concentrations depending on its growth status and ambient environmental conditions. Hydrilla plants grown in culture were used for both the bioassay and barrel studies (since hydrilla is not yet present in Indiana waters). Therefore, under natural growing conditions, hydrilla may require higher concentrations of flurprimidol than those suggested by this study.

Our results indicate that flurprimidol can reduce main stem lengths of hydrilla and Eurasian watermilfoil under outdoor culture conditions and that only short exposure times of 1 to 2 h may be required for significant stem length reduction. Further studies are needed to determine if the plants that still show reduced main stem lengths even after exposure to untreated water for 4 weeks retain the flurprimidol in their tissues or take it up from the sediments over the 4 week recovery period. When flurprimidol is added to a plant-sediment-water barrel system, approximately 88% of the flurprimidol dissipates after 4 weeks; however, the majority of the remaining flurprimidol is present in the water and the top 5 cm of sediment (Chand and Lembi 1991). This suggests that when the water is flushed from the system, flurprimidol in the sediment may still be available for plant uptake. We plan to continue our studies on flurprimidol efficacy and dissipation in small ponds in 1992.

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Growth of Monoecious Hydrilla on Different Soils Amended with Peat or Barley Straw

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ABSTRACT

Monoecious hydrilla (*Hydrilla verticillata* (L. f.) Royle) was grown in six soil types amended with two levels of barley straw or peat to test the hypothesis that substrate organic matter would cause reduced growth. Soil type significantly influenced hydrilla dry weight and weight of tubers produced during 8 weeks of growth under outdoor conditions. Also, increased organic matter content (measured as loss on ignition) of the substrate over the range of 1.5 to 27.2% was associated with increased growth of hydrilla. Of 14 substrate properties, multiple regression revealed that the square root of Kjeldahl N and the square root of soil conductivity were the best predictors of hydrilla weight. These results suggest that variability in the responses of rooted aquatic plants to substrate organic matter content reported previously may be partially explained by considering properties of the organic matter, especially nutrient content.

Key words: Hydrilla verticillata (L. f.) Royle., submersed aquatic macrophyte, tubers, Kjeldahl N, organic matter, conductivity, nutrients.

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INTRODUCTION

Hydrilla is an introduced plant that has caused serious problems in many aquatic systems in the United States. Growth requirements and capabilities of the monoecious strain of hydrilla appear to differ in important ways (i.e., responses to photoperiod and perhaps temperature, and allocation of dry matter to tubers and turions) from those of the dioecious strain (Spencer and Anderson 1986; Spencer *et al.* 1987; Steward and Van 1987; Van 1989). These differences may influence its response to management techniques developed for plants of the dioecious strain.

One management approach involves altering the substrate or rooting medium. Sediment covers such as sand, gravel, or plastic sheeting and dredging have been used to this end (Barko *et al.* 1986). Altering organic matter content of sediments also has been proposed as a potential method for managing aquatic plants (Gunnison and Barko 1989). In green house experiments, increased organic matter content of sediments was identified as the cause of reduced growth of Eurasian watermilfoil (*Myriopyyllum spicatum* L.) and dioecious hydrilla (Barko and Smart 1983, 1986). McFarland and Barko (1987) compared growth of monoecious and dioecious hydrilla on sediments with two levels of organic matter (5.6 vs. 50%), and reported reduced yields for plants grown on sediments containing 50% organic matter. However, other reports have suggested that increasing sediment organic matter content was associated with increased growth of submersed (Spencer 1990; Kiorboe 1980; Sand-Jensen and Sondergaard 1979) or emergent rooted aquatic plants (Sharp and Keddy 1985; Lee 1986, 1987). The objective of this study was to test the hypothesis that adding organic matter to the substrate would result in decreased growth of monoecious hydrilla.

MATERIAL AND METHODS

We grew hydrilla on six soils that had been amended with two types of organic matter. We focused on soils with textural characteristics and organic matter contents similar to those found in a survey of irrigation systems in northern California. In this region, many irrigation canals are not used for water conveyance during the winter (typically November through March). As a consequence canal sediments are exposed to the atmosphere during this period and may thus differ in several ways from continuously flooded sediments.

