Effects of Light Quality on Growth and Chlorophyll Composition in Hydrilla[1]

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ABSTRACT

Growth characteristics of hydrilla (*Hydrilla verticillata* (L.F. Royle) grown under equal photon flux density at various portions of the visible spectrum were compared. Stem elongation was most pronounced under green light, whereas shorter and highly-branching plants were produced under red light. Dry weight yields were higher under red and blue light, while green and white light produced the lowest yields. The total chlorophyll content was not affected by these light quality regimes. However, the chlorophyll a:b ratio was lower in plants grown under green light than in other treatments. A similar decrease in the a:b ratio was observed in hydrilla plants sampled at increasing water depths under natural conditions. In vallisneria (*Vallisneria neotropicalis* Marie-Vict.), however, no change in the a:b ratio was observed under similar natural conditions. The changes in chlorophyll composition, in favor of chlorophyll b, is discussed in terms of a possible adaptation by hydrilla to the spectral change of solar radiation in deeper waters.

INTRODUCTION

Hydrilla and vallisneria are both submersed fresh-water angiosperms in the family Hydrocharitaceae. Since hydrilla was found in Florida in 1960, this species has proved to be extremely competitive and has become the most troublesome aquatic weed in the State. The rapid rate with which hydrilla spreads and dominates the vascular flora in many water bodies is probably related to its very efficient utilization of light (9) and its prolific asexual reproduction by subterranean propagules or tubers (7). Haller and Sutton (7) also noted that the growth habit of hydrilla in forming a canopy near the water surface reduces light penetration and enables it to outcompete certain desirable, native aquatic plants such as vallisneria. Moreover, hydrilla can adapt effectively to shade environments (4), such as may be found in deeper parts of a lake.

The light penetration in water is characterized by a change in spectral composition with depth, because of the different absorption coefficients in water of radiant energy of different wavelengths. In very clear waters, the deepest penetration of light is by blue wavelengths. However, in lakes with normal concentrations of dissolved organic compounds, it is common for the green and longer wavelengths of the visible spectrum to penetrate most deeply (11). It has been shown that many marine algae and phytoplankton living at different depths or in different waters can adapt their pigments to take advantage of these differences in spectral composition (10). The changes in pigment concentration as a function of wavelength are frequently discussed in terms of Engleman's theory of chromatic adaptation (6).

The effects of various portions of the spectrum on the pigment content and growth of vascular aquatic plants has not been studied as extensively as it has been with marine algae and phytoplankton. For rooted submersed aquatic plants, chromatic adaptation would be especially important to new growth in early spring when the plants are growing under a maximum depth of water. Blackburn et al. (3) measured elongation of Brazilian elodea (*Egeria densa* Planch.) and water stargrass (*Heteranthera dubia* (Jacq.) MacM.) grown under equal illuminance at various portions of the visible spectrum. They reported that both aquatic species elongated rapidly under red light, but water stargrass grew three times faster under green light than under white light. However, stem elongation may be solely a morphogenetic response to different wavelengths of the spectrum (8) and is not necessarily correlated with growth in terms of photosynthetic dry matter production. Further, these experiments were performed with light intensities calibrated and equated in terms of foot candles. It is now widely recognized that quantum or absolute energy values would be more desirable for these studies. Wilkinson (12) observed that the light compensation points for coontail (*Ceratophyllum demersum* L.) and water stargrass were lower under red light, suggesting that spectral selectivity is probably an important factor in aquatic plant growth. Dutton and Juday (5), however, failed to correlate the pigment composition of several pondweeds (*Potamogeton* spp.) with their natural depth distribution in a lake. Further, they found no evidence of chromatic adaptation in vallisneria.

In the present study, hydrilla was grown under equal photon flux densities from different regions of the spectrum. Their pigment composition was then analyzed and compared with that in plants sampled at different depths under natural conditions.

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[1] This study was supported in part by a Florida Department of Natural Resources Research Grant, and by special funds from the Center for Environmental Programs of the Institute of Food and Agricultural Sciences. Published as Journal Series No. 498 of the Florida Agricultural Experiment Station.

METHODS AND MATERIALS

Hydrilla and vallisneria were collected from adjoining earthern ponds in Orange County, Florida. The plants were pulled from the hydrosoil and 5-cm sections from depths of 0.0, 0.5, 1.0, and 1.5 m were placed in glass jars containing pond water. The jars were stored overnight in ice, and chlorophyll content was determined the following morning. Chlorophyll was determined by the method of Arnon (1).

