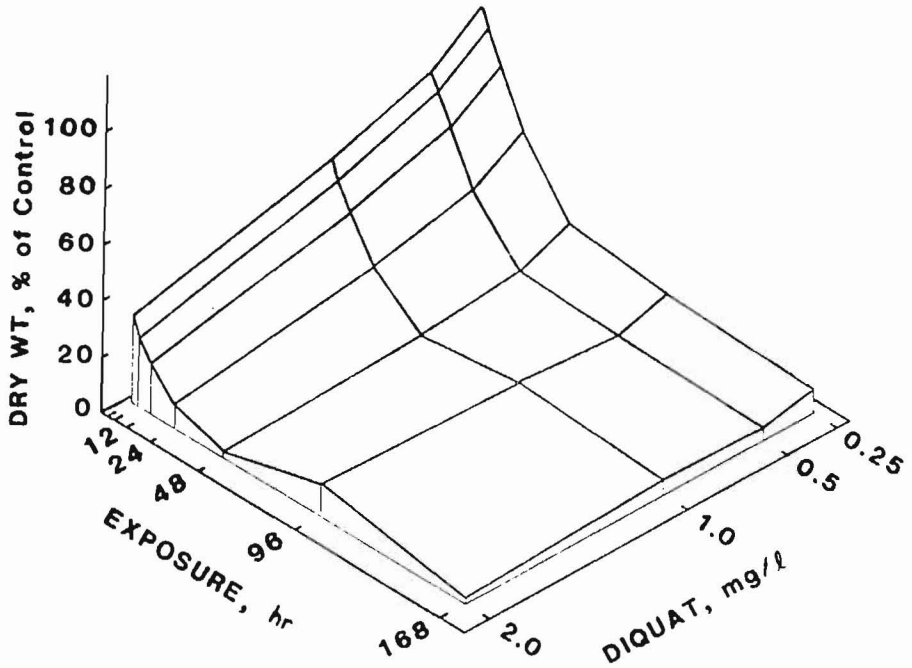
33. The dry weight data for both hydrilla biotypes were then summarized as three-dimensional response surfaces to facilitate visualization of the combined effects of diquat treatment rates and contact time (Figure 8). These response surfaces were generated by fitting the data to a third-order polynomial equation.

34. The effects of similar diquat concentrations and contact times on hydrilla grown from plant cuttings were also investigated. The treatments with hydrilla grown from cuttings were designed to have more plant biomass and more older plant tissue at the time chemical applications were made. Under these conditions, hydrilla appeared to require a longer contact time to achieve the same level of control at similar ambient diquat levels. A 12-hr contact time to 2.0 mg/ℓ diquat was required to provide adequate control of the monoecious biotype grown from plant cuttings (Table 6).

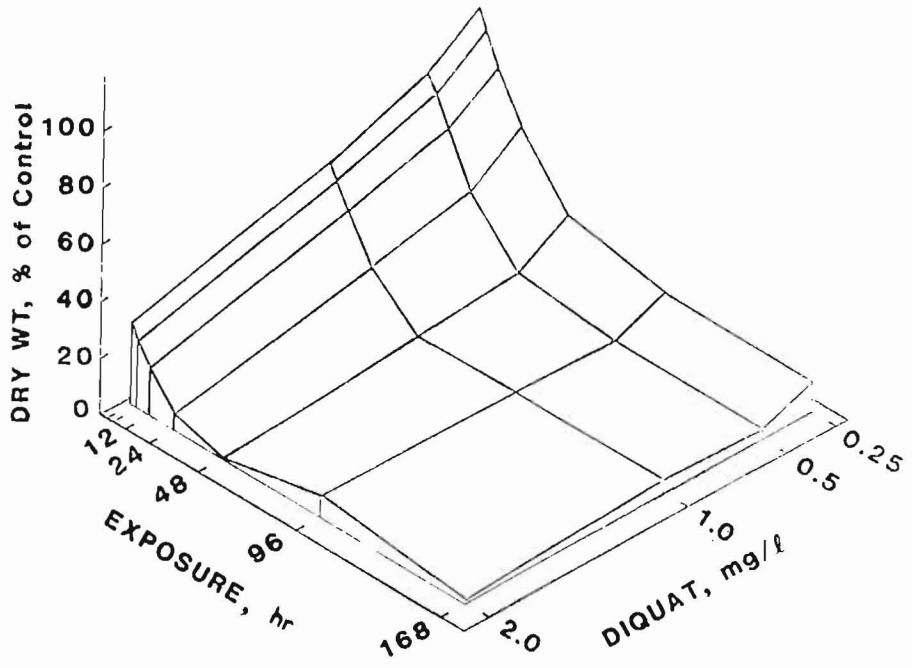
35. Similar responses were again obtained with the dioecious biotype (Table 7). Response surfaces for dry weight of both hydrilla biotypes grown from plant cuttings are presented in Figure 9.

36. In the tidal environment of the Potomac River, diquat treatments would probably have more chance of success if they were made earlier in the growing season, long before peak biomass conditions and prior to the plant reaching the water surface. To further enhance the contact time of diquat with the target plants, use of an invert and/or adjuvant in combination with the herbicide is recommended.

37. Hydrilla appeared to be more tolerant to diquat than several other submersed species in the Potomac River. Under laboratory conditions, Eurasian watermilfoil (*Myriophyllum spicatum*) was controlled by 0.1 mg/ℓ diquat with a required contact time of 12 hr (Figure 10). However, the same diquat

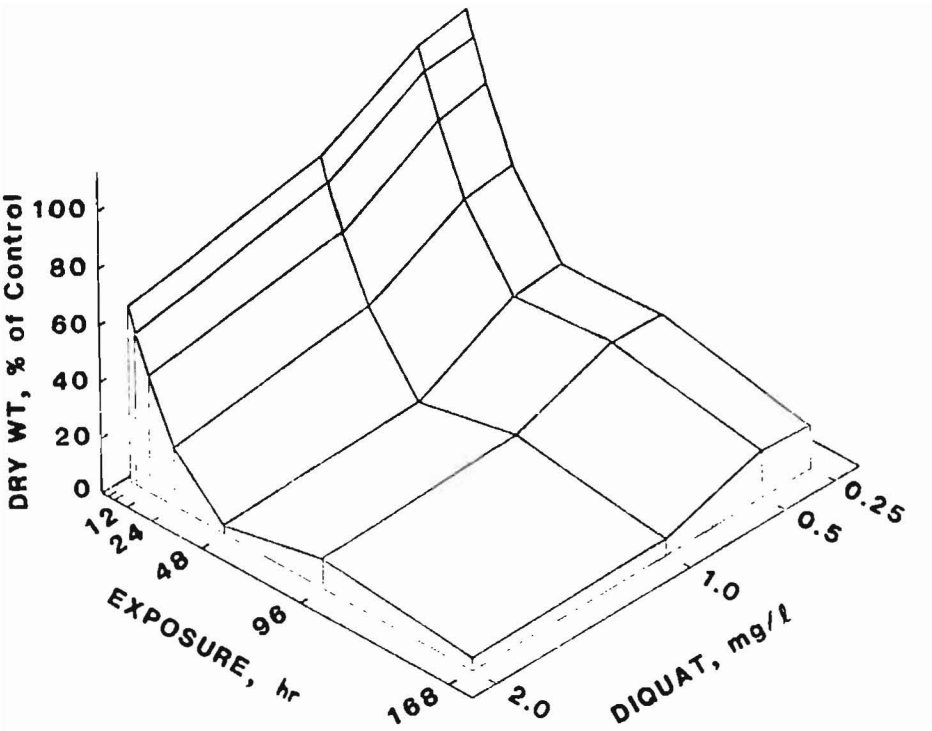


a. Monoecious/germ tubers

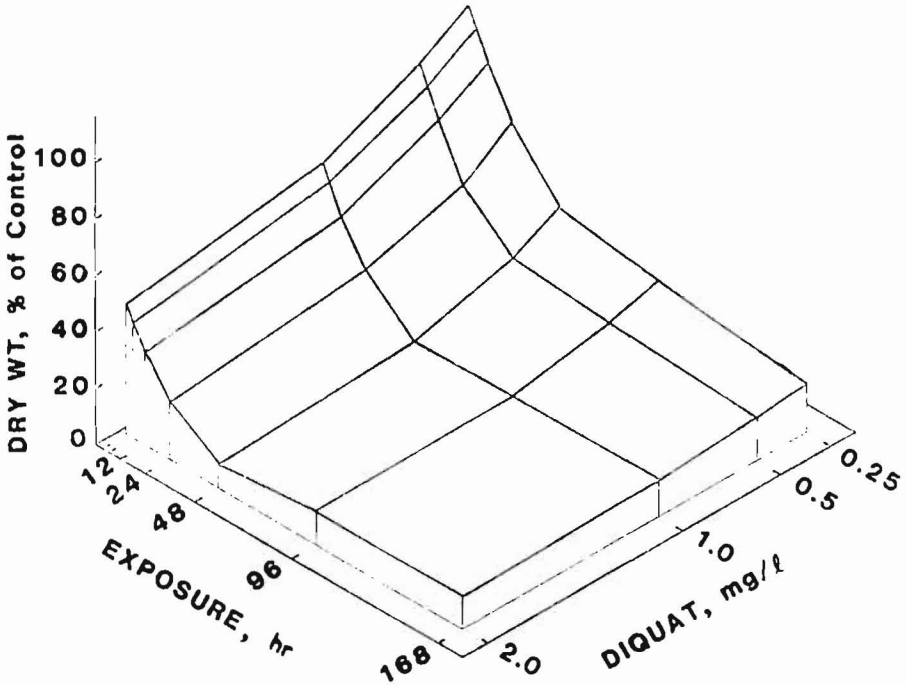


b. Dioecious/germ tubers

Figure 8. Response surfaces for dry weight of hydrilla grown from tubers and treated at 28 combinations of diquat concentrations and exposure periods



a. Monoecious/plant cuttings



b. Dioecious/plant cuttings

Figure 9. Response surfaces for dry weight of hydrilla grown from plant cuttings and treated at 28 combinations of diquat concentrations and exposure periods

