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Growth of Dioecious and Monoecious Hydrilla from Single Tubers[1]

DAVID L. SUTTON, T. K. VAN AND K. M. PORTIER[2]

ABSTRACT

Dioecious and monoecious biotypes of hydrilla (*Hydrilla verticillata* Royle) were cultured outdoors in 1.0 m^2 boxes filled with sand amended with fertilizer. The boxes were placed in cement tanks filled with pond water to a depth of 0.8 m. A single sprouted tuber was planted in the center of each box and allowed to grow for 16 weeks. Total plant dry weight was generally higher in the summer (May to September) than in the winter (November to late February or early March). Maximum observed biomass was 4,043 g and 4,559 g per box for dioecious and monoecious biotypes, respectively. Monoecious hydrilla produced tubers year-round, up to 6,046 per box during the summer, while tubers of the dioecious biotype were produced only in the winter. Although monoecious hydrilla produced an average of 56% more tubers than dioecious hydrilla, the average individual weight of monoecious tubers was 32% less than for dioecious tubers. Tubers produced by both hydrilla biotypes were uniformly distributed horizontally in low numbers in the middle of the box and increased in number towards the sides and corners. These data demonstrate tremendous growth potential of a single hydrilla tuber under favorable environmental conditions such as those found in South Florida.

Key words: Aquatic plants, *Hydrilla verticillata*, propagules, biotypes.

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INTRODUCTION

Hydrilla, an aquatic plant native to Asia (Cook 1985), can be a serious submersed weed problem in many tropical and sub-tropical areas (Cook and Lüönd 1982; Pieterse 1981). Its documented ability to colonize and grow essentially as a monoculture by replacing indigenous plants in a variety of aquatic habitats creates several problems for aquatic plant managers. Hydrilla is difficult to manage because it produces numerous subterranean turions, commonly called tubers, that provide a source of vegetative propagules for growth of new plants once the parent plants have been controlled with herbicidal, mechanical, or biological methods.

Both dioecious and monoecious biotypes of hydrilla have been identified in the United States (US) (Verkleij et al. 1983). The dioecious form was first identified in 1959 (Blackburn et al. 1969), and is the predominant form in Florida and other locations in the US. The monoecious form was first identified in 1982 in the Potomac River near Washington, DC (Steward et al. 1984), and is now present in several locations in the northeast portion of the US. Although the monoecious biotype of hydrilla has the ability to produce seeds, its principal method of reproduction has been established as vegetative, at least for plants in North Carolina (Harlan et al. 1985).

Information on production of tubers by the dioecious and monoecious biotypes will be of benefit to managers in developing management techniques for hydrilla. Current knowledge of tuber population dynamics in natural aquatic habitats is based on a meager amount of information perhaps because of difficulty in collecting samples, but estimates for numbers of dioecious tubers produced per 1.0 m^2 have been reported to range from 36 (Sutton and Portier 1985) to 510 (Bowes et al. 1979). Under tank conditions, numbers as high as 4,250 tubers per 1.0 m^2 have been reported for dioecious plants (Steward 1984). In Lake Anne, North Carolina, tuber density estimates for monoecious plants of 410 to 1,312 per 1.0 m^2 were reported during a monthly survey of five replicate 0.1 m^2 samples beginning in September 1982 and continuing until the following September of 1983 (Harlan et al. 1985).

It is well known that the dioecious biotype of hydrilla produces tubers in response to a short-day photoperiod (Van et al. 1978) but monoecious plants can produce tubers under both short- and long-day photoperiods (Van 1989). To provide more information on the growth potential of hydrilla, sprouted tubers of dioecious and monoecious biotype were planted individually in a 1.0-m^2 box and allowed to grow during both summer and winter growth conditions found in south Florida.

MATERIALS AND METHODS

Experiments were conducted outdoors at the Fort Lauderdale Research and Education Center (FLREC) in cement tanks (6.2 m in length by 3.1 m in width) filled with pond water. The FLREC is located at coordinates 26°05′N and 80°14′W. Pond water, from the same source as described by Steward (1984), flowed into the tanks at the surface of one end and out from bottom drains at the other at a rate which allowed for a complete exchange of water every 24 hours.

Boxes were constructed of marine plywood with dimensions of 1.0 m in width by 1.0 m in length by 20 cm in height. Boxes were placed two in each tank, and tanks were filled with pond water to a depth of 0.8 m.

