Applications of Far-Red LEDs in Plant Production under Controlled Environments

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LEDs in Horticulture

- Increasing interest worldwide
- Challenges
  - High fixture costs
  - Limited information on optimization (light quality, design and application methods)
- Opportunities
  - Maximizing photosynthesis
  - Photomorphology or photoperiodic control

Incandescent Lamps

- 100-year old technology
- Rich in yellow, red, and far-red in addition to thermal radiation.
- Used in horticulture for photoperiodic as well as supplemental photosynthetic lighting.
- The only widely available light source containing far-red radiation.
- Currently horticulture use is exempt from the phase-out, but the limited access may increase the price.

Far-red LEDs

- Current LED market is for visible range (~380 – 680 nm), UV and NIR (>800 nm), leaving far-red (700 – 800 nm) without much development.
- Far-red (response peak at 735 nm) is a light quality relevant to plant growth/development.
- LED technology enables monochromatic far-red lighting.

Supplemental Far-Red Light
Potential Applications

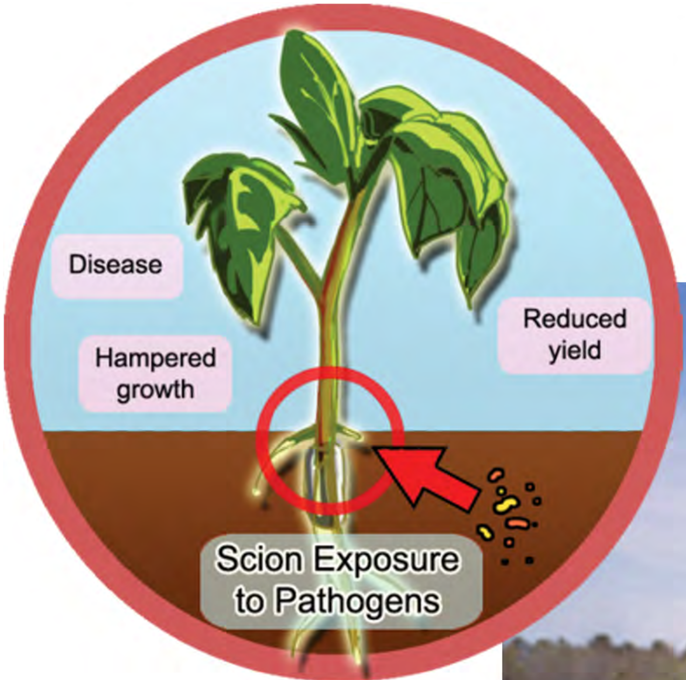
- Greenhouse conditions
  - Extending stem/hypocotyl of plants (cut flower and seedlings)
  - Expanding leaf and enhancing growth rate (leafy greens)
- Growth chamber (plant factory) conditions
  - Extending stem/hypocotyl of plants (seedlings)
  - Expanding leaf and enhancing growth rate (leafy greens)

End-of-Day Light Treatment

- Classic photobiology (phytochrome response)
- Light quality at the end of day (photoperiod) determines stem elongation during the successive night (dark period)
  - **EOD red light** >> shorter plants
  - **EOD far-red light** >> taller plants
- Effective at **VERY low light** intensity
- Responses are light quality dependent (i.e., P_{fr}/P_{total})
- **EOD-FR:** Limited applications in the past (there was no pure FR light source).
- **EOD-FR:** Potential non-chemical control of stem or hypocotyl elongation

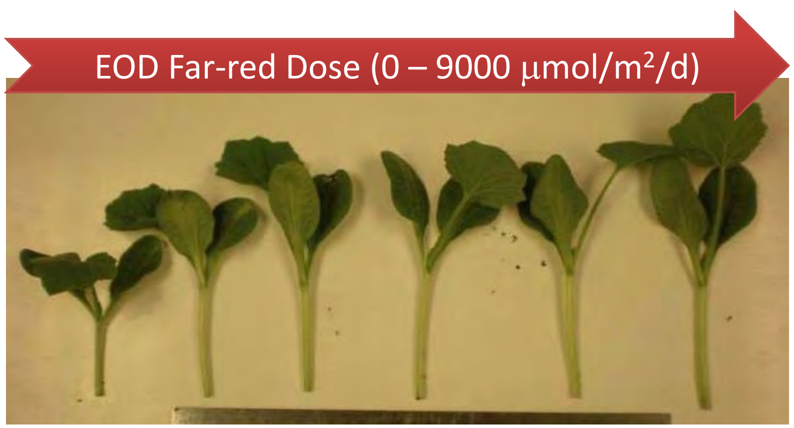
EOD-FR Application for Vegetable Rootstock

- Longer hypocotyls are needed in vegetable grafting
  - Greater grafting speed
  - Keeping grafted unions above the soil line.