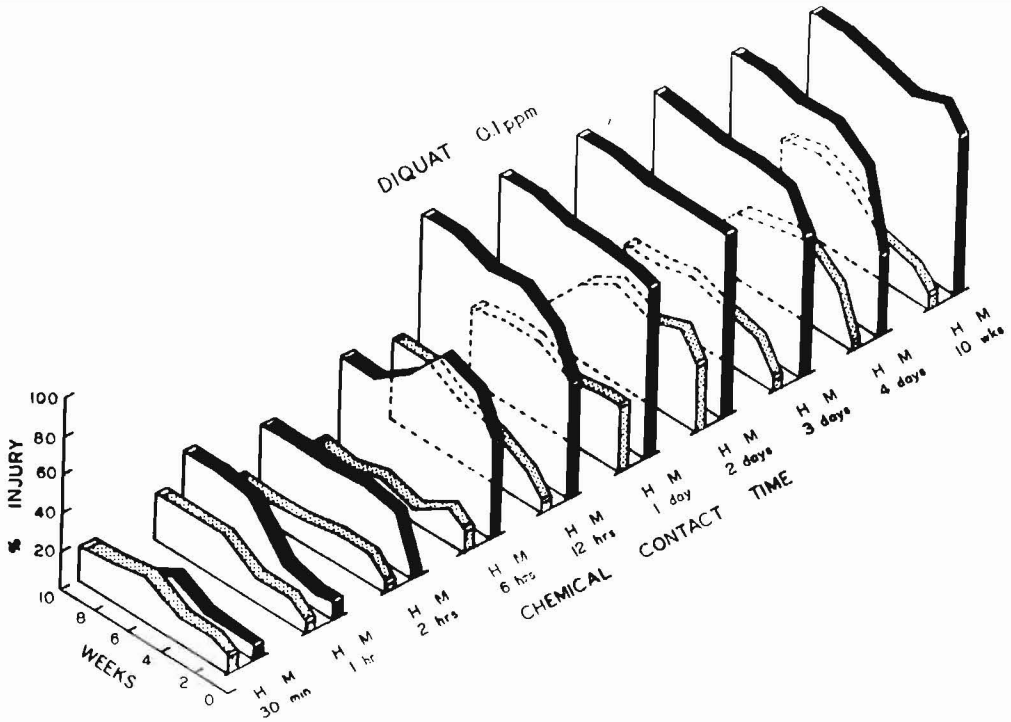


Figure 10. Laboratory evaluation of various exposure periods to 0.1 ppm diquat for phytotoxicity toward hydrilla (H) and Eurasian watermilfoil (M)

treatment rate was too low to achieve hydrilla control at any contact time. When the treatment rate was increased to 1.0 mg/ℓ diquat, control of Eurasian watermilfoil was obtained with only a 1-hr contact, whereas hydrilla control still required 12 hr of contact to 1.0 mg/ℓ diquat in water (Figure 11).

38. The differential responses to diquat were probably related to differences in herbicide uptake characteristics between the two species (Figure 12).

Endothall

39. The uptake of ^{14}C by excised hydrilla tissue treated at various ^{14}C-endothall concentrations and exposure periods is illustrated in Figure 13. The time course of uptake at all test concentrations of endothall was best described by second-order polynomial equations, with maximum levels of ^{14}C in plant tissue measured 4 days after treatment.

40. Again, it was observed that concentrations of ^{14}C in plant tissue increased proportionally with the ambient concentrations of ^{14}C-endothall in

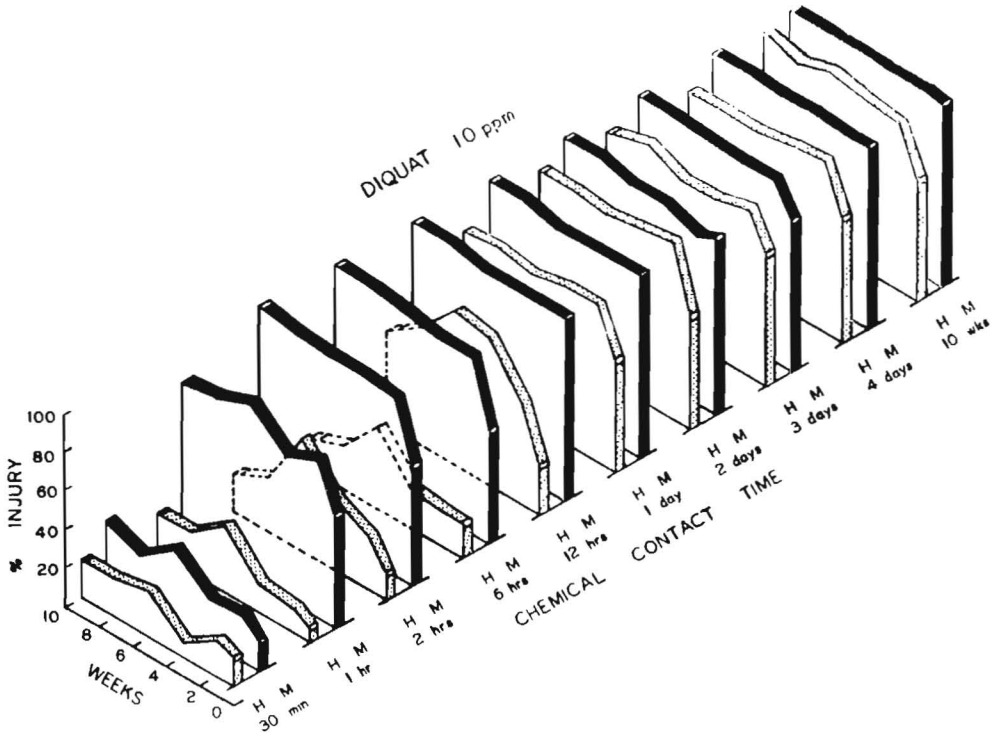


Figure 11. Laboratory evaluation of various exposure periods to 1.0 ppm diquat for phytotoxicity toward hydrilla (H) and Eurasian watermilfoil (M)

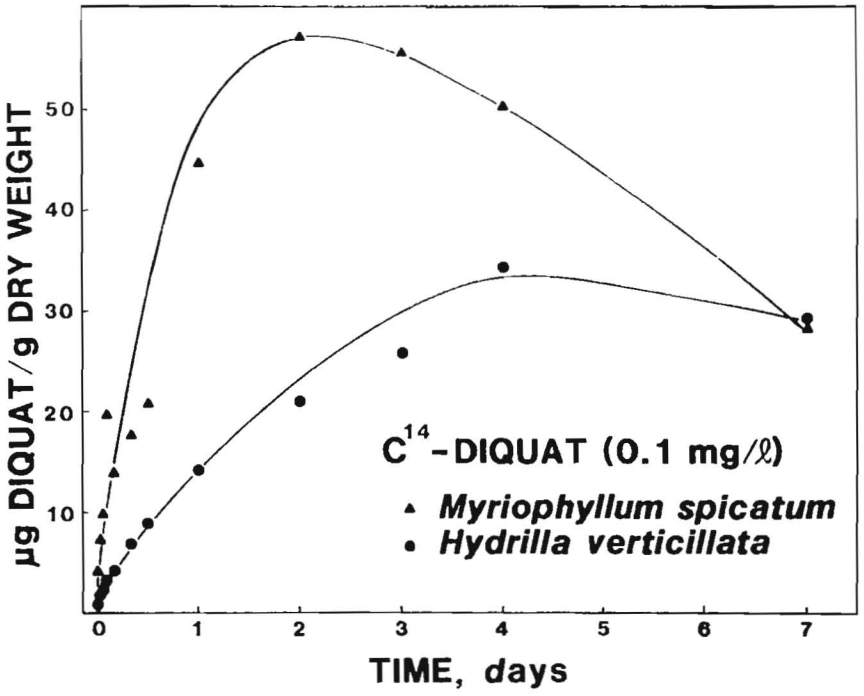


Figure 12. Time course, ^{14}C uptake by excised apical tissue of hydrilla and Eurasian watermilfoil from various ^{14}C-diquat concentrations and exposure periods

