Lighting Decisions for Greenhouse Production

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