Lighting Plugs and Cuttings – Regimes & Lamps

Erik Runkle
Professor of Horticulture

MICHIGAN STATE UNIVERSITY

Acknowledgments

- Former graduate students Roberto Lopez, Brian Poel, and Lee Ann Pramuk; technican Nate DuRussel
- Horticulture and lighting companies and granting agencies that supported this research, especially:

Horticultural Lighting Applications

	Photoperiodic
Location	Greenhouses, sometimes outdoors
Use or objective	Promote or inhibit flowering
Plants targeted	Crops that flower in response to day length
Typical intensity	1–2 $\mu mol \cdot m^{-2} \cdot s^{-1}$
Typical lamps used	Incandescent or R ± FR LEDs
When used	During the night from Sept. to Mar.
Hours used per day	Usually up to 4
Control of morphology	Little to moderate

Horticultural Lighting Applications

	Photoperiodic	**Supplemental**
Location	Greenhouses, sometimes outdoors	Greenhouses
Use or objective	Promote or inhibit flowering	Increase growth, harvestable yield, and plant quality attributes
Plants targeted	Crops that flower in response to day length	Young plants and high-value crops
Typical intensity	1–2 $\mu mol \cdot m^{-2} \cdot s^{-1}$	50–100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (2X for vegetables)
Typical lamps used	Incandescent or R ± FR LEDs	HPS or R, B, W LEDs
When used	During the night from Sept. to Mar.	At night and on cloudy days from fall to spring
Hours used per day	Usually up to 4	Usually up to 20
Control of morphology	Little to moderate	Little to none

Horticultural Lighting Applications

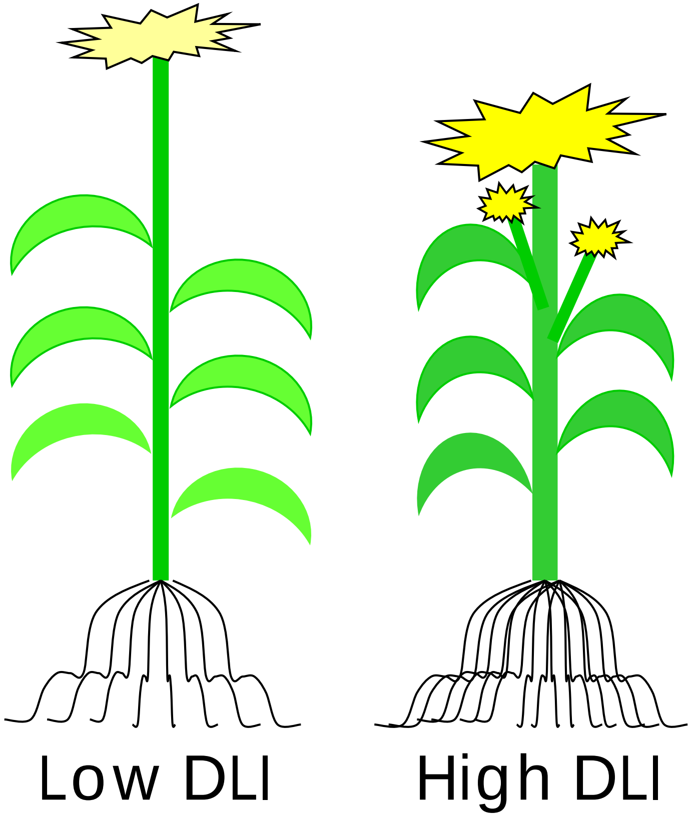
	Photoperiodic	Supplemental	Sole-Source
Location	Greenhouses, sometimes outdoors	Greenhouses	Indoors (vertical farms)
Use or objective	Promote or inhibit flowering	Increase growth, harvestable yield, and plant quality attributes	Pronounced regulation of plant growth; consistency of product
Plants targeted	Crops that flower in response to day length	Young plants and high-value crops	Leafy greens, herbs, and young plants
Typical intensity	1–2 $\mu mol \cdot m^{-2} \cdot s^{-1}$	50–100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (2X for vegetables)	125–175 $\mu mol \cdot m^{-2} \cdot s^{-1}$
Typical lamps used	Incandescent or R ± FR LEDs	HPS or R, B, W LEDs	Fluorescent or R, B, W LEDs
When used	During the night from Sept. to Mar.	At night and on cloudy days from fall to spring	Every day
Hours used per day	Usually up to 4	Usually up to 20	12–24
Control of morphology	Little to moderate	Little to none	Strong