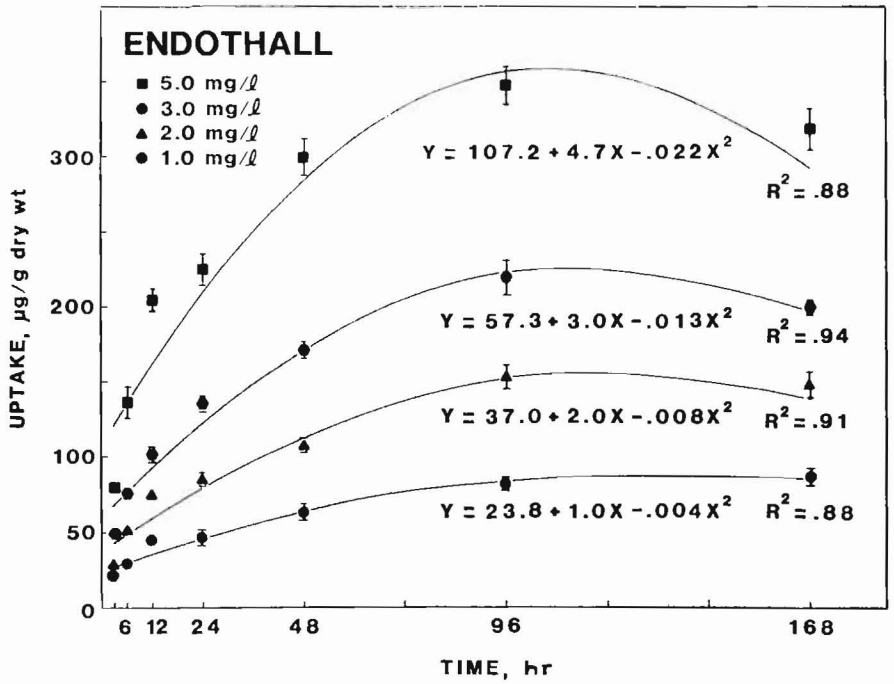


Figure 13. Time course of ^{14}C uptake by excised hydrilla tissue from various combinations of ^{14}C-endothall concentrations and exposure periods

water, so that, within a given exposure period, the ratios of ^{14}C concentration in plant tissue divided by the concentration in water (bioconcentration factors) remained unchanged (Figure 14).

41. Over the 7-day experiment, the bioconcentration factors for ^{14}C-endothall uptake increased to a maximum of 77 after 4 days (Figure 14), as compared to a factor of 550 previously determined for ^{14}C-diquat under similar conditions (Figure 6).

42. The ability of diquat to be taken up much more easily than endothall is one possible explanation of why diquat is effective in hydrilla control at a lower rate than is endothall. Under our laboratory conditions, a threshold concentration of 0.25 mg/ℓ diquat was required for hydrilla control (Figure 2). Similar control of hydrilla with endothall required a minimum treatment rate of 1.0 mg/ℓ (Figure 3).

43. As was previously found with diquat, examination of the regression curves for endothall uptake indicated the presence of an initial adsorption phase into the plant surfaces. Again, this initial adsorption increased with increasing ambient concentrations of endothall in water (Figure 13).

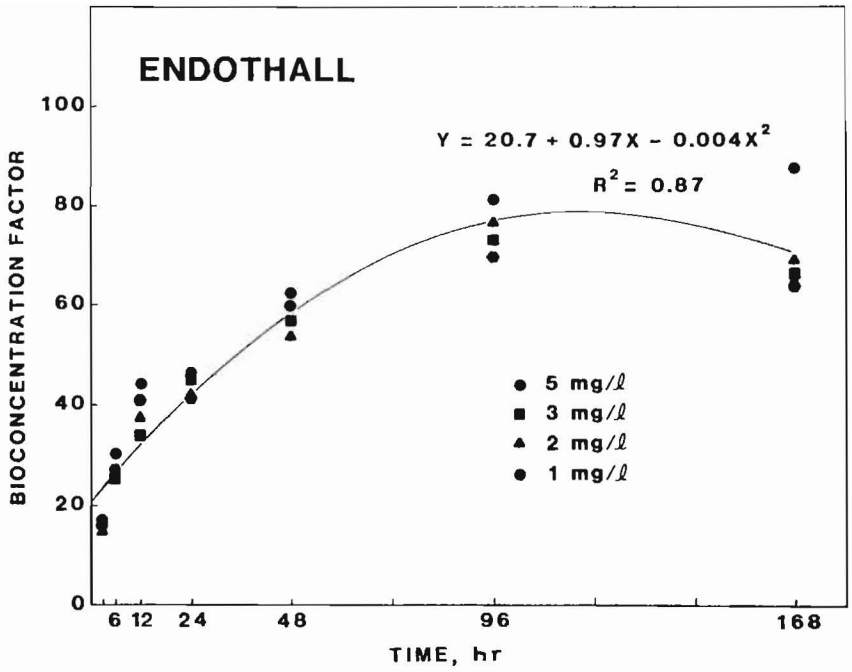


Figure 14. Bioconcentration factors of ^{14}C-endothall uptake by excised hydrilla tissue treated with various herbicide concentrations and exposure periods

44. Figure 15 illustrates the phytotoxic responses of excised hydrilla tissue to the ^{14}C-endothall treatments. At 1.0 mg/ℓ endothall, a 72-hr contact was required to obtain about 80-percent hydrilla control. This required contact time was reduced to between 6 and 12 hr when the endothall treatment rate was increased to 5.0 mg/ℓ.

45. A lethal endothall concentration of 75 µg/g was determined in hydrilla tissue after 72 hr of contact to 1.0 mg/ℓ ambient endothall (Figure 13). However, higher tissue levels of 135 to 160 µg/g endothall were observed at the 5.0-mg/ℓ treatment rate and 6- to 12-hr contact time. As previously discussed, these different tissue concentrations at various herbicide lethal doses may be partially explained by the increasing initial adsorption phase in treatments with higher levels of ambient endothall.

46. Also, as stated, young hydrilla plants emerging from sprouting tubers were about as equally susceptible to endothall as excised apical tissue. Tables 8 and 9 indicate that a 6- to 12-hr contact to 5.0 mg/ℓ endothall provided a 73- to 81-percent reduction of plant biomass as compared to control plants, and there were no significant differences between the two biotypes in their responses to endothall treatments (see Figures 16-17).

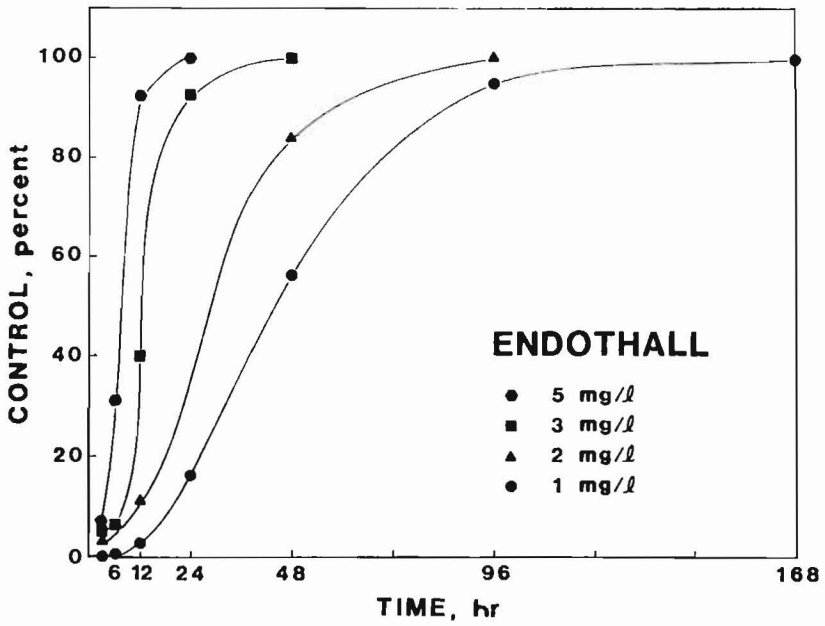


Figure 15. Phytotoxic response of excised hydrilla tissue to various ^{14}C-endothall concentrations and exposure periods

47. For treatments using hydrilla grown from plant cuttings, control of both biotypes required between 48 and 96 hr of contact to 1.0 mg/ℓ endothall. However, at the high treatment rate of 5.0 mg/ℓ endothall, a 12-hr contact was sufficient to provide a 72- to 82-percent reduction of plant biomass of the monoecious and dioecious biotypes, respectively (Tables 10 and 11).

Fluridone

48. Uptake of ^{14}C by excised hydrilla tissue increased in a linear fashion with time when ambient ^{14}C-fluridone concentrations in water were at 0.1 to 0.5 mg/ℓ (Figure 18). However, a biphasic uptake curve that fitted best to a third-order polynomial regression equation was observed at the treatment rate of 1.0 mg/ℓ fluridone. This biphasic pattern of fluridone uptake by hydrilla was previously observed,* and field trials have been conducted in Florida with split application of fluridone to take advantage of this uptake characteristic.

