Analysis of Spectral and Cosine Errors in Quantum Sensors

Mark Blonquist[1] & Bruce Bugbee[2]

[1]Apogee Instruments, Inc., Logan, UT
[2]Plants, Soils, & Climate Dept., Utah State University

Definitions

Photosynthetically Active Radiation (PAR): radiation that drives photosynthesis

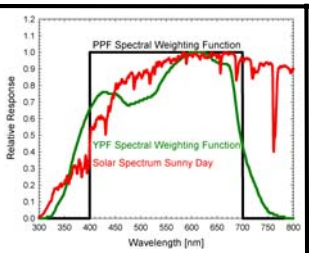
Photon Flux (PF): number of photons that flow through a unit area per unit time (e.g. μmol m^{-2} s^{-1}, mol m^{-2} d^{-1})

Photosynthetic Photon Flux (PPF): photon flux integrated over the 400-700 nm waveband

Yield Photon Flux (YPF): photon flux weighted and integrated according to plant response (McCree, 1972a; McCree, 1972b; Inada, 1976; Sager, 1988)

Quantum: one mole of photons

Quantum Sensor: transducer designed to measure PPF, or potentially YPF

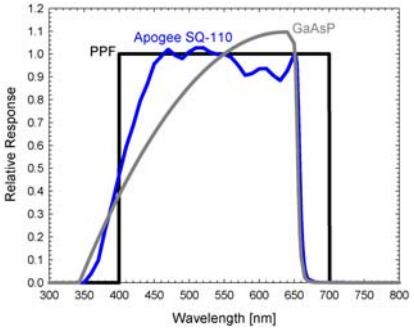


PPF = 2000 μmol m^{-2} s^{-1}
YPF = 1798 μmol m^{-2} s^{-1}

YPF is better correlated to **photosynthesis**, and spectral response is similar among species

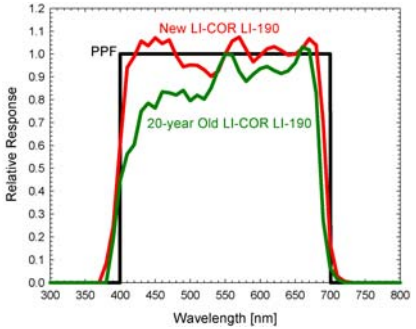
PPF is easier to define and measure, and **widely accepted**

Sensor Spectral Responses



GaAsP photodiodes cutoff at approximately 650 nm and are more sensitive to longer (**red**) versus shorter (**blue**) wavelengths

Apogee SQ-110 (sunlight) and SQ-120 (electric light) quantum sensors use a **blue filter** (diffusion disk) to counteract the lower sensitivity at shorter wavelengths

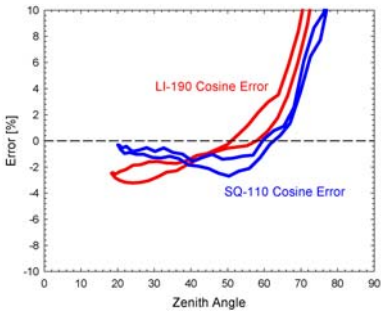


LI-COR LI-190 quantum sensors use a **series of filters** to approximate the PPF spectral weighting factors.

Spectral response to **blue** wavelengths decreases with age. This may also happen in Apogee sensors. It cannot be fully corrected by recalibration with the LI-1800 optical radiation calibrator.

Cosine Responses

Reference for cosine response calculation is a Kipp & Zonen model CM21 pyranometer (calibrated at NREL) with **zenith angle-dependent factors** applied to calculate PPF



Error for both models is **approximately 5 %** at a 70˚ zenith angle

Relative Advantages

Apogee Instruments Models SQ-110 and SQ-120

-Lower cost ($139 versus $365)
-More rugged (no internal air space, single filter)
-Dome shape (self-cleaning, doesn't trap water and dust)
-Higher output (400 mV versus 10 mV at 2000 μmol m^{-2} s^{-1})

LI-COR Model LI-190

-Higher accuracy under all conditions (one calibration, less than ± 5 % error)
-Most widely used (industry standard)

Relative Spectral Comparisons

The method of Federer and Tanner (1966) was used to determine **quantum sensor spectral errors for PPF measurement** based on radiation source spectral outputs and sensor spectral responses.

The method calculates spectral error only and does not consider **cosine** and **calibration** errors

PPF Spectral Errors – Relative to Sunlight (Clear Sky)

Radiation Source	LI-COR New*	LI-COR New	LI-COR 20-year Old	Apogee Blue Filter	Unfiltered GaAsP Diode
Sun Clear Sky	0.0	0.0	0.0	0.0	0.0
Sun Cloudy Sky	--	0.2	-0.2	0.8	0.1
Under Corn Leaf	--	-0.8	4.7	9.9	19.1
Under Pepper Leaf	--	-0.8	4.6	10.4	20.3
Under Soybean Canopy	1.9	--	--	--	--

PPF Spectral Errors – Relative to Cool White Fluorescent

Radiation Source	LI-COR New*	LI-COR New	LI-COR 20-year Old	Apogee Blue Filter	Unfiltered GaAsP Diode
CWF T12	0.0	0.0	0.0	0.0	0.0
CWF T8	--	-0.3	0.8	0.5	0.8
Compact Fluorescent	--	-0.8	1.5	-0.7	2.2
Metal Halide	0.1	-0.5	-1.6	-1.5	-3.2
High Pressure Sodium	0.1	0.2	2.0	-1.3	7.3
Incandescent	-1.8	-4.2	-6.1	-28.0	-27.1

*Data from LI-COR Technical Note #126 Comparison of Quantum Sensors with Different Spectral Sensitivities

YPF Spectral Errors – Relative to Sunlight (Clear Sky)

Radiation Source	LI-COR New	LI-COR 20-year Old	Apogee Blue Filter	Unfiltered GaAsP Diode
Sun Clear Sky	0.0	0.0	0.0	0.0
Sun Cloudy Sky	-0.4	-0.7	0.1	-0.6
Under Corn Leaf	-13.2	-8.8	-2.9	4.3
Under Pepper Leaf	-35.9	-32.3	-27.0	-21.5

YPF Spectral Errors – Relative to Cool White Fluorescent

Radiation Source	LI-COR New	LI-COR 20-year Old	Apogee Blue Filter	Unfiltered GaAsP Diode
CWF T12	0.0	0.0	0.0	0.0
CWF T8	-0.4	0.7	0.4	0.8
Compact Fluorescent	-1.6	0.6	-1.2	1.5
Metal Halide	-2.3	-3.1	-3.5	-5.0
High Pressure Sodium	0.6	2.2	-0.4	7.3
Incandescent	-12.4	-13.0	-32.1	-31.5