In the growth experiment, we used soils that were collected from various sites in northern California in 1976. Location of the sites and some soil properties are summarized in Table 1. Either of two types of organic matter, barley straw or peat (a natural peat collected from the Sacramento River Delta near Terminus, California), was added to the soils in 1978 to yield the following treatments: 5% peat, 20% peat, 5% barley straw, or 20% barley straw. Portions of each soil were used in a study of the influence of edaphic factors on growth of spikerush (*Eleocharis acicularis* (L.) R. & S.) in 1978 (Bissell unpublished data). Soils were stored air-dried in closed cardboard containers until they were used in this study in 1989. Drying sediments or soils causes changes, however if stored moist sediments also undergo changes. The effect of drying sediments on growth of rooted aquatic plants is not known for many species, but Sutton (1990) reported increased growth of hydrilla on air-dried sediments relative to similar sediments which were not dried. Dried sediments or soils are also easier to use in growth experiments and for nutrient analysis (Sutton 1990). Since many irrigation canals do not continuously have water flowing in them, the sediments undergo periodic drying, thus the use of air-dried soils does not seem overly unrealistic.

Three replications were randomly assigned to each treatment combination (Figure 1). A replication consisted of a sprouted tuber planted in a 950 ml plastic container filled with 475 g of the appropriate soil mixture. Washed sand (55 g per container) was placed over the soil to retard soil/water exchanges (Smart and Barko 1985). Tubers were collected from cultures maintained at the USDA Aquatic Weed Lab on July 17, 1989. On July 19 they were placed in a growth chamber (25 C; 12:12 light:dark cycle) to sprout. All were between 175 and 250 mg fresh weight prior to sprouting. Sprouted tubers were planted on August 2, 1989. At this time, mean length was 73 mm (± 13 mm, standard deviation, N = 10). Containers were placed in an outdoor concrete tank (1000 l) filled with well water which was replaced weekly (from August 2, 1989 to September 25, 1989). Water temperature was measured at 30 minute intervals for twenty four hours, on twenty eight days during the course of this experiment using a Datasonde II H (Hydrolab Corp., Austin, Texas). Minimum daily water temperature ranged from 14 to 23 C and maximum daily water temperature varied from 18 to 30 C. After eight weeks, the plants were harvested, dried at 80 C, and weighed. Individual tubers were counted and the fresh weight of each recorded. One shoot tip (2.5 cm long) was removed from each plant and analyzed for carbon and nitrogen content with a Perkin-Elmer 2400 CHN Elemental Analyzer with acetanilide used as the standard.

A number of soil charactistics were measured in 1978. Unless required by the analytical procedure, air-dried soil was used and the results adjusted to an oven-dry basis (at 80 C). Analytical techniques used standard methods (Black 1965). Specific methods were as follows: organic carbon, Wakley-Black method; cation exchange capacity, sodium saturation method; soil conductivity, saturation extract method; pH, extraction with $CaCl_2$; Kjeldahl N, semimicro-Kjeldahl; exchangeable P, sodium bicarbonate extraction procedure. Exchangeable fractions of Mg, K, and Zn were determined by atomic absorption following extraction of 10 g of soil with 100 ml of neutral 1.0 N

TABLE 1. PARTICLE SIZE ANALYSIS FOR SOILS USED IN THE GROWTH EXPERIMENT.

Soil	Percent			Collection Site
	Sand	Silt	Clay	
Sand (SN)	95	0	5	Knights Landing (38°49′N, 121°43′W)
Loam 1 (L1)	30	52	18	Roseville (38°46′N, 121°17′W)
Loam 2 (L2)	49	36	15	Knights Landing (38°49′N, 121°43′W)
Silt Loam (SL)	34	48	18	Woodland (38°40′N, 121°50′W)
Sandy Clay Loam (SCL)	53	25	22	Ione (38°22′N, 120°55′W)
Clay (CY)	0.5	36	63.5	Woodland (38°40′N, 121°50′W)

Soil	No Addition	Straw 5 %	Straw 20 %	Peat 5 %	Peat 20 %
SL	3	3	3	3	3
L1	3	3	3	3	3
L2	3	3	3	3	3
SCL	3	3	3	3	3
CY	3	3	3	3	3
SN	3	3	3	3	3

Figure 1. Diagram of the experimental design. Abbreviations for soils are as follows: SL, silt loam; L1, loam 1; L2, loam 2; SCL, sandy clay loam; CY, clay; and SN, sand.