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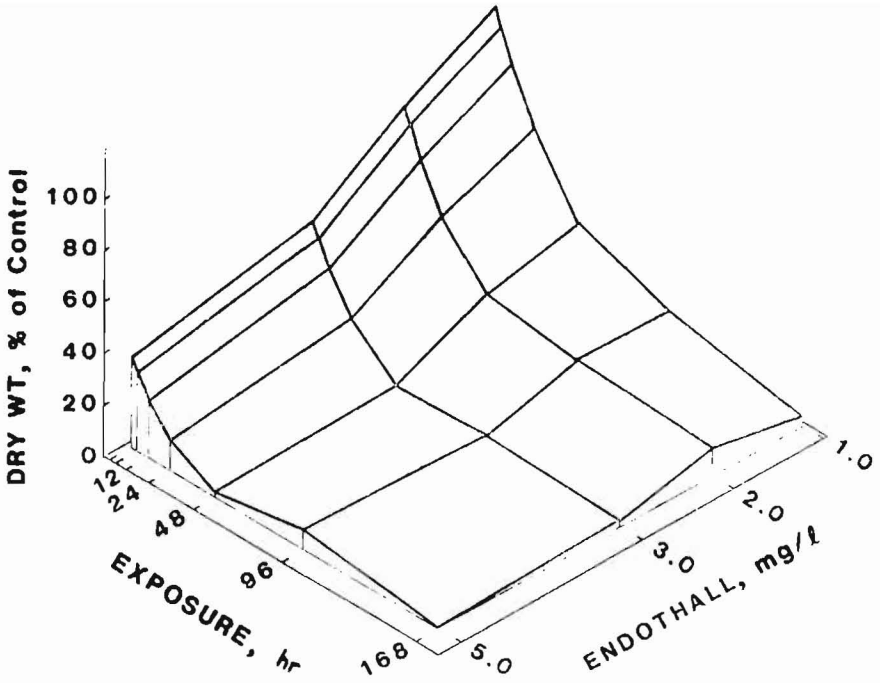
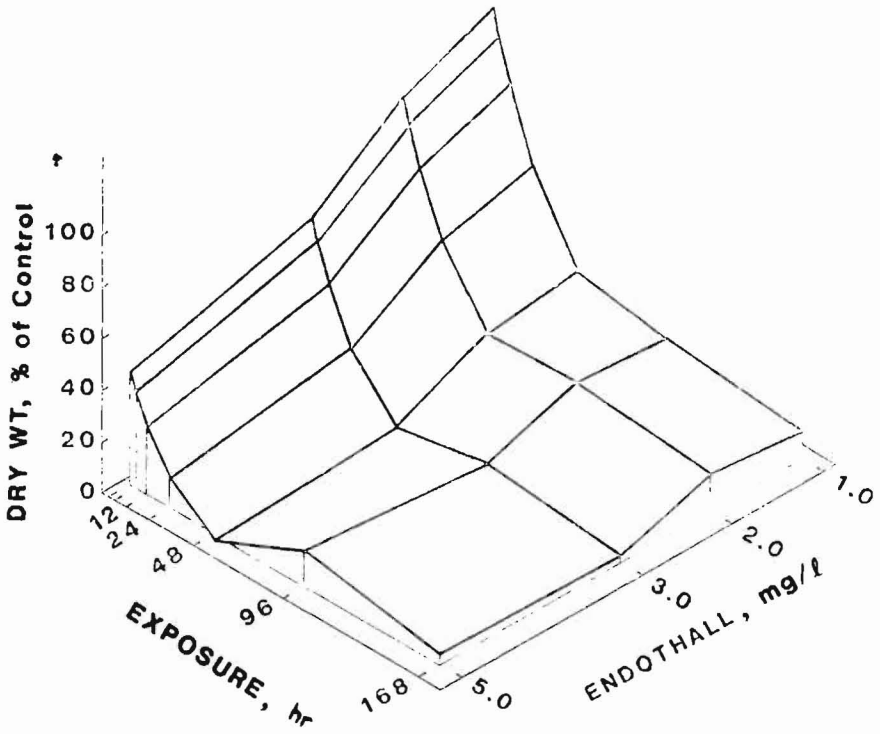
* Personal Communication, 1983, W. T. Haller, University of Florida, Gainesville, Fla.

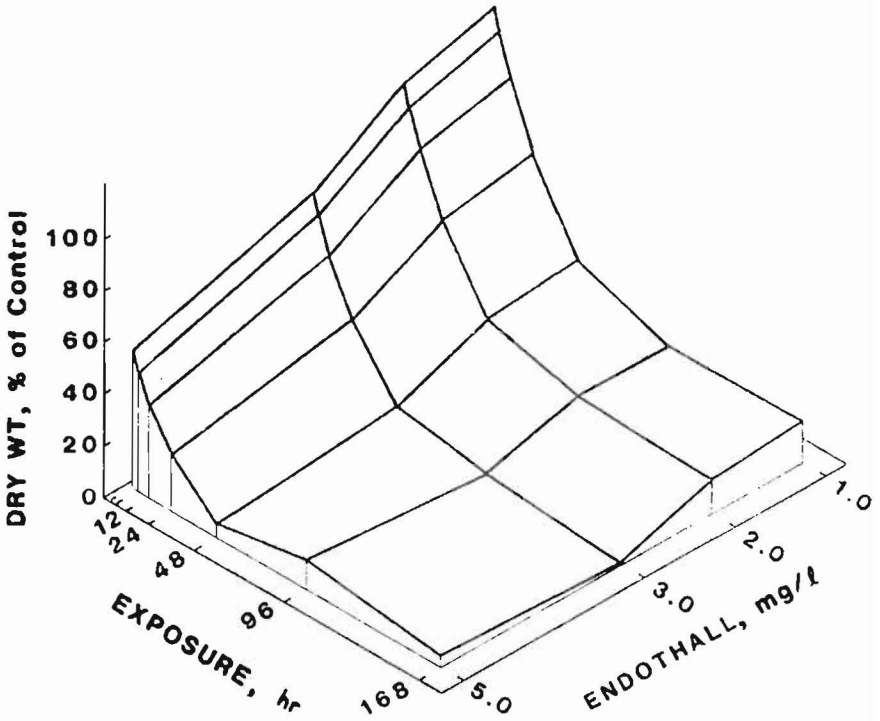


a. Monoecious/germ tubers

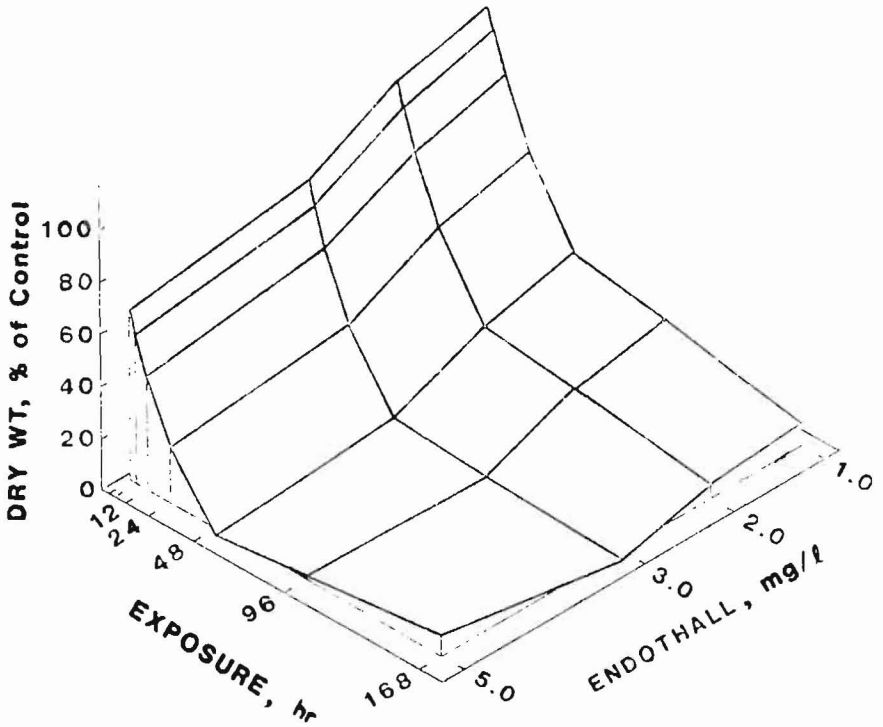


b. Dioecious/germ tubers

Figure 16. Response surfaces for dry weight of hydrilla grown from tubers and treated at 28 combinations of endothall concentrations and exposure periods



a. Monoecious/plant cuttings



b. Dioecious/plant cuttings

Figure 17. Response surfaces for dry weight of hydrilla grown from cuttings and treated at 28 combinations of endothall concentrations and exposure periods

