2^{nd} International Webinar Conference

Sponsored by: PHILIPS

1:00 to 2:00 Eastern

Uncovering the Potential uses for Light-Emitting Diodes (LEDs) in Greenhouses and Indoor Production of Ornamental and Leafy Green Crops

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Greenhouse Lighting

Light quantity (intensity) → Light quality (distribution) → Light duration (photoperiod)

Light-emitting diodes (LEDs)

↓

Photosynthetic, photomorphogenic, and photoperiodic Lighting

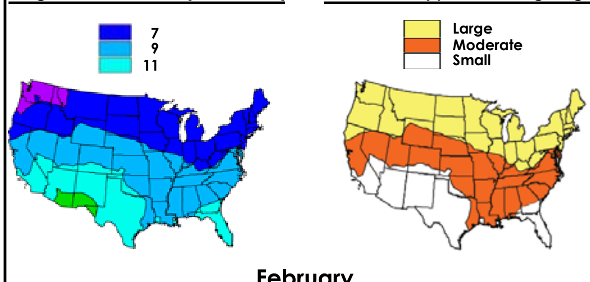
Greenhouse Grower Challenges: Light Intensity

- Propagators of young plants are interested in:
  1) Minimizing production time for seedlings (plugs) and rooting of cuttings (liners) to reduce energy costs
  2) Optimizing quality of young and finished plants
- The production environment and culture impacts crop quality and timing

Greenhouse Grower Challenges: Light Intensity

- During young plant production, the Pn DLI outdoors can range from 5 to 20 $mol \cdot m^{-2} \cdot d^{-1}$ across the northern U.S.
- Light levels can be 50% or less of that outdoors due to structures, glazing, shading, and obstructions
- Therefore, the DLI can be as low as 1 to 5 $mol \cdot m^{-2} \cdot d^{-1}$ and even lower during extended periods of cloudy weather

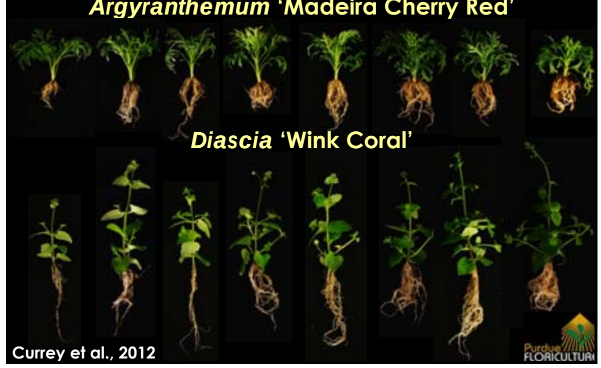
Daily Light Integral (DLI) and Young Plants



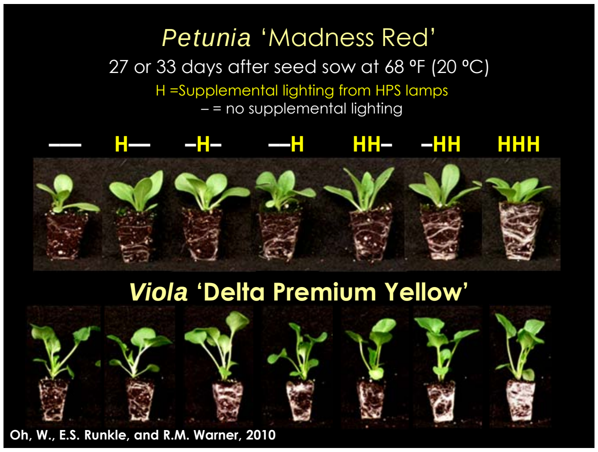
Korczynski et al., 2002 — Runkle, 2011

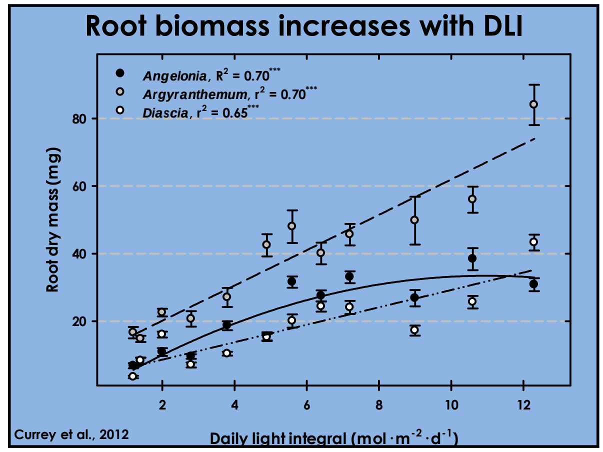
DLI ($mol \cdot m^{-2} \cdot d^{-1}$)

