Yield Responses to Supplemental Lighting

Celina Gómez, PhD
Environmental Horticulture Department
University of Florida

Northeast Greenhouse Conference and Expo
November 10, 2016
Boxborough, MA

Solar radiation
Sunlight’s full spectrum ranges from 300 to 3000 nm

Photosynthetically Active Radiation (PAR, 400 to 700 nm)

Heat

Light for plant growth and development
Three dimensions

Quantity (intensity)
Quality (spectrum)
Duration (photoperiod)

Photosynthesis/biomass
Morphology
Development

The different properties of light interact to control growth and development

After Runkle, 2015

Plant Physiology
3rd edition, 2002

Chlorophyll absorbs minimal green light

After Bugbee, 2015

Plant Physiology

Multiple pigments absorb nearly all radiation from 400 to 700 nm

Metrics for plant lighting

• PAR

• Photosynthetic Photon Flux (PPF, μmol·m⁻²·s⁻¹)

• Daily Light Integral (DLI, mol·m⁻²·d⁻¹)

Accumulated measurement is key to determine the real output (accumulated energy is really important)

Runk and Fanwick, 2015

400 μmol·m⁻²·s⁻¹ for 16 h =
400 × 16 × 60 × 60 = 23,040,000 μmol·m⁻²·d⁻¹ = 23.04 mol·m⁻²·d⁻¹

Note: Lux and footcandle units should be avoided

Plant Physiology and Development
300 to 400 nm

Photosynthesis
Biomass
Development

Fisher and Runkle, 2004

Note: Lux and footcandle units should be avoided
Sensitivity to light
Humans vs. plants

Human eye perception
Relative Quantum Efficiency (RQE)

Adapted from McCree, 1972
"Biologically Active Radiation" (300 to 800 nm)

Plant responses to higher DLI
- Higher biomass production
- Smaller, thicker leaves
- More, larger flowers
- Reduced time to flower (partly due to temperature)
- Thicker stems
- More roots

Warrington and Norton, 1991
"A 1% reduction in light will reduce production (harvestable yield) by 1%.”

Supplemental light (SL)
- Important PAR source in Northern latitudes
- Additional DLI needed to enhance canopy photosynthesis and crop growth

SL for greenhouse-vegetable production
1. Installation and lamp types
2. Light intensity and photoperiod for specific crops
3. Crop management
4. Spectral composition

Seasonal solar DLI
Affected by photoperiod × PPF

The importance of using the right sensor
LI-COR Apogee

Plant responses to higher DLI
- Higher biomass production
- Smaller, thicker leaves
- More, larger flowers
- Reduced time to flower (partly due to temperature)
- Thicker stems
- More roots

Warrington and Norton, 1991
"A 1% reduction in light will reduce production (harvestable yield) by 1%.”
Installation

- Overhead lamps
- 3 ft above support wiring (over the canopy)
- ~100 to 150 \( \mu \text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \)
- Above plant rows
  - (different from Europe)
- Fewer but higher wattage (up to 1000 W) fixtures
- Turned off:
  - Solar radiation exceeds 450-600 \( \mu \text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \)
  - DLI of 20-25 mol m\(^{-2}\) d\(^{-1}\) is reached
- Consider heat contribution from SL

Note: overhead = top-lighting

Lamp types

Current standard: High-pressure sodium (HPS) lamps

- Metal halide:
  - Their energy efficiency is not as high as HPS lamps (1.5 vs. 1.7 \( \mu \text{mol} \cdot \text{J}^{-1} \))
  - Their useful bulb life is about half as long as HPS lamps
  - "Balanced" spectrum

Note: overhead = top-lighting

Mutual shading between/within foliar canopies

Common issue with overhead SL

Light-Emitting Diodes (LEDs)

Alternative sources for plant lighting

- Photon-emitting surfaces are not hot
- Can be placed close to plant surfaces
- Efficiency is improving rapidly
- Potential for advances in light distribution
- Wavelength selectable
Intracanopy LED (ICL-LED) lighting

Same concept as interlighting

Other high-wire crops

Sweet pepper

Eggplant

Overhead LED lighting

It all relates back to the average DLI (received by plants)

- Specific recommendations for SL depend on the crop
- Lamp and electrical cost
- Heating requirements
- Most vegetables are day-neutral plants
  - [i.e., no particular photoperiod hastens or delays flowering (and thus, fruit production)]

Lettuce

- Production:
  - PPF: 250 μmol·m⁻²·s⁻¹
    (50 to 150 μmol·m⁻²·s⁻¹ from SL)
  - Photoperiod: 16 h·d⁻¹
  - DLI: ~14 mol·m⁻²·d⁻¹

Extending the photoperiod from 16 to 24 h can increase plant biomass by 20% and reduce production cycle by 7 days

SL can increase tip-burn incidence

Sweet pepper

- Production:
  - PPF: 150 to 175 μmol·m⁻²·s⁻¹
    from SL
  - Photoperiod: 16 to 20 h·d⁻¹
  - DLI: ≥ 12 mol·m⁻²·d⁻¹

Continuous lighting (24 h) does not improve growth/yield compared to a 20-h photoperiod

Gotham Greens, Brooklyn, NY

Extending the photoperiod from 16 to 24 h can increase plant biomass by 20% and reduce production cycle by 7 days