The amount of fertilizer added to each 10 cm square of sediment surface area of each box was 5.35 g of Osmocote, 0.14 g of Esmigran, and 0.86 g of dolomite[3], and this amount of fertilizer was placed individually in each of the 100 10-cm^2 squares in the box. Prior to adding these fertilizers, the box was filled with a 15-cm bottom layer of clean, white builders sand with a top layer of sand 2.5 cm deep covering the layer of fertilizer. Nutrient properties of the sand have been described by Langeland et al. (1983).

Tubers were collected from stock hydrilla maintained at the FLREC. Dioecious tubers were from plants originally collected from Lake Okeechobee. Tubers were allowed to sprout in pond water prior to use in the study (Sutton 1986). Monoecious tubers were from cultures originally collected from the Potomac River in Virginia (Steward et al. 1984). One sprouted tuber was planted in the center of each box and allowed to grow for 16 weeks. Culture periods are listed in Table 1. In the initial years of the study only dioecious tubers were used, but beginning with the November 23, 1987 culture period, sprouted monoecious tubers were added. Tanks were covered with a 2.5-cm mesh screen to prevent removal of monoecious hydrilla by birds, and the drain was covered by a 1-mm mesh screen to prevent escape of vegetative material.

Water temperatures were recorded during these culture periods as previously described by Sutton (1986). An emulsifiable concentrate of malathion (0,0-dimethyl dithiophosphate of diethyl mercaptosuccinate) was added

Table 1. Culture period designation, culture period dates, number of tanks, and number of 1.0 m^2 boxes for study of culture of hydrilla from single tubers. Each tank contained two 1.0 m^2 boxes. Beginning with Winter 1987, each tank contained two boxes each planted with a single sprouted tuber of either dioecious or monoecious hydrilla.

Culture period designation	Culture period dates	Number of tanks	Number of boxes
Dioecious hydrilla			
Winter 1985	November 6, 1985 to February 26, 1986	1	2
Summer 1986	May 13 to September 2, 1986	2	4
Winter 1986	November 17, 1986 to March 9, 1987	2	4
Summer 1987	May 11 to August 31, 1987	2	4
Dioecious and mooecious hydrilla			
Winter 1987	November 23, 1987 to March 14, 1988	2	4
Summer 1988	May 9 to August 29, 1988	2	4
Winter 1988	November 21, 1988 to March 13, 1989	2	4
Summer 1989	May 8 to August 28, 1989	2	4

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[3] Osmocote (18-6-12) with an 8- to 9-month release time is manufactured by Sierra Chemical Company, Milpitas, CA 95035; Esmigran by Mallinckrodt, Inc., St. Louis, MO 63147; and Dolomite (Soil Doctor) by Soil Doctor, Inc., Crystal River, FL 32629. Mention of a trademark or a proprietary product does not constitute a guarantee or warranty of the product by the University of Florida or the USDA and does not imply its approval to the exclusion of other products that also may be suitable.

weekly to tanks to achieve a concentration of 1.0 ppm to control feeding activity of the herbivorous moth, *Parapoynix diminutalis* Snellen. Periodically, each tank was cleaned with a siphon to remove debris, or algae, or both which built-up on the bottoms and sides of the tanks.

At the end of the 16-week growth period, hydrilla shoot growth was cut at the sand surface, washed with pond water to remove adhering algae and debris, and dried at 60 C in a forced-air oven to a constant weight. The sand in the box was then partitioned into 100 10-cm^2 units that were labeled according to location within the box as shown in Figure 1. Partitioning of each box was always carried out in the same manner to ensure uniformity of data collection for all culture periods. Prior to tuber enumeration, below ground biomass including roots, rhizomes, and stem fragments (hereinafter referred to as roots) along with sand rooting medium were removed from each unit. Roots and tubers were washed with pond water to remove sand, fertilizer, and any other adhering debris, and dried at 60 C.

Dry weight of shoots, roots and tubers, and number of tubers were statistically analyzed using General Linear Models (GLM) procedures of the Statistical Analyses System (SAS)[4] for personal computers. Where appropriate, means separation was accomplished with the Duncan-Waller Empirical Bayes LSD procedure (Peterson 1985).

