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Hydrilla Growth and Tuber Production In Response To Bensulfuron Methyl Concentration and Exposure Time[1]

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ABSTRACT

Hydrilla (*Hydrilla verticillata* (L.f.) Royle) in concrete tanks was treated with 25, 50, 100 or 200 ppb bensulfuron methyl for 12, 24, 48, 96 or 192 hours to determine the herbicides effect on root and shoot dry weight accrual, shoot elongation and number of shoots produced. Growth responses were inconsistent at concentrations less than 200 ppb and exposure less than 192 hours. All growth responses were reduced to zero when exposed to 200 ppb bensulfuron methyl for 192 hours, and all growth responses were correlated, which suggest a general reduction in growth. In another experiment, in which exposure of the plants to 25 or 50 ppb bensulfuron methyl in June, and 25, 50 or 100 ppb, in November was uninterrupted, root weight and shoot weight were reduced in relation to the initial herbicide concentration. All concentrations of bensulfuron methyl applied in either June or November prevented tuber production.

Key words: shoots, roots, elongation, photoperiod, viability.

INTRODUCTION

Problems associated with the aquatic weed hydrilla are well known. Mechanical removal of the plant is expensive and usually not feasible. Biological controls have not been identified that are effective or predictable, or that can be used in all situations. Only three herbicides or herbicide combinations, endothall, fluridone, and diquat with chelated copper are commonly used for hydrilla control. Therefore, additional control methods will be an important benefit to hydrilla management programs.

Sulfonylureas are a group of herbicides that were first recognized in 1966, and by the mid 1970s had become "one of the most exciting breakthroughs in the field of herbicide research in several decades (Beyer et al. 1988)." Bensulfuron methyl (methyl2-[[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]solfonyl]methyl]benzoate) is the active ingredient in Londax^R, a herbicide that is used to control several aquatic weeds, which are problems in rice production and also in Mariner^R, a herbicide that is being evaluated as a potential aquatic herbicide.

An aquatic plant's response to a herbicide is related to the length of time the plant is exposed and the concentration of the herbicide in the water (Netherland et al. 1991). The response will also be related to unique properties of individual herbicides and the sensitivity of the target species to each herbicide. Application rate and concentration of herbicide in the water is limited by the herbicide label directions and tolerances established by the Environmental Protection Agency in the United States. When an entire, enclosed body of water is treated with a nonvolatile herbicide, exposure time is dependent on the rate of herbicide degradation or sorptive processes. When a water body is partially treated, herbicide dilution, which can be affected by water movement and diffusion, is usually the dominant factor that influences exposure time. Therefore, it is necessary to determine concentrations and exposure times that are necessary to achieve control or plant growth regulation with a new herbicide so that it can be used most efficiently.

Hydrilla responses to various concentrations and exposure times to bensulfuron methyl have been studied. Dioecious hydrilla shoot length and dry weight of shoots and roots was less than untreated plants 4 weeks after 14-day exposure to as little as 1 ppb bensulfuron methyl (Anderson and Dechoretz 1988) . However, the response was slight and 50 ppb were necessary for 60% reduction. Shoot elongation was also somewhat reduced when exposed to as little as 10 ppb for 1 hour or 100 ppb for 3 hours, while shoot dry weight was not affected by 24 hours exposure to 10 ppb or 100 ppb. Van and Vandiver (1992) exposed hydrilla to 50, 100 and 200 ppb bensulfuron methyl for 4 weeks and reduced dry weight accrual by 90% after 2 months with all concentrations but regrowth occurred at various levels after this initial inhibition. Tuber formation was also suppressed by all concentrations and appeared to be independent of the general retardation of plant growth. Haller et al. (1992) also observed inhibition of tuber formation when dioecious hydrilla root crowns or sprouted tubers were exposed to various concentrations of bensulfuron methyl for an undetermined exposure period.

The purpose of this study was to determine hydrilla growth responses to different concentrations of bensulfu-

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ron methyl for various short exposure periods to simulate partial water body treatments and uninterrupted exposure to simulate whole lake treatments. This additional information is essential for designing Mariner® field trials for hydrilla management.