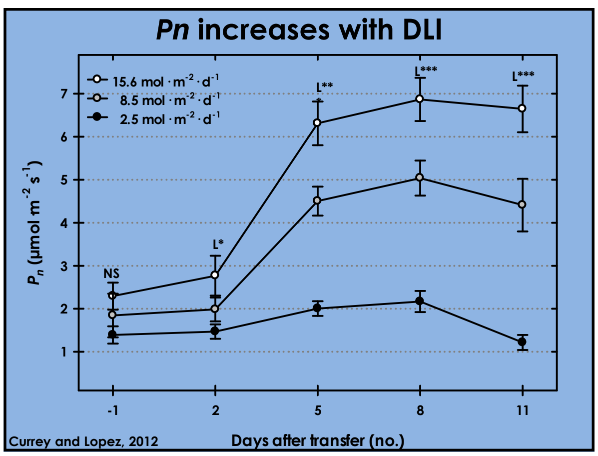
1.4 2.0 3.8 5.6 6.4 7.2 10.6 12.3



Currey et al., 2012







- 16-h photoperiod with the following 4 supplemental lighting treatments providing 70 µmol·m⁻²·s⁻¹:

LEDs

Orbitec 2nd generation LED modules:

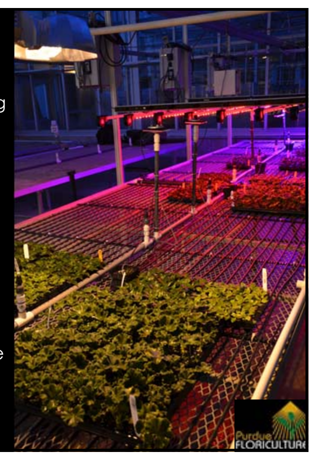
- 100% Red : 0% Blue
- 85% Red : 15% Blue
- 70% Red : 30% Blue

