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A Photosynthetically Active Radiation Sensor

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Abstract. A sensor for measuring photosynthetically active radiation was constructed using a silicon photocell in combination with a glass absorption filter. A trimmer potentiometer was used for standardization of sensor output. The sensors were calibrated using a commercially available quantum sensor. Average correlation coefficient between constructed sensors and the standard was 0.94. The sensors had a quantum response, were sensitive only in the wavelengths between 400 and 700 nm, exhibited a linear response to varying PAR light levels, and were inexpensive to construct.

Light levels inside tree canopies influence fruit production and quality. Levels of photosynthetically active radiation (PAR) above 30% full sun were reported as necessary for sufficient flowering of spurs in apples (2, 4, 5, 10). In peaches, Kappel (7) indicated that fruit maturity increased with percent sky, and Johnson (6) found that 92% shade reduced fruit size and that the intensity of blush coloration was correlated with light levels.

Measurement of PAR is essential in studies of light relationships in tree canopies. Uranylactate actinometers (3), fisheye photography (9), and integrating pyranometers (8) have been used to measure it.

PAR sensors based on photocell/filter combinations have been developed (1, 12, 13). This paper describes a sensor that has the advantages of low cost, small size, and versatility. Values integrated over time or space as well as single readings may be obtained.

A standard 1 × 1 cm silicon photocell

(TOI, Texas Optoelectronics Inc. Garland, Texas) was used in combination with a glass absorption filter (BG38, Schott Optical Glass Inc., Duryea, Pa.). A silicon photocell was chosen mainly because of the low temperature coefficient and small time constant. Silicon photocells do not fatigue as selenium photocells do. The circuit configuration is a resistance in series with sensor output current (Fig. 1). The readings are taken in millivolts, with a resistance load below 100Ω; and the output voltage of the cell can be adjusted to a range from 0 (total obscurity) to ≈10 mV (solar noon on clear, bright days).

The body of the sensor was machined from a piece of transparent plastic into a U-shaped block (Fig. 2A). Another plastic block was cut to fit the slot in the sensor body (Fig. 2E). A hole was drilled in this block to allow passage for the wire from the photocell.

The filter (Fig. 2D) was cut in 1 × 1 cm squares to fit the shape and size of the photocell. The filter was glued 0.5 cm below the top of the sensor body. The photocell (Fig. 2C) was placed under the filter, the cell wires soldered to a shielded cable, and the cable passed through the hole in the block that was used to close the slot in the sensor body. The hole in the block was filled with silicon glue to ensure a seal.

The space below the photocell was filled either with rubber foam or with another plastic block (Fig. 2B). A flat piece of plastic (Fig. 2G) was glued to the bottom of the

sensor. All plastic parts were glued together with methylene chloride.

The top of the sensor was made of diffusive Plexiglas (Fig. 2F) to provide cosine correction. The sensors were covered with black electric tape, leaving a 1 × 1 cm window of diffusive Plexiglas above the photocell. Trimmer potentiometers (100Ω, 10 turn) were used for standardization of sensor output.

Calibration of 10 sensors was performed by paired readings taken on a clear day using a Lambda Quantum Sensor (Li 190S, LICOR) as a reference. Turning the screw on the potentiometer allowed for adjustment of output of each individual sensor. After calibration, the sensors and the Li 190S were compared for uniformity of reading under

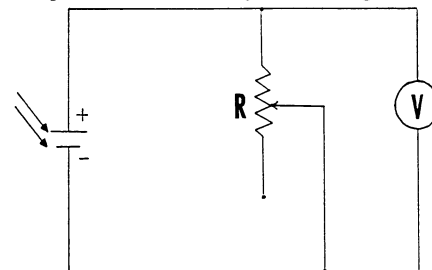


Fig. 1. Circuit diagram of photosynthetically active radiation sensor.

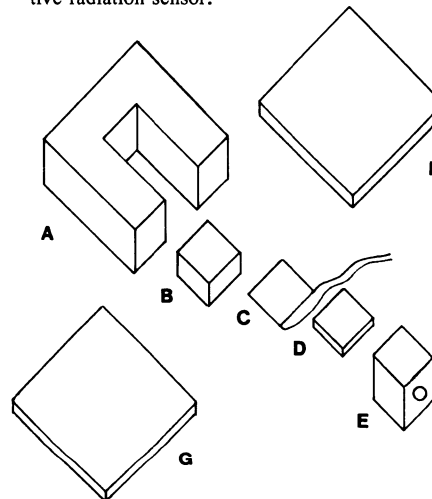


Fig. 2. Construction of sensor: (A) plastic body, (B) block of plastic for securing photocell, (C) photocell, (D) filter, (E) block of plastic to seal sensor, (F) diffusive Plexiglas top, and (G) plastic bottom.