MATERIALS AND METHODS

Experiment I. Two 15 cm long apical hydrilla cuttings were planted in 10 cm square plastic pots that contained potting soil (Metro-mix 200) and 3 g of 18-6-12 slow release fertilizer covered by a layer of coarse builders sand. Forty-two pots were placed in each of twelve, plastic-lined, concrete tanks that contained 280 l of well water. On June 26, 1989 (twelve days after the hydrilla was planted) seven hydrilla-containing pots were removed from each tank (untreated checks), and then sufficient Mariner® was mixed into the water of the tanks to achieve three replications each of tanks that contained theoretical bensulfuron methyl concentrations of 25, 50, 100, or 200 ppb.

Seven hydrilla-containing pots were removed after 12, 24, 48, 96, or 192 hours of contact to the herbicide treated water. After removal, the plants were rinsed and placed in a single concrete tank (grow out tank) that contained 1000 l of untreated well water. Fresh well water (pH 6.7) was run in one end of the tank at a rate of 1000 l per day and allowed to exit through a stand pipe at the other end. Twenty-one untreated plants were placed into the grow out tank along with the treated plants. An additional twenty-one untreated plants were placed in a separate grow out tank that contained 1000 l of untreated well water. The purpose of this was to have a check to compare to the plants that were removed before herbicide application but grown afterward with treated plants, to determine if there was an effect of growing with herbicide treated plants.

Three replicate hydrilla-containing pots of each concentration/exposure combination and untreated plants were collected at 3, 7, 14, 21, 28, 35, and 42 days after initial exposure to the herbicide. Plant height was determined by measuring the distance from the soil surface to the tip of the longest shoot and number of shoots were counted. Shoot and root dry weights were determined separately.

Growth rates were calculated as slope coefficients by regression analysis using the growth parameter (dry weight, number of shoots, or height) as the dependent variable, time after planting as the independent variable, and herbicide concentrations/exposure combinations as classification variables (SAS Institute Inc. 1988). Growth rates of treated plants were compared to untreated plants also by Student's t. When coefficients are reported as different in the text, they are significantly different at the 0.05 level of probability. When no growth (elongation, shoot production, or dry weight accrual) is reported, slope coefficients were not significantly ($p<0.05$) greater than zero by Student's t.

Water samples were collected in opaque plastic bottles 5, 24, 48, 96, and 192 hours after application of the herbicide to the tanks, to determine the concentration of bensulfuron methyl in the water. Water samples were stored at -30 C and shipped with dry ice to the E. I. du Pont de Nemours Experiment Station in Wilmington, Delaware where they were analyzed for bensulfuron methyl by reversed phase HPLC. Water samples were received in a frozen state and stored in a freezer until they were removed and thawed at a temperature that did not exceed 40 C prior to being analyzed. After thawing, samples were filtered through an AcroDisc PTFE CR 0.45 mm syringe filter into 2 ml autosampler vials. The samples were placed on an autosampler and analyzed or placed in the freezer until analysis. Standards were analyzed at intervals during the sample analysis. Calibration standards were prepared by dissolving a 99.56% pure bensulfuron methyl standard in HPLC grade acetonitrile and diluting this stock solution with Milli-Q water to achieve the desired concentration range, and peak heights of these calibration standards were used to construct a calibration curve. Separation conditions for standards and water samples were as follows:

HPLC:	Hewlett Packard 1090 l
Column:	2.1 x 100 mm Hypersil ODS, 5 micron particles
Flow rate:	0.05 ml/min
Mobil Phase:	35% HPLC grade acetonitrile 65% pH 2.9 water (Milli-Q)
Detector:	photodiode array
Wavelength:	236 nm
Bandwidth:	4 nm
Injection volume:	200 microliters
Oven temperature:	45 C

Regression analysis was used to determine if bensulfuron methyl concentration changed during the exposure periods. Changes are reported in the text when the slope coefficient for hours after application is significantly ($p<0.05$) greater than zero according to Student's t.

Experiment II. Experiment II was begun on July 8, 1989 and differed from Experiment I in the following manner: (1) Only one hydrilla cutting was placed in each pot, and (2) in addition to rinsing under running water, the potted plants were placed in an untreated tank for a period of 24 hours, where water was run at a volume sufficient to replace the water in the tank approximately 35 times, before they were placed into the grow out tank. Growth rates were calculated as in Experiment I.

Water samples were collected 5, 12, 24, 48, 96 and 192 hours after herbicide application and analyzed as in Experiment I.