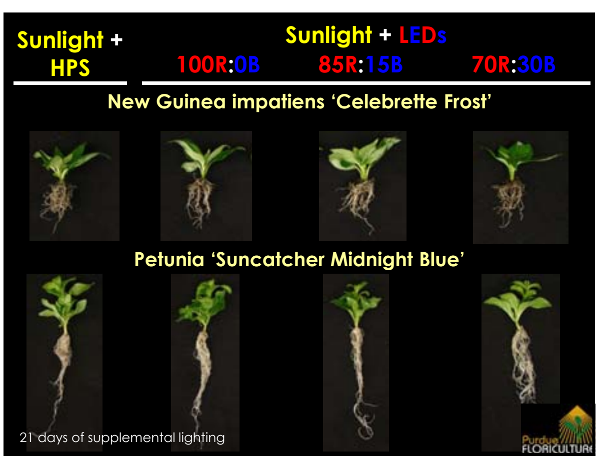
High-pressure sodium

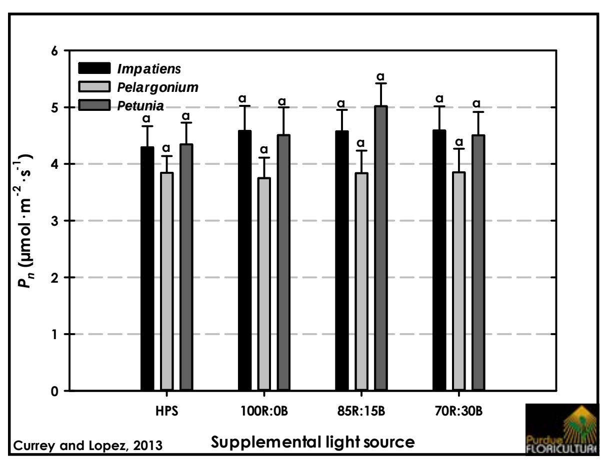
P.L. Light Systems

- 150 W

- 73 °F (23 °C) air temperature set point

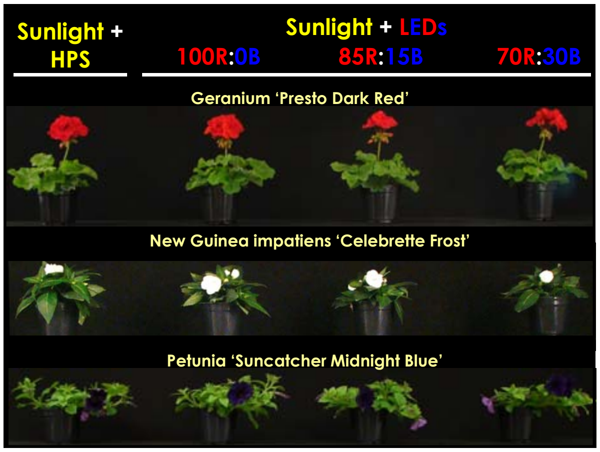


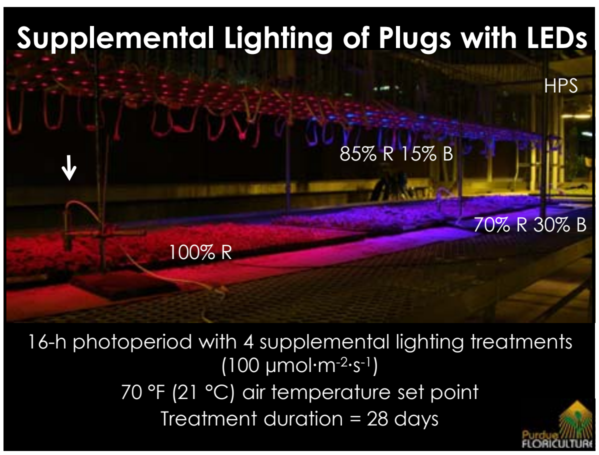




e-GRO Electronic Grower Resources Online

PHILIPS

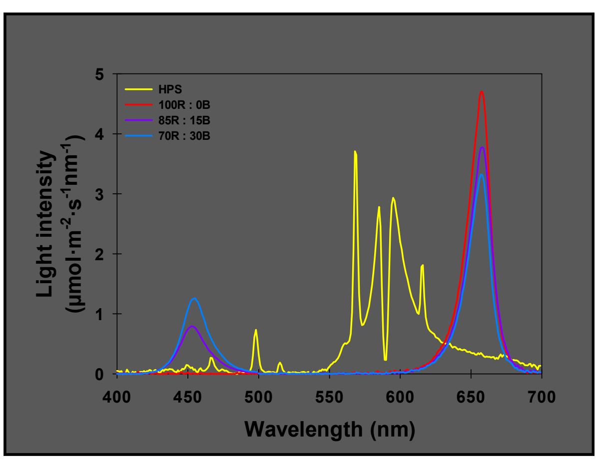


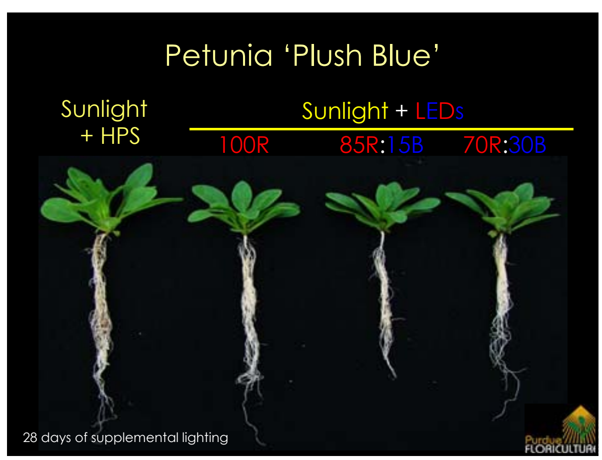


Materials and Methods

Plant Material

- Begonia 'Yang Red Green Leaf'
- Celosia 'Fresh Look Gold'
- Geranium 'Bullseye Scarlet'
- Marigold 'Bonanza Flame'
- Pansy 'Mammoth Big Red'
- Petunia 'Plush Blue'
- Salvia 'Vista Red'
- Seed impatiens 'Dazzler Blue Pearl'
- Snapdragon 'Rocket Pink'
- Vinca 'Titan Punch'





Finish Materials and Methods

- 4 inch container filled with a commercial medium
- 70 °F (21°C) constant (day/ night)
- 16-hr ambient solar + supplemental HPS light
- DLI ≈ 10 – 12 $mol \cdot m^{-2} \cdot d^{-1}$

Petunia ‘Plush Blue’

Sunlight + HPS	Sunlight + LEDs		
	100R	85R:15B	70R:30B

3 weeks after transplant

Young Plant LED Lighting Conclusions

- LEDs are comparable to HPS for use in cutting propagation
- LEDs are suitable for providing supplemental light for plug production with some benefits compared to HPS lamps
  – Compact plugs that have greener foliage
- Finished plant quality of most species was not significantly influenced by propagation supplemental lighting from HPS or LEDs

Production
Lighting

Comparing LED Lighting To HPS Lamps For Plug Production

Comparison of Supplemental Lighting from High-pressure Sodium Lamps and Light-emitting Diodes during Bedding Plant Seedling Production

Objectives

To quantify the difference between seedlings grown under ambient light, supplemental or sole-sources lighting

Materials and Methods

- 73 °F (23 °C) constant (day/ night)
- DLI ≈ 10.5 $mol \cdot m^{-2} \cdot d^{-1}$
- Two 288-cell plug trays of each species in each treatment for 21 or 28 d

Greenhouse Supplemental Lighting (SL) Materials and Methods

Sunlight + Supplemental lighting

- 16-h photoperiod with the following treatments providing 70 µmol·m^{-2}·s^{-1}:
  - High pressure sodium (HPS) – 150 watt
  - Plasma lamps (PL) – 300 watt
  - Philips production module (87% Red : 13% Blue)
  - No supplemental light (Ambient)

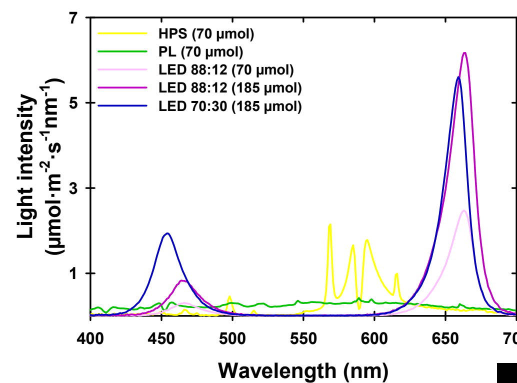
Chamber Sole Source Lighting (SS) Materials and Methods

16-h photoperiod with the following 2 sole-source lighting treatments providing 185 µmol·m^{-2}·s^{-1}:

LEDs
- Philips Production Module (87% Red : 13% Blue)
- Philips Research Module (70% Red : 30% Blue)

Materials and Methods

Plant Material
- Geranium ‘Bullseye Red’
- Impatiens ‘Super Elfin XP Blue Pearl’
- Marigold ‘Durango Yellow’
- Petunia ‘Dreams Midnight’
- Vinca ‘Titan Red Dark’