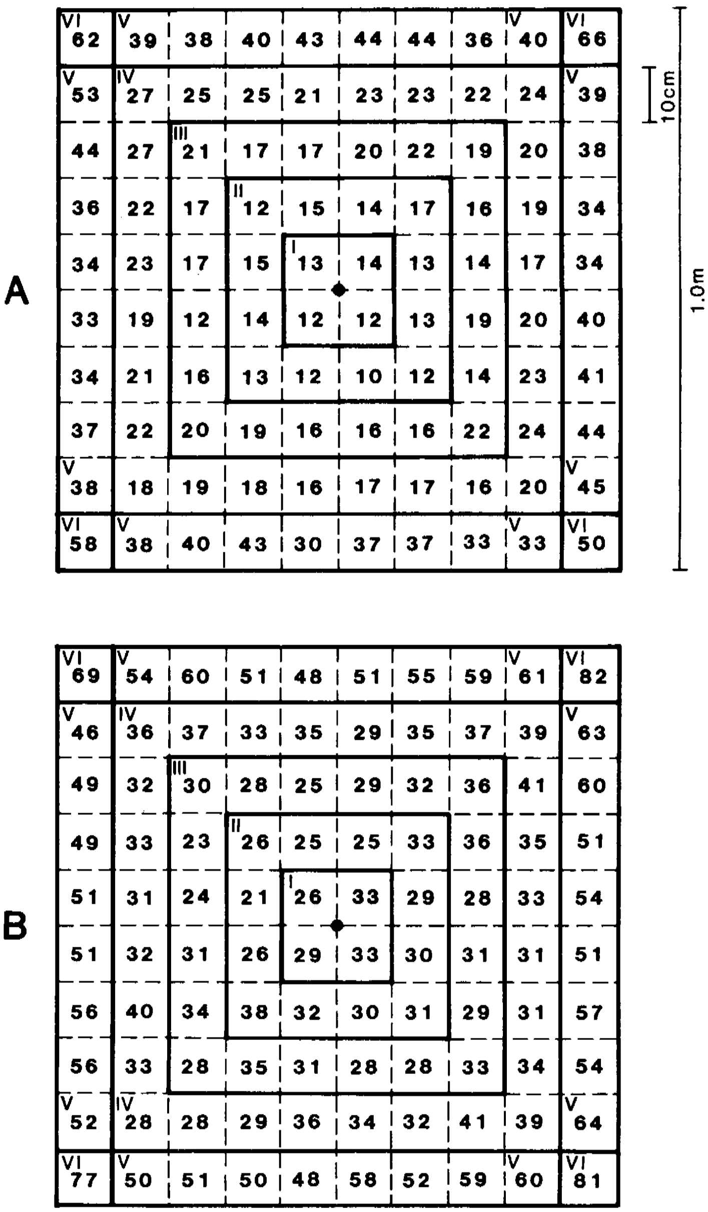
RESULTS AND DISCUSSION

Water temperatures for the eight culture periods are presented in Table 2. Mean temperature for summer culture periods was 29.6 C with a range of 34.5 C to 24.3 C. For winter culture periods, a mean of 23.0 C was calculated with a range of 30.3 C to 11.0 C.

Release of nitrogen, phosphorus, and potassium from the Osmocote fertilizer used in this study depends on temperature and the rate of release is greater above 21 C[5]. Mean water temperatures for all culture periods were higher than the 21 C requirement, although temperatures below 21 C were recorded for long periods during some of the winter culture periods. These low temperatures may have slowed the rate of release of nutrients from the Osmocote and in turn could have reduced the availability of nutrients for growth of hydrilla during winter periods.

When dioecious hydrilla was cultured in two boxes in a tank, total plant dry weight was higher in summer than during winter culture periods (Table 3). Shoot dry weight averaged 97% and 79%, respectively, of total plant weight for summer and winter culture periods. For the winter culture period, roots and tubers contributed 6% and 9%, respectively, of mass to total dry weight.

Shoot dry weight of monoecious hydrilla plants was eight times higher in summer than in winter (Table 4). For the monoecious biotype cultured during winter months, weight of shoots, roots, and tubers comprised an average of 76, 4, and 20%, respectively, of total plant dry weight. During the summer growth period, a percentage breakdown of dry weight reveals that shoots accounted for 89%, roots 4%, and tubers 7% of the total plant dry weight biomass.