Experiment III. Fifteen apical hydrilla cuttings were planted in 970 cm^2 plastic pans, which contained the rooting media described above, on June 6, 1989 and October 10, 1989. The pans were placed into 300-L, plastic-lined, concrete tanks. Bensulfuron methyl was applied at concentrations of 25 and 50 ppb to the June 6 planted hydrilla 23 days after planting; and at concentrations of 25, 50, and 100 ppb to the October 10 planted hydrilla, 27 days after planting. Three replications of each concentration were applied and three replications of untreated plants were included. Water in the tanks was not intentionally replaced for the duration of the experiment, however undetermined dilution from rainwater would have occurred. In March 1990, all plant material was harvested, numbers of tubers in each pan determined, and separate weights for roots and shoots determined after drying to constant weight. Tuber viability was determined by placing tubers in a Petri dish that contained a saturated paper towel and counting sprouted tubers for a four week period (until all tubers had sprouted or rotted). Effects of uninterrupted exposure to bensulfuron methyl on final root weight, shoot weight and tuber number were determined by regression analysis, using g dry wt or number of tubers as the dependent variable and bensulfuron methyl concentration (ppb) as the independent variable. Effects are reported in the text when the slope coefficient for the independent variable is significantly ($p<0.05$) greater than zero according to Student's t.

RESULTS AND DISCUSSION

Experiment I and II. Bensulfuron methyl concentrations decreased slowly between 5 and 192 hours after application in the tanks treated with 50 ($y=55-4.4\ln x$, $r^2=.61$) and 100 ($y=131-14\ln x$, $r^2=.58$) ppb in Experiment I, but did not change in other tanks. Average bensulfuron methyl concentrations were consistently lower than the calculated initial concentrations (Table 1) in all tanks, which may suggest that some disappearance occurred before the initial water sample was collected after 5 hours. Some herbicide would, in theory, have been absorbed by hydrilla plants, and sulfonylurea herbicides are known to degrade by photolysis, chemical and microbial hydrolysis, and to adsorb to clay and organic matter (Beyer et al. 1988). Herbicide decrease in two tanks and not others can not be explained.

In Experiment I, rates of dry weight accrual by shoots (66 mg dry wt/day, SE = 17) and roots (12.8 mg dry wt/day SE = 2.3) of untreated plants grown in the grow out tank with treated plants, were less than shoots (103 mg dry wt/day, SE = 12) and roots (29 mg dry wt/day, SE = 20) of untreated plants grown separately from treated plants. This observation can be interpreted to mean that some bensulfuron methyl was transferred along with the treated plants and released into the untreated water in the grow out tanks. However, dry weight accrual by shoots of plants grown in grow out tanks with treated plants in Experiment I (Table 2) and II (Table 3) compare well; and dry weight accrual by roots of plants grown in the grow out tank with treated plants in Experiment II (Table 5), in which plants were amply flushed, was more than twice as high as those in Experiment I (Table 4). Likewise, although elongation (8 mm/day, SE = 2.7) of plants grown separately in Experiment I was less than those grown with treated plants (Table 6), elongation of plants grown with treated plants in Experiment I and II (Table 7) compares well. Therefore, differences between plants grown in the grow out tank with treated plants and those grown separately are probably coincidental. Dry weight accrual, elongation, and shoot production of treated plants are compared to untreated checks grown in the grow out tanks (Tables 2-9).

Table 1. Average bensulfuron methyl concentrations in water collected from concrete tanks at 5, 24, 48, 96 and 192 hours (Experiment I) or 5, 12, 24, 48, 96, and 192 (Experiment II) hours after application of 25, 50, 100, or 200 ppb. Each measured value is an average of samples collected from three replicate tanks at each time. Numbers in ( ) are standard errors.

Calculated concentration (ppb)	Measured concentration	
	Experiment I	Experiment II
25	18 (0.7)	14 (0.7)
50	39 (1.9)	32 (2.4)
100	78 (6.2)	71 (2.6)
200	160 (8.6)	150 (3.6)

Table 2. Rate of hydrilla shoot growth (mg dry wt/day) in response to varying concentration and exposure time to bensulfuron methyl (Experiment I).

Hours	Bensulfuron methyl (ppb)				
	O[1]	25	50	100	200
0[1]	66(17)[2]	—	—	—	—
12	—	38 (18)	35 (12)	36 (17)	51 (11)
24	—	43 (16)	37 (13)	74 (21)	42 (10)
48	—	37 (15)	43 (15)	51 (15)	65 (11)
96	—	40 (27)	37 (19)	16 (17)	77 (15)
192	—	96 (15)	72 (14)	40 (11)	3 (15)

[1] Untreated plants grown in the same grow out tank with treated plants.
[2] Numbers in parentheses are standard errors of estimates.

