Applications of supplemental LED lighting in vegetable propagation

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UA LED Research Objectives

1. To conduct research necessary for vegetable propagators to adopt LED lighting technology
   – Light quality requirement for LED lighting
   – Side-by-side comparison with the conventional HID lighting
   – Testing new fixture designs and application methods

2. To explore new LED applications beneficial to vegetable propagators
   – Low intensity applications of red and far-red LEDs for controlling plant morphology
   – Pulsed lighting

University of Arizona 2014, Not for Publication
Phase I: Supplemental LED B:R photon flux ratios for vegetable transplants

- **Objective**
  - Test different supplemental LED Blue:Red photon flux ratios for growth and development of vegetable transplants.

- **Hypothesis**
  - Vegetable seedlings respond different to B:R PF ratios under different solar DLI conditions.

Phase I: Materials & Methods

Testing different RED:BLUE ratios providing $55 \, \mu\text{mol m}^{-2} \text{s}^{-1}$ for 18 hours = $3.54 \, \text{mol m}^{-2} \text{d}^{-1}$ of supplemental LED light.

Blue = 455 nm, Red = 661 nm

Tested under different DLIs
- Controlling sun radiation by deploying different shade cloths.

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Phase I: Materials & Methods

Phase I: Results
Effects of supplemental LED light

Similar results for Tomato ‘Komeett’, and Pepper ‘Fascinato’

Phase I: Results

Effects of LED B:R PF ratios

CUCUMBER LEAF AREA RESPONSE

Leaf area reduction: 13%
Dry mass reduction: 12%


Conclusion Phase I

- LED supplemental lighting increased plant growth even under high DLI conditions.
- 100% red supplemental LED lighting is preferred at the current LED efficiencies.
- Responses to LED light quality vary under different solar DLI.
- Responses to LED light quality are species specific.
Phase II

• Objective

– Quantify plant responses of vegetable transplants grown side-by-side under LED and HPS supplemental lighting

– Compared electrical efficiencies between HPS and LED supplemental lighting

Materials & methods: treatments

Testing different lighting technologies providing 60 μmol m$^{-2}$ s$^{-1}$ for 18 hours = 3.9 mol m$^{-2}$ d$^{-1}$ of supplemental light.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Red-Led</th>
<th>Blue-Led</th>
<th>600W HPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red = 632 nm peak</td>
<td>100%</td>
<td>100%</td>
<td>5%</td>
</tr>
<tr>
<td>Blue = 443 nm peak</td>
<td></td>
<td></td>
<td>53%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>42%</td>
</tr>
</tbody>
</table>
Phase III: Materials & methods

Phase III: Results

Cucumber ‘Cumlaude’

Similar results for tomato ‘Komeett’

Hernández, R., Kubota, C. In press
Phase III Results: morphology

100% blue  HPS  100% red

Hernández, R., Kubota, C. In press

Phase III: Discussion

Tomato and cucumber plants had higher dry mass under the HPS treatment than the LED treatments.

Air T measured directly under the leaf was 1 °C higher in the HPS treatment.

Higher leaf T in HPS than LED
Phase III: energy consumption

<table>
<thead>
<tr>
<th>Lamp type and ballast</th>
<th>Input power (W)</th>
<th>Fixture efficiency (µmol J⁻¹)</th>
<th>Fixture photon emission rate (PER, µmol s⁻¹)</th>
<th>UF</th>
<th>MF</th>
<th>Effective photons (EP, µmol s⁻¹)</th>
<th>Number of fixtures per hectare</th>
<th>Areal power consumption (W m⁻²)</th>
<th>Fixture growing efficiency (g kWh⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue-LEDs</td>
<td>43°</td>
<td>1.9°</td>
<td>81.2°</td>
<td>1.00°</td>
<td>0.85°</td>
<td>69</td>
<td>8258</td>
<td>55</td>
<td>3.3</td>
</tr>
<tr>
<td>600W HPS</td>
<td>656</td>
<td>1.6°</td>
<td>1075°</td>
<td>0.90°</td>
<td>0.90°</td>
<td>871</td>
<td>655</td>
<td>43</td>
<td>3.5</td>
</tr>
<tr>
<td>Red-LEDs</td>
<td>22°</td>
<td>1.7°</td>
<td>37°</td>
<td>1.00°</td>
<td>0.85°</td>
<td>31</td>
<td>18124</td>
<td>59</td>
<td>3.0</td>
</tr>
</tbody>
</table>

* Values provided by the manufacturer.
* Values provided by Nelson and Bugbee (2013) for red-LED (655 nm) and blue-LED (455 nm).
* Calculated using fixture photon emission rate and fixture efficiency. Input power does not include fixture controller and cooling system.
* Calculated using fixture photon emission rate and measured input power.
* Reported for HPS lamps by Aldrich and Bartok (1994).

UF is a high value due to the directional nature of the emitted light, MF is 0.85 since LED lamp life is defined as the time to reach 70% of initial output and LED light output almost linearly declines over time (EERE, 2009).

Hernández, R., Kubota, C. unpublished (a)
Phase II: Energy Consumption

Conclusion

- At the current technology state, supplemental HPS lighting is more efficient than supplemental LED lighting as over-head lighting for the production of tomato and vegetable transplants.

Phase II: Leaf Curling Index in bell peppers
Phase II: Leaf Curling Index

Greenhouse pepper varieties

- Viper
- PP0710
- Orangela
- Fascinato

Hernández, R., Kubota, C. unpublished (b)
Phase III: R:B photon flux ratio sole-source LEDs

Objectives

Evaluate LED technology for the production of vegetable transplants.

Find the optimal B:R Photon flux ratio for the production of vegetable transplants using LEDs.

Phase III: Materials & Methods

Testing different RED:BLUE ratios providing 100 μmol m$^{-2}$ s$^{-1}$ for 18 hours = 6.48 mol m$^{-2}$ d$^{-1}$ DLI.

- 0B-100R
- 10B-90R
- 20B-28G-52R
- 30B-70R
- 50B-50R
- 75B-25R
- 100B-0R

Growing temperature: 25 °C
CO$_2$ concentration: Maintained at ambient
RH: 40-70%
Phase III: Materials & Methods

Phase III: Cucumber R:B ratio Results

Percent blue
Phase III: Cucumber R:B ratio Results

P<0.0001

Hernández, R., Kubota, C. unpublished (c)
Phase III: Cucumber R:B ratio Results

Hernández, R., Kubota, C. unpublished (c)

Phase III: Tomato R:B ratio Results

Hernández, R., Kubota, C. unpublished (d)
Light quality effect on plant growth can be **photosynthetic** or **photomorphogenic**.

**Plant growth rate**

\[ \text{Plant growth rate} = \text{Leaf photosynthetic rate} \times \text{Leaf area} \]
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