A

VI 62	V 39	38	40	43	44	44	36	V 40	VI 66
V 53	IV 27	25	25	21	23	23	22	24	V 39
44	27	III 21	17	17	20	22	19	20	38
36	22	17	II 12	15	14	17	16	19	34
34	23	17	15	I 13	14	13	14	17	34
33	19	12	14	12	12	13	19	20	40
34	21	16	13	12	10	12	14	23	41
37	22	20	19	16	16	16	22	24	44
V 38	18	19	18	16	17	17	16	20	V 45
VI 58	V 38	40	43	30	37	37	33	V 33	VI 50

B

VI 69	V 54	60	51	48	51	55	59	V 61	VI 82
V 46	IV 36	37	33	35	29	35	37	39	V 63
49	32	III 30	28	25	29	32	36	41	60
49	33	23	II 26	25	25	33	36	35	51
51	31	24	21	I 26	33	29	28	33	54
51	32	31	26	29	33	30	31	31	51
56	40	34	38	32	30	31	29	31	57
56	33	28	35	31	28	28	33	34	54
V 52	IV 28	28	29	36	34	32	41	39	V 64
VI 77	V 50	51	50	48	58	52	59	V 60	VI 81

Figure 1. Average number of hydrilla tubers produced by (A) dioecious and (B) monoecious hydrilla under outdoor conditions. A single sprouted tuber was planted in the middle of each box (black dot). Dark lines enclose zones with a Roman numeral written in the upper left corner to designate the Zone Number. The dash lines delineate the 10-cm^2 units within the zones. Values for each 10-cm^2 unit are averages of all culture periods for each hydrilla biotype.

Casual observations of monoecious hydrilla in the Potomac River indicate that the plant behaves as an annual with no observed shoot growth in winter and maximum growth in summer months. In South Florida, monoecious hydrilla in this experiment was observed to grow as a perennial although shoot biomass was considerably lower in winter than in summer. Opportunities for winter or perennial growth of monoecious hydrilla may be limited to those

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[4] SAS Institute Inc., Cary, NC 27511.

[5] Harbaugh, B. K. and G. J. Wilfret. 1981. Factors to consider when using Osmocote for poinsettia production in Florida. Univ. Fl. Bradenton AREC Res. Rpt. GC1981-5. 4 pp.

TABLE 2. WATER TEMPERATURE DURING STUDY OF CULTURE OF HYDRILLA FROM SINGLE TUBERS. EACH VALUE IS THE MEAN OF READINGS COLLECTED FROM A SINGLE MAXIMUM/MINIMUM THERMOMETER PLACED 30 CM BELOW THE WATER SURFACE IN EACH CULTURE TANK. READINGS WERE COLLECTED 5 DAYS A WEEK.

Culture period	Water temperature (C) Mean	High	Low
Dioecious hydrilla			
Winter 1985	22.4	28.0	11.0
Summer 1986	29.7	33.5	24.8
Winter 1986	23.5	30.3	15.8
Summer 1987	29.5	33.0	25.5
Dioecious and monoecious hydrilla			
Winter 1987	22.4	27.3	14.3
Summer 1988	29.3	33.3	25.0
Winter 1988	23.5	28.5	11.3
Summer 1989	29.7	34.5	24.3

areas of the country with environmental conditions similar to South Florida.

Shoot dry weight of monoecious hydrilla was significantly lower than dioecious plants only during winter culture periods. Also, shoot dry weight averages between summer and winter culture periods for dioecious hydrilla were generally not different; however, two winters of cool weather especially at critical growth times may have caused significant growth reductions during the first 2 years (Table 3). No differences in total dry weight were observed between the monoecious biotype for summer culture periods and dioecious hydrilla for both culture periods.

Dry weight of dioecious hydrilla was fairly consistent for summer culture periods with total plant dry weight values ranging from 3,558 g per box for the summer of 1986 to 4,043 g per box for plants cultured during the summer of 1987. But for winter culture periods, growth was somewhat variable in that total dry weight per box averaged 1,052 g for the winter of 1986 to 3,026 for the winter of 1989. Part of this variability could be due to the period of cool weather experienced after planting sprouted tubers. For example, during the winter of 1985, Hurricane Kate hit 11 days after planting, causing several days of cloudy weather, and 1 month later there was a 27-day cool period followed by a 22-day cool period 1 week later. In all, there were 6 days when the water temperature did not reach 21 C. The following winter had one 17-day cool period, and the next two winters were mild with little cool weather.

TABLE 3. DRY WEIGHT AND NUMBER OF PROPAGULES OF HYDRILLA PLANTS CULTURED IN OUTDOOR TANKS FROM SINGLE DIOECIOUS TUBERS PLANTED IN 1.0 m^2 BOXES.[a]

	Shoot dry weight (g)	Root dry weight (g)	Total plant weight (g)	Number of tubers	Individual tuber dry weight (g)
Winter 1985	789 b	136 a	1,052 c	1,979 b	0.064 a
Winter 1986	1,552 b	188 a	1,912 b	2,722 a	0.063 a
Summer 1986	3,491 a	67 b	3,558 a	0 c	–
Summer 1987	3,856 a	187 a	4,043 a	0 c	–

[a]Values within a column followed by the same letter are not significantly different at the 5% level according to the Waller-Duncan multiple range test.

