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Tibbitts, T. W.
Department of Horticulture University of Wisconsin

Mcsparron, Donald A.
National Bureau of Standards U. S. Department of Commerce

Krizek, Donald T.
Plant Stress Laboratory U.S. Department of Agriculture

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SPECTRAL EFFECTS ON THE USE OF PHOTON FLUX SENSORS FOR MEASUREMENT OF PHOTOSYNTHETIC PHOTON FLUX IN CONTROLLED ENVIRONMENTS*

T. W. TIBBITTS,**, Donald A. MCSPARRON*** and Donald T. KRIZEK****

***Department of Horticulture, University of Wisconsin, Madison, WI 53706, U.S.A.*
****National Bureau of Standards, U.S. Department of Commerce, Gaithersburg, MD 20899, U.S.A.*
*****Plant Stress Laboratory, U.S. Department of Agriculture, ARS Beltsville, MD 20705, U.S.A.*

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TIBBITTS T. W., MCSPARRON D. A. and KRIZEK D. T. *Spectral effects on the use of photon flux sensors for measurement of photosynthetic photon flux in controlled environments.* BIOTRONICS **15**, 31–36, 1986. Measurements of photosynthetic photon flux (PPF) were made under various radiation sources in eleven different controlled environment facilities to compare two commercially available photon-flux sensors and companion meters. Calibration of the sensors was checked by the National Bureau of Standards with both tungsten-filament quartz-halogen lamps and with cool-white fluorescent lamps. Readings from the two lamps agreed for each sensor/meter set within 1 to 2%. Measurements made with the two sensor/meter sets by investigators in each of the laboratories showed excellent agreement (SD=$\pm$1%) in the relative output of the two sensors under a given lamp type, even in different types of plant growth chambers. The two sensor outputs differed systematically with lamp type, however, with the greatest deviation seen between high pressure sodium lamps and incandescent lamps. The #1 sensor reading was about 4% higher than sensor #2 under high pressure sodium lamps and 2% lower under incandescent lamps. This study emphasizes the need for calibration of photosynthetic photon flux sensors/meters under the particular types of lamps being utilized for plant irradiation. Limitations of the PPF concept should also be recognized.

Key words: environmental measurement; radiation measurement; photosynthetically active radiation; PPF; radiation sources, plant growth chambers.

INTRODUCTION

The need to accurately describe the radiation conditions in controlled-environment facilities has long been recognized but is frought with many problems (*2–4*,

* Mention of a trademark name or a proprietary product does not imply its approval by the USDA or the U.S. Department of Commerce to the exclusion of other products that may also be available.

8, *9*, *14*, *16*, *17*). The use of different types of radiation sources by plant researchers in different laboratories makes accurate measurement difficult because sensors are commonly calibrated under only one type of lamp (*6*, *7*, *14*, *16*).

The present study was undertaken by members of the North Central Regional Committee on Growth Chamber Use (NCR 101) in cooperation with the National Bureau of Standards (NBS) in an attempt to learn the extent of agreement between PPF measurements obtained with two different but essentially identical photon-flux sensors when used under various radiation sources. This brief report is part of a continuing cooperative effort (dating back to the mid-1970's) by NCR 101 and NBS to improve the accuracy and precision of irradiance measurements under different radiation sources.

Sensors in commercially available meters for monitoring PPF levels under different radiation sources are filtered to provide a uniform measurement of photon flux in the 400 to 700 nm wavelength band and to exclude all photons outside of this range (*1*, *6*, *10–12*). A silicon sensor is commonly utilized in combination with interference filters at 400 and 700 nm and differential filtering between 400 and 700 nm to provide a nearly equal photon response over this waveband. However, the silicon sensors and the interference and differential filters used in different meters do not have precisely the same spectral response; thus small differences in total response will result from different sensors under different lamp types and perhaps in different growth chambers.

The response of photon flux sensors in commercially available meters is generally established by calibration with a tungsten filament quartz halogen standard lamp (*15*). This source provides essentially a continuous spectrum of increasing irradiance between 400 and 700 nm. Since the sun also produces a nearly continuous spectrum for irradiance between 400 and 700 nm, photon flux sensors provide accurate readings when utilized for sunlight measurements. However, when these sensors are utilized under lamp types that have discrete line spectra, as found under fluorescent and high pressure discharge lamps, there is a potential for significant measurement error.

This study was undertaken to obtain information on the magnitude of this variation in photon flux response between two LI-COR sensor/meter sets in eleven different laboratories under various types of artificial light sources commonly utilized in plant research.

MATERIAL AND METHODS

Two commercially available photon flux sensor/meter sets (*1*, *10*) were sent to the National Bureau of Standards (NBS) at Gaithersburg, MD, where separate checks of the calibrations were made for each sensor with a 1000-W tungsten filament quartz halogen lamp and then with a 40-W (430 mA) cool-white fluorescent (CWF) lamp. These were standard lamps calibrated for spectral irradiance. The total irradiance used in determining sensor response was obtained by numerical integration of the spectral irradiance from the two lamps over the wavelength range 400–700 nm (*5*, *13*). The ambient temperature was 25 ± 2°C. These tests were undertaken in April, 1980 and repeated in May, 1981.

Following checking, the instruments were distributed to different laboratories in the United States and New Zealand for measurements of comparative response to different radiation sources in different types of controlled-environment facilities during the period of July, 1980 through December, 1981. After use in each laboratory, the sensor/meter sets were returned to the University of Wisconsin (Madison, WI) for quality control testing under a Mole-Richardson standard graphite arc radiation source. This 'auditing' program was conducted to insure that there was no significant deviation in instrument response during the various trials. This carbon arc source was maintained in the Instrumentation Systems Center at the University of Wisconsin.

RESULTS AND DISCUSSION

Test results at NBS

The two sensors maintained similar calibration over the 18-month period of measurement with less than a 1% change in response during this time as shown by the two checks at NBS and by quality control testing at the University of Wisconsin.

During the first check at NBS in 1980 with a quartz halogen standard lamp, the two sensors were found to provide indicator readings that were 0.7% and 2.8% low, thus demonstrating a 2.1% difference in response for the two sensors. When checked by NBS with a CWF source, the two sensor indicators were 0.4% and 1.1% high, thus demonstrating a 0.7% difference in response.

During the second calibration in 1981, the difference in output of the two sensors under a quartz halogen lamp was similar, but under a 40-W (430 mA) CWF source, the two sensor readings were 1.7% less and equal to the true calibration values. A summary of the NBS data is shown in Table 1.

Comparative performance of photo-flux sensors

The difference in readings of PPF taken with the two photon flux sensors was nearly constant (SD $=\pm 1$%) when lamps of similar types were compared in different laboratories (Table 2). When the two sensors were compared under different lamps, however, the difference between the two sensors was not constant. The greatest difference was seen in measurements made under high pressure sodium and incandescent lamps. Under high pressure sodium lamps, sensor #1 gave readings

Table 1. National Bureau of Standards comparison of duplicate LI-COR photon flux sensors*

Radiation source	Deviation between photon flux sensors	
	Date of measurement	
	4/11/80	5/18/81
INC	1.022	1.020
CWF	1.007	1.017

* Ratio of readings: sensor #2 ÷ Sensor #1.

Table 2. Comparative measurements of photosynthetic photon flux (PPF) made with duplicate photon flux sensors under different radiation sources. Data expressed as a ratio of photon flux sensor readings*

Date	Laboratory and location	Cool-white fluores-cent	Metal halide	High pressure sodium	Tungsten halogen	Incan-descent
July 1980	Purdue University	0.997**				1.020
	Lafayette, IN	1.000				
Oct. 1980	Cornell University	1.017				1.027
	Ithaca, NY					
Dec. 1980	Western Washington	1.022	1.013**	0.973		
	Mount Vernon, WA		1.000			
Jan. 1981	USDA, Plant Stress Lab.	1.036**				1.037**
	Beltsville, MD	1.030				
Feb. 1981	University of Nebraska		1.014		1.000	
	Lincoln, NE					
Mar. 1981	University of Wisconsin	1.020	1.000	0.946		1.015
	Madison, WI					
June 1981	Penn. State University	1.019**				1.016**
	University Park, PA	0.993				1.013
July 1981	Texas A & M	1.010	1.011	0.933		
	College Station, TX					
Aug. 1981	Climate Laboratory	1.016	0.985	0.968	0.966	
	Palmerston North, NZ					
Sep. 1981	Smithsonian Institution	1.000			1.007	
	Rockville, MD					
Dec. 1981	Purdue University	1.021**		0.969	1.008**	
	Lafayette, IN	1.009			0.969	
Average		1.014	1.004	0.958	0.990	1.020
(±SD)		(±.012)	(±.011)	(±.017)	(±.021)	(±.009)

* Ratio of readings: sensor #2÷sensor #1.

** Two readings were obtained through measurements in two separate chambers or rooms.

about 4% *higher* than sensor #2; under incandescent lamps, sensor #1 gave readings about 2% *lower* than sensor #2.

