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The laser as a light source for the photosynthesis and growth of *Chlorella vannielii*

The development of the laser has added a new tool to those available to the photobiologist. The coherence and relatively high light intensities obtainable make these instruments useful for photosynthetic studies. Although reports exist using lasers to produce rapid absorption changes in photosynthetic intermediates[1–4] nothing has been done to compare the effects of coherent light[5,6] to incoherent light over long time periods on photosynthetic organisms.

The work reported here contrasts the effects of light from a Spectra-Physics Model 112 helium–neon continuous-wave gas laser, emitting light of 6328 ± 0.01 Å, a Bausch and Lomb 500-mm grating monochromator set at 633 mμ, half-band width 20.8 mμ, and a tungsten source with an infrared filter on *Chlorella vannielii* Shihira and Krauss. Inocula for the experiments were maintained in 18 mm × 150 mm test tubes on inorganic medium at 25°, bubbled with 1 % CO_2-in-air and irradiated from two sides with two banks of 40-W cool white fluorescent lamps. The light intensity was adjusted to 10000 lux per bank. Frequent transfers assured that they were in the optimal exponential phase of growth.

TABLE I

GROWTH RATES OF *C. vannielii* IRRADIATED WITH WHITE LIGHT AND WHITE LIGHT *plus* LASER LIGHT

The cultures were placed in a dark growth chamber and irradiated from one side with various intensities of white light (*W*). One set of cultures in addition to the white light received 12.3 mW/cm² of laser light (*W* + *L*) delivered on a 0.632-cm² area at the bottom of the test tube culture. The inorganic cultures were incubated at 25° and bubbled with 1 % CO_2-in-air for 24 h.

White light (lux)	*Doublings per day*		*Difference*
	W	*W + L*	
0	0.0	0.9	0.9
860	0.5	1.6	1.1
4 300	2.3	2.7	0.4
8 600	3.1	3.2	0.1
12 900	3.2	3.3	0.1
23 700	3.5	3.5	0.0
43 000	3.9	3.8	–0.1

The growth of the algae over 24 h was stimulated when 12.3 mW/cm² of 6328-Å laser light was superimposed on white light up to 12900 lux of white light (Table I). These data show that no detriment to the overall performance of the organism resulted from the laser radiation.

Further studies illustrate (Table II) that 24 mW/cm² of 6328-Å laser light was sufficient for growth of *C. vannielii*. In comparison to white light of equal intensities the laser was 20 % more efficient at 25° and 100 % more efficient at 30° over 24 h.

The steady-state photosynthetic rates of the alga were compared by monitoring the rate of oxygen evolution with a platinum-electrode system of our own design. The linearity of the sensor was established using known amounts of oxygen. Oxygen

TABLE II

COMPARISON OF THE GROWTH RATES OF *C. vannielii* IRRADIATED WITH WHITE LIGHT AND LASER LIGHT ON INORGANIC MEDIUM AND GLUCOSE MEDIUM AT 25° AND 30°

The inorganic and glucose cultures had an initial absorbance of 0.02–0.05 were bubbled with 1 % CO_2-in-air and contained in 18 mm × 150 mm test tubes. The tubes were irradiated from the bottom for 24 h with 24 mW/cm^2 either white light or laser light.

Light	*Temp.*	*Medium*	*Doublings per day*	*Ratio of rates*
Laser	25°	Inorganic	1.6	1.2
White	25°	Inorganic	1.3	
Laser	30°	Inorganic	1.2	2.0
White	30°	Inorganic	0.6	
Laser	25°	Glucose	2.9	1.0
White	25°	Glucose	2.8	

evolution rates were compared employing the laser, white light, and light from a monochromator. The light beams were compared in two ways; first by adjusting the beams to equal intensities and measuring the photosynthetic rate, and second by adjusting the beams to an intensity such that the photosynthetic rates were equal prior to measuring the intensities. These data (Table III) show that the laser light is 20–30 % more efficient than either white light or light from a monochromator.

An explanation for the greater long-term photosynthetic efficiency obtained in laser light can be looked for in the ordered nature of coherent radiation. The current view of steady-state photosynthesis indicates a quantum requirement of nine for the overall process and a minimum of 4 quanta for each molecule of oxygen produced[7]. The efficiency of utilization of many quanta evidently depends on the rate of delivery

TABLE III

RATE OF PHOTOSYNTHETIC OXYGEN PRODUCTION BY *C. vannielii* IN THREE DIFFERENT LIGHT BEAMS

The cultures were irradiated with laser light, light from a monochromator, and white light. The three light beams were adjusted to equivalent configuration. Each beam had a diameter of 1 cm at the surface of the culture vessel. The photosynthetic rates produced by the beams were matched by adjusting the intensities of the beams. Then the beams were adjusted to equal intensities and the relative photosynthetic rates recorded.

Light	*Intensity* (mW/cm^2)	*Ratio of intensity*	*Rate of photosynthesis*	*Ratio of rates*
Laser	3.1	1.2	2.3	1.0
White	3.7		2.3	
Laser	3.1	1.0	2.3	1.3
White	3.1		1.8	
Laser	1.0	1.3	1.2	1.0
Monochromator	1.3		1.2	
Laser	1.3	1.0	1.1	1.2
Monochromator	1.3		0.9	

to the system; for, DUYSENS[8] has demonstrated with Chlorella that the fluorescence yield is less the higher the intensity of a flash. It may be assumed that the lower yield indicates more efficient utilization of the quanta in photosynthesis *per se*. The data with the laser, showing more efficient growth in coherent radiation, reflect a similar phenomenon. Consequently this simultaneous arrival of quanta, periodically in large numbers, apparently provides more efficient alternatives than the photosynthetic trapping system normally has at its disposal in the light-dependent region. That the long term result is a more effective use of light quanta is obvious from the data presented in this paper.

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Department of Botany,
University of Maryland,
College Park, Md. (U.S.A.)

EDWARD P. KARLANDER
ROBERT W. KRAUSS

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