Daily Light Integral (DLI)

- The DLI is the total amount of photosynthetic light (400-700 nm) that is received per square meter each day
- It is an “accumulation measurement” and can not be measured at one point in time
- Unit: $mol \cdot m^{-2} \cdot d^{-1}$ or moles/day
- Conversion for sunlight: 1 MJ = 2.04 $mol \cdot m^{-2} \cdot d^{-1}$

General Plant Responses to DLI

- Leaves (smaller and thicker)
- Branching (increased)
- Stem diameter (increased)
- Root growth (increased)
- Time to flower (faster, due partly to temperature)
- Flowers (more and larger)
- Fruit (more and larger)



New Guinea Impatiens

Stock Plants

Average DLI ($mol \cdot m^{-2} \cdot d^{-1}$):

6.1 10.9 17.2

New Guinea impatiens 'Harmony White'

Photo taken after 16 days of propagation

Average DLI ($mol \cdot m^{-2} \cdot d^{-1}$):

1.3	2.1	4.0	4.7	6.3	10.8

Sunlight | Sunlight + HPS

Root dry mass (mg)

8.0	14.5	30.0	35.5	48.5	55.5

Argyranthemum ‘Madiera Cherry Red’

Photo taken after 21 days of propagation

Average DLI ($mol \cdot m^{-2} \cdot d^{-1}$):

Sunlight				Sunlight + HPS			
1.4	2.0	3.8	5.6	6.4	7.2	10.6	12.3

Root dry mass (mg)

14.9	22.6	27.1	48.0	40.1	45.6	56.0	84.0

Salvia 'Vista Red'

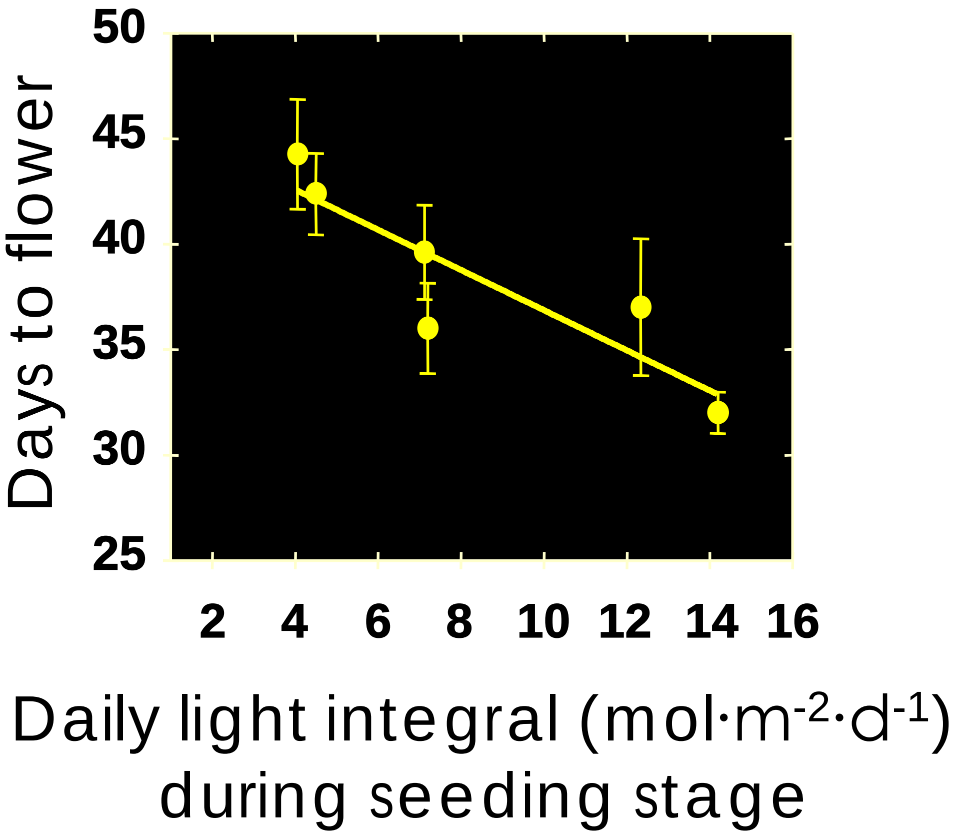
22 Days from seed sow at 23 °C
Grown under an average DLI of: (mol·m^{-2}·d^{-1})