The small differences in readings obtained among different laboratories could not be correlated with the range of sensor readings, type of barrier, or type of reflective surface in the chamber. Repeat readings taken in the same laboratory were found to have a variation (±1%) that was as great as that among laboratories, and this was assumed to be associated with operator variation. The fact that sensors responded similarily in different growth facilities having different types of reflective wall surfaces indicates that possible differences in cosine correction are apparently of only minor concern in PPF measurements.

This study demonstrates that different photon flux sensors can exhibit measurable differences in response depending upon the radiation sources used. This fact emphasizes the need to have sensors calibrated for each particular type of lamp used in a controlled environment experiment. Based on our findings, we recommend that investigators obtain calibrations and/or meter corrections for each type of lamp utilized in their research. However, a caution must be extended that even though a correction is made for different lamp types, this correction may not necessarily produce a proportional correction in the photosynthetic rate for plants growing under these lamps. This could result since the photons over the total PPF range of 400 and 700 nm are not of equal effectiveness for plant photosynthesis. Thus because corrections for different lamps likely will involve different wavelengths, the effect on photosynthetic rate may vary.

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REFERENCES

1. Biggs W. (1986) Radiation measurement. Pages 3–20 *in* W. G. Gensler (ed) *Advanced Agricultural Instrumentation: Design and Use. NATO ASI Series E: Applied Sciences No. 111.* Martinus Nijhoff Publishers, Dordrecht, Boston and Lancaster.

2. Campbell L. G., Thimijan R. W. and Cathey H. M. (1979) *Plant Science Measurements of Irradiation and Temperature.* Mimeo. Publ., Agr. Res. Cent., Beltsville, MD.

3. Carpenter G. A. and Moulsley L. J. (1960) The artificial illumination of environmental chambers for plant growth. *J. Agric. Eng. Res.* **5**, 283–306.

4. Cathey H. M. and Campbell L. E. (1982) Plant response to light quality and quantity. Pages 213–257 *in* M. N. Christiansen and C. F. Lewis (eds) *Breeding Plants for Less Favorable Environments.* John Wiley & Sons, New York.

5. CIE (Commission Internationale de l'Eclairage) (1982) Methods of characterizing the performance of radiometers and photometers. CIE, Ottawa, Canada.

6. Federer C. A. and Tanner C. B. (1966) Sensors for measuring light available for photosynthesis. *Ecology* **47**, 654–657.

7. Flowers E. C. (1978) Comparison of solar radiation sensors from various manufacturers. *in 1978 Annual Report from NOAA to Department of Energy.*

8. Holmes M. G. (1984) Radiation measurement. Pages 81–107 *in* H. Smith and M. G. Holmes (eds) *Techniques in Photomorphogenesis.* Academic Press, New York.

9. Krizek D. T. and Ormrod D. P. (1980) Growth response of 'Grand Rapids' lettuce and 'First Lady' marigold to increased far-red and infrared radiation under controlled environments. *J. Amer. Soc. Hort. Sci.* **105**, 936–939.

10. LI-COR, Inc. (1982) Radiation measurements and instrumentation. Publ. No. 8208-LM. LI-COR, Inc., Lincoln, Nebraska.

11. McCree K. J. (1979) Radiation. Pages 11–27 *in* T. W. Tibbitts and T. T. Kozlowski (eds) *Controlled Environment Guidelines for Plant Research.* Academic Press, New York.

12. McCree K. J. (1981) Photosynthetically active radiation. Pages 41–55 *in* O. L. Lange, P. Nobel, B. Osmond and H. Ziegler (eds) *Physiological Plant Ecology. Vol. 12A. Encyclopedia of Plant Physiology.* Springer-Verlag, New York.

13. NBS (National Bureau of Standards) (1956) *Instructions for Using the Radiation Standards.* NBS, Washington, D. C.

14. Norris K. H. (1968) Evaluation of visible radiation for plant growth. *Ann. Rev. Plant Physiol.* **19**, 490–499.

15. Saunders R. D. and Shumaker J. B. (1977) Optical radiation measurements: The 1973 NBS scale of spectral irradiance. NBS Technical Note 594-13. U. S. Government Printing Office, Washington, D. C.

16. Tibbitts T. W., McFarlane J. C., Krizek D. T., Berry W. L., Hammer P. A., Langhans R. W. and Ormrod D. P. (1976) Radiation environment of growth chambers. *J. Amer. Soc. Hort. Sci.* **101**, 164–170.

17. Trickitt E. S., Moulsley L. J. and Ddwards R. I. (1957) Measurement of solar and artificial radiation with particular reference to agriculture and horticulture. *J. Agric. Eng. Res.* **2**, 86–110.