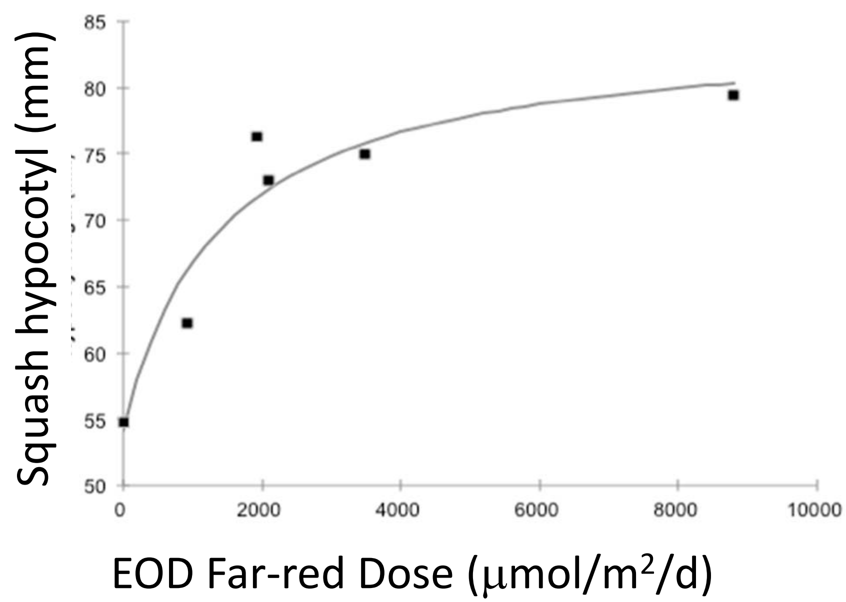


End-of-day light quality treatment for controlling morphology of vegetable seedlings in greenhouse

Tomato rootstock seedlings



Squash rootstock seedlings



(Chia and Kubota, 2010; Kubota et al., 2011)

Indoor Grafted Seedling Production

- Technology widely used in Japan
- However, application for cucurbits is limited (i.e., plants become *<u>too</u>* short)