6 10 16

Increase in DLI → Earlier Flowering

Celosia 'Gloria Mix'

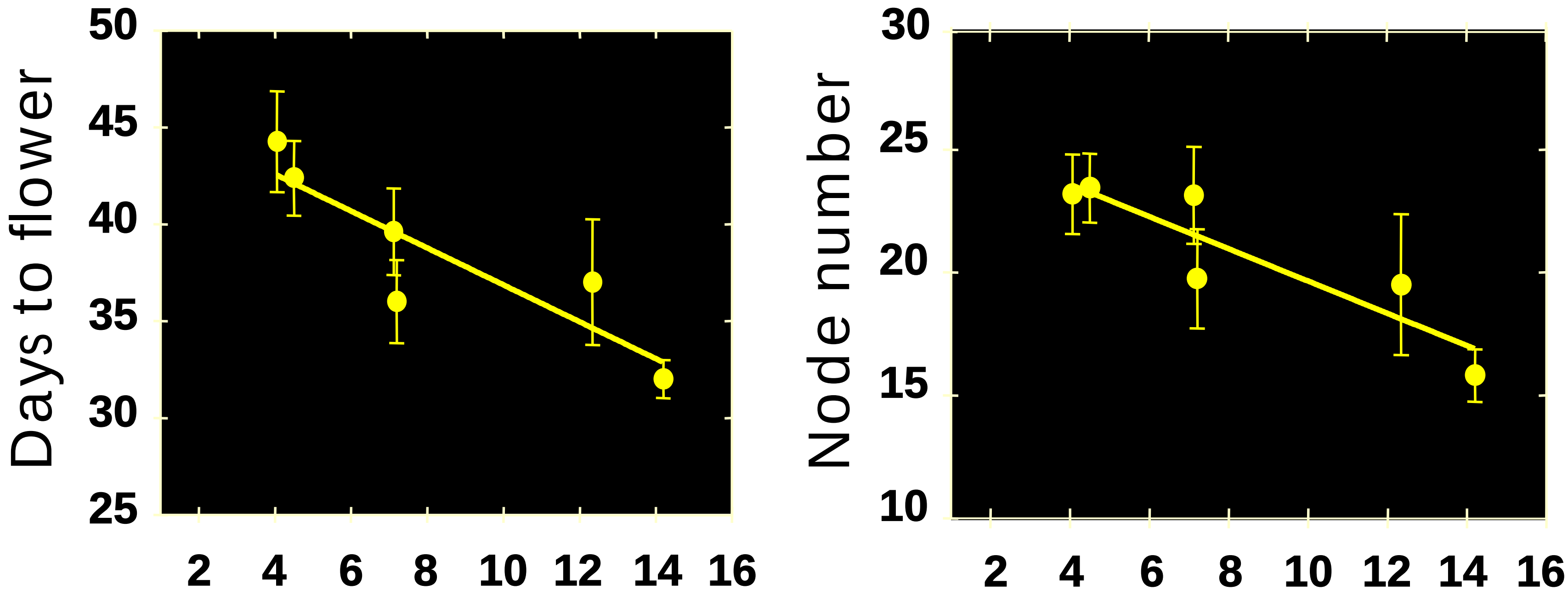
Common Environment: 23 °C and DLI of 8.5 mol·m^{-2}·d^{-1}



Increase in DLI → Earlier Flowering

Celosia ‘Gloria Mix’

Common Environment: 23 °C and DLI of 8.5 $mol \cdot m^{-2} \cdot d^{-1}$



Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$)
during seeding stage


Question: At what stage(s) of
seedling growth does supplemental
lighting provide the greatest benefit?

Lighting Treatments

- The seedling stage was divided into thirds, each lasting 9 or 11 days
- Plugs were lighted for 1/3 or 2/3 of the plug stage, not at all, or during the entire period.

