Estimating Phytochrome Photoequilibrium with Red / Far Red Sensors and PAR-FAR Sensors

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Phytochrome, a pigment in plant leaves, regulates stem elongation and leaf expansion. Multiple studies have been conducted to measure phytochrome absorption and conversion rates (Butler et al., 1964; Gardner and Graceffo, 1982; Sager et al., 1988). One of the results of these studies was development of phytochrome photoequilibrium (PPE), the ratio of active phytochrome to total phytochrome. An estimate of PPE from spectral measurement of light sources used to grow plants can be used as metric for characterizing influence of a specific light source and lighting environment on plant morphology. This requires a spectroradiometer to make the spectral photon flux density measurement.

The red to far red ratio (R / FR) has been used as a proxy measure of PPE for characterizing light sources because phytochrome has absorption peaks at about 665 nm and 730 nm (Figure 1), in the middle of the red and far red ranges, respectively. Thus, only red and far red photon flux density measurements are required. Both metrics, PPE and R / FR, work well in sunlight because it contains a relatively uniform distribution of light across the red range and far red range. In other words, sunlight does not have large, narrow output bands like most electric light sources.

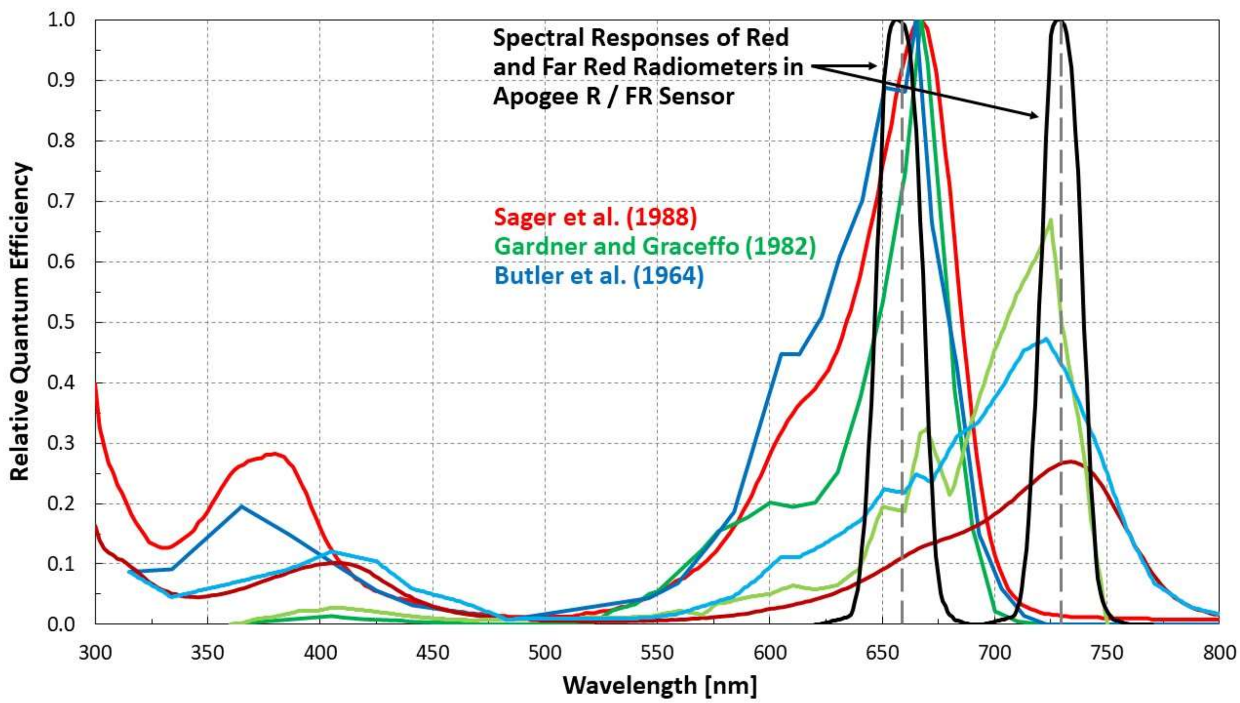

Figure 1. *Phytochrome red and far absorption peaks from three studies (colored lines) and spectral responses of the red and far radiometers in the Apogee R / FR sensor (black lines). The traditionally accepted phytochrome absorption peaks are 660 nm and 730 nm (vertical dashed lines).*

Recently, the percentage of far red photons (summed from 700 to 760 nm) relative to photosynthetically active photons (summed from 400 to 700 nm) was found to be a better predictor of stem length and leaf area than PPE or R / FR, independent of the spectral output of the light source (Kusuma and Bugbee, 2019).

Sensors to measure R / FR and the FAR-PAR ratio (percentage of far red photons relative to photosynthetically active photons) are available from Apogee Instruments. **The R / FR sensor (model S2-131) is recommended for measurements in sunlight where comparison to historical R / FR data is desired.** Measurements of R / FR from sensors from Apogee Instruments and Skye Instruments were compared to R / FR measured with a spectroradiometer under full sunlight and in the shade beneath a plant canopy (Table 1). The Apogee sensor matched the R / FR measurement from spectroradiometer better than the Skye sensor, likely because the spectral response of the red and far red detectors in the Apogee sensor better match the phytochrome red and far red peaks. Calibration of the red and far red detectors may also influence the R / FR ratio.

Table 1. *Comparison of R / FR ratio measurements from Apogee Instruments and Skye Instruments Sensors to R / FR ratio measurements from a Spectroradiometer.*

Sensor	Full Sunlight	Shade Underneath Plant Canopy
Spectroradiometer*	1.11	0.24
Apogee R / FR	1.08	0.22
Skye R / FR	1.04	0.51

**An Apogee Instruments model PS-300 was used to make spectral photon flux density measurements. Photon flux density was integrated from 645-685 nm for red and 710-750 nm for far red because these bands approximate the phytochrome absorption peaks.*

The PAR-FAR sensor (model S2-141) is recommended for measurements of electric lights. Not only does it provide the FAR-PAR ratio (percentage far red photons relative to photosynthetically active photons), indicating the influence of the lighting environment on plant morphology, but it also provides measures of the photons driving photosynthesis, PAR and FAR.

References

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