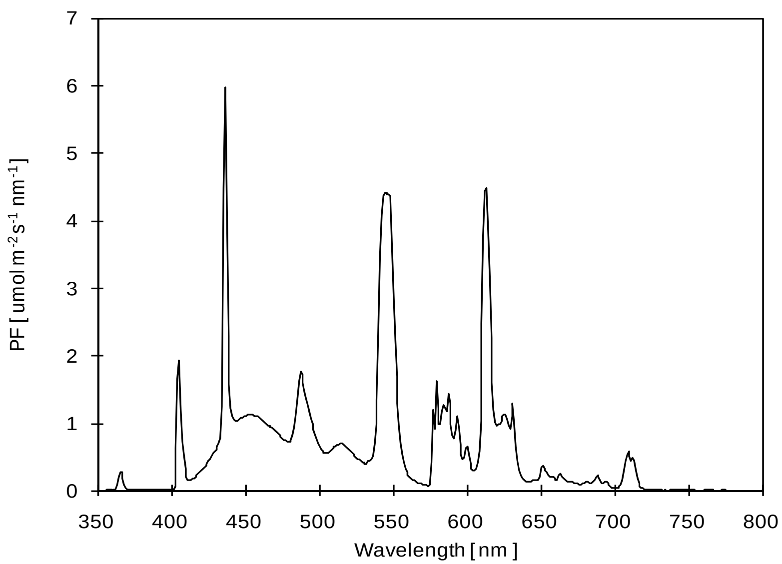


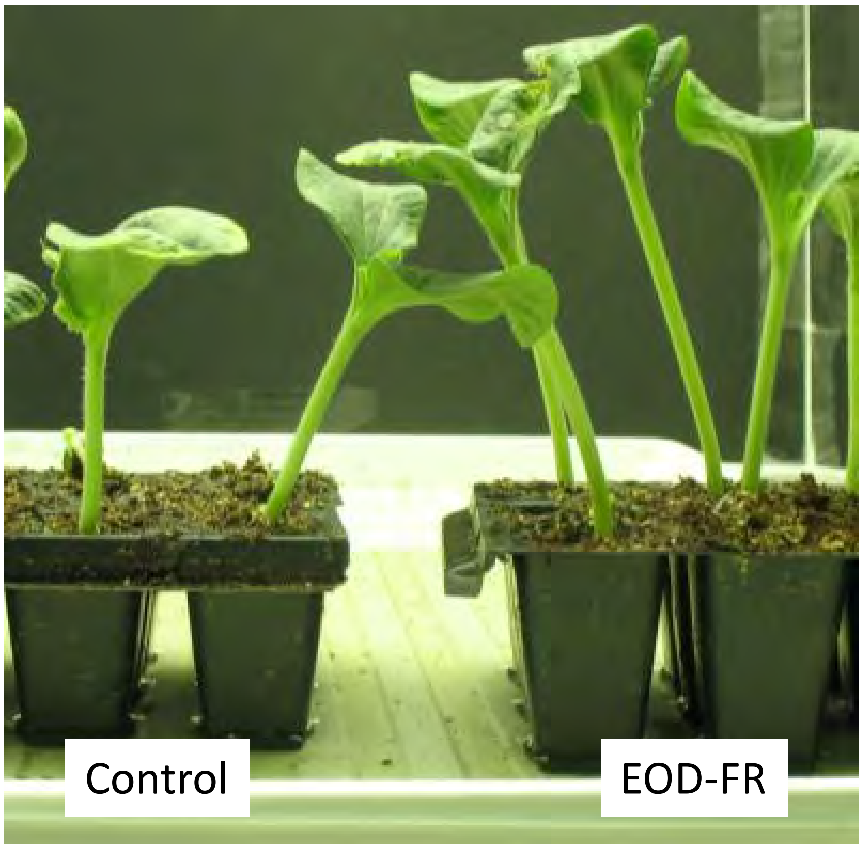
Figure. Typical light quality of T5 white fluorescent lamps.

P_{fr}/P_{total} = 0.807 (R/FR = 10.2)

[Sunlight P_{fr}/P_{total}: ~0.7 (R/FR: ~1)]

End-of-day FR Light Treatment for Cucurbit Seedlings Grown under Artificial Lighting

Preliminary Experiment



Plant species:

C. maxima x C. moschata ‘Tetsukabuto’

Main light source:

Cool White fluorescent lamp
PPF: 150 μmol m^{-2} s^{-1} (400-700 nm)
Photoperiod: 12 hours

EOD FR treatment:

Intensity: 4 μmol m^{-2} s^{-1} (700-800 nm)
Duration: 30 min EOD for 3 days
FR Dose: 7200 μmol m^{-2} d^{-1}

Moving Far-Red Lighting

New application method

- End-of-Day FR light dose response showed saturation at around 4000 μmol m^{-2} d^{-1} (700-800 nm)
- There was also reciprocity (intensity vs. duration) demonstrated for tomato and squash rootstock seedlings.

FR light intensity (μmol/m²/s)	FR light duration (min)	FR light dose (μmol/m²/d)	Hypocotyl (mm)
1.3	24	1800	72a
2.7	12	1900	76a
0 (Control)	0	0	55b

(Squash result after Chia (2009))

- Prototype of moving Far-Red LED lighting was designed and tested.

Moving Far-Red Lighting

New application method

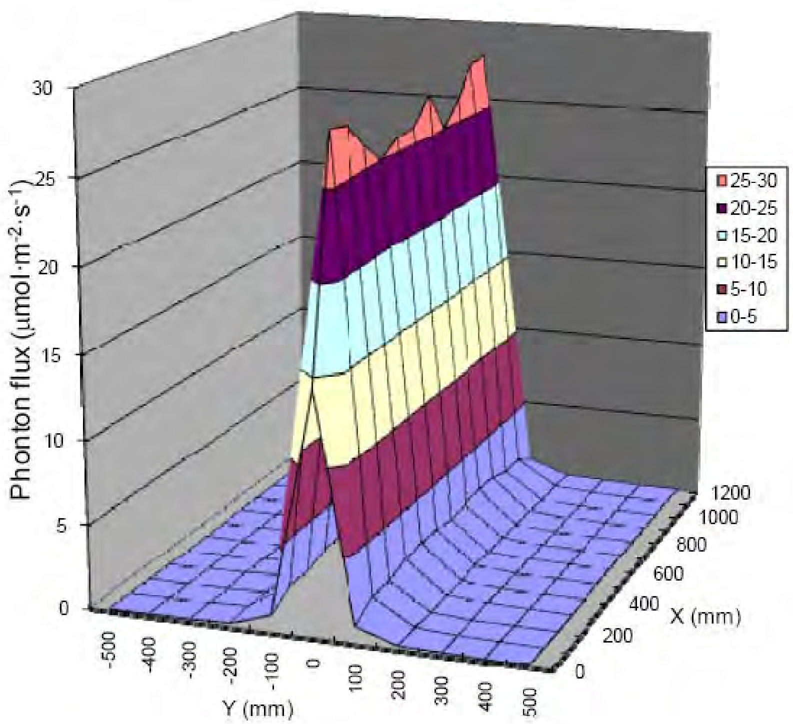


Figure. FR photon flux distribution at the horizontal plane 5 cm below the light source.