Petunia ‘Dreams Midnight’

Sunlight + LEDs (Red:Blue)

SL = supplemental lighting
SS = sole-source lighting

Finish Materials and Methods

- 4.5 inch containers filled with a commercial medium
- 68/65 °F (20/18 °C) (day/ night)
- 16-hr ambient solar + supplemental HPS light
- DLI ≈ 10 – 12 mol·m^{-2}·d^{-1}

Petunia 'Dreams Midnight'

Sunlight + | LEDs (Red:Blue)

Amb HPS PL SL87:13 SS70:30
SS87:13

3 Weeks after transplant

SL = supplemental lighting
SS = sole-source lighting

Sole-source Lighting Conclusions

- The quality of all species grown under SL was similar or greater than seedlings grown under ambient light
- Seedling quality of species grown under SSL was similar or greater than seedlings grown under SL

Sole-source Lighting Conclusions

- Time to flower was similar for all species under both SL and SSL treatments except for Impatiens and petunia
- SL and SSL are both viable methods of producing annual bedding plant seedlings

Objectives

To quantify the effect of SS far-red light on seedling quality and subsequent time to flower

To quantify the effect of SS DLI on seedling quality and subsequent time to flower

Materials and Methods

Three species evaluated

- Coreopsis 'Sunfire'
- Pansy 'Matrix Yellow'
- Petunia 'Purple Wave'

Environment

- 68 °F (21°C) air temperature
- 70/80% day/night relative humidity
- 500 ppm CO_2
- Photoperiod: 16-hr

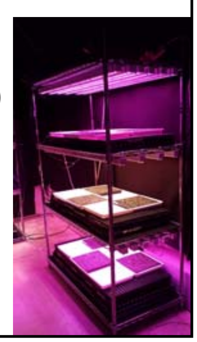
Materials and Methods

Light Quality

- Philips Production Modules Deep Red/Blue (87R :13B)
- Deep Red/Far-red/Blue (84R:7FR:9B)
- Deep Red/White (R74:G18:B8)

Daily Light Integral

- 6 $mol \cdot m^{-2} \cdot d^{-1}$ (2 modules)
- 12 $mol \cdot m^{-2} \cdot d^{-1}$ (4 modules)
- 18 $mol \cdot m^{-2} \cdot d^{-1}$ (6 modules)



Pansy 'Matrix Yellow'

- Increasing DLI led to decreased stem elongation
- Slightly smaller stem caliper at lower DLIs
- Higher DLIs led to greater root and shoot dry mass

Daily Light Integral ($mol \cdot m^{-2} \cdot d^{-1}$)

6			12			18		
R:B	R:FR:B	R:W	R:B	R:FR:B	R:W	R:B	R:FR:B	R:W

21 days of sole-source lighting

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Materials and Methods

- Seedlings transplanted at 21 and 28 days
- Finishing environment
  - 4.5 inch containers filled with a commercial medium
  - 16-hr ambient solar + supplemental HPS light
  - Air temperature: 68 °F (20 °C)
  - DLI ≈ 10 – 12 $mol \cdot m^{-2} \cdot d^{-1}$

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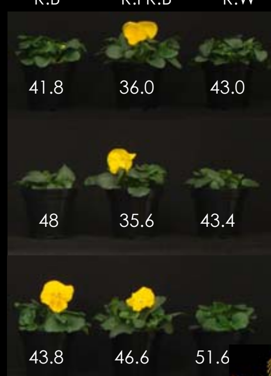
Pansy – Time to Flower

- R:FR:B flowered ~ 6 days earlier for High DLI
- R:FR:B flowered ~ 8 days earlier for Medium DLI

Light Quality; Daily Light Integral ($mol \cdot m^{-2} \cdot d^{-1}$)

	R:B	R:FR:B	R:W
18	41.8	36.0	43.0
12	48	35.6	43.4
6	43.8	46.6	51.6



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Preliminary Conclusions

- Higher quality plugs under higher DLIs
- Light quality does not appear to have a significant effect within DLIs on plug quality
- Earlier flowering for some species under R:FR:B LEDs with higher DLIs
- Results are still very preliminary

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Objective

- Quantify the effects of sole-source (SS) LED lighting providing different light intensities and qualities on: growth, morphology, and nutritional content of *Brassica* microgreens

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Materials and Methods

Plant Material
- *Brassica oleracea* var. *gongylodes* (kohlrabi)
- *Brassica juncea* (mustard)
- *Brassica rapa* spp. nipposinica (mizuna)

Substrate
- Polyethylene terephthalate fiber pad hydroponic tray

Environment
- 70/63 °F (21/17 °C) day/night (16 h/8 h)
- 50/60% day/night relative humidity
- 500 ppm CO_2

Materials and Methods

Light Quality
- Philips Production Modules:
  - Deep Red/Blue (87R :13B)
  - Deep Red/Far-red/Blue (84R:7FR:9B)
  - Deep Red/White (R74:G18:B8)