TABLE 4. DRY WEIGHT AND NUMBER OF PROPAGULES OF HYDRILLA PLANTS CULTURED IN OUTDOOR TANKS FROM SINGLE DIOECIOUS OR MONOECIOUS TUBERS PLANTED IN 1.0 m^2 BOXES.[a]

	Shoot dry weight (g)	Root dry weight (g)	Total plant weight (g)	Number of tubers	Individual tuber dry weight (g)
Monoecious hydrilla					
Winter 1987	339 c	17 b	445 c	1,784 c	0.050 cd
Winter 1988	591 c	32 b	778 bc	3,697 ab	0.042 d
Summer 1988	3,506 a	168 a	3,994 a	6,046 a	0.053 c
Summer 1989	4,147 a	159 a	4,559 a	4,687 ab	0.054 c
Dioecious hydrilla					
Winter 1987	1,487 ab	165 a	1,973 ab	3,524 ab	0.091 a
Winter 1988	2,743 ab	128 a	3,026 ab	2,126 bc	0.073 b
Summer 1988	3,428 a	211 a	3,639 a	0 d	–
Summer 1989	3,329 a	162 a	3,491 a	0 d	–

[a]Values within a column followed by the same letter are not significantly different at the 5% level according to the Waller-Duncan multiple range test.

Growth of dioecious hydrilla under outdoor conditions in the boxes was in agreement with data presented by McFarland and Barko (1990). They reported that under controlled environmental conditions of long photoperiods and high temperatures total biomass production was high for dioecious hydrilla.

Tubers were produced by the monoecious hydrilla during both the winter and summer culture periods (Table 4). An average of 6,046 tubers per box was produced by the monoecious biotype during summer of 1988 and a minimum of 1,784 per box for the 1987 winter period. These data indicate potential for year-round production of tubers if the monoecious biotype were to become naturalized in water bodies in South Florida.

Even though total number of tubers differed for culture periods for both biotypes (Tables 3 and 4), there was no interaction between location of tubers within each box and culture periods. Therefore, the average number of tubers for each 10-cm^2 unit for either monoecious or dioecious hydrilla was pooled in order to present an overall distribution pattern of these propagules (Figure 1).

The distribution pattern of tubers was similar for both biotypes, but monoecious hydrilla produced greater numbers of tubers for similar zones (Table 5). Differences were found for number of tubers between some zones, but the

TABLE 5. SUMMARY FOR ROOT WEIGHT, NUMBER OF TUBERS, AND INDIVIDUAL TUBER WEIGHT FOR HYDRILLA PLANTS CULTURED IN OUTDOOR TANKS. TUBER ZONE NUMBER REFERS TO LOCATION WITHIN EACH BOX. SEE FIGURE 1 FOR EXPLANATION OF RELATION OF TUBER ZONE NUMBER TO LOCATION WITHIN EACH BOX.

Tuber zone number	Number of samples	Root weight (g)	Number of tubers	Individual tuber weight (g)
Dioecious hydrilla				
I	40	0.933 d	13 d	0.071 a
II	120	1.032 d	13 d	0.069 a
III	200	1.271 cd	17 d	0.069 a
IV	280	1.534 c	21 c	0.068 a
V	320	3.013 b	39 b	0.074 a
VI	40	4.850 a	59 a	0.076 a
Monoecious hydrilla				
I	32	0.599 c	30 c	0.048 a
II	96	0.628 c	29 c	0.048 a
III	160	0.717 c	30 c	0.048 a
IV	224	0.861 c	34 c	0.048 a
V	256	1.237 b	54 b	0.049 a
VI	32	1.582 a	77 a	0.049 a

[a] Values within a column for dioecious or monoecious hydrilla followed by the same letter are not significantly different at the 5% level according to the Waller-Duncan multiple range test.

distribution of tubers was fairly uniform within zones. Higher numbers of tubers present in the corners and along the edges than towards the center of boxes may perhaps be due to stress related factors of plant roots coming in close contact with the sides and corners. The four corners, Zone VI, produced the highest number of tubers with an average of 59 per 10-cm^2 unit for dioecious hydrilla and 77 per 10-cm^2 unit for monoecious hydrilla. When data for Zones V and VI were excluded, no differences were noted among Zones I to IV for the monoecious biotype—the same results as when Zones V and VI were included (Table 5). However, when data for Zones V and VI of dioecious hydrilla were excluded, the order of differences among the zones was Zone I = Zone II < Zone III < Zone IV.