TABLE 2. MEAN (± STANDARD ERROR) HYDRILLA WEIGHT AND MEAN WEIGHT OF TUBERS PER PLANT GROWN ON VARIOUS SUBSTRATES. VALUES ARE GRAMS DRY WEIGHT. N = NUMBER OF REPLICATES. S = STRAW; PT = PEAT.

Sub-strate	Amend-mend	Plant Weight SE	N	Tubers SE	N
SL	none	4.22 ± 1.27	3	0.06 ± 0.03	3
SL	5% S	13.51 ± 5.06	3	0.17 ± 0.08	3
SL	20% S	7.60 ± 2.32	2	0.12 ± 0.08	2
SL	5% PT	6.65 ± 3.19	3	0.17 ± 0.08	3
SL	20% PT	9.29 ± 1.66	3	0.18 ± 0.093	
L1	none	2.90 ± 1.09	3	0.03 ± 0.02	3
L1	5% S	4.84 ± 1.25	3	0.08 ± 0.01	3
L1	20% S	7.42 —	1	0.14 —	1
L1	5% PT	3.49 ± 0.87	3	0.04 ± 0.00	3
L1	20% PT	5.75 ± 0.88	3	0.16 ± 0.07	3
L2	none	4.08 ± 0.63	2	0.05 ± 0.02	2
L2	5% S	6.35 ± 0.53	3	0.20 ± 0.03	3
L2	20% S	3.43 ± 0.71	3	0.12 ± 0.07	3
L2	5% PT	5.74 ± 1.62	3	0.15 ± 0.07	3
L2	20% PT	9.45 ± 2.25	3	0.17 ± 0.02	3
SCL	none	2.26 ± 0.10	3	0.02 ± 0.02	3
SCL	5% S	3.02 ± 0.79	3	0.03 ± 0.03	3
SCL	20% S	2.27 ± 0.26	3	0.17 ± 0.04	3
SCL	5% PT	4.75 ± 1.32	3	0.06 ± 0.01	3
SCL	20% PT	8.42 ± 0.68	2	0.23 ± 0.04	2
CY	none	6.47 ± 1.94	3	0.10 ± 0.07	3
CY	5% S	8.32 ± 1.11	3	0.07 ± 0.02	3
CY	20% S	6.62 ± 2.21	3	0.15 ± 0.05	3
CY	5% PT	6.91 ± 0.31	3	0.25 ± 0.14	3
CY	20% PT	9.12 ± 3.00	2	0.14 ± 0.00	2
SN	none	1.11 ± 0.17	3	0.02 ± 0.01	3
SN	5% S	9.88 ± 1.79	3	0.08 ± 0.02	3
SN	20% S	4.32 ± 1.24	3	0.08 ± 0.01	3
SN	5% PT	4.27 ± 1.22	3	0.07 ± 0.01	3
SN	20% PT	8.94 ± 2.92	3	0.16 ± 0.01	3

ammonium acetate. Fe, Mn, and inorganic N were extracted from 10 g of wet sediment with 50 ml of 2.0 N KC1. Fe and Mn were determined by atomic absorption; inorganic N in the extract was determined by the semimicro-Kjeldahl method. Organic matter (loss on ignition) and particle size analysis followed the procedures outlined in Brower and Zar (1984). Organic matter was estimated as loss on ignition to allow comparison with earlier studies (Sand-Jensen and Sondergaard 1979, Kiorboe 1980, Barko and Smart 1986). Because we were concerned about the effect of storage, we measured Kjeldahl N again in 1990. Comparison of the 1978 and 1990 values using a t-test (SAS Institute, 1988) indicated no significant difference ($P > 0.05$).