	1st	2nd	3rd
L-L-L	Low DLI		
H-L-L	High DLI		
L-H-L			
L-L-H			
H-H-L			
L-H-H			
H-H-H			

Sowing **Emergence** **Potting**

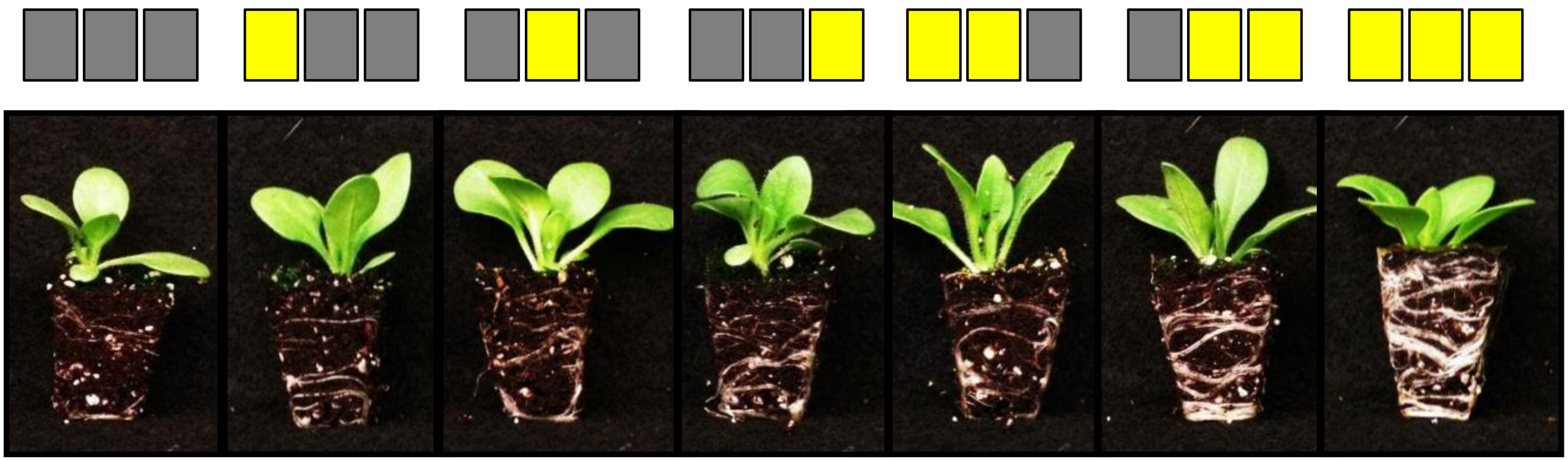
Petunia:
27 days

Pansy:
33 days

Petunia ‘Madness Red’