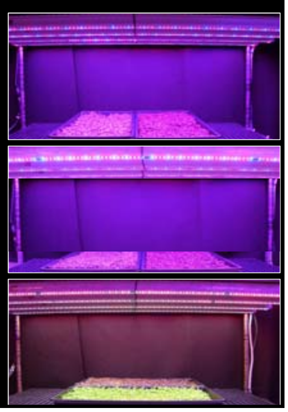
Daily Light Integral
- 6 mol·m^{-2}·d^{-1} (2 modules)
- 12 mol·m^{-2}·d^{-1} (4 modules)
- 18 mol·m^{-2}·d^{-1} (6 modules)

Light Treatments

87:13 (%) Red:Blue

84:7:9 (%) Red:Far-Red:Blue

74:18:8 (%) Red:Green:Blue



Results - *Brassica oleracea* (kohlrabi)

Daily Light Integral (mol·m^{-2}·d^{-1})

6 | 12 | 18

87:13 (%) Red:Blue

84:7:9 (%) Red:Far-Red:Blue

74:18:8 (%) Red:Green:Blue

Results - *Brassica oleracea* (kohlrabi)

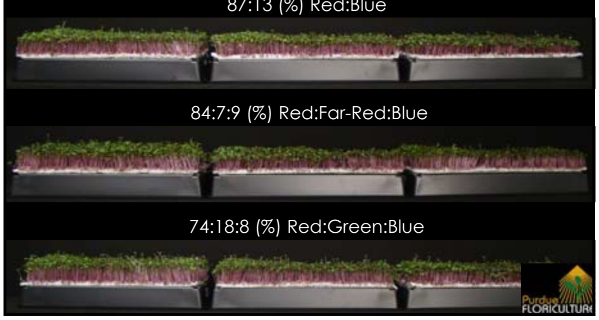
Daily Light Integral (mol·m^{-2}·d^{-1})

6 | 12 | 18

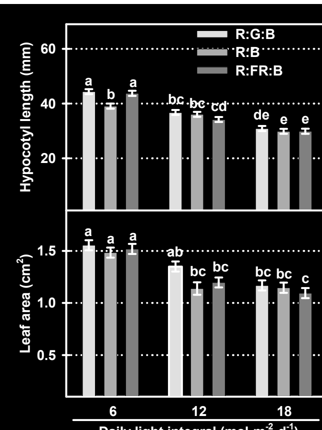
87:13 (%) Red:Blue

84:7:9 (%) Red:Far-Red:Blue

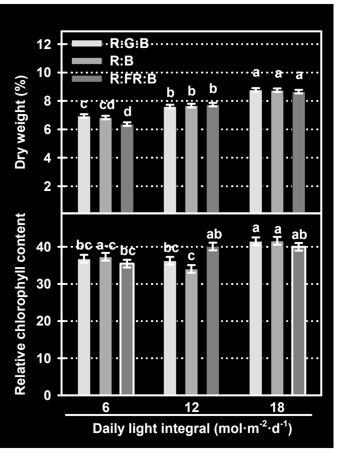
74:18:8 (%) Red:Green:Blue



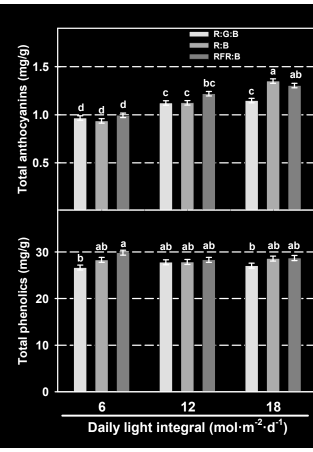
Results - Kohlrabi



Results - Kohlrabi



Results - Kohlrabi



Conclusions

- Biomass production increased with higher light intensities
- Increased DLI led to increased anthocyanin content
- Lower DLI may lead to increased carotenoid content
- Electrical savings are greatest with low light intensities

Background

Under low-light greenhouse conditions, foliage of *P. setaceum* 'Rubrum' and red leaf lettuce is:

- Often pale green to light purple
- Not as aesthetically appealing to consumers

Background

- Color is a key component
  - Influences and registers with consumer's initial perception of product quality (Ryder, 1999)

Background

- Color of plants is attributed to pigments:
  - Chlorophylls
  - Carotenoids
  - Flavonoids
    - Copigments (colorless)
    - Anthocyanins (colored) (Lightbourn et al, 2008)

Background

- Addition of blue (450 nm) light
  - Significantly increased the concentration of anthocyanins in leaf tissue (Stutte, 2009)

Background

- End-of-production (EOP) Supplemental Lighting:
  - Finishing stage of crop cycle
  - Proposed practice to enhance color
    - Increase product quality and aesthetic value

- **Plant Material:**
  - Purple fountain grass 'Rubrum'
  - Transplant into 13-cm diameter plastic containers

