4 ~~~ - 74
N96- 18163

GUIDELINES FOR LIGHTING OF PLANTS IN CONTROLLED ENVIRONMENTS

p. 3

Gerald Dietzer, Department of Horticulture, University of Maryland, College Park, MD, Robert Langhans, Department of Floriculture, Cornell University, Ithaca, NY, John Sager, Code MD-RES-L, Kennedy Space Center, FL, L. Art Spomer, Department of Horticulture, University of Illinois, Urbana, IL, Ted Tibbitts, Department of Horticulture, University of Wisconsin, Madison, WI

The organizing committee outlined draft guidelines for plants to provide a focus for the discussions at the workshop. These were distributed to the participants before the meeting. It was recognized that there was insufficient data to support many of the particular quantities presented. The guidelines served as a basis for discussion amongst the workshop attendees and led to a number of recommendations that were recorded by the session chairpersons. The organizing committee indicated they would incorporate the recommendations and suggestions into a revised set of guidelines for additional discussion. Interested participants were then asked to indicate their willingness to review this revised set of guidelines to lead toward the future development of guidelines for lighting in controlled environments. It was understood that these guidelines will not be standards and will require upgrading and modifications as lamps and equipment become available and as new insights are obtained on plants response to light.

Revised draft guidelines are included as Tables 1 and 2 that have been developed by the organizing committee following the suggestions obtained at the workshop. Table 1 are the guidelines for growth chambers and Table 2 for greenhouses. These have been distributed to the participants that indicated a willingness to review proposals that were developed. It is hoped that these proposals will lead to the development of guidelines that will have general acceptance by plant scientists.

TABLE 1. GUIDELINES FOR LIGHTING IN GROWTH CHAMBERS

The purpose of these guidelines is to help writers of specifications, engineers, and architects, who have to make recommendations for the installation of lighting in growth chambers. It is not the intent of these guidelines to mandate the lighting a researcher may need for specific projects, but rather guidelines that indicate reasonable lighting that can grow acceptable crops any time of the year.

PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

A daily average irradiance of 26 mol m^{-2} day^{-1} will effectively grow most species of higher plants. This equates to an instantaneous irradiance of 300 μmol m^{-2} s^{-1} for 24 hours or 600 μmol m^{-2} s^{-1} for 12 hours. For comparison in the continental United States, the average annual daily irradiance is about 26 mol m^{-2} for Madison, WI and Washington, DC. In the summer the maximum daily irradiance is 62 mol m^{-2} at Phoenix, AZ and in the winter the minimum irradiance is 8 mol m^{-2} at Madison, WI (see Table 1). The maximum solar irradiance around midday of 2000 μmol m^{-2} s^{-1} is transient and is not necessary for normal plant growth since the plants response is based on the average daily irradiance.

UNIFORMITY

Less than $\pm$ 10% variation on a horizontal plane over the growing area at the plant canopy height. The variation should be based on measurements taken in the center of each square meter of the plant growing area.

SPECTRAL

280-320 nm (Ultraviolet-B)	Unspecified, but in general the effects of UV-B are deleterious to plant growth and development. However, some plants, such as members of the Solonaceae, may require a small quantity ($\sim$3 W m^{-2}) to avoid abnormal development.
320-400 nm (Ultraviolet-A)	Unspecified, but may have an additive effect with the requirement for blue.
400-500 nm (Blue)	An absolute quantity for elongation control is required for most higher plants ($\geq$ 30 μmol m^{-2} s^{-1}).
500-600 nm (Green)	Not necessary for photosynthesis, but contributes to photosynthesis and is a significant component of most radiation sources.
600-700 nm (Red)	Optimize output for maximal photosynthesis. Monochromatic red will cause abnormal development in some species.
700-750 nm (Far-red)	Enhancement of flowering, stem elongation, etc. of certain species (as a function of the red/far-red ratio) with the quantity centered around 725 nm equal to or greater than the quantity centered around 660 nm.