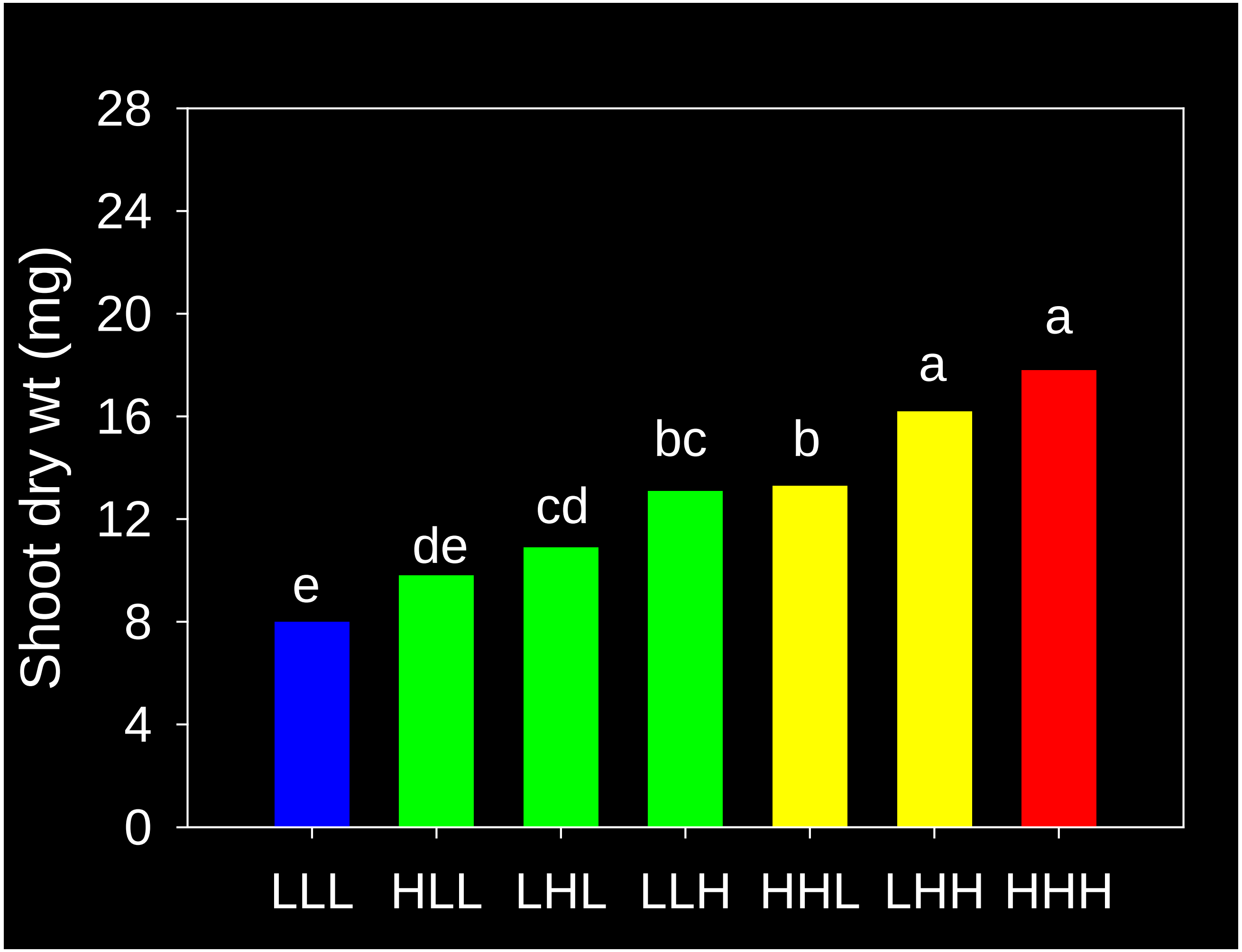
27 days after seed sow at 20 °C

■ = Low-intensity lighting (3 $\mu mol \cdot m^{-2} \cdot s^{-1}$)
■ = High-intensity lighting (90 $\mu mol \cdot m^{-2} \cdot s^{-1}$)



Each ■ or ■ represents 9 days

Petunia 'Madness Red'

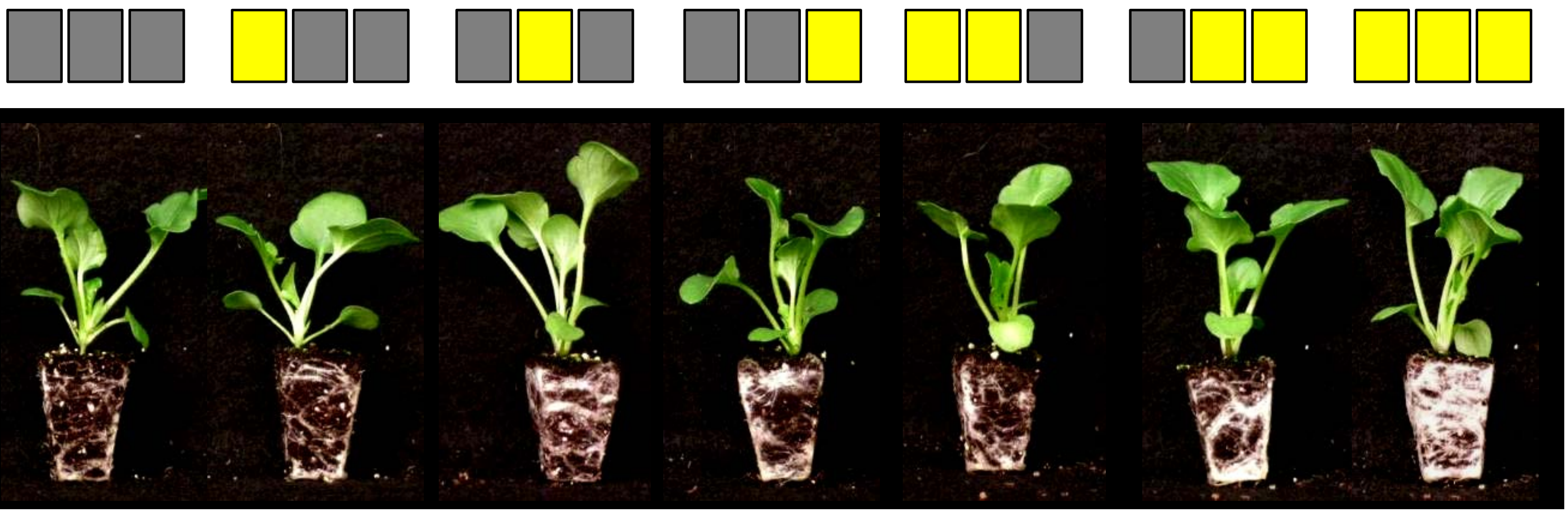


Supplemental lighting treatment

Pansy ‘Delta Premium Yellow’