Available data from natural aquatic plant populations suggest considerable non-uniformity in distributions with respect to vertical distribution of vegetative propagules (Rybicki and Carter 1986; Spencer 1987; Spencer and Ksander 1990), but little data are available on horizontal distribution of tubers under field conditions. Data from these 1.0 m^2 boxes suggest that a fairly uniform horizontal distribution of tubers for plants cultured under homogeneous sediment conditions. Stresses placed on plants, such as that caused by the sides and corners of these boxes, may result in 'pockets' of tubers which could bias estimates of field grown hydrilla tubers. Collection of large number of samples may help overcome this bias. For example, the 25 sediment core samples collected for each location at each sampling time for a study of density of hydrilla propagules in South Florida provided a good estimate of pooled within-location variability (Sutton and Portier 1985), but the study did not address the question of distribution of propagules within sites sampled.

Individual tuber weights for both hydrilla biotypes were uniform throughout boxes regardless of tuber zone location (Table 5). However, average individual weight of monoecious tubers was 32% less than for dioecious tubers. These results confirm an earlier report by Spencer et al. (1987) and McFarland and Barko (1987) that monoecious tubers are smaller than dioecious tubers. Under field conditions, the small monoecious tubers may not survive as long as larger dioecious tubers because monoecious tubers would presumably contain less food reserves than dioecious ones.

Steward and Van (1987) reported no difference in growth response to temperature between monoecious and dioecious hydrilla. However, culture of these biotypes in large boxes starting at the beginning of summer and winter growth periods in South Florida suggest that growth of monoecious hydrilla, at least for the first 16 weeks, will be different depending on season, and it appears that growth of dioecious hydrilla during the winter season could be quite variable.

When all culture periods were averaged together, monoecious hydrilla produced 56% more tubers than dioecious hydrilla. Production of a higher number of tubers by the monoecious biotype of hydrilla as compared to dioecious tubers cultured under similar conditions confirms the results of Van (1989). However, in the study by Van (1989), monoecious hydrilla produced tubers sooner than dioecious hydrilla with five to seven times more monoecious tubers recorded 10 weeks after planting. In the 1.0 m^2 boxes, monoecious hydrilla produced only twice as many tubers as dioecious hydrilla after 16 weeks of growth. Growth of hydrilla in 1.0 m^2 boxes for the 16-week periods may closely approximate expected tuber production under field conditions when adequate nutrients and favorable environmental conditions are available for hydrilla growth.

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Organic Sedimentation Associated with Hydrilla Management[1]

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ABSTRACT

The production of organic sediment by hydrilla was determined for five different management schemes under experimental conditions in outdoor, concrete tanks. Levels of hydrilla management evaluated represented percent of water volume occupied prior to herbicide treatment of 0%, 33%, 66%, 100%, and 100% (untreated). Hydrilla management at levels which prevented the plant from forming canopies (0, 33%, and 66%) produced significantly (as much as 2.1 times) less organic sediment than untreated hydrilla and also reduced tuber number and total weight. These results indicate an ecological advantage to maintenance control of hydrilla.

Key Words: Hydrilla verticillata, maintenance control, sediment production, organic matter, herbicides, endothall.

INTRODUCTION

Aquatic weed problems are most often associated with an exotic plant's ability to occupy aquatic habitats not normally colonized by native plant species and results in interference with man's use of the waterbody. Large scale management of these problems typically relies on mechanical removal or the use of approved aquatic herbicides. A public concern over the management of nuisance aquatic vegetation with herbicides is the deposition of organic material onto the lake or river bottom by the decaying plants. The public generally does not understand that the plants' productivity and growth habit naturally contribute large amounts of organic material to lake sediments whether treated or not.

Due to difficulties of "in situ" measurement, there is a paucity of published data which quantifies sedimentation contributions from the natural senescence or man-induced necrosis of submersed macrophytes. It is known however, that the chemical decomposition of organic matter produced by algae and aquatic macrophytes and thus their relative contribution to the sediments is variable (Godshalk and Wetzel 1976). This variability is a function of the plant species, its environment, seasonal factors, growth form,

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