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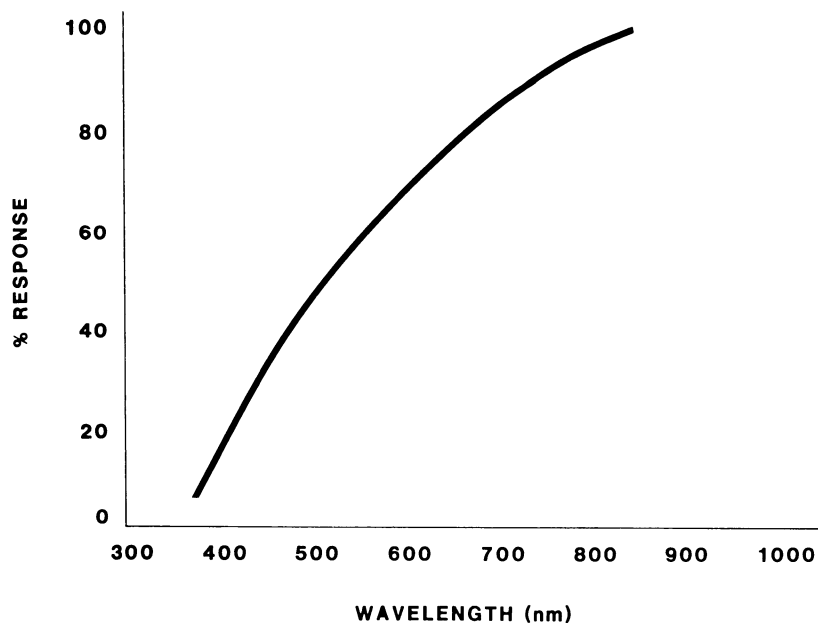


Fig. 3. Response of silicon photocell at varying wavelengths.

the same light conditions. They were set on the ground on a clear day and connected to an HP 3421 (Hewlett Packard, Corvallis, Ore.) data logger, which was programmed to scan each sensor every 3 min for 3 hr and 15 min (from 1100 to 1415 HR EDT).

A conversion factor of $200 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ per mV was used to convert millivolt readings into photosynthetic photon flux (PPF) values. Paired readings were taken during Summer 1985, and acceptable accuracy of the conversion factor was found (data not shown).

The photocell's sensitivity begins at wavelengths slightly below 400 nm and increases with increasing wavelength up to ≈ 900 nm (Fig. 3). This range demonstrates the quantum response characteristic of silicon photocells. The filter is necessary to eliminate the radiation of longer wavelengths. Particularly important when using a silicon photocell is the cut-off at the near infrared region, between 700 and 750 nm.

Interference-type filters provide good optical characteristics, but they require that light strikes them at a specific angle. It is possible to include in the sensor an optical system to satisfy this requirement, but the dimensions and the cost of the unit would increase considerably (11). Spectral correction by absorption filters is not quite as good, but performance improves under scattered light conditions such as in tree canopies. A glass absorption filter was used because the stability under field conditions was greater than that provided by wratten gelatin filters. These transmittance values for the filter (Fig. 4) are comparable to those found in other sensors (1). The cutoff between 700 and 750 nm ensures blocking of the near-infrared radiation, which is usually found inside canopies. In the UV region, no cutoff is necessary since the silicon cell does not respond to UV radiation.

A linear relationship was found between the means of readings of the sensors and those

of the LI-COR sensor (Fig. 5). The equation for this line is $y = 0.29 + 1.08 x$, with $r = 0.94$. Correlation coefficients for individual sensors ranged from 0.88 to 0.97. The diffusive Plexiglas corrected only for angles of incident radiation up to 30° . Biggs et al. (1) indicated that a flat diffusive head can correct for angles only up to 30° from the vertical: at greater angles, significant error develops. Kerr et al. (8) described a cosine-corrected head that corrects for angles up to 84° from the vertical. Such a head could be adapted to this sensor; however, for the purposes of this study, it was not considered necessary to provide the sensors with it. For this reason, the calibration runs were always performed at mid-day hours, when the angle of the sun from the zenith is $< 30^\circ$. To expand the range of tested readings, reduced light levels were imposed by using artificial shading.

The voltage output of similar silicon cells is not identical under the same light condition, even when good care is taken in manufacturing. The current output is not linear with light intensity, but can be made linear by placing a trimming potentiometer resistance in series with the sensor output current. With adjustable resistance, the responses of different photocells can be standardized and made uniform.

Sensors for measurement of PAR should have a quantum response, be sensitive only in the range of 400 to 700 nm, and exhibit a linear response to varying light levels. In addition, to ensure reliability, they should have low temperature coefficients, small time constants, and good stability and under field conditions. Last, they should not be expensive, since the type of studies in which they are usually involved requires large numbers of them. The sensors described here meet these performance criteria and can be constructed inexpensively.

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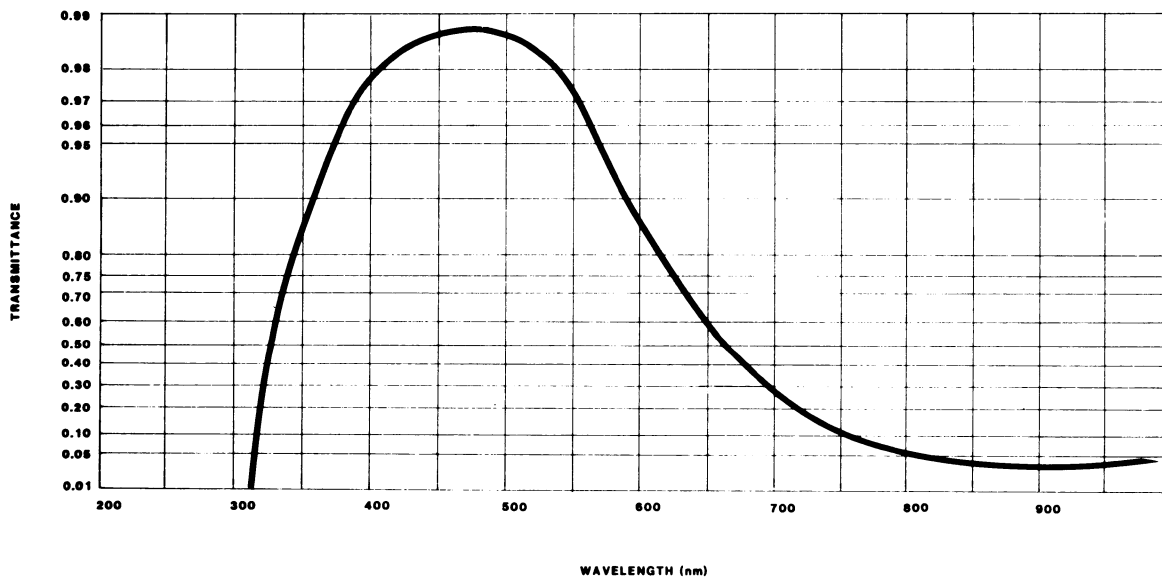


Fig. 4. Transmittance of BG38 glass absorption filter at varying wavelengths.

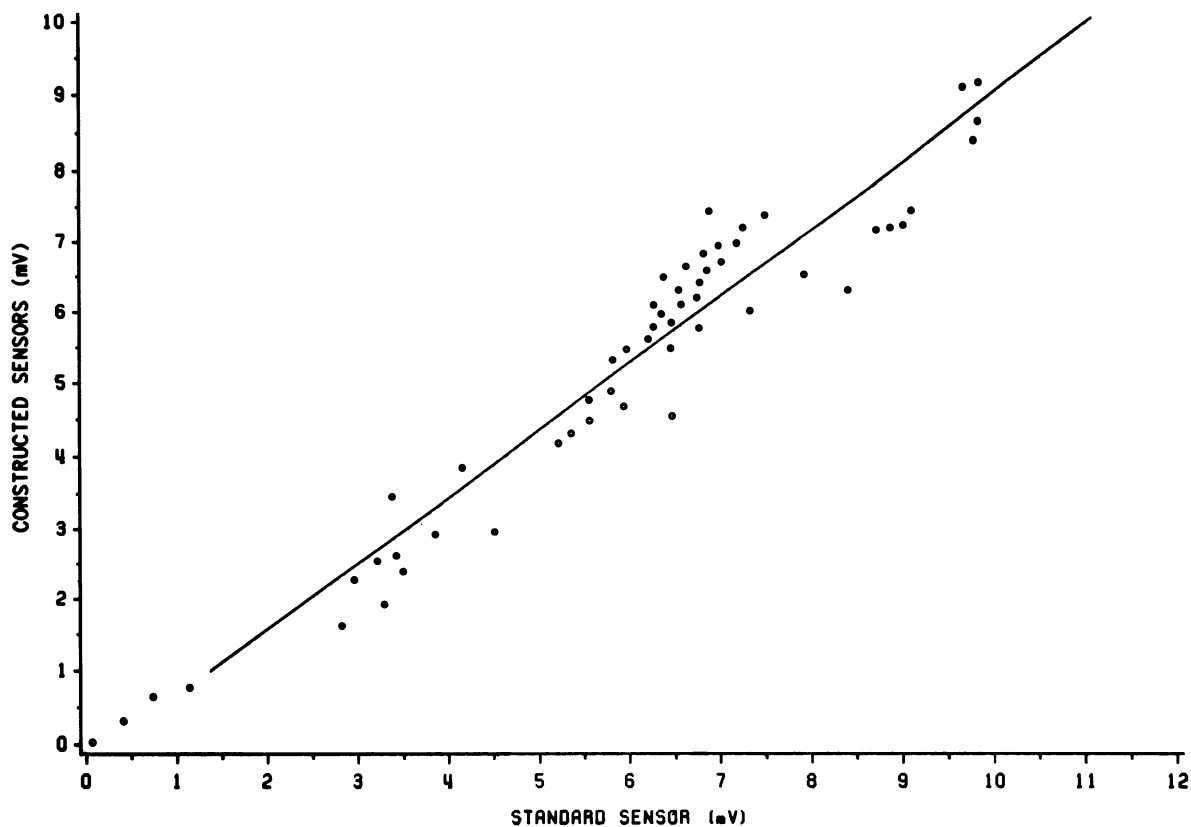


Fig. 5. Regression line between standard sensor readings and average of constructed sensors (mV).

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