33 days after seed sow at 20 °C

= Low-intensity lighting (3 $\mu mol \cdot m^{-2} \cdot s^{-1}$)
= High-intensity lighting (90 $\mu mol \cdot m^{-2} \cdot s^{-1}$)



Each or represents 11 days

Pansy ‘Delta Premium Yellow’

61 days after seed sow at 20 °C

= Low-intensity lighting (3 $\mu mol \cdot m^{-2} \cdot s^{-1}$)
= High-intensity lighting (90 $\mu mol \cdot m^{-2} \cdot s^{-1}$)

13% 13% 25% 32% 44% 69% 75%

Flowering percentage

Supplemental Greenhouse Lighting

Tomato ‘Supersweet’

Greenhouse supplemental lighting from 6am to 10pm at a PPFD (in µmol·m^{-2}·s^{-1}) of:

90 | **10**

HPS | **$B_{10}R_{90}$** | **$B_{20}R_{80}$** | **$B_{10}G_{5}R_{85}$** | **$B_{15}G_{5}R_{80}$** | **HPS**

HPS = high-pressure sodium lamps. B=blue (peak=453 nm), R=red (peak=660 nm), G=green from white (peak=560 nm) LEDs. Values after each waveband indicate their percentage of the total PPFD in each treatment.

Photo taken after 21 days at 20 °C, DLI = 7.7 mol·m^{-2}·d^{-1}

Petunia 'Wave Misty Lilac'

Greenhouse supplemental lighting from 6am to 10pm at a PPFD (in $\mu mol \cdot m^{-2} \cdot s^{-1}$) of:

90					10
HPS	**$B_{10}R_{90}$**	**$B_{20}R_{80}$**	**$B_{10}G_5R_{85}$**	**$B_{15}G_5R_{80}$**	**HPS**

HPS = high-pressure sodium lamps. B=blue (peak=453 nm), R=red (peak=660 nm), G=green from white (peak=560 nm) LEDs. Values after each waveband indicate their percentage of the total PPFD in each treatment.

Photo taken after 37 days at 20 °C, DLI = 8.2 $mol \cdot m^{-2} \cdot d^{-1}$

Petunia 'Wave Misty Lilac'

Greenhouse supplemental lighting of seedlings from 6am to 10pm (for 37 days) at a PPFD (in $\mu mol \cdot m^{-2} \cdot s^{-1}$) of:

90					10
HPS	**$B_{10}R_{90}$**	**$B_{20}R_{80}$**	**$B_{10}G_5R_{85}$**	**$B_{15}G_5R_{80}$**	**HPS**

HPS = high-pressure sodium lamps. B=blue (peak=453 nm), R=red (peak=660 nm), G=green from white (peak=560 nm) LEDs. Values after each waveband indicate their percentage of the total PPFD in each treatment.

Photo taken after 25 days after transplant at 20 °C

Petunia ‘Ramblin Peach Glo’

23 °C with ambient DLI = 4 to 5 mol·m^{-2}·d^{-1}
Supplemental lighting fixture and intensity (µmol·m^{-2}·s^{-1}):

Control	HPS		R+W LED	
	Cont. 70	Thresh. 90	Cont. 70	Thresh. 90

Allison Hurt and Roberto Lopez, MSU

Impatiens ‘Accent Premium Salmon’

23 °C with ambient DLI = 4 to 5 mol·m^{-2}·d^{-1}

Supplemental lighting fixture and intensity (µmol·m^{-2}·s^{-1}):

Control	HPS		R+W LED	
	Cont. 70	Thresh. 90	Cont. 70	Thresh. 90

Allison Hurt and Roberto Lopez, MSU


9
10
11

Supplemental Light Intensities

- Greatest benefit when the ambient DLI is less than 8 mol·m^{-2}·d^{-1} (4 MJ·d^{-1})
- For young plants, deliver 50 to 75 μmol·m^{-2}·s^{-1} at the growing surface