Table 3. Rate of hydrilla shoot growth (mg dry wt/day) in response to varying concentration and exposure time to bensulfuron methyl (Experiment II).

Hours	Bensulfuron methyl (ppb)				
	0[1]	25	50	100	200
0[1]	65(9)[2]	—	—	—	—
12	—	33 (13)	57 (11)	68 (19)	89 (21)
24	—	63 (11)	52 (15)	39 (10)	35 (11)
48	—	30 (9)	86 (20)	81 (15)	60 (20)
96	—	47 (11)	61 (15)	85 (16)	70 (16)
192	—	61 (13)	55 (15)	49 (20)	12 (12)

[1] Untreated plants grown in the same grow out tank with treated plants.
[2] Numbers in parentheses are standard errors of estimates.

Dry weight accrual by hydrilla shoots was reduced in Experiment I (Table 2) by exposure to 100 ppb bensulfu-

Table 4. Rate of hydrilla root growth (mg dry wt/day) in response to varying concentration and exposure time to bensulfuron methyl (Experiment I).

Hours	Bensulfuron methyl (ppb)				
	0[1]	25	50	100	200
0[1]	12.8 (2.3)[2]	—	—	—	—
12	—	9.6 (2.1)	9.8 (1.8)	11.3 (1.9)	10.8 (1.9)
24	—	10.4 (2.7)	11.2 (1.5)	16.0 (1.4)	9.3 (1.5)
48	—	12.7 (1.9)	11.7 (1.3)	11.7 (1.4)	10.8 (1.4)
96	—	10.2 (1.9)	10.5 (1.0)	8.3 (1.6)	12.8 (2.0)
192	—	15.7 (2.5)	12.4 (2.3)	7.7 (1.2)	1.0 (0.9)

[1] Untreated plants grown in the same grow out tank with treated plants.
[2] Numbers in parentheses are standard errors of estimates.

TABLE 5. RATE OF HYDRILLA ROOT GROWTH (MG DRY WT/DAY) IN RESPONSE TO VARYING CONCENTRATION AND EXPOSURE TIME TO BENSULFURON METHYL (EXPERIMENT II).

Hours	Bensulfuron methyl (ppb) 0[1]	25	50	100	200
0[1]	6.6 (1.6)[2]	—	—	—	—
12	—	6.0 (1.6)	7.2 (1.2)	6.2 (2.1)	8.8 (2.2)
24	—	6.9 (1.3)	4.6 (1.3)	4.0 (1.3)	3.2 (1.2)
48	—	5.1 (0.9)	8.8 (2.9)	8.2 (1.8)	6.3 (4.6)
96	—	6.1 (1.3)	10.6 (3.5)	8.5 (2.9)	6.1 (1.5)
192	—	4.7 (1.3)	6.1 (1.7)	11.5 (4.8)	1.9 (1.3)

[1]Untreated plants grown in the same grow out tank with treated plants.
[2]Numbers in parentheses are standard errors of estimates.

TABLE 6. RATE OF HYDRILLA ELONGATION (MG DRY WT/DAY) IN RESPONSE TO VARYING CONCENTRATION AND EXPOSURE TIME TO BENSULFURON METHYL (EXPERIMENT I).

Hours	Bensulfuron methyl (ppb) 0[1]	25	50	100	200
0[1]	15 (1.8)[2]	—	—	—	—
12	—	10 (2.7)	3 (2.8)	3 (1.6)	11 (2.9)
24	—	9 (3.0)	6 (2.5)	6 (2.0)	10 (2.4)
48	—	9 (1.9)	4 (2.3)	4 (2.0)	10 (2.0)
96	—	10 (2.3)	3 (1.6)	5 (2.2)	11 (2.1)
192	—	10 (1.6)	9 (2.0)	7 (2.5)	–3 (2.5)

[1]Untreated plants grown in the same grow out tank with treated plants.
[2]Numbers in parentheses are standard errors of estimates.

TABLE 7. RATE OF HYDRILLA ELONGATION (MM/DAY) IN RESPONSE TO VARYING CONCENTRATION AND EXPOSURE TIME TO BENSULFURON METHYL (EXPERIMENT II).