In 1984 and 1985 soil samples were collected from canals in three irrigation districts in northern California: Madera Irrigation District (36°58′N, 120°07′W), Solano Irrigation District (38°26′N, 121°51′W) and Richvale Irrigation District (39°30′N, 121°44′W). Seventy-one samples from the Madera Irrigation District were collected at thirteen irregularly spaced locations (0.2 to 2 km apart) along a 5.5 km stretch of the Big Main Canal in the spring of 1984. Sixty-six samples were collected from a 1 km stretch of the Pratt Supply Canal in the Richvale Irrigation District in autumn of 1984 and the spring of 1985. Sixty-eight samples were collected from four canals in the Solano Irrigation District in 1984. The samples were collected within 0.4 km stretches of each of the following canals: Byrnes, Dally, Vaughn, and Weyend. All samples were analyzed for organic matter content following the procedures described in Brower and Zar (1984). The samples collected from the Solano Irrigation District in 1984 and the Richvale Irrigation District in 1985 were analyzed for particle size distribution (Brower and Zar 1984).

The effects of adding either straw or peat to the soil on growth of hydrilla and carbon and nitrogen content of shoot tips were tested using a two-way analysis of variance. To determine if the measured soil characteristics were good predictors of hydrilla growth, we used multiple regression (SAS Institute, 1988) in the manner described by Henderson and Velleman (1981) and recommended by James and McCulloch (1990). Adequacy of the resulting model was evaluated by examining plots of the residuals versus the predicted values and the independent variables (Schlotzhauer and Littell 1987).

RESULTS

Sediments in the surveyed irrigation canals were fine textured with low levels of organic matter. Most of the sediment samples from the irrigation canals could be classified as clay or silty clay (Figure 2A). Although some values exceeded 20%, mean organic matter content for the sediment samples from each of three irrigation districts was less than 15% (Figure 2B).

In the growth experiment, mean hydrilla weight ranged from 1.1 to 13.5 g (Table 3) and was influenced by both soil type and organic amendment ($P < 0.05$). For unamended soils, growth and tuber production were lowest on sand while plants grown on clay weighed more and produced a greater mass of tubers (Table 3). Adding either peat or barley straw to the substrate resulted in significantly increased ($P < 0.05$) growth and tuber production (Table 3).

Carbon and nitrogen content of shoot tips were unaffected by either soil type or organic amendment ($P > 0.05$). Mean carbon content (averaged over all treatments) was 33.5% (coefficient of variation = 9.5%) and mean nitrogen content was 3.2% (coefficient of variation = 14.3%.

Substrate properties varied considerably (Tables 1, 4, and 5). The high levels of Fe for soils L1 and CY with added straw may have been partly due to the decrease in pH for these soils following the straw additions. Levels of exchangeable P may have been influenced by interactions with different levels of Fe and A1 (not measured) in the soils. The range of substrate nutrient levels were generally similar to those used in other studies (Steward 1984; Barko and Smart 1986).

Relationships among hydrilla weights and substrate properties were examined prior to use in the multiple regression analysis to ensure that they met assumptions of this technique (Henderson and Velleman 1981). Examination of plots of hydrilla weight versus each of the measured substrate properties (data not shown) did not reveal obvious nonlinear relationships. The values of the measured soil properties were examined for normality. The distribu-