Production

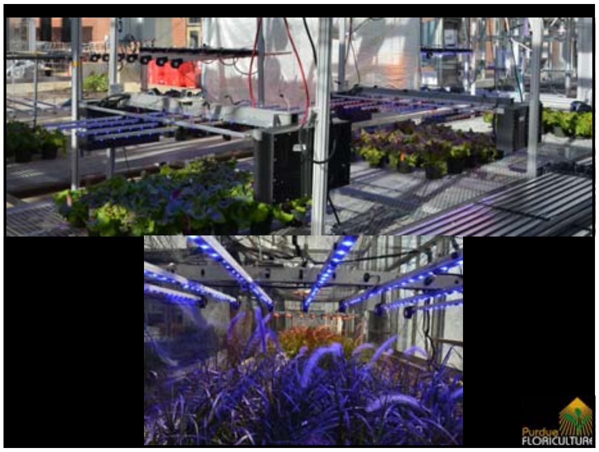
- Grown for 55 days prior to EOP lighting:
  - Under a 50% black shade cloth
    - Simulate the DLI of March
  - Natural day length
  - DLI ≈6.0 $mol \cdot m^{-2} \cdot d^{-1}$
  - Air temperature 73 °F (23 °C) constant
  - Fertilized with 200 $mg \cdot L^{-1}$ N (21N–5P–20K)

End-of-production Lighting

- Finished for 21 d under EOP lighting:
  - Air temperature 73 °F (23 °C) constant
  - 16-h photoperiod
  - DLI ≈ 8.9 $mol \cdot m^{-2} \cdot d^{-1}$

End-of-production Lighting

Light source	Light type	Spectral ratio (Red:Blue)	Intensity ($\mu mol \cdot m^{-2} \cdot s^{-1}$)
Control (No EOP)	Photoperiodic	---	4.1
HPS	End of Production Supplemental lighting (SL)	---	70.0
Light-emitting diodes (LEDs)		100:0	100.0
		50:50	100.0
		87:13	100.0
		0:100	25.0
		0:100	50.0
		0:100	100.0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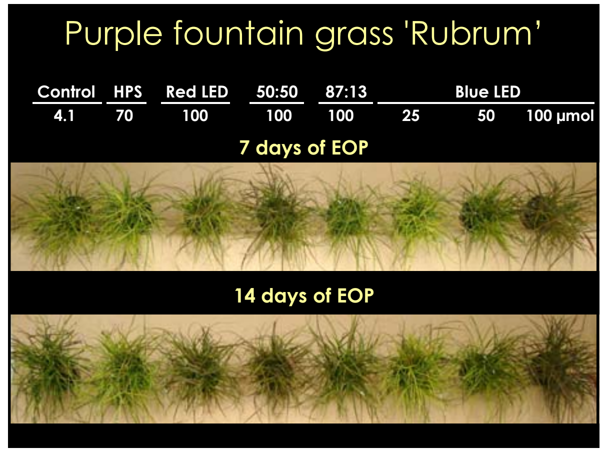
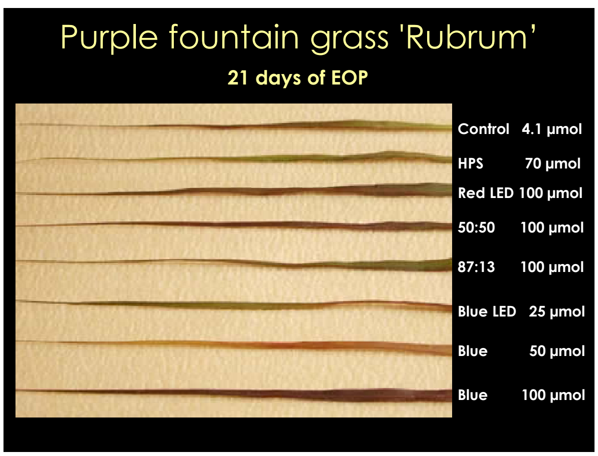
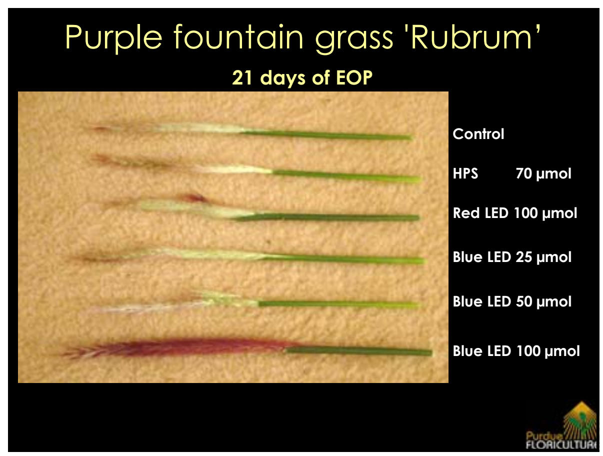

Purple fountain grass 'Rubrum'
Control HPS Red LED 50:50 87:13 Blue LED
4.1 70 100 100 100 25 50 100 µmol
7 days of EOP
14 days of EOP


Purple fountain grass 'Rubrum'
21 days of EOP
Control 4.1 µmol
HPS 70 µmol
Red LED 100 µmol
50:50 100 µmol
87:13 100 µmol
Blue LED 25 µmol
Blue 50 µmol
Blue 100 µmol