Hydrilla tubers were collected from the Kenwood area, Rodman reservoir, Florida. Tubers were selected for uniform size and germinated in glass trays filled with distilled water. The trays were placed inside four open-topped boxes. Each box was covered with a cellophane filter of a different spectral transmittance corresponding to the blue, red, and green regions of the spectrum, with white as a control. The light source was a combination of four General Electrics Cool-White 40-W and two Sylvania Gro-Lux 40-W fluorescent bulbs. The distances between the trays and the light source were adjusted so the photon flux densities at the level of the tubers were approximately 30 μeinstein/m^2•sec (400-700 nm) in each box. Photon flux density was determined with a Lambda quantum meter, model LI-185. The relative transmittance through the cellophane filters was measured with a Beckman scanning spectrophotometer, Model 25 (Figure 1). Except for a small peak in the ultraviolet, the red filter transmitted only wavelengths above 580 nm. The blue and green filters showed peaks at 380-480 nm and 500-540 nm respectively, but did not completely exclude other wavelengths. Preliminary experiments indicated no differences in the percent germination of hydrilla tubers under these different light quality regimes. Three young shoots developing from tubers were planted in a 5-cm^2 plastic pot filled with washed sand. Four pots were placed in each 3.8-liter culture jar, and each light quality treatment contained two jars. The jars were filled with water from Orange Lake supplemented with 5% Hoagland's solution and 50 ppm $NaHCO_3$. The water was changed every 2 weeks. The photoperiod during the experiment was 16-hr day and the temperature was kept at 25 ± 3 C. At the end of each test period, two pots in each jar were harvested and each pot was considered a replicate for statistical comparison.

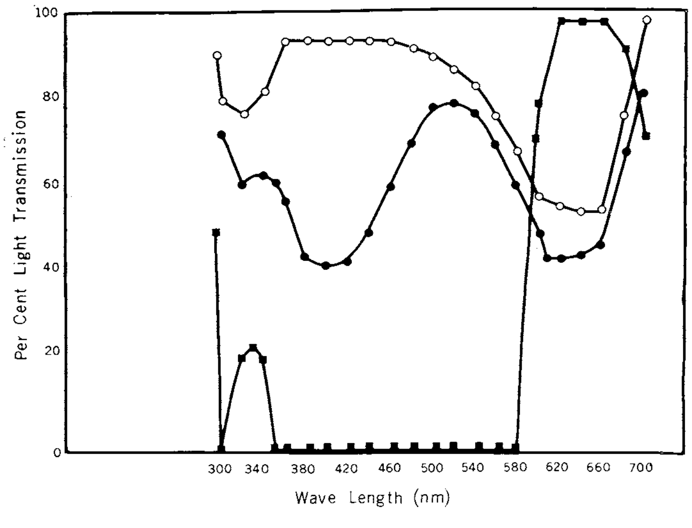

Figure 1. The spectral transmittance of light through red, green, and blue cellophane filters. Square is red filter; open circle is blue filter; and filled circle is green filter.

RESULTS AND DISCUSSION

The chlorophyll content of hydrilla and vallisneria plants grown in water 1.5 m deep is shown in Table 1. Plant samples for chlorophyll analyses were taken from water depths of 0.0 (surface), 0.5, 1.0, and 1.5 m. With the exception of hydrilla at the water surface, the total chlorophyll in these two aquatic species was generally less than 1.0 mg Chl/g fr wt. The low chlorophyll content probably reflects the low percent dry weight in submersed aquatic species, being about 6 to 8% as compared to 20 to 30% in terrestral plants. Further, hydrilla and vallisneria have lower chlorophyll a:b ratios than are found with terrestral plants. Black (2) classified the a:b ratios of C_3 plants between 2.4 and 3.2, and C_4 plants between 3.3 and 4.5. The range of a:b ratios in the two submersed aquatic plants studied was 1.15 to 2.27 (Tables 1 and 3). The relatively higher proportion of chlorophyll b found in these species suggests that this pigment may play a role in aquatic plant production, probably by enabling the plants to more effectively use longer wavelengths of light for photosynthesis.

TABLE 1. CHLOROPHYLL CONTENT OF HYDRILLA AND VALLISNERIA AS A FUNCTION OF WATER DEPTH.[a]

Species	Depth (m)	Chlorophyll Content (mg/g fr wt)			Chlorophyll a/b Ratio
		a	b	total	
Hydrilla	0.0	0.7835 d	0.4420 c	1.2252 d	1.77 cd
	0.5	0.3787 c	0.2408 b	0.6194 c	1.57 b
	1.0	0.2887 b	0.1784 a	0.4667 b	1.54 b
	1.5	0.1736 a	0.1508 a	0.3253 a	1.15 a
Vallisneria	0.0	0.5296 c	0.3012 c	0.8270 c	1.96 cd
	0.5	0.5011 c	0.2392 b	0.7402 bc	2.09 d
	1.0	0.4062 b	0.2262 b	0.6323 b	1.94 cd
	1.5	0.0842 a	0.0411 a	0.1227 a	2.00 d

[a] Values in a column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Each value is the mean of four replications.

