Greenhouse Supplemental Lighting: Fundamental, Benefits, and Strategies

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Outline

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- Lighting basics
  - Intensity
  - Quality
- Measuring light
- Lighting strategies and considerations

Lighting Basics

Lighting Basics

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- Three properties of light we are concerned with for greenhouse applications
  1. Quantity (intensity)
  2. Quality (color)
  3. Duration (photoperiod)
- All three are important in plant growth and development

Lighting Basics

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Lighting Basics - Intensity

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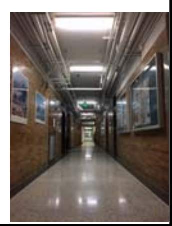
- Light is a form of energy (electromagnetic radiation)
- Measuring light based on what we see
  - Foot-candles, lumens, and lux are common measurements
  - Based on perceived brightness
  - Not appropriate for plants



Lighting Basics - Intensity

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- Quantum
  - More appropriate measure for plants
  - Refers to number of photons available for photosynthesis and growth

Lighting Basics - Intensity

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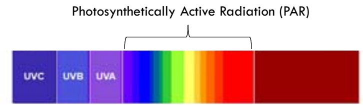
- We want to measure the number of photons (packets of energy)
- Light intensity (quantity)
  - Photosynthetically active radiation (PAR)
  - Instantaneous measurement



Light Spectrum

Lighting Basics - Intensity

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- What is a mole of light?
  - Mole is a constant in chemistry (6.02×10^{23})
  - 1 mol = 1,000,000 µmol
- Number of µmol of photons reaching one square meter each second
- $\mu mol \cdot m^{-2} \cdot s^{-1}$

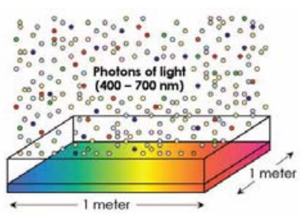

Image Source: Lopez, R., P. Fisher, and E. Runkle. 2017. Introduction to specialty crop lighting, p. 12-20 *In:* Light Management in Controlled Environments. Meister Media Worldwide.

Lighting Basics - Intensity

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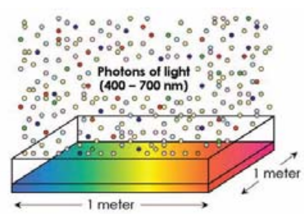
- Daily light integral (DLI): Cumulative amount of light received by the plant each day as a function of light intensity and duration
  - Similar to a rain gauge
  - $mol \cdot m^{-2} \cdot d^{-1}$



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Lighting Basics - Intensity

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- Factors affecting DLI
  - Time of the year
  - Day length (photoperiod)
  - Greenhouse glazings and coverings
  - Greenhouse structures
  - Hanging baskets

Lighting Basics - Intensity

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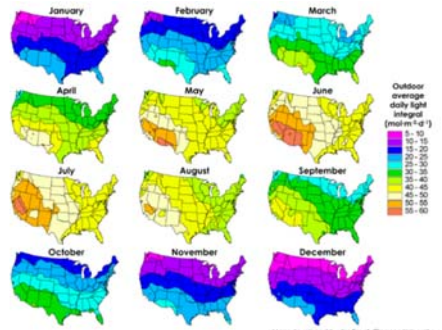


Lighting Basics - Intensity

- Average greenhouse DLI in winter (U.S)
  - North: 4-5 mol·m^{-2}·d^{-1}
  - South: 10-12 mol·m^{-2}·d^{-1}

Lighting Basics - Intensity

- Benefits of a higher DLI
  - Higher quality
    - Compaction
    - Increased biomass
    - Increased branching
  - Flowering
    - Earlier
    - Increased
  - Greater yield

Lighting Basics - Intensity

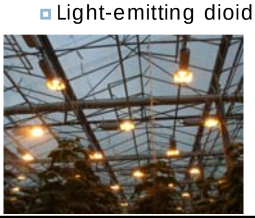
How do we increase DLI in the greenhouse?

Greenhouse Lighting

- Supplemental lighting
  - Increasing the quantity of light
  - 50-75 µmol·m^{-2}·s^{-1} (floriculture crops)
  - 100-200 µmol·m^{-2}·s^{-1} (vegetable crops)

Greenhouse Lighting

- Common lamp types include
  - High-intensity discharge (HID)
    - High-pressure sodium (HPS)
    - Metal halide (MH)
  - Light-emitting dioides (LEDs)




Lighting Basics

- Three properties of light we are concerned with for greenhouse applications
  1. **Quantity (intensity)**
  2. Quality (color)
  3. Duration (photoperiod)

- All three are important in plant growth and development

Lighting Basics

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  1. Quantity (intensity)
  2. **Quality (color)**
  3. Duration (photoperiod)
- All three are important in plant growth and development