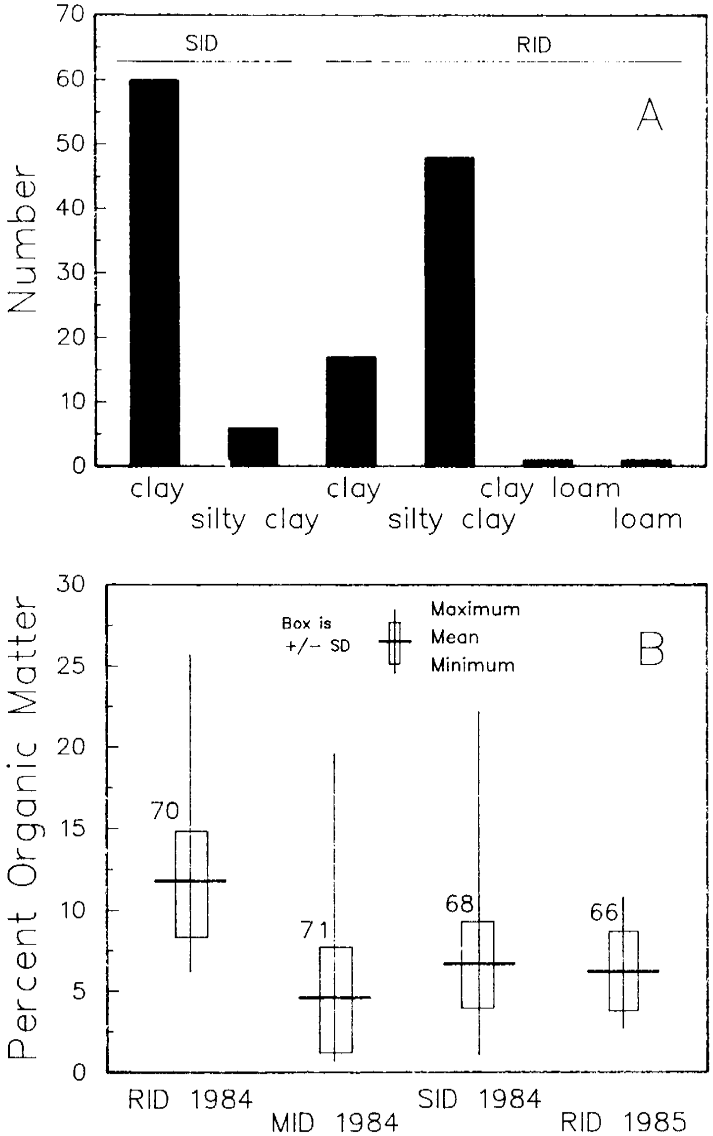

Figure 2. Classification of soil samples (A) and organic matter content of soils (B) from three northern California irrigation districts. RID indicates samples from the Richvale Irrigation District; SID denotes samples from the Solano Irrigation District; and MID signifies Madera Irrigation District.

tions of Zn, K, and organic matter content followed a normal distribution after transforming to the natural logarithm. Conductivity, soil density, and Kjeldahl N were normally distributed after taking the square root of each value. Cation exchange capacity, Mn, Fe, organic C, inorganic N, exchangeable P, and pH were not normally distributed. Pearson correlation coefficients and plots of hydrilla weight against sediment properties suggested that the square root of Kjeldahl N might be the best single predictor of hydrilla weight (Table 3). Regression of hydrilla weight on the square root of Kjeldahl N produced Eq. 1 in Table 6. Inclusion of the square root of conductivity yielded an equation with a greater R^2 (Eq. 2, Table 6). Adding other independent variables into the regression equation did not noticeably improve R^2, nor were the resulting coefficients significant (Eq. 3, Table 6).

TABLE 3. PEARSON CORRELATION COEFFICIENTS FOR HYDRILLA WEIGHT AND 14 SOIL PROPERTIES MEASURED PRIOR TO GROWTH. SIGNIFICANCE PRESENTS THE T-TESTS FOR THE HYPOTHESIS THAT R = 0.

Parameter	r	Significance	N
Kjeldahl N[a]	0.46	0.0001	84
Conductivity[a]	0.40	0.0003	84
Mn[b]	0.37	0.0006	84
K[c]	0.36	0.0008	84
Cation Exch. Capacity	0.35	0.001	84
Organic C	0.34	0.002	84
Inorganic N	0.32	0.003	84
PO_4–P	0.29	0.007	84
Organic Matter[a]	0.29	0.01	75
Mg	0.21	0.05	84
Fe	0.05	0.61	84
pH	0.03	0.80	84
Density[c]	0.01	0.90	84
Zn[c]	–0.01	0.91	84

[a]square root
[b]negative reciprocal
[c]natural log

TABLE 4. SUBSTRATE CHARACTERISTICS FOR HYDRILLA GROWTH STUDY. VALUES ARE MEANS (N = 3). UNITS FOR VARIABLES ARE UG G^{-1}, EXCEPT ORGANIC CARBON AND ORGANIC MATTER, OM (%), CATION EXCHANGE CAPACITY, CEC (MEQ l^{-1}), AND pH (pH UNITS). P IS EXCHANGEABLE INORGANIC P, N IS EXCHANGEABLE INORGANIC N, AND KJEL IS TOTAL KJELDAHL N. S = STRAW; PT = PEAT.