Collaboration with Dr. Murat Kacira (UA, ABE)

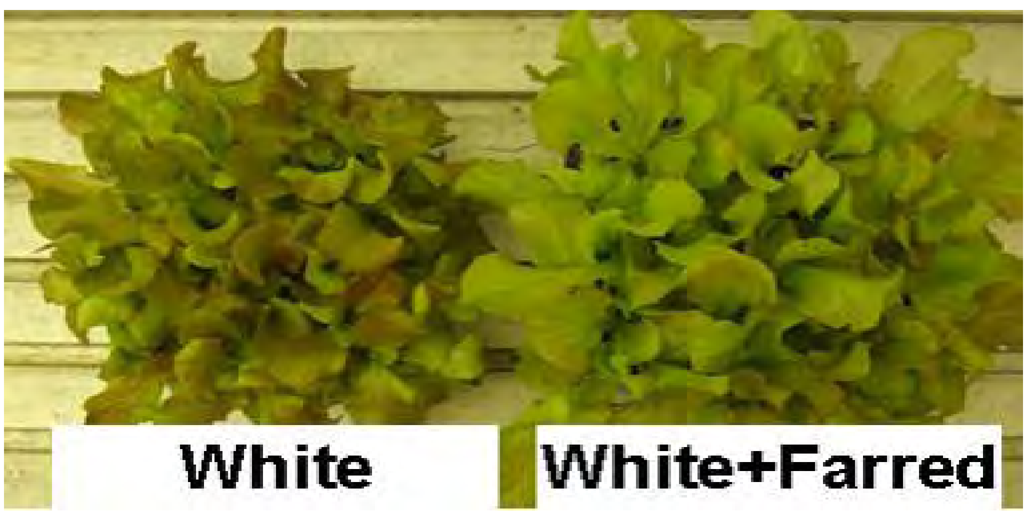
End-of-Day FR Treatment with Moving fixture vs. Stationary fixture

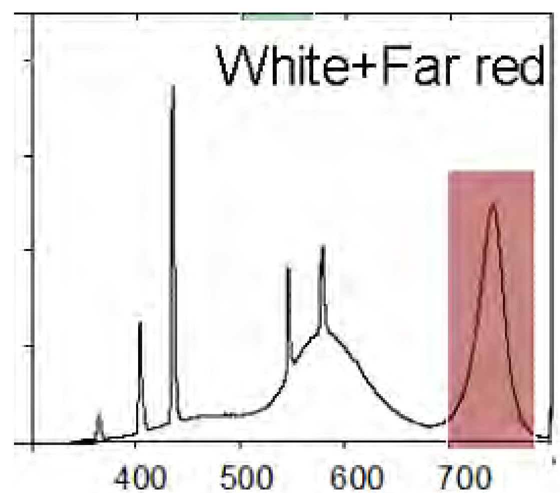
Main factor	Hypocotyl (mm)
EOD FR treatment and LED fixture type (dose = 4000 μmol/m^2/d)	
Moving fixture	82.2 a
Stationary fixture	89.6 a
Non-treated control	53.0 b
Traveling speed (application times) of moving fixture	
0.8 mm/s (one application per EOD)	73.6 a
3.1 mm/s (four applications per EOD)	90.9 a

Yang et al. (submitted)

Supplemental FR Lighting for Baby Leaf Lettuce under Artificial Lighting

- Supplemental far-red light significantly increased the biomass of baby lettuce plants by 28%.
- This was due to the increased light interception caused by enhanced leaf elongation.
- Similar observation by Stutte et al. (2009).





(Li and Kubota, 2009)

End-of-Day FR Light Treatment for Baby Leaf Lettuce in Greenhouse

Preliminary Experiment

Non treated control

EOD FR light treatment

Intensity: 46 μmol m^{-2} s^{-1} (700-800 nm)
Duration: 3.3 min at EOD for 10 days
Dose: 9,200 μmol m^{-2} d^{-1}

Conclusions

- Far-red light is a well-studied light quality in relation to phytochrome responses with limited applications in the past.
- We successfully demonstrated the applications of far-red LED lighting for seedling production (as EOD lighting) as well as lettuce production (supplemental or possibly, EOD lighting).
- However, wider applications will be dependent on availability and costs of far-red LEDs. We will continuously develop new applications (part of USDA SCRI LED project).

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