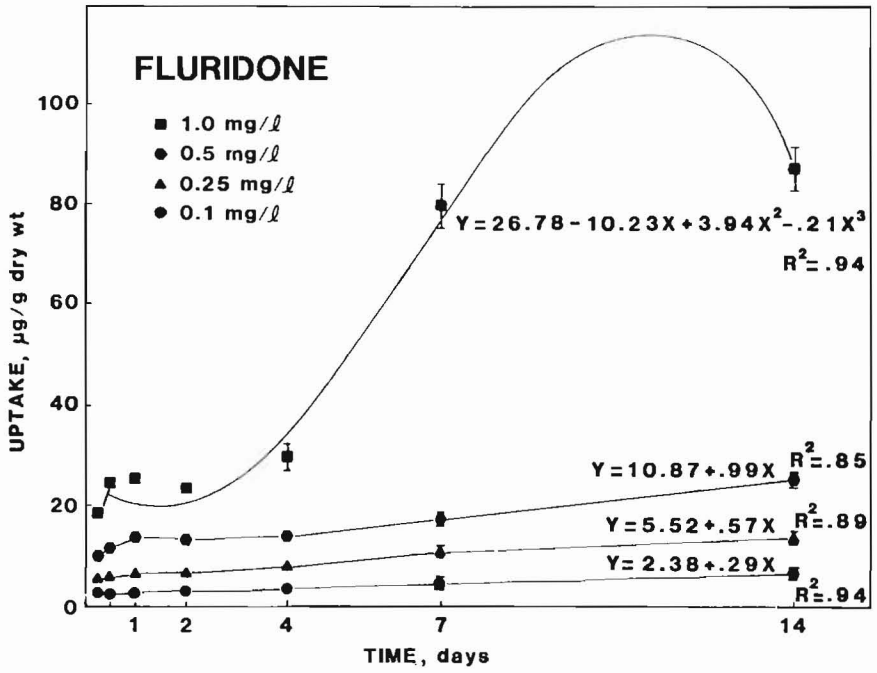


Figure 18. Time course of $^{14}C_{14}$ uptake by excised hydrilla tissue from various $^{14}C_{14}$-fluridone concentrations and exposure periods

49. After 14 days, the bioconcentration factors for fluridone uptake were 64, 54, and 50 when the herbicide concentrations in water were 0.1, 0.25, and 0.5 mg/ℓ, respectively. West, Day, and Burger (1979) also reported very low bioconcentrations, ranging from 0 to 32, after treating hydrilla in a small pond in Florida with 0.02 mg/ℓ fluridone. Similarly, we have previously observed a bioconcentration factor of 44 after 21 days in a treatment solution of 0.05 mg/ℓ fluridone (Van and Steward 1986).

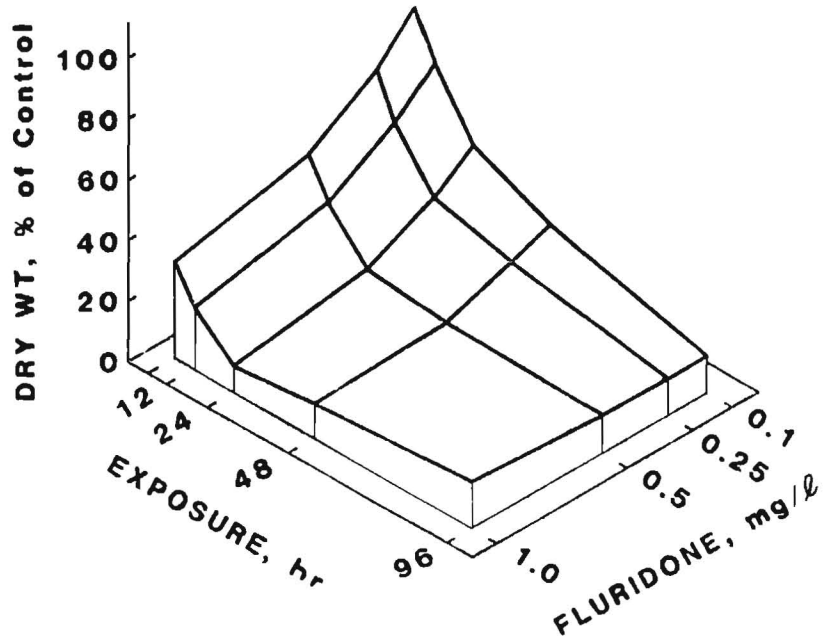
50. For the 1.0-mg/ℓ fluridone treatment rate, a bioconcentration factor of 35 was observed at the end of the first phase of uptake 4 days after treatment. Then, the bioconcentration increased sharply to a maximum value of 115 after 11 days.

51. Tables 12 and 13 present the phytotoxic responses of hydrilla grown from tubers and exposed to various treatment rates of fluridone over periods ranging from 6 hr to 4 days. Visual ratings of plant injury were low for all treatments and did not reflect the reduction in plant biomass, suggesting that the observed effects may represent mostly growth inhibition due to the fluridone treatments.

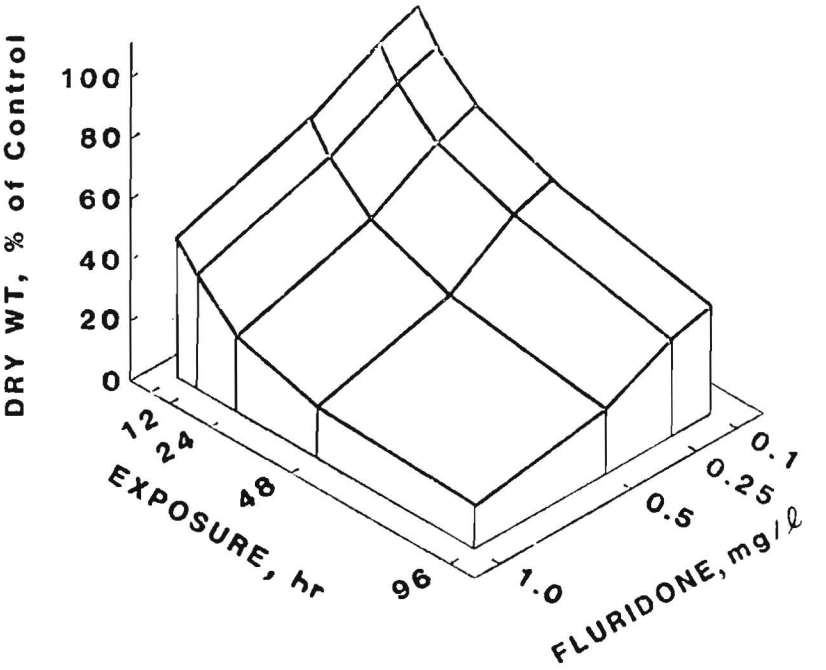
52. For the dioecious biotype, a 2- to 4-day exposure to 1.0 mg/ℓ fluridone provided a 76- to 86-percent reduction of dry weight as compared to control plants (Table 13). The same treatment yielded concentrations of fluridone in plant tissue of 20 to 35 µg/g dry weight (Figure 18). Again, no attempt was made to distinguish between the proportion of material absorbed into plant tissues and the amount initially adsorbed to plant surfaces.

53. The monoecious biotype appeared to be much more susceptible to fluridone (Figure 19). Control of monoecious hydrilla early growth from tubers was achieved after only 12 hr of contact to 1.0 mg/ℓ fluridone (Table 12). Treatment at 0.1 mg/ℓ also provided a 90-percent reduction in plant biomass when exposure to the chemical was extended to 4 days. Analysis of variance indicated significant differences between the two biotypes in their response to the fluridone treatments.

54. Similar differences between the two biotypes were also observed in treatments using hydrilla grown from plant cuttings (Figure 20). Control of the dioecious biotype required 10 days of contact to 0.5 mg/ℓ or 7 days to 1.0 mg/ℓ fluridone (Table 14), while it was possible to control monoecious hydrilla with similar exposure periods to fluridone treatments as low as 0.1 mg/ℓ (Table 15).