Hours	Bensulfuron methyl (ppb) 0[1]	25	50	100	200
0[1]	16 (2.2)[2]	—	—	—	—
12	—	12 (4.3)	13 (3.2)	17 (2.8)	13 (2.1)
24	—	17 (2.6)	11 (2.1)	10 (1.9)	12 (1.8)
48	—	7 (1.9)	13 (1.9)	13 (2.2)	12 (3.0)
96	—	13 (2.3)	14 (2.9)	12 (3.2)	12 (1.9)
192	—	19 (4.5)	13 (2.6)	8 (1.9)	2 (3.4)

[1]Untreated plants grown in the same grow out tank with treated plants.
[2]Numbers in parentheses are standard errors of estimates.

ron methyl for 96 hours. However, this was not consistent with Experiment II, where shoot growth was only reduced by exposure to 200 ppb for 192 hours (Table 3). Exposure to 200 ppb for 192 hours completely stopped shoot growth and root growth (Table 3-4) in both Experiment I and II.

Reduced elongation was observed for plants exposed to 50 ppb bensulfuron methyl for 12, 24, 48, or 96 hours, 100 ppb for 12, 24, 48, 96, or 192 hours and 200 ppb for 192 hours in Experiment I (Table 6). The reduced elongation in Experiment I at 50 and 100 ppb is difficult to interpret because elongation was not reduced by 200 ppb at the same exposure times and because the observations are inconsistent with Experiment II. In Experiment II, reduced elongation was only observed at exposure to 25 ppb for 48 hours, 100 ppb for 192 hours, and 200 ppb for 192 hours (Table 7). No elongation was observed by plants exposed to 200 ppb for 192 hours in Experiment I or II. The only effects observed on number of shoots produced were an increase by plants exposed to 25 ppb for 192 hours in Experiment I (Table 8) and 100 ppb for 96 hours in Experiment II (Table 9), and no shoot production by plants exposed to 200 ppb for 192 hours in Experiment I.

Hydrilla elongation in Experiment I and II was not as sensitive to short bensulfuron methyl exposure as in previous studies by Anderson and Dechoretz (1988), while results from Experiments I and II are in agreement with the lack of reduction in dry weight accrual in the previous studies. Inconsistent results, as observed in Experiment I and II, can be expected when a compound is tested at concentrations and exposures that are close to the threshold for activity, under out-of-door conditions where within treatment variance is high. The data suggest that activity of bensulfuron methyl on shoot and root growth parameters will be sensitive to exposure time and use of adequate application rates will be necessary when limited exposure is expected, such as in flowing water or partial water body treatments.

Hydrilla growth reduction with bensulfuron methyl has been demonstrated at or below the current rate (100 ppb) allowed by the Mariner® label when exposure was 14 days (Anderson and Dechoretz 1988) or 4 weeks (Van and Vandiver 1992). The consistent reduction of all growth

TABLE 8. RATE OF HYDRILLA SHOOT PRODUCTION (SHOOTS/DAY) IN RESPONSE TO VARYING CONCENTRATION AND EXPOSURE TIME TO BENSULFURON METHYL (EXPERIMENT I).

Hours	Bensulfuron methyl (ppb) 0[1]	25	50	100	200
0[1]	0.9 (0.3)[2]	—	—	—	—
12	—	0.6 (0.4)	0.5 (0.3)	0.5 (0.4)	0.8 (0.3)
24	—	0.8 (0.3)	0.8 (0.2)	1.1 (0.3)	0.9 (0.3)
48	—	0.8 (0.4)	0.5 (0.3)	0.7 (0.2)	1.2 (0.3)
96	—	1.3 (0.4)	0.8 (0.3)	0.8 (0.3)	1.6 (0.4)
192	—	2.0 (0.5)	1.6 (0.2)	1.1 (0.2)	–0.1 (0.3)

[1]Untreated plants grown in the same grow out tank with treated plants.
[2]Numbers in parentheses are standard errors of estimates.

TABLE 9. RATE OF HYDRILLA SHOOT PRODUCTION (SHOOTS/DAY) IN RESPONSE TO VARYING CONCENTRATION AND EXPOSURE TIME TO BENSULFURON METHYL (EXPERIMENT II).

Hours	Bensulfuron methyl (ppb) 0[1]	25	50	100	200
0[1]	1.1 (0.2)[2]	—	—	—	—
12	—	0.6 (0.2)	0.9 (0.2)	1.1 (0.3)	1.8 (0.4)
24	—	1.2 (0.2)	1.0 (0.2)	0.7 (0.2)	0.6 (0.1)
48	—	0.9 (0.2)	1.5 (0.3)	1.7 (0.3)	1.1 (0.3)
96	—	1.5 (0.2)	1.9 (0.4)	2.3 (0.7)	1.5 (0.3)
192	—	1.7 (0.2)	1.8 (0.4)	1.4 (0.1)	0.5 (0.2)

[1]Untreated plants grown in the same grow out tank with treated plants.
[2]Numbers in parentheses are standard errors of estimates.

parameters by exposure to 200 ppb for 192 hours in Experiments I and II suggest the potential of bensulfuron methyl for aquatic plant management, even where exposure time is limited. However, according to these data, greater than 200 ppb will be necessary when exposure time is known to be less than 192 hours, and this is greater than the current maximum concentration allowed by the herbicide label.

All growth parameters measured were simultaneously decreased when the plants were exposed to 200 ppb for 192 hours and all growth parameters were positively correlated ($p<0.0001$). This suggests that bensulfuron methyl caused a general decrease in growth. Although the mechanism of action has not been identified in hydrilla, this observation would be consistent with inhibition of protein synthesis, which is the established mechanism in other plants (Beyer et al. 1988)

Experiment III. Root weight at the end of the Experiment III (Table 10) was decreased in relation to bensulfuron methyl concentration when applied in June ($y=4.4-0.07x$, $r^2=0.56$) or November ($y=2.21-0.01x$, $r^2=0.58$). Similarly, shoot weight (Table 4) was decreased as bensulfuron methyl concentration increased when applied in June ($y={}^{3.79-0.024x}$, r^2 0.45) or November ($y=e^{3.12-0.005x}$, $r^2=0.35$). Shoot growth, which is the more important parameter from an operational weed control standpoint, was reduced by 65% as a result of 50 ppb bensulfuron methyl application in June and 38% by application of 100 ppb in November (Table 10). Although the level of control that can be achieved with a certain concentration of bensulfuron methyl cannot be accurately predicted because of the high within concentration variability (evidenced by low r^2 values), the data suggest that bensulfuron methyl has the potential for limiting hydrilla growth for a growing season when applied to entire, enclosed water bodies in Spring.

Hydrilla tuber production was very sensitive to bensulfuron methyl. Little variability was observed and all concentrations applied in either June ($y=e^{4.6-1.1\ln x}$, $r^2=0.92$) or November ($y=24.4-5\ln x$, $r^2=0.89$) essentially stopped tuber production (Table 10). Hydrilla begins forming tubers in October in North Florida (Haller et al. 1976) and those few tubers produced where bensulfuron methyl was applied in November were probably formed prior to the herbicide application.

Hydrilla begins forming tubers in response to short days (Van et al. 1978). Anderson (1988), Van and Vandiver (1992) and Haller et al. (1992) have observed tuber inhibition in dioecious hydrilla by bensulfuron methyl when the compound was applied during short photoperiod. Inhibition of tuber formation by June application in this study suggests that either sufficient bensulfuron methyl remained in the water to inhibit tuber formation throughout the duration of the experiment, the herbicide remained active in the plant tissue, or a physiological response was triggered that inhibited the short-day response.

Bensulfuron methyl residue was not measured in this experiment. However, we have found the half life of bensulfuron methyl to be approximately 13 days under similar conditions (unpublished data). If the compound degraded at this rate, the concentration would have been extremely small by the end of the tuber forming period in this study. The mechanism of hydrilla tuber inhibition by bensulfuron methyl is not understood. Reduced tuber formation would be expected as a secondary response when shoot biomass is reduced. However, Van and Vandiver (1992) have suggested that inhibition of tuber formation by bensulfuron methyl is independent from general retardation of plant growth. The magnitude of tuber inhibition compared to shoot inhibition in this study also suggests that tuber inhibition may be independent from general growth inhibition, or at least is much more complete. Additional studies will be necessary to determine the mechanism of hydrilla tuber inhibition by bensulfuron methyl.

Tuber viability was not affected by bensulfuron methyl application.

Herbicide evaluation under artificial conditions, such as plants growing in concrete tanks, do not necessarily predict the usefulness of the herbicide under field conditions. However, the growth regulation activity of bensulfuron methyl, especially inhibition of tuber formation, along with low toxicity to aquatic organisms (Weed Science Society of America 1989), suggest that this herbicide has important potential as an aquatic herbicide.

TABLE 10. HYDRILLA GROWTH RESPONSE TO DIFFERENT CONCENTRATIONS OF BENSULFURON METHYL, APPLIED AT TWO DIFFERENT SEASONS. EACH VALUE IS AN AVERAGE OF THREE REPLICATIONS.

ppb	Roots[1]	Shoots[1]	Tubers number[2]	Tubers viability[3]
Treated June 29, 1989				
0	4.3	46	107	93
25	3.0	30	1	86
50	0.8	16	1	83
Treated November 6, 1989				
0	2.3	24	26	89
25	1.9	21	4	96
50	1.5	17	5	100
100	1.0	15	5	100

[1] g dry wt./970 cm^2 pan

[2] Tubers/970 cm^2 pan

[3] % germination

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Improving Herbicide Efficacy in Spring-Fed Tidal Canals by Timing and Application Methods

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ABSTRACT

Over a three year period starting in 1987, endothall, rhodamine WT dye and herbicide/dye combinations were applied to tidally influenced canals for aquatic weed control in Crystal River, Florida, in addition to an operational mechanical harvesting program. Applications were accomplished using unweighted-hoses, long weighted-hoses and granules at different times of year, when dye half-lives (indicating rates of water exchange) in the canals varied from 11 to 120 hours. Placement of dye or herbicides by weighted-hoses and granules near the bottom of the canals in summer and winter conditions, reduced rates of dye or herbicidal tidal dilution out of the canals and increased their theoretical contact time with hydrilla (*Hydrilla verticillata* (L.f.) Royle.). Comparison of hydrilla regrowth following herbicide application or mechanical harvesting showed that herbicide treatments usually provided acceptable weed control for at least twice as long as mechanical harvesting.

Key words: Hydrilla, water exchange, rhodamine WT dye, regrowth, endothall, mechanical harvesting.

INTRODUCTION

Research has been conducted in the freshwater, tidally influenced Three Sisters canals of Crystal River, Florida, since 1987 to determine factors such as tides, vegetation density, water temperature, etc. that may have caused unpredictable results in the use of herbicides for control of hydrilla (Fox et al. 1988, 1989, 1991a, and 1991b). A total of 24 rhodamine WT dye treatments were made, with and without concurrent herbicide applications, to three canals under the various conditions outlined above. Rhodamine WT was found to be stable under conditions in the canals (Fox et al. 1991b) so that reductions in its concentration (measured in half-lives) were used to estimate rates of water exchange over several tidal cycles. It was determined that water exchange in these three canals was nearly identical and that they could be used as replicates to compare different herbicide application conditions and methods (Fox et al. 1988).

Patterns of tidal water circulation are driven by differences in temperature from water surface to canal bottom and in relation to groundwater temperatures. Fastest rates of water exchange occur in the summer with dye half-lives of <25 hours, followed by winter conditions with dye half-lives of 25 to 60 hours, and rates are slowest during fall and spring isothermal conditions with dye half-lives of 70 to 120 hours (Fox et al. 1991a). After developing a model which effectively predicted rates of water exchange based on standardized bottom water temperature data in the canals (Fox et al. 1991a), previous dye and herbicide application results were reviewed.

The longer a herbicide is in contact with target vegetation, the more likely acceptable weed control will be achieved. Netherland et al. (1991) showed under laboratory conditions that the minimum contact time for endothall (the dipotassium salt of 7-oxabicyclo[2,2,1]heptane-2,3-dicarboxylic acid) required to achieve >85% hydrilla biomass reduction was 24 hours, at a concentration of 3 mg l^{-1}, the maximum rate permitted for use in Florida. Thus, it appeared that if uniformly diluted in the water column, endothall (the primary herbicide permitted in Crystal River) would not be effective in the summer due to its short retention time in the canals. Results of endothall applications during fall isothermal conditions, however, were found to be predictable and effective (Fox et al. 1991b).

The objective of this study was to investigate different herbicide application techniques using treatments of dye, or dye plus herbicide combinations, to determine whether herbicide placement in specific areas of the canals could increase contact time with the target weeds. Results from these studies were then compared to the standard methods of herbicidal and mechanical management of hydrilla previously used in these canals.

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