Lighting Basics - Quality

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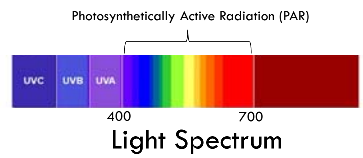
- Light quality (color)
  - Measured in nanometers (nm)
- Photosynthetically active radiation (PAR)
  - 400 - 700 nm
  - Wavelengths of light used for photosynthesis



Lighting Basics - Quality

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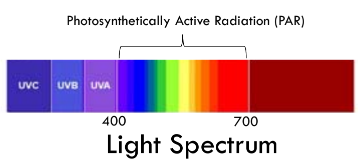
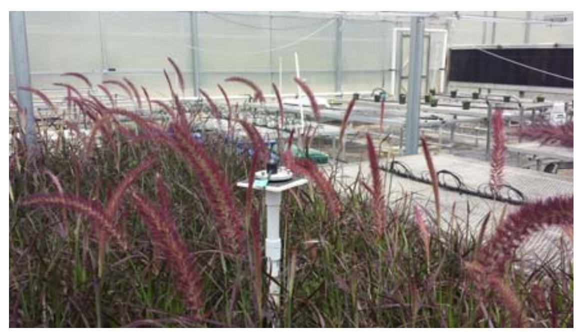
- Blue light (400-500 nm)
- Green light (500-600 nm)
- Red light (600-700 nm)
- Far-red light (700-800 nm)



Measuring Light



Measuring Light

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- Types of sensors available
  - Quantum sensor (intensity)
  - Spectroradiometer (intensity)
  - Datalogger (DLI)

Measuring Light

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- Light sensor considerations
  - Make sure the sensor measures $\mu mol \cdot m^{-2} \cdot s^{-1}$
  - Conversions for LEDs vary by product

Unit	Sunlight	HPS	Metal Halide
Footcandles	5.02	7.62	6.60
Lux	54	82	71
$\mu mol \cdot m^{-2} \cdot s^{-1}$ (PAR)	1	1	1
$W \cdot m^{-2}$ (PAR)	4.57	4.98	4.59

Fisher, P., A.J. Both, and B. Bugbee. 2017. Supplemental lighting technology, costs, and efficiency, p. 74-81 *In:* Light Management in Controlled Environments. Meister Media Worldwide.

Nelson J.A. and B. Bugbee. 2014. Economic analysis of greenhouse lighting: Light emitting diodes vs. high intensity discharge fixtures. PLoS ONE 9(6):e99010.

Measuring Light

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- Light sensor considerations
  - Calibration is appropriate for light source
    - 400-700 nm
    - Some sensors are less flexible
  - Less expensive meters tend to be less accurate
  - Line quantum meters (multiple diodes)

Measuring Light

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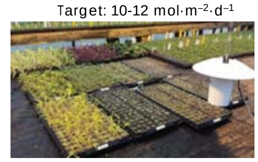
- Example: plug production in January

Ambient: 6 $mol \cdot m^{-2} \cdot d^{-1}$

Target: 10-12 $mol \cdot m^{-2} \cdot d^{-1}$



Measuring Light

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- Example: plug production in January

Supplemental: 75 $\mu mol \cdot m^{-2} \cdot s^{-1}$

Ambient: 6 $mol \cdot m^{-2} \cdot d^{-1}$

Target: 10-12 $mol \cdot m^{-2} \cdot d^{-1}$

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:

Example:

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:

Instantaneous light measurement

Example:

75 $\mu mol \cdot m^{-2} \cdot s^{-1}$

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:
Instantaneous light measurement × 60 (sec/min)

Example:
75 $\mu mol \cdot m^{-2} \cdot s^{-1}$ × 60

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:
Instantaneous light measurement × 60 (sec/min) × 60 (min/hour)

Example:
75 $\mu mol \cdot m^{-2} \cdot s^{-1}$ × 60 × 60

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:
Instantaneous light measurement × 60 (sec/min) × 60 (min/hour) × operation hours

Example:
75 $\mu mol \cdot m^{-2} \cdot s^{-1}$ × 60 × 60 × 18

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:
Instantaneous light measurement × 60 (sec/min) × 60 (min/hour) × operation hours / 1,000,000 (µmol/mol)

Example:
75 $\mu mol \cdot m^{-2} \cdot s^{-1}$ × 60 × 60 × 18 / 1,000,000 = 4.9 $mol \cdot m^{-2} \cdot d^{-1}$

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:
Instantaneous light measurement × 60 (sec/min) × 60 (min/hour) × operation hours / 1,000,000 (µmol/mol)

Example:
75 $\mu mol \cdot m^{-2} \cdot s^{-1}$ × 60 × 60 × 18 / 1,000,000 = 4.9 $mol \cdot m^{-2} \cdot d^{-1}$