SL can increase tip-burn incidence

Gotham Greens, Brooklyn, NY

Continuous lighting (24 h) does not improve growth/yield compared to a 20-h photoperiod

Gotham Greens, Brooklyn, NY

Extending the photoperiod from 16 to 24 h can increase plant biomass by 20% and reduce production cycle by 7 days

SL can increase tip-burn incidence
10/24/2016

Cucumber

- **Production:**
  - PPF: 150 to 300 μmol·m⁻²·s⁻¹ from SL
  - Photoperiod: 18 to 20 h·d⁻¹
  - DLI: up to 30 mol·m⁻²·d⁻¹

A dark period ≥4 h should be provided

Tomato

- **Propagation:**
  - PPF: 180 to 200 μmol·m⁻²·s⁻¹ from SL
  - Photoperiod: 18 to 20 h·d⁻¹
  - DLI: ~16 mol·m⁻²·d⁻¹

- **Production:**
  - PPF: 150 to 300 μmol·m⁻²·s⁻¹ from SL
  - Photoperiod: 16 to 18 h·d⁻¹
  - DLI: 25 to 30 mol·m⁻²·d⁻¹

Physiological injuries can be caused by long photoperiods (>16 h) during production

Cultural practices

Leaf pruning (removal) and intercropping

- Usually done with high plant density
  - (12 to 15 leaves are kept)
- A similar strategy is used with cucumber
  - (highest fruit quality and greatest shelf life)
- Intercropping can optimize space and light utilization:
  - New plants are planted as older plants mature.
  - Bottom leaves of the old crop are pruned and both crops share production area for a period of 6-8 weeks.

Crop Management

Other environmental parameters need to be considered

- To optimize use of SL, CO₂ is often enriched to 700-1000 ppm (μmol·mol⁻¹)
  
  But...
- Optimal growing temperature for vegetable production generally increases as DLI and CO₂ concentration increase
- As light becomes more available, plants can be spaced closer together because competition to harvest light becomes less of a limiting factor

Spectral composition

**Spectral composition**

**importance of wavebands**

3-way environmental interactions

Light intensity vs. CO₂ concentration
Broadband percentage of sunlight's blue, green, red (BGR) at noon

The BGR percentages of midday solar PPF are similar across seasons

The broadband definitions:
- Blue (400 - 500 nm)
- Green (500 - 600 nm)
- Red (600 - 700 nm)

Wavebands within PAR

- Red: most efficient waveband at driving photosynthesis
  - Promotes leaf expansion = increases light capture
- Blue: waveband typically adds value
  - Second-most efficient driving photosynthesis
  - Reduces stem elongation/leaf expansion (?) = reducing light interception, which possibly reduces whole-plant PPs
  - Regulates flower induction (?)
  - Phototropic growth movements
  - Regulates stomatal aperture (gas-exchange)
  - Important for chlorophyll synthesis

This is why most commercial LED arrays are red- and blue-biased

Green penetrates deeper into the leaf (than red or blue)

Canopy closure affects the spectral distribution of light

Plant responses to blue light

Increased blue light fraction causes
1. decreased cell expansion
2. reduced radiation capture
3. reduced growth

But it makes plant shape more similar to sunlight

Phosphor-coating effect

Note two fold greater scale
Manipulating plant characteristics I
blue light

Potential to improve quality (phytochemical content) of crops, and control morphology and/or flowering

Manipulating plant characteristics II
red/far-red light

Potential to control morphology (stem elongation/leaf expansion), quality, and for photoperiodic control

Early-generation commercial LED arrays
• Because initial capital investment is high, present commercial LED arrays tend to have:
  o Limited spectral choices
  o Fixed-color ratios
  o Modest output intensities (low LED density)
  o Passive heat sinking
  o Limited light-distribution geometry
• Limited capability to determine optimum light recipes for specific crops

(Re)-discovering the solar spectrum
From previous and ongoing sole-source lighting research
• Adding green to overhead red + blue light promotes growth
• Adding far-red
  o Promotes stem elongation
  o Promotes flowering in some photoperiodic classes
  o Prevents intumescence growth in some species
• Adding UV
  o Prevents intumescence
  o Promotes pigment and phytochemical accumulations
• Are white LEDs the answer?
  o Are blue LEDs + phosphor
  o Electrically inefficient (<50% as efficient as blue LEDs)
  o Lack FR, UV

Alternative to greenhouse SL
Improvements in glazing technology

Effect of direct and diffuse light in the greenhouse
Diffuse light penetrates deeper into plant canopies than direct light
Summary

• Typical PPF = 100 to 150 $\mu$mol·m$^{-2}$·s$^{-1}$

• Typical photoperiod = 8 to 16 h·d$^{-1}$

• Typical DLIs from SL = 2.9 to 8.6 mol·m$^{-2}$·d$^{-1}$
  – 20 mol·m$^{-2}$·d$^{-1}$ is a general target DLI for most fruiting vegetables
  – 10 mol·m$^{-2}$·d$^{-1}$ is the minimum acceptable DLI for many vegetable crops

• Benefit of SL is greatest when sunlight intensity is low

• Consider alternative technologies

Questions?

cgomezv@ufl.edu