A general decrease in the total chlorophyll content with increasing water depths was observed in both hydrilla and vallisneria (Table 1). In vallisneria, however, the chlorophyll a:b ratios remained constant at all water depths. On the other hand, the a:b ratios of hydrilla decreased from 1.77 at the water surface to 1.15 at the 1.5 m depth. Hydrilla sampled for chlorophyll analyses had longer internodes at greater depths. This increase in proportion of stem to leaf may contribute, at least partially, to the lower total chlorophyll content and lower chlorophyll a:b ratios at increasing water depths. The differential change in chlorophyll composition, in favor of chlorophyll b, also suggests a possible adaptation by hydrilla to the spectral changes in deeper waters. In light-limited systems, such pigment adaptation could have a pronounced effect on production.

In an attempt to determine if pigment adaptation occurs in hydrilla, the plants were grown under light of different spectral compositions and their photosynthetic pigments were analyzed. Table 2 shows some growth characteristics of the 2-week old hydrilla plants grown under the four different light quality regimes. Stem elongation was most pronounced under the green light, whereas plants grown under red light were shorter, stockier, and highly-branched. Red light was the most effective in inhibiting stem elongation. Meijer (8) reviewed some morphogenetic effects by lights of different spectral regions on terrestrial plants. He observed that both red and blue wavelengths decreased stem elongation, and the red was more effective in this respect than the blue, at relatively low light intensities. Our results with hydrilla (Table 2) confirm these findings. The red light effect in decreasing stem elongation and promoting branching suggest that the red portion of the visible spectrum may be responsible for the growth habit of hydrilla in forming a dense canopy at the water surface where these wavelengths are more available. In deeper waters, lower light intensities and green wavelengths may promote internode elongation with a limited amount of branching which in effect causes hydrilla to elongate toward the water surface where more light is available for photosynthesis.

TABLE. 2. GROWTH OF HYDRILLA GROWN FOR 2 WEEKS UNDER FOUR DIFFERENT LIGHT QUALITIES.[a]

Light Color During Growth	Shoot Length (mm)	Number of Branches	Fresh Weight (g)	Dry Weight (mg)
White	106 bc	4.8 ab	0.867 a	51.0 ab
Green	142 a	3.5 b	0.756 a	47.4 b
Blue	112 b	4.3 ab	0.973 a	59.1 ab
Red	83 c	5.9 a	0.891 a	65.7 a

[a] Values in a column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Each value is the mean of four replications.

At the end of the 2-week test period (Table 2), the differences in fresh weights were not significant among the different light quality regimes. On a dry weight basis, however, green light produced the lowest yield. With a 5-week growth period (Table 3), the yield differences were more apparent. The relative effectiveness of the various portions of the spectrum was red, blue, white, and green, with red light causing significantly higher yields and the lowest yield being obtained under green light. Thus, when light intensities are equalized in quantum terms, the relative efficiency of different wavelengths in increasing yields in hydrilla appears to follow the absorption spectrum of chlorophyll.

TABLE 3. YIELDS AND CHLOROPHYLL COMPOSITION OF HYDRILLA GROWN FOR 5 WEEKS UNDER FOUR DIFFERENT LIGHT QUALITIES.[a]

Light Color During Growth	Fresh Weight (g)	Dry Weight (mg)	Chlorophyll Content (mg/g fr wt)	Chlorophyll a/b Ratio
White	1.884 ab	114.3 b	1.132 a	2.27 a
Green	1.824 b	111.0 b	1.313 a	1.95 b
Blue	2.487 a	162.9 a	1.180 a	2.22 a
Red	2.523 a	172.5 a	1.260 a	2.01 ab

[a] Values in a column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test. Each value is the mean of four replications.

No difference in the total chlorophyll contents was observed under the four different light regimes (Table 3). However, the chlorophyll a:b ratio was lower in plants grown under green light than in other treatments. These pigment changes, with relative increase in the amount of chlorophyll b, under green light and at deeper waters (Table 1) may indicate an adaptation by hydrilla to the prevailing radiation under which they are grown. However, because the green filter used did not completely eliminate red and blue wavelengths, this conclusion has to remain speculative. Also, several other pigments such as carotenes and xanthophylls, as well as light penetration in Florida waters should be investigated to further clarify the role of chromatic adaptation in aquatic vascular plants.

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