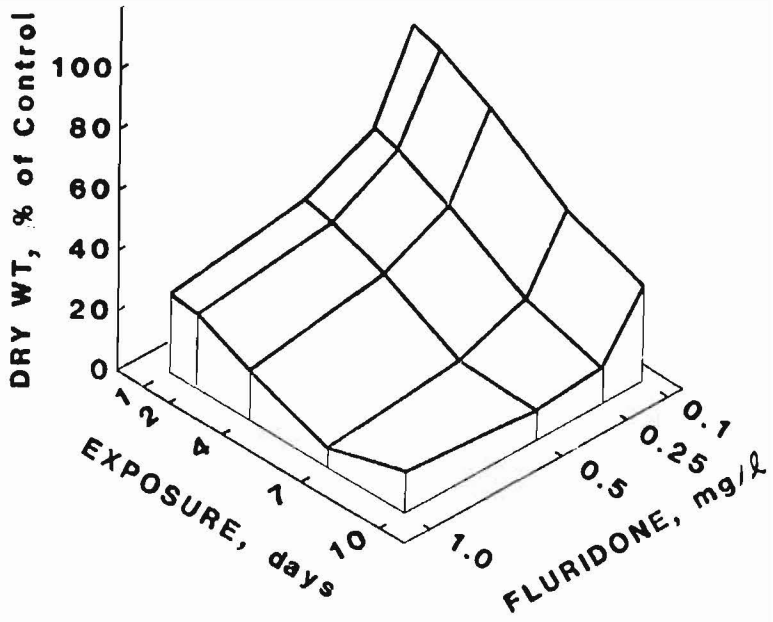


a. Monoecious/germ tubers

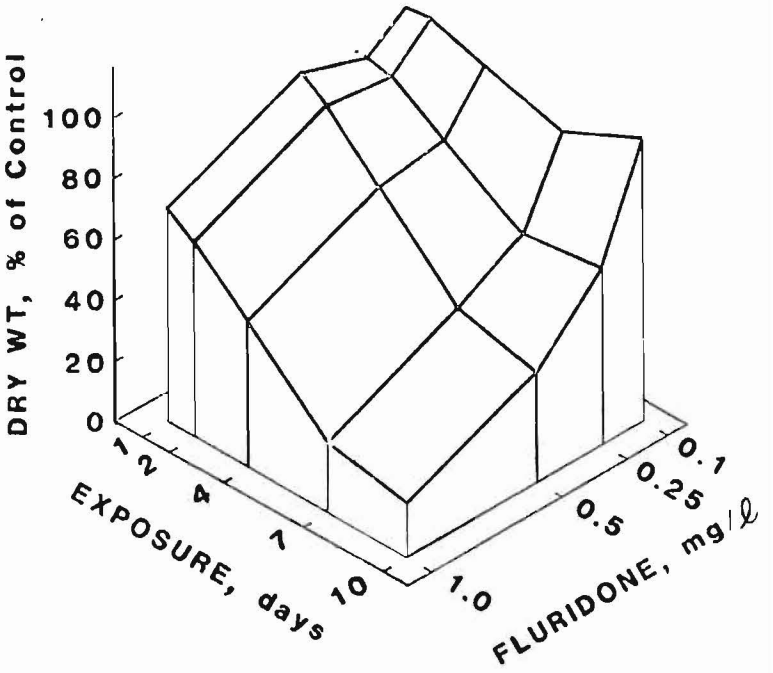


b. Dioecious/germ tubers

Figure 19. Response surfaces for dry weight of hydrilla grown from tubers and treated at 20 combinations of fluridone concentrations and exposure periods



a. Monoecious/plant cuttings



b. Dioecious/plant cuttings

Figure 20. Response surfaces for dry weight of hydrilla grown from cuttings and treated at 20 combinations of fluridone concentrations and exposure periods

PART IV: CONCLUSIONS AND RECOMMENDATIONS

55. Results from laboratory studies suggest that providing an adequate herbicide contact time would be crucial for the success of a chemical treatment of the monoecious hydrilla in the Potomac River. A minimum of 6 hr contact to 2.0 mg/ℓ diquat or 5.0 mg/ℓ endothall is required. To achieve this minimum contact time, the chemical would have to be applied in the 6-hr tidal window, 3 hr before and after flood tide. A preliminary dye study to assess the potential herbicide contact time under different conditions in the tidal system of the Potomac River could contribute significantly to the success of the chemical control operation.

56. Also, it will be necessary to use invert, and/or adjuvant, or other special application techniques to achieve the concentration of 2.0 mg/ℓ diquat in the hydrilla mat with the maximum allowable treatment rate of 2 gal/surface acre (0.002 dm^3/m^2).

57. Since early growth of hydrilla appeared more susceptible to the herbicides investigated, chemical treatments would probably have more chance of success if they were made early in the growing season, long before peak biomass conditions and prior to the plant reaching the water surface. Laboratory results also indicated higher rates of regrowth when hydrilla was treated with high herbicide concentrations and short contact time. Consequently, at least two or more annual applications would be required for effective hydrilla control in the Potomac River.

58. A field appraisal of the mixture of aquatic plant species should be conducted before and after herbicide treatment. Treatments of diquat and endothall required to control hydrilla will also kill several other nontarget species that may be considered valuable to the aquatic resource. Localized control such as that achieved by applications of granular dichlobenil needs to be investigated.

59. Further studies are required to verify the observed differences in susceptibility to fluridone between the two hydrilla biotypes. The potential of bottom treatments using fluridone pellets to inhibit early growth from tubers of the more susceptible monoecious biotype should be investigated.

REFERENCES

Anderson, L. W. J. 1981. "Effect of Light on the Phytotoxicity of Fluridone in American Pondweed (*Potamogeton nodosus*) and Sago Pondweed (*P. pectinatus*)," Weed Science, Vol 29, pp 723-728.

Barrett, P. R. F. 1981. "Aquatic Herbicides in Great Britain, Recent Changes and Possible Future Development," Proceedings, Aquatic Weeds and Their Control, Association of Applied Biologists, Oxford, pp 95-103.

Blackburn, R. D., Weldon, L. W., Yeo, R. R., and Taylor, T. M. 1969. "Identification and Distribution of Certain Similar-Appearing Submersed Aquatic Weeks in Florida," Hyacinth Control Journal, Vol 8, No. 1, pp 17-21.

Bowes, F., Holaday, A. S., Van, T. K., and Haller, W. T. 1977. "Photosynthetic and Photorespiration Carbon Metabolism in Aquatic Plants," Proceedings of the Fourth International Congress of Photosynthesis, D. O. Hall, J. Coombs, and T. W. Goodwin, eds., The Biochemical Society, London, pp 289-298.

Bowmer, K. H., Sainty, G. R., Smith, G., and Shaw, K. 1979. "Management of Elodea in Australian Irrigation Systems," Journal of Aquatic Plant Management, Vol 17, pp 4-12.

Conant, R. D., Jr., Van, T. K., and Steward, K. K. 1984. "Monoecious Hydrilla Produces Viable Seeds in the United States," Aquatics, Vol 6, p 10.

Davies, P. J., and Seaman, D. E. 1968. "Uptake and Translocation of Diquat in Elodea," Weed Science, Vol 16, pp 293-295.

Ennis, W. B., Jr., and Vandiver, V. V., Jr. 1979. "Trend in Aquatic Weed Management," Proceedings of the Seventh Asian-Pacific Weed Science Society Conference, pp 213-217.

Hall, J. F., Westerdahl, H. E., and Stewart, T. J. 1984. "Growth Response of *Myriophyllum spicatum* and *Hydrilla verticillata* When Exposed to Continuous, Low Concentrations of Fluridone," Technical Report A-84-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Haller, W. T., and Sutton, D. L. 1973. "Factors Affecting the Uptake of Endothall-^{14}C by Hydrilla," Weed Science, Vol 21, pp 441-448.

Hoagland, D. R., and Arnon, D. I. 1950. "The Water Culture Method for Growing Plants Without Soil," University of California Agricultural Experiment Station Circular, No. 347.

Langeland, K. A., and Pesacreta, G. J. 1985. "Management of a Monoecious Strain of Hydrilla in North Carolina," Aquatics, Vol 7, pp 15-20.

MacKenzie, J. W. 1968. "Factors Affecting Control of Florida Elodea with Diquat in Southeast Florida Canals," Hyacinth Control Journal, Vol 8, No. 1, pp 13-16.

Price, A. 1969. "The Use of an Amine Salt of Endothall in Irrigation Canals," Hyacinth Control Journal, Vol 8, No. 2, pp 32-33.

Steward, K. K., Van, T. K., Carter, C., and Pieterse, A. H. 1984. "Hydrilla Invades Washington, D.C., and the Potomac River," American Journal of Botany, Vol 71, pp 162-163.

Sutton, D. L., Haller, W. T., Steward, K. K., and Blackburn, R. D. 1972. "Effect of Copper on Uptake of Diquat-^{14}C by Hydrilla," Weed Science, Vol 20, pp 581-583.

Thomas, T. M., and Seaman, D. E. 1968. "Translocation Studies with Endothall-^{14}C in *Potamogeton nodosus* Poir," Weed Research, Vol 8, pp 321-326.

Van, T. K., Haller, W. T., and Bowes, G. 1976. "A Comparison of the Photosynthetic Characteristics of Three Submersed Aquatic Plants," Plant Physiology, Vol 58, pp 761-768.

Van, T. K., and Steward, K. K. 1986. "The Use of Controlled-Release Fluridone Fibers for Control of Hydrilla (*Hydrilla verticillata*)," Weed Science, Vol 34, pp 70-76.

West, S. D., Day, E. W., and Burger, R. O. 1979. "Dissipation of the Experimental Aquatic Herbicide Fluridone from Lakes and Ponds," Journal of Agriculture and Food Chemistry, Vol 27, pp 1067-1072.

Table 1

Average Monthly Water Quality Measurements from Surface Water Supply During the Study (January to November 1985)

Parameter	Mean ± SE	Range
pH	7.84 ± 0.22	7.43-8.18
Oxygen, mg/ℓ	5.4 ± 0.4	3.0-7.5
Total $CaCo_3$ hardness, mg/ℓ	167 ± 3	157-176
$CaCo_3$ alkalinity, mg/ℓ	148 ± 2	128-162
Conductivity, μmhos/cm	318 ± 9	241-361
No_3 - N, mg/ℓ	0.06 ± 0.02	ND*-0.32
NH_4 - N, mg/ℓ	0.19 ± 0.05	ND-1.00
PO_4 - P, mg/ℓ	ND	ND
Potassium, mg/ℓ	0.86 ± 0.06	0.54-2.00

* Not detectable (detection limit = 0.005 mg/ℓ).