Substrate	Amendment	pH	P	N	KJEL	C	OM	CEC	Fe
SL	none	7.6	9	2	864	1.1	4.1	20.7	28
SL	5% S	7.2	17	12	1327	2.0	5.9	20.0	33
SL	20% S	6.7	42	15	2260	4.5	9.2	23.3	71
SL	5% PT	7.4	23	10	1685	2.5	6.0	24.7	36
SL	20% PT	7.1	36	14	3939	6.6	13.0	38.1	31
L1	none	7.1	5	1	254	0.1	2.1	23.1	26
L1	5% S	5.8	16	3	605	1.2	4.1	20.3	214
L1	20% S	5.2	25	5	1669	5.4	11.0	22.3	307
L1	5% PT	6.7	16	2	1009	1.5	4.0	25.9	31
L1	20% PT	6.3	40	7	3296	5.2	10.7	39.2	48
L2	none	7.6	12	3	622	0.7	3.2	14.9	33
L2	5% S	7.2	16	3	1072	1.5	4.4	14.8	41
L2	20% S	6.7	31	10	1835	3.5	8.0	15.4	73
L2	5% PT	7.4	14	1	1327	1.9	5.0	19.5	40
L2	20% PT	7.0	34	22	3290	5.4	11.1	33.4	35
SCL	none	6.5	2	2	121	0.0	5.7	5.7	28
SCL	5% S	5.5	28	3	459	1.4	7.8	5.6	69
SCL	20% S	5.8	40	8	1384	5.9	18.6	10.6	56
SCL	5% PT	6.6	14	2	807	1.3	7.3	10.1	34
SCL	20% PT	6.1	31	7	2468	4.3	11.9	21.3	44
CY	none	6.8	30	4	1852	1.7	5.4	42.2	36
CY	5% S	5.9	41	13	2260	2.6	7.8	40.5	242
CY	20% S	5.6	38	11	3383	5.4	11.8	34.1	296
CY	5% PT	6.7	38	7	2513	3.0	8.7	41.5	39
CY	20% PT	6.3	42	24	5215	8.0	27.2	57.0	40
SN	none	7.7	3	1	244	0.1	1.5	5.5	26
SN	5% S	6.8	7	3	673	1.2	2.3	6.4	34
SN	20% S	5.7	18	8	1160	2.5	5.1	8.2	51
SN	5% PT	7.3	10	3	916	1.4	3.1	10.2	28
SN	20% PT	6.5	30	3	3085	5.3	6.8	27.2	37

TABLE 5. SUBSTRATE CHARACTERISTICS FOR HYDRILLA GROWTH STUDY. VALUES ARE MEANS (N = 3). UNITS FOR PARAMETERS ARE UG G^{-1}, EXCEPT CONDUCTIVITY (UMHO CM^{-1}) AND BULK DENSITY (G CM^{-3}). S = STRAW; PT = PEAT.

Sub-strate	Amend-ment	Mn	Zn	Mg	K	Conduc-tivity	Bulk Density
SL	none	4	0.04	78	13.5	603	1.15
SL	5% S	29	0.06	70	25.5	765	0.99
SL	20% S	68	0.11	84	26.3	499	0.76
SL	5% PT	27	0.07	95	11.1	724	1.16
SL	20% PT	36	0.05	120	13.0	602	0.98
L1	none	16	0.04	86	6.9	275	1.04
L1	5% S	58	0.12	56	10.4	365	0.92
L1	20% S	36	0.14	87	20.1	448	0.53
L1	5% PT	4	0.08	88	6.1	269	0.96
L1	20% PT	58	0.05	106	6.3	336	0.99
L2	none	13	0.05	97	9.0	602	1.22
L2	5% S	10	0.05	68	19.3	776	1.12
L2	20% S	44	0.06	63	19.0	457	0.87
L2	5% PT	5	0.07	79	10.0	593	1.23
L2	20% PT	51	0.07	94	10.1	736	1.06
SCL	none	4	0.06	26	2.8	249	1.11
SCL	5% S	7	0.11	25	6.1	333	0.95
SCL	20% S	8	0.16	129	6.6	391	0.65
SCL	5% PT	6	0.05	32	5.9	293	0.99
SCL	20% PT	16	0.07	44	5.3	301	0.99
CY	none	6	0.03	361	26.8	577	1.18
CY	5% S	238	0.09	228	34.5	924	1.05
CY	20% S	163	0.08	200	53.5	469	0.75
CY	5% PT	84	0.06	173	24.2	602	1.09
CY	20% PT	122	0.11	289	18.2	529	0.96
SN	none	3	0.06	26	5.1	426	1.54
SN	5% S	13	0.05	25	11.0	519	1.34
SN	20% S	11	0.07	25	7.2	388	0.97
SN	5% PT	11	0.04	36	4.8	499	1.47
SN	20% PT	11	0.04	62	6.2	406	1.32