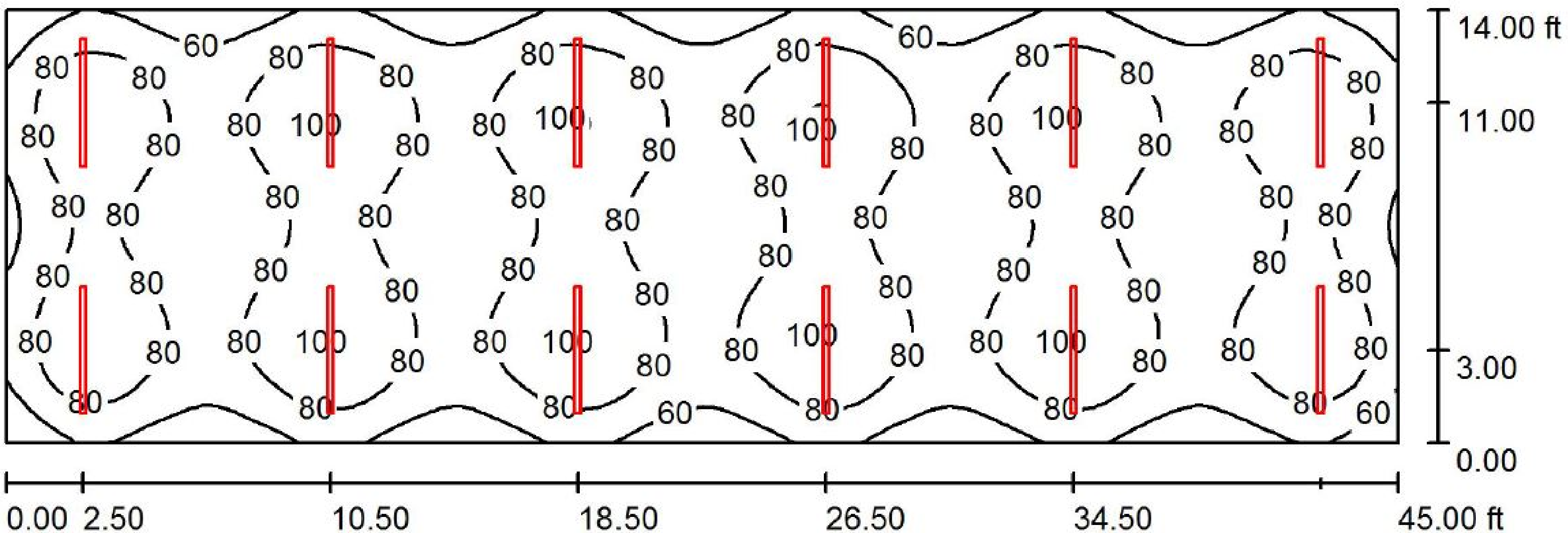
Hours per day	PAR intensity (μmol·m^{-2}·s^{-1})				
	50	75	100	150	200
	Daily light integral (mol·m^{-2}·d^{-1})				
8	1.4	2.2	2.9	4.3	5.8
12	2.2	3.2	4.3	6.5	8.6
16	2.9	4.3	5.8	8.6	11.5
20	3.6	5.4	7.2	10.8	14.4

Lamp Type Considerations

- Greenhouse dimensions, especially hanging height or position
- Reliability: Use trusted brands with warrantees
- Fixture longevity and maintenance
- Light spectrum (for plants and people)
- Hours of operation
- Uniformity of intensity

Lamp Type Considerations

- Review the lighting map and consider the uniformity of the light intensity
- A 10-20% variation in light intensity is generally acceptable



Lamp Type Considerations

- Electrical supply available
- Cost of electricity
- Plants under HPS are typically 1-2 °C warmer than under LEDs
- Purchase and installation costs (including required accessories), availability of utility rebates, etc.
- Lamp efficacy: Photons per joule (µmol/J)

Fixture Efficacy (Efficiency)

- The efficacy of a lamp refers to the number of photons of light emitted per amount of energy consumed
- The total output of a lamp is usually measured in an integrating sphere and requires expertise to operate

Examples of Fixture Efficacy

Fixture model	Measured power (W)	Photosynthetic photon flux ($\mu mol \cdot s^{-1}$)	Photosynthetic photon efficacy ($\mu mol \cdot J^{-1}$)
High-pressure sodium			
Sunlight Supply Sun Star (magnetic)	443	416	**0.9**
P.L. Light SON-T PIA (electronic)	690	926	**1.3**
Gavita Pro 1000e, (electronic; DE)	1,069	1,837	**1.7**
LEDs			
Heliospectra LX601C	595	673	**1.1**
Hubbell Cultivaire	358	736	**2.1**
Illumitex PowerHarvest W	268	475	**1.8**
Lumigrow Pro 325e	300	540	**1.8**
Philips (Signify) GreenPower DR/W	195	504	**2.6**
P.L. Light HortiLED TOP Full Spec.	330	696	**2.1**
P.L. Light HortiLED TOP Red-Blue	313	798	**2.6**

DE = Double ended

Sources: Nelson and Bugbee, 2014, 2017; Leora Radetsky, RPI, 2018.

LEDs vs. HPS: A Matter of Economics

General inputs		
Electricity price ($/kWh)	0.12	
Hours of lamp operation per year	2,500	
HPS bulb replacement cost	40	
Expected HPS bulb replacement (hours)	12,000	
Lamp purchase comparisons	**HPS**	**LED**
Number of fixtures (lamps)	288	340
Cost per fixture ($)	340	710
Total fixture cost ($)	97,920	241,400
Additional cost for accessories	0	0
Additional cost for added electricity	60,000	0
Energy rebate	0	18,000
Total purchase cost ($)	**157,920**	**223,400**
Lamp operation comparisons	**HPS**	**LED**
Energy consumption (watts per lamp)	630	320
Total power draw (kW)	181	109
Electricity cost per year ($)	54,432	32,640
HPS bulb replacement cost ($)	2,400	
Total operating cost per year ($)	**56,832**	**32,640**
Approximate return on investment (years)		**2.7**
(Excludes interest, depreciation, opportunity cost, etc.)		

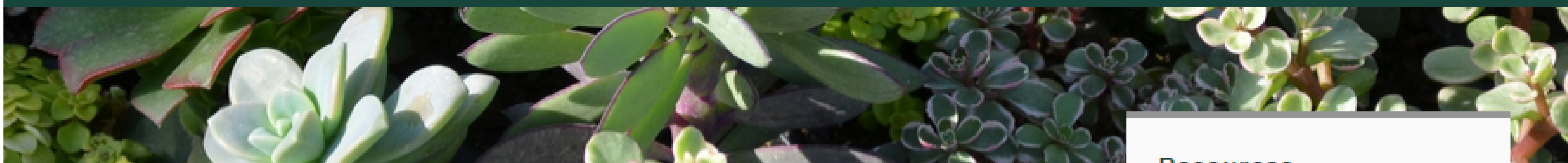
www.canr.msu.edu/floriculture

MICHIGAN STATE UNIVERSITY

Search...

MSU Extension
Floriculture & Greenhouse Crop Production

Resources | Experts | College Of Knowledge | Michigan Garden Plant Tour | Environmental Assurance | Support Us



Resources /

Light Management in Greenhouses & Controlled Environments

Electric lighting is used in greenhouses to regulate the photoperiod to control flowering, or to increase growth to increase crop quality and yield. It is also used for sole-source lighting of plants produced indoors. A few summary articles are below, followed by more in-depth articles on specific topics.

- **Light Management in Controlled Environments**, a book edited by Roberto Lopez and Erik Runkle, contains 18 chapters on the subject of light in horticulture. It presents the underlying biology of how light influences plant growth and development of specialty crops, especially those grown in greenhouses and controlled-environment growth rooms. Over 20 leading plant scientists from 16 different universities/institutes/companies discuss technology options for shade and lighting, including the latest developments in greenhouse and sole-source lighting.
- **LED Lighting for Urban Agriculture**, a book, edited by Toyoki Kozai, Kazuhiro Fujiwara, and Erik Runkle, focuses on light-emitting diode (LED) lighting, mainly for the

Resources

- Annual Bedding Plants
- Greenhouse Energy
- Greenhouse Pest Management
- Greenhouse Temperature Management
- Height Management of Ornamentals
- Herbaceous Perennials
- Leafy Greens & Edibles
- **Light Management in Greenhouses & Controlled Environments**
- Marketing & Economics of Ornamentals
- Potted Flowering Plants
- Root-zone Management
- Young Plant Production

More Plant Lighting Information

- Book contains 18 chapters with 20 chapter authors, edited by Lopez and Runkle
- Targeted audience is growers, lighting reps, and college students
- Available in print and digital versions through Amazon