Table 2

Concentrations of ^{14}C-Diquat in Excised Hydrilla Tissue Treated at Various Lethal Herbicide Doses

Lethal Doses*		Tissue Concentration**	Initial Adsorption**	Tissue Concentration Adjusted for Adsorption
Concentration mg/ℓ	Time hr	µg diquat/g dry weight	µg diquat/g dry weight	µg diquat/g dry weight
0.25	48	80.5	13.8	66.7
0.50	24	85.5	17.1	68.4
1.0	12	91.3	29.3	62.0
2.0	6	150.9	76.3	74.6

* Based on phytoxicity data in Figure 7.

** Based on regression equations for diquat uptake in Figure 5.

Table 3

Prediction of Tissue Concentrations of Diquat Based on Bioconcentration Factors

Lethal Doses*		Tissue Concentration** µg diquat/g dry weight	Initial Adsorption** µg diquat/g dry weight	Tissue Concentration Adjusted for Adsorption µg diquat/g dry weight
Concentration mg/ℓ	Time hr			
0.25	48	74.9	11.3	63.6
0.50	24	86.3	22.7	63.6
1.0	12	108.9	45.3	63.6
2.0	6	154.2	90.6	63.6

* Based on phytoxicity data in Figure 7.

** Based on the regression equation for bioconcentration factors in Figure 6.

Table 4

Response of Monoecious Hydrilla Grown from Tubers to Different Diquat Concentrations and Exposure Periods Under Laboratory Conditions

Diquat Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	1	2	7	0.315
0.25	6	--	--	--	--
	12	--	--	--	--
	24	53	77	67	0.123 (39)
	48	92	90	90	0.038 (12)
	96	63	92	90	0.050 (16)
	168	87	92	93	0.028 (9)
0.5	6	27	40	72	0.180 (57)
	12	57	67	80	0.122 (39)
	24	85	90	92	0.062 (20)
	48	88	93	93	0.041 (13)
	96	90	95	93	0.034 (11)
	168	87	95	92	0.012 (4)
1.0	6	52	75	70	0.171 (54)
	12	80	87	95	0.063 (20)
	24	82	82	93	0.065 (21)
	48	88	95	95	0.028 (9)
	96	92	95	95	0.028 (9)
	168	83	93	95	0.012 (4)
2.0	6	57	78	93	0.046 (15)
	12	88	93	93	0.045 (14)
	24	82	95	93	0.048 (15)
	48	90	95	95	0.015 (5)
	96	92	95	95	0.024 (8)
	168	83	95	95	0.010 (3)
Least Significant Difference (0.05)					0.042 (13)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.

Table 5

Response of Dioecious Hydrilla Grown from Tubers to Different Diquat Concentrations and Exposure Periods Under Laboratory Conditions

Diquat Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	0	0	7	0.306
0.25	6	--	--	--	--
	12	--	--	--	--
	24	50	75	77	0.137 (45)
	48	92	90	85	0.030 (10)
	96	87	88	82	0.048 (16)
	168	83	90	95	0.026 (9)
0.5	6	27	35	68	0.159 (52)
	12	67	65	80	0.138 (45)
	24	83	88	92	0.069 (23)
	48	87	95	93	0.016 (5)
	96	90	95	93	0.013 (4)
	168	87	95	93	0.019 (6)
1.0	6	52	67	88	0.161 (53)
	12	83	87	95	0.053 (17)
	24	83	80	90	0.064 (21)
	48	87	95	95	0.030 (10)
	96	92	95	95	0.016 (5)
	168	83	93	95	0.014 (5)
2.0	6	57	77	88	0.072 (24)
	12	82	88	92	0.042 (14)
	24	88	95	92	0.024 (8)
	48	87	95	95	0.010 (3)
	96	92	95	95	0.011 (4)
	168	83	95	95	0.006 (2)
Least Significant Difference (0.05)					0.045 (15)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.

Table 6

Response of Monoecious Hydrilla Grown from Cuttings to Different Diquat Concentrations and Exposure Periods Under Laboratory Conditions

Diquat Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	10	15	8	0.464
0.25	3	10	7	10	0.418 (90)
	6	35	28	10	0.352 (76)
	12	27	30	7	0.352 (76)
	24	35	38	25	0.294 (63)
	48	53	76	43	0.170 (37)
	96	75	80	83	0.089 (19)
	168	67	83	80	0.086 (19)
0.5	3	17	12	10	0.466 (100)
	6	38	33	13	0.520 (112)
	12	27	47	13	0.253 (55)
	24	37	72	67	0.149 (32)
	48	42	73	80	0.114 (25)
	96	63	80	82	0.091 (20)
	168	83	87	80	0.074 (16)
1.0	3	32	42	22	0.360 (78)
	6	38	60	25	0.353 (76)
	12	28	62	43	0.206 (44)
	24	55	80	77	0.072 (16)
	48	77	83	88	0.053 (11)
	96	90	88	85	0.088 (19)
	168	88	92	82	0.028 (6)
2.0	3	28	43	17	0.401 (86)
	6	43	62	50	0.213 (46)
	12	47	78	75	0.070 (15)
	24	68	75	83	0.046 (10)
	48	80	82	85	0.077 (17)
	96	92	95	83	0.046 (10)
	168	92	95	87	0.014 (3)
Lease Significant Difference (0.05)					0.100 (22)

* Average of three replicates.

** Numbers in parentheses represent percent of control dry weight.

Table 7

Response of Dioecious Hydrilla Grown from Cuttings to Different Diquat Concentrations and Exposure Periods Under Laboratory Conditions

Diquat Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	10	15	8	0.771
0.25	3	13	8	7	0.822 (107)
	6	27	25	10	0.776 (101)
	12	30	27	8	0.659 (86)
	24	42	42	27	0.560 (73)
	48	57	73	43	0.404 (52)
	96	50	72	82	0.124 (16)
	168	61	82	82	0.164 (21)
0.5	3	20	13	12	0.598 (78)
	6	40	43	17	0.553 (72)
	12	27	48	22	0.395 (51)
	24	37	73	60	0.215 (28)
	48	48	82	82	0.157 (20)
	96	57	75	85	0.188 (24)
	168	73	85	80	0.144 (19)
1.0	3	38	52	33	0.658 (85)
	6	43	70	27	0.494 (64)
	12	32	70	62	0.295 (38)
	24	55	77	83	0.184 (24)
	48	75	85	87	0.109 (14)
	96	80	87	82	0.138 (18)
	168	87	90	90	0.133 (17)
2.0	3	38	52	28	0.566 (73)
	6	40	65	65	0.291 (38)
	12	43	75	82	0.144 (19)
	24	75	80	85	0.120 (16)
	48	75	85	82	0.179 (23)
	96	77	92	87	0.101 (13)
	168	85	95	88	0.096 (13)
Least Significant Difference (0.05)					0.108 (14)

* Average of three replicates.

** Numbers in parentheses represent percent of control dry weight.

Table 8

Response of Monoecious Hydrilla Grown from Tubers to Different Endothall Concentrations and Exposure Periods Under Laboratory Conditions

Endothall Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	5	3	7	0.400
1	3	8	10	17	0.336 (84)
	6	3	3	3	0.316 (79)
	12	7	13	17	0.348 (87)
	24	13	30	20	0.278 (70)
	48	62	67	65	0.128 (32)
	96	83	80	80	0.041 (10)
	168	93	83	87	0.024 (6)
2	3	2	3	0	0.386 (97)
	6	5	10	10	0.353 (88)
	12	18	38	43	0.130 (33)
	24	57	68	68	0.096 (24)
	48	83	80	80	0.079 (20)
	96	92	83	80	0.022 (6)
	168	93	87	87	0.026 (7)
3	3	13	23	5	0.260 (65)
	6	45	48	47	0.127 (32)
	12	73	75	80	0.072 (18)
	24	87	82	80	0.064 (16)
	48	95	87	82	0.053 (13)
	96	93	87	82	0.064 (16)
	168	95	93	93	0.020 (5)
5	3	23	37	50	0.183 (46)
	6	83	70	70	0.095 (24)
	12	85	73	70	0.074 (19)
	24	95	92	85	0.040 (10)
	48	93	88	83	0.044 (11)
	96	95	95	93	0.001 (0)
	168	95	95	95	0.000 (0)
Least Significant Difference (0.05)					0.088 (22)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.

Table 9

Response of Dioecious Hydrilla Grown from Tubers to Different Endothall Concentrations and Exposure Periods Under Laboratory Conditions

Endothall Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	0	3	7	0.339
1	3	13	10	15	0.336 (99)
	6	3	3	3	0.282 (83)
	12	7	13	17	0.313 (92)
	24	10	30	17	0.192 (57)
	48	62	70	77	0.106 (31)
	96	90	87	83	0.056 (17)
	168	92	87	87	0.038 (11)
2	3	2	3	0	0.399 (118)
	6	2	10	10	0.340 (100)
	12	15	38	47	0.170 (50)
	24	55	70	82	0.073 (22)
	48	85	90	92	0.065 (19)
	96	95	92	90	0.033 (10)
	168	95	95	92	0.040 (12)
3	3	17	23	5	0.245 (72)
	6	43	55	47	0.169 (50)
	12	85	82	80	0.092 (27)
	24	88	88	90	0.046 (14)
	48	95	90	90	0.055 (16)
	96	95	90	92	0.041 (12)
	168	95	95	95	0.021 (6)
5	3	28	38	50	0.198 (58)
	6	83	87	73	0.091 (27)
	12	93	80	80	0.064 (19)
	24	95	95	93	0.020 (6)
	48	95	97	90	0.041 (12)
	96	95	95	92	0.022 (6)
	168	95	95	95	0.012 (4)
Least Significant Difference (0.05)					0.097 (28)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.

Table 10

Response of Monoecious Hydrilla Grown from Cuttings to Different Endothall Concentrations and Exposure Periods Under Laboratory Conditions

Endothall Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	0	13	12	0.348
1	3	3	18	18	0.362 (104)
	6	0	0	27	0.315 (91)
	12	3	12	30	0.382 (110)
	24	7	13	22	0.300 (86)
	48	63	57	60	0.108 (31)
	96	87	92	88	0.045 (13)
	168	80	87	82	0.063 (18)
2	3	3	13	25	0.401 (115)
	6	0	7	22	0.363 (104)
	12	37	20	47	0.185 (53)
	24	52	67	58	0.157 (45)
	48	92	78	78	0.068 (20)
	96	93	87	83	0.031 (9)
	168	93	90	87	0.047 (14)
3	3	3	7	23	0.317 (91)
	6	0	7	23	0.310 (89)
	12	37	53	67	0.117 (34)
	24	87	77	80	0.087 (25)
	48	85	83	83	0.072 (21)
	96	95	90	82	0.042 (12)
	168	95	93	90	0.016 (5)
5	3	0	27	33	0.212 (61)
	6	40	57	58	0.179 (51)
	12	72	68	77	0.097 (28)
	24	85	85	85	0.057 (16)
	48	93	90	83	0.063 (18)
	96	95	92	83	0.038 (11)
	168	95	93	92	0.009 (3)
Least Significant Difference (0.05)					0.076 (22)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.

Table 11

Response of Dioecious Hydrilla Grown from Cuttings to Different Endothall Concentrations and Exposure Periods Under Laboratory Conditions

Endothall Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	3	10	7	0.590
1	3	10	13	8	0.553 (94)
	6	13	22	22	0.518 (88)
	12	13	30	43	0.576 (98)
	24	15	37	47	0.547 (93)
	48	62	80	85	0.191 (32)
	96	87	90	95	0.061 (10)
	168	87	83	83	0.075 (13)
2	3	13	18	17	0.595 (101)
	6	8	20	27	0.566 (96)
	12	25	57	68	0.418 (71)
	24	63	85	88	0.149 (25)
	48	87	87	88	0.105 (18)
	96	90	92	93	0.010 (2)
	168	88	90	92	0.013 (2)
3	3	15	15	17	0.586 (99)
	6	12	37	43	0.499 (85)
	12	68	83	85	0.148 (25)
	24	80	83	87	0.106 (18)
	48	87	90	90	0.062 (11)
	96	90	85	87	0.038 (6)
	168	90	92	92	0.011 (2)
5	3	13	23	27	0.609 (103)
	6	22	63	70	0.308 (52)
	12	87	85	88	0.106 (18)
	24	83	85	85	0.059 (10)
	48	88	88	87	0.048 (8)
	98	92	90	90	0.042 (7)
	168	88	88	92	0.023 (4)
Least Significant Difference (0.05)					0.072 (12)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.

Table 12

Response of Monoecious Hydrilla Grown from Tubers to Different Fluridone Concentrations and Exposure Periods Under Laboratory Conditions

Fluridone Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	0	0	8	0.381
0.10	6	5	7	15	0.226 (59)
	12	8	7	8	0.246 (65)
	24	13	17	13	0.127 (33)
	48	17	18	20	0.120 (31)
	96	13	20	22	0.039 (10)
0.25	6	8	8	10	0.242 (64)
	12	12	17	22	0.173 (45)
	24	12	15	18	0.083 (22)
	48	15	17	22	0.065 (17)
	96	17	20	28	0.050 (13)
0.5	6	12	12	20	0.171 (45)
	12	18	20	22	0.097 (25)
	24	12	12	23	0.068 (18)
	48	15	17	28	0.037 (10)
	96	13	18	33	0.058 (15)
1.0	6	18	17	22	0.110 (29)
	12	13	15	27	0.077 (20)
	24	10	13	32	0.045 (12)
	48	17	18	43	0.043 (11)
	96	17	18	48	0.054 (14)
Least Significant Difference (0.05)					0.058 (15)

* Average of three replicates.

** Numbers in parentheses represent percent of control dry weight.

Table 13

Response of Dioecious Hydrilla Grown from Tubers to Different Fluridone Concentrations and Exposure Periods Under Laboratory Conditions

Fluridone Treatment mg/ℓ	Exposure Time hr	Percent Injury,* Weeks Posttreatment 2	4	6	Dry Weight** g
Control	--	0	0	12	0.316
0.10	6	5	7	17	0.267 (84)
	12	7	7	8	0.310 (98)
	24	10	17	18	0.240 (76)
	48	15	17	23	0.174 (55)
	96	18	20	23	0.148 (47)
0.25	6	7	8	10	0.311 (98)
	12	17	20	22	0.224 (71)
	24	12	15	18	0.190 (60)
	48	18	18	22	0.135 (43)
	96	20	18	27	0.094 (30)
0.50	6	10	10	23	0.261 (83)
	12	17	18	22	0.179 (57)
	24	12	12	23	0.106 (34)
	48	17	18	28	0.134 (42)
	96	18	18	33	0.104 (33)
1.0	6	17	15	25	0.186 (59)
	12	18	15	32	0.121 (38)
	24	12	15	35	0.101 (32)
	48	17	18	43	0.077 (24)
	96	15	13	53	0.044 (14)
Least Significant Difference (0.05)					0.055 (17)

* Average of three replicates.

** Numbers in parentheses represent percent of control dry weight.

Table 14

Response of Dioecious Hydrilla Grown from Cuttings to Different Fluridone Concentrations and Exposure Periods Under Laboratory Conditions

Fluridone Treatment mg/ℓ	Exposure Time days	Percent Injury,* Weeks Posttreatment 4	8	12	Dry Weight** g
Control	--	3	0	0	1.292
0.10	1	12	3	5	1.057 (82)
	2	13	18	12	1.025 (79)
	4	13	2	10	1.056 (82)
	7	17	18	17	0.814 (63)
	10	28	13	18	1.046 (81)
0.25	1	23	23	18	0.861 (67)
	2	23	25	20	0.755 (58)
	4	17	20	28	1.012 (78)
	7	10	23	37	0.750 (58)
	10	20	23	28	0.889 (69)
0.50	1	28	17	32	1.119 (87)
	2	12	12	30	1.013 (78)
	4	23	13	40	0.943 (73)
	7	28	37	63	0.417 (32)
	10	22	30	75	0.251 (19)
1.0	1	30	47	32	0.823 (64)
	2	32	20	37	0.805 (62)
	4	15	18	58	0.515 (40)
	7	30	28	80	0.237 (18)
	10	32	27	78	0.276 (21)
Least Significant Difference (0.05)					0.279 (22)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.

Table 15

Response of Monoecious Hydrilla Grown from Cuttings to Different Fluridone Concentrations and Exposure Periods Under Laboratory Conditions

Fluridone Treatment mg/ℓ	Exposure Time days	Percent Injury,* Weeks Posttreatment 4	8	12	Dry Weight** g
Control	--	5	0	0	0.622
0.10	1	12	3	5	0.485 (78)
	2	13	10	12	0.326 (52)
	4	15	0	7	0.437 (70)
	7	12	12	17	0.236 (38)
	10	27	12	20	0.177 (28)
0.25	1	28	15	15	0.251 (40)
	2	32	13	22	0.248 (40)
	4	13	8	23	0.261 (42)
	7	18	23	37	0.077 (12)
	10	23	32	40	0.122 (20)
0.50	1	43	12	20	0.207 (33)
	2	23	12	22	0.227 (36)
	4	30	18	40	0.108 (17)
	7	33	48	67	0.067 (11)
	10	32	25	75	0.049 (8)
1.0	1	47	42	32	0.172 (28)
	2	33	17	30	0.130 (21)
	4	13	20	47	0.102 (16)
	7	18	22	65	0.053 (9)
	10	20	30	68	0.080 (13)
Least Significant Difference (0.05)					0.170 (27)

* Average of three replicates.
** Numbers in parentheses represent percent of control dry weight.