6 $mol \cdot m^{-2} \cdot d^{-1}$

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:
Instantaneous light measurement × 60 (sec/min) × 60 (min/hour) × operation hours / 1,000,000 (µmol/mol)

Example:
75 $\mu mol \cdot m^{-2} \cdot s^{-1}$ × 60 × 60 × 18 / 1,000,000 = 4.9 $mol \cdot m^{-2} \cdot d^{-1}$

6 $mol \cdot m^{-2} \cdot d^{-1}$ + 4.9 $mol \cdot m^{-2} \cdot d^{-1}$ = **10.9 $mol \cdot m^{-2} \cdot d^{-1}$**

Measuring Light

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- Converting $\mu mol \cdot m^{-2} \cdot s^{-1}$ to $mol \cdot m^{-2} \cdot d^{-1}$

Formula:
Instantaneous light measurement × 60 (sec/min) × 60 (min/hour) × operation hours / 1,000,000 (µmol/mol)

Example:
$75\ \mu mol \cdot m^{-2} \cdot s^{-1} \times 60 \times 60 \times 18 / 1{,}000{,}000 = 4.9\ mol \cdot m^{-2} \cdot d^{-1}$

$6\ mol \cdot m^{-2} \cdot d^{-1} + 4.9\ mol \cdot m^{-2} \cdot d^{-1} =$ **$10.9\ mol \cdot m^{-2} \cdot d^{-1}$**

Target: $10\text{-}12\ mol \cdot m^{-2} \cdot d^{-1}$

Measuring Light

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- Tips for measuring light in the greenhouse
  - Measure light from lamps at night
  - Use appropriate settings (e.g. solar/electric)
  - Measure at multiple locations
  - Keep sensor clean
  - Place sensor near top of plant canopy

Lighting Considerations

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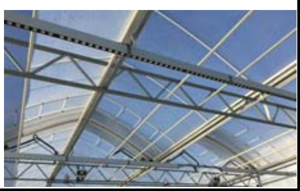
- Important considerations for purchase
  - Lamp efficacy (µmol/J)
  - Cost
  - Type of production
  - Production area
  - Etc.



Lighting Considerations

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- Lamp efficacy

Lamp	Lamp efficacy (µmol/J)
315 W, metal halide	1.25-1.46
400 W, magnetic ballast HPS	0.94
1000 W, magnetic ballast HPS	1.02-1.16
1000 W, double-ended HPS	1.70
Light-emitting diode (LED)	0.89-2.4

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Lighting Considerations

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- Cost per fixture

Lamp	Cost per fixture ($)
315 W, metal halide	500-640
400 W, magnetic ballast HPS	200
1000 W, magnetic ballast HPS	275-350
1000 W, double-ended HPS	500-600
Light-emitting diode (LED)	860-1400

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Lighting Considerations

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- High wattage (600-1000 W)
  - Lower cost (fewer lamps needed)
  - Height greater than 6 ft.
- Low wattage (400 W)
  - Higher cost (more lamps needed)
  - Height less than 6 ft.
  - More uniform light distribution

Lighting Considerations

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- PAR output

Lamp	µmol/s per fixture
315 W, metal halide	409-491
400 W, magnetic ballast HPS	416
1000 W, magnetic ballast HPS	1090-1161
1000 W, double-ended HPS	1751-1767
Light-emitting diode (LED)	163-653

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Lighting Considerations

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- Light-emitting diodes (LEDs)
  - More directional light distribution
  - Produce very little radiant heat
  - Position to increase photon capture
  - Allows for versatility in applications and placement
  - High capitol cost
    - Values constantly changing
    - Perform own analysis

Image Source: Roberto Lopez, Michigan State Univ.

Lighting Considerations

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- Intra-canopy lighting

Lighting Considerations

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- How many lamps do I need?
  - Lamp type
  - Wattage
  - Reflectors
  - Greenhouse dimensions
  - Desired intensity
- Lighting designs
  - Uniformity is key
  - Always test with quantum sensor

Lighting Considerations

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- Practices to get the most out of your investment
  - Only use when necessary
    - Winter months
    - Cloudy days
  - Automated control systems
    - Shut off lamps when ambient sunlight exceeds a target
    - Target a specific DLI
  - Lighting is just one variable to consider

Acknowledgements

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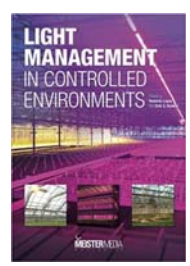
- Ph.D. advisors
  - Roberto Lopez
  - Cary Mitchell
- Research
  - Galema's Greenhouse
  - Philips Lighting
  - P.L. Light Systems
  - Ball Horticultural Co.



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