Examination of the studentized residuals for Eq. 2 indicated that one observation, observation 50, was likely to be an outlier. When this observation was excluded and the regression recalculated, R^2 increased to 0.38 (Eq. 4, Table 6). An additional improvement in R^2 was obtained by excluding all observations for plants that were grown in sand or sand + organic amendments (Eq. 5, Table 6). It seemed reasonable to exclude these observations since sandy soils were not observed in the survey of irrigation canals. Examination of plots of the residuals versus the predicted values for Eq. 5 suggested that the relationship between hydrilla weight and the square root of Kjeldahl N and the square root of conductivity was linear.

DISCUSSION

In this study, hydrilla weight was positively associated with sediment organic matter content, over a range of organic matter values (1.5 to 27.2 %) and soil types similar to those found in several California irrigation canals. This is in contrast with the findings of Barko and Smart (1986) who reported that growth of Eurasian watermilfoil (*Myriophyllum spicatum* L.) and dioecious hydrilla was inversely related to sediment organic matter content. According to the data of Barko and Smart (1986), weight of Eurasian watermilfoil and hydrilla decreased most rapidly as the organic matter content of the sediment increased from 0 to 20%. Data from the present study do not show a similar relationship over this range of organic matter values. The difference may be partially due to differences in growth requirements for monoecious and dioecious hydrilla (McFarland and Barko 1987) and Eurasian watermilfoil.

An alternative explanation for differences between these results and those reported by Barko and Smart (1986) may involve differences in the quality of organic matter present in the two studies. Barko and Smart (1986) used surficial sediments collected from lakes and reservoirs. While organic sediments from lakes may be expected to be similar to soils from the uppermost A_0 horizon (Hansen 1959), there may have been differences between the sediments used by Barko and Smart (1986) and the soils used in the present study. For example, organic matter in lake sediments would be in various stages of decomposition (Wetzel 1983, p. 591) and that in the sediments used by Barko and Smart (1986) may have undergone greater or lesser decomposition than the peat or barley straw used in the present study. Differences are also indicated by the substrate C:N ratios. The mean C:N ratio for sediments used by Barko and Smart (1986) was 30.7. For the modified soils used in the present study the C:N ratio varied from 3.3 to 42.6 with an average value of 16.3. A conse-

TABLE 6. MULTIPLE REGRESSION RESULTS FOR VARIOUS EQUATIONS RELATING HYDRILLA WEIGHT TO SUBSTRATE PROPERTIES.

Parameter	Coefficient	SE of Coefficient	t-value
Eq. 1			
Intercept	1.478	1.012	1.460
Kjeldahl N[a]	0.117	0.025	4.741
R^2 = 0.215	Significance for regression = 0.0001		
Eq. 2			
Intercept	–2.784	1.792	–1.553
Kjeldahl N[a]	0.096	0.025	3.821
Conductivity[a]	0.232	0.296	2.828
R^2 = 0.286	Significance for regression = 0.0001		
Eq. 3			
Intercept	–2.841	1.807	–1.572
Kjeldahl N[a]	0.091	0.027	3.330
Conductivity[a]	0.215	0.092	2.330
Mn[b]	5.585	3.212	1.739
R^2 = 0.312	Significance for regression = 0.0001		
Eq. 4 (Eq. 2 excluding observation 50)			
Intercept	–2.853	1.454	–1.962
Kjeldahl N[a]	0.098	0.020	4.832
Conductivity[a]	0.222	0.067	3.330
R = 0.380	Significance for regression = 0.0001		
Eq. 5 (Eq. 4 excluding "sand" observations)			
Intercept	–2.816	1.357	–2.076
Kjeldahl N[a]	0.913	0.020	4.503
Conductivity[a]	0.224	0.062	3.628
R^2 = 0.438	Significance for regression = 0.0001		

[a]square root
[b]negative reciprocal

quence of this difference is that organic matter additions in the present study on average resulted in relatively more N being added to the substrate than would be expected at similar levels of organic matter in the sediments used by Barko and Smart (1986).

In field studies Kiorboe (1980) and Sand-Jensen and Sondergaard (1979) reported that areas of lake sediments with higher organic content were associated with higher levels of nutrients, especially N. Thus results from separate field and culture studies indicate that sediment organic matter content as measured by loss on ignition may not always be associated with decreased growth of rooted aquatic plants. It may be necessary to include some other property of the organic matter, such as the C:N ratio or another measure of nutrient content to explain the responses of rooted aquatic plants to additions of organic matter to the substrate.

Although the statistical relationship observed here does not address specific mechanisms relating substrate nitrogen to hydrilla growth, identification of organic N as an important regulator of monoecious hydrilla growth agrees with earlier studies. Steward (1984) reported that sediment Kjeldahl N was the best predictor of dioecious hydrilla growth. Keenan and Lee (1988) reported a similar finding for wild rice growing in Oval Lake. Carignan (1985) conducted a detailed study of sediment nutrient dynamics within a Eurasian watermilfoil bed in Lake Memphremagog, and concluded that mineralization of organic matter was an important source of NH_4^+, and that the quantity of NH_4^+ produced was comparable to that required by Eurasian watermil foil. Caffrey and Kemp (1990) studied N cycling in estuarine sediments inhabited by *Potamogeton perfoliatus* and *Zostera marina* and concluded that available sediment N was directly related to levels of organic matter inputs to the sediment.

Although the predictive capabilities of soil conductivity have not been reported in other studies, its inclusion in the regression equation improved predictive capabilities for the present results. Conductivity reflects levels of dissolved ionic materials in interstitial water and is a reasonable estimate of substrate nutrient levels. Its inclusion in the regression model is supported by the results of other studies which found that dioecious hydrilla growth was directly related to sediment fertility (Langeland *et al.* 1983; Bruner and Batterson 1984; Sutton 1985).

The fact that adding other sediment properties to the regression model did not noticeably improve predictive capabilities is probably due to the high correlations between Kjeldahl N, conductivity and the remaining variables. For example, soil conductivity was significantly ($P < 0.05$) correlated with the measures of K ($r = 0.52$), inorganic N ($r = 0.48$), Mn ($r = 0.43$), Mg ($r = 0.30$), pH ($r = 0.28$), and cation exchange capacity ($r = 0.30$) used in this study. The final equation (Eq. 5 in Table 6) suggests that the growth of hydrilla on fine-textured soils can be predicted reasonably well from a knowledge of the Kjeldahl N content and conductivity of the soil. Eq. 5 is, of course, appropriate for situations where growing conditions (i.e., temperature and light) are similar to those used in this study.

Altering organic matter content of sediments has been proposed as a potential method for managing growth of rooted aquatic plants (Gunnison and Barko 1989). Organic materials such as straw or peat would be likely materials for use in some areas since they may be relatively abundant. Findings from this study and elsewhere suggest that organic matter used in such an approach should be carefully evaluated before it is applied on a large scale. The results of this study also suggest that the addition of some types of organic matter to fine-textured soils actually may enhance growth of rooted aquatic plants, rather than suppress growth.

Barko and Smart (1986) proposed a mechanism to explain reduced macrophyte growth on organic sediments. They suggested that the addition of organic matter to sediment increased the diffusion distances for nutrient ions and resulted in reduced macrophyte growth. The present findings and those reported elsewhere suggest that this mechanism may not apply for all types of organic matter, especially that having high available N content. Results from this study support the suggestion by others (Carignan 1985; Keenan and Lee 1988; Barko *et al.* 1988; Caffrey and Kemp 1990) that understanding the interactions between sediment organic matter and the structure and dynamics of N pools in sediments may enhance capabilities for predicting the distribution and abundance of rooted aquatic plants.

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

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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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