Purple fountain grass 'Rubrum'
21 days of EOP
Control
HPS 70 µmol
Red LED 100 µmol
Blue LED 25 µmol
Blue LED 50 µmol
Blue LED 100 µmol
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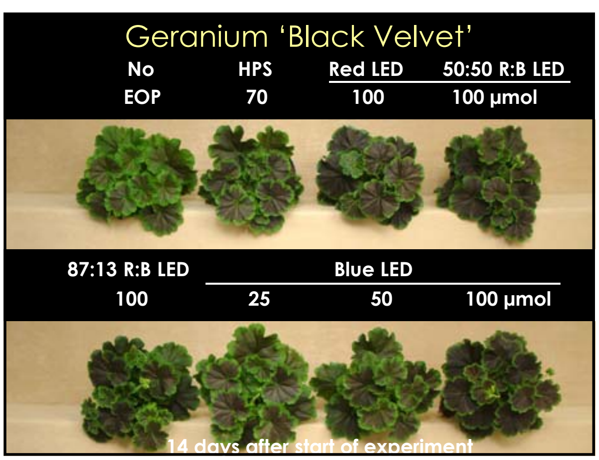
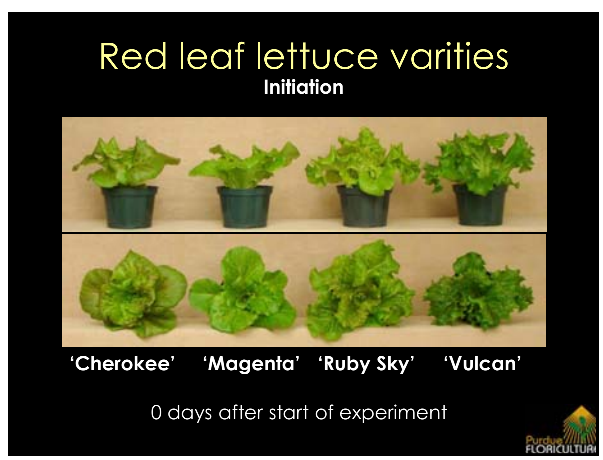

Geranium 'Black Velvet'
No EOP
HPS 70
Red LED 100
50:50 R:B LED 100 µmol
87:13 R:B LED 100
Blue LED
25
50
100 µmol
14 days after start of experiment


Red leaf lettuce varities
Initiation
'Cherokee' 'Magenta' 'Ruby Sky' 'Vulcan'
0 days after start of experiment
Purdue
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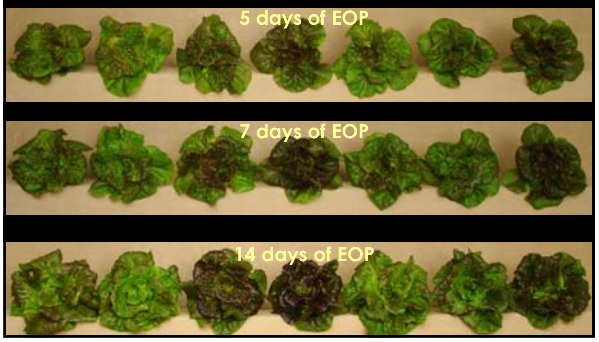
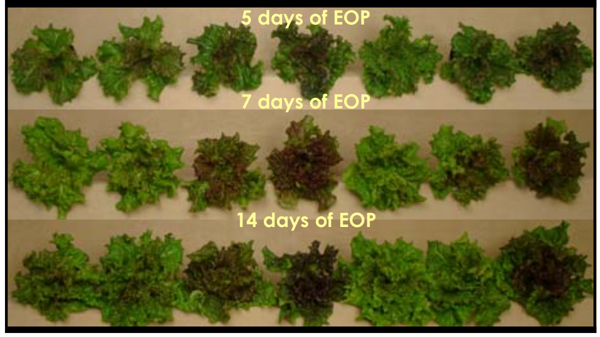
Lettuce 'Cherokee'

Control	HPS	Red LED	R:B LED	Blue LED		
	70	100	100	25	50	100 µmol



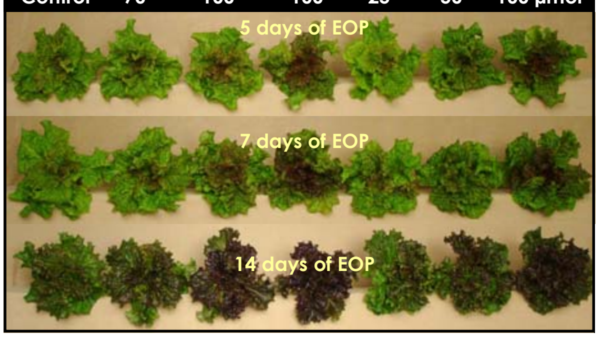
Lettuce 'Vulcan'

Control	HPS	Red LED	R:B LED	Blue LED		
	70	100	100	25	50	100 µmol



Lettuce 'Ruby Sky'

Control	HPS	Red LED	R:B LED	Blue LED		
	70	100	100	25	50	100 µmol



Conclusions – Purple Fountain Grass

- Seven to 14 days of EOP SL of 100 µmol·m^{-2}·s^{-1} red:blue, red or blue LED light
  - Promotes enhanced purple pigmentation of purple fountain grass 'Rubrum' and geranium 'Black Velvet' geranium when grown under a low greenhouse DLI

Conclusions – Lettuce

- Five to 7 days of EOP SL of 100 µmol·m^{-2}·s^{-1} red:blue, red or blue LED light
  - Promotes enhanced red pigmentation of lettuce 'Cherokee', 'Ruby Sky' and 'Vulcan' foliage when grown under a low greenhouse DLI