TOTAL IRRADIANCE (Over the range of 280-50,000 nm)

A ratio of total irradiance to PAR of 0.50 or less W m^{-2} per μmol m^{-2} s^{-1} (2.3 W m^{-2} per W m^{-2} PAR) is desirable to reduce thermal heating of plants and soil. The solar radiation ratio is less than 0.50 W m^{-2} per μmol m^{-2} s^{-1} PAR. A ratio below 0.50 cannot be obtained with most lamps without a barrier and adequate ventilation or a luminaire specifically designed to dissipate infra-red radiation. For example, the ratios for metal halide lamps without a barrier, with an acrylic barrier, and with an acrylic barrier with 5 cm of water was shown to be 0.60, 0.53, and 0.24 W m^{-2} per μmol m^{-2} s^{-1} PAR, respectively. Low temperature sources such as low pressure sodium lamps and light emitting diodes (LEDs) without barriers have been shown to have ratios of 0.41 and 0.28, respectively.

TABLE 2. GUIDELINES FOR INSTALLATION OF SUPPLEMENTAL LIGHTING IN GREENHOUSES

The purpose of these guidelines is to help writers of specifications, engineers, and architects, who have to make recommendations for the installation of supplemental lighting in greenhouses. It is not the intent of these guidelines to mandate the lighting a researcher may need for specific projects, but rather guidelines that indicate reasonable lighting that can grow acceptable crops any time of the year.

PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

A daily average irradiance of 26 mol m^{-2} day^{-1} from sunlight plus added supplementation will effectively grow most species of higher plants. Lamp lighting should be used to supplement sunlight and provide 26 mol m^{-2} day^{-1}. Installations of lighting providing greater than 200 µmol m^{-2} s^{-1} generally add too much heat to the greenhouse environment and the extra luminaries add too much shade. Lighting can be provided during the sunlight hours or during the night period depending upon the plant's photoperiod requirements, and/or depending upon the most cost-effective time to activate the lamps. Shading systems should be utilized under high sunlight conditions to reduce the average irradiance to 26 moles day^{-1}.

UNIFORMITY

Less than ± 15% variation on a horizontal plane over the growing area at the plant growing canopy height. The variation should be based on measurements taken in the center of each square meter of the total lighted area. Installation of a uniform lighting system in the greenhouse is difficult. It is seldom possible to obtain this uniformity on the outside edges of the growing area, particularly against the walls of the greenhouse.

SPECTRAL

There are no special spectral requirements for the supplemental lighting for photosynthesis in greenhouses. Sunlight should supply the balance of wavelengths required by plants. Most glazings remove some portion of the ultraviolet radiation from sunlight and thus certain plant species, including most *Solonaceous* species, may have some abnormal development (oedema) as a consequence. However daylength extensions should use lamps high in red and far-red.

TOTAL IRRADIANCE (Over the range of 280-50,000 nm)

Recommend that supplemental lighting produce no more than 0.6 Wm^{-2} of total irradiation for each µmol m^{-2} s^{-1} of PPF.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1994

3. REPORT TYPE AND DATES COVERED
Conference Publication March 27-30, 1994

4. TITLE AND SUBTITLE
Proceedings International Lighting in Controlled Envirnments Workshop

5. FUNDING NUMBERS
NASW 4527
(NASA Code UL)

6. AUTHOR(S)
Ted W. Tibbitts (Ed)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Wisconsin-Madison
Department of Horticulture
Madison, WI 53706

8. PERFORMING ORGANIZATION REPORT NUMBER
None

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Agriculture
Agricultural Experiment Stations
National Aeronautics and Space Administration
National Science Foundation
Department of Energy
Wisconsin Center for Demand Side Research

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
CP-3309

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited

Subject Category: 54

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Lighting is a central and critical aspect of control in environmental research for plant research and is gaining recognition as a significant factor to control carefully for animal and human research. Thus this workshop was convened to reevaluate the technology that is available today and to work toward developing guidelines for the most effective use of lighting in controlled environments with emphasis on lighting for plants but also to initiate interest in the development of improved guidelines for human and animal research.

14. SUBJECT TERMS
Photosynthesis, Plant requirements, Phytochrome, Blue and Ultraviolet, Animal requirements, Lighting, lamps, lighting distribution filter, heat dissipation, guidelines

15. NUMBER OF PAGES
405

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT
UL