Background

- Low intensity LEDs
  - Designed to replace INC
  - Longer operating life
  - Spectra tailored to elicit desired plant responses, such as flowering

Materials and Methods

- Plant material
  - Marigold 'Moonsong Deep Orange'
  - Osteospermum 'Serenity Bronze'
  - Pansy 'Matrix Yellow'
  - Petunia 'Dreams Midnight'
  - Snapdragon 'Oh Snap Pink'
  - Sunflower 'Pacino Gold'
  - Zinnia 'Magellan Cherry'

Materials and Methods

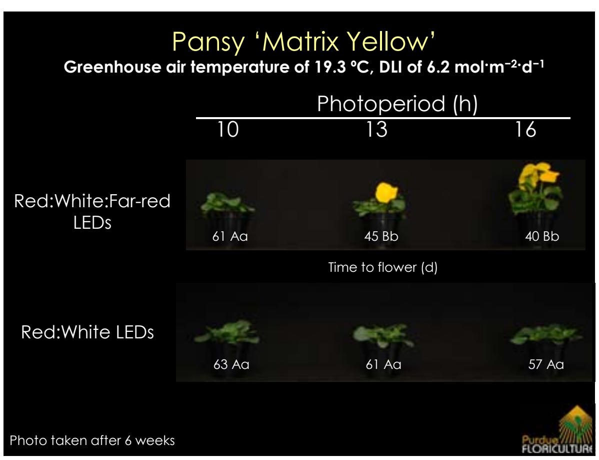
- Automatic blackout curtain system
  - Blackout curtains were retracted to create a truncated 9-h photoperiod
    - 0800 to 1700 HR
  - Natural day length supplemented with HPS lamps
    - *PPF* of ≈70 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at plant height

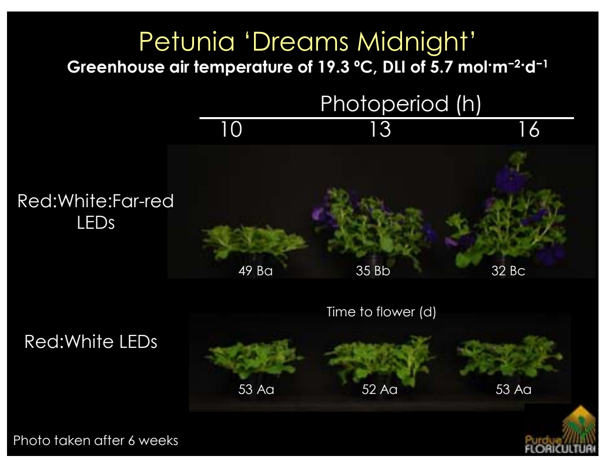
Materials and Methods

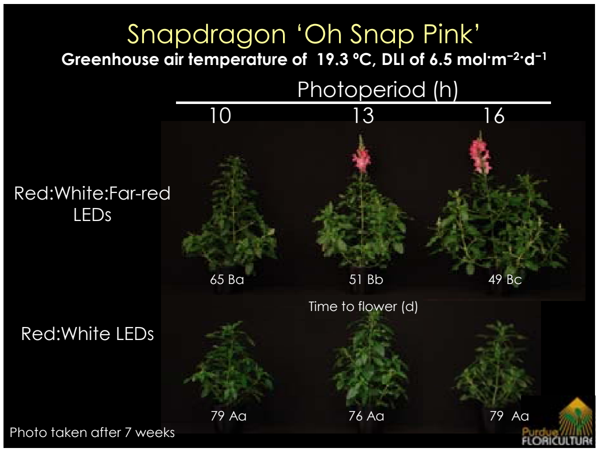
- Glass-glazed greenhouse
  - Air temperature 68/65 °F (20/18 °C) day/night
  - Low DLI ≈ 5 to 8 $mol \cdot m^{-2} \cdot d^{-1}$
  - High DLI ≈ 13 to 15 $mol \cdot m^{-2} \cdot d^{-1}$

Materials and Methods

- 10, 13, or 16-h photoperiods
  - DE lighting ≈4 $\mu mol \cdot m^{-2} \cdot s^{-1}$
    - R:W:FR Philips Flowering Lamp
      - 1, 4, or 7 h
    - R:W Philips Flowering Lamp
      - 1, 4, or 7 h







Conclusions

- Under low DLI, low intensity LEDs with far-red light:
  - Increased stem elongation
  - Hastened time to flower of LD plants
- Under low DLI, low intensity LEDs **WITHOUT** far-red light:
  - Reduced stem elongation
  - Delayed time to flower of LD plants

Conclusions

- Under low DLI, DE with R/W/FR photoperiodic lighting
  - Hastened time to flower
    - Market ready
    - Species dependent
  - Promoted stem elongation
    - Require plant growth regulators

LED Website and Conferences

http://leds.hrt.msu.edu

- **LED Symposium: Developing LED Lighting Technologies and Practices for Sustainable Specialty-Crop Production**
  - February 19 (tour/reception) and 20 (full day), 2015
  - Tucson, AZ and online
  - $40 online; $70 onsite
  - Register: http://leds.hrt.msu.edu/meeting

Acknowledgments

- We also thank the USDA, private horticulture and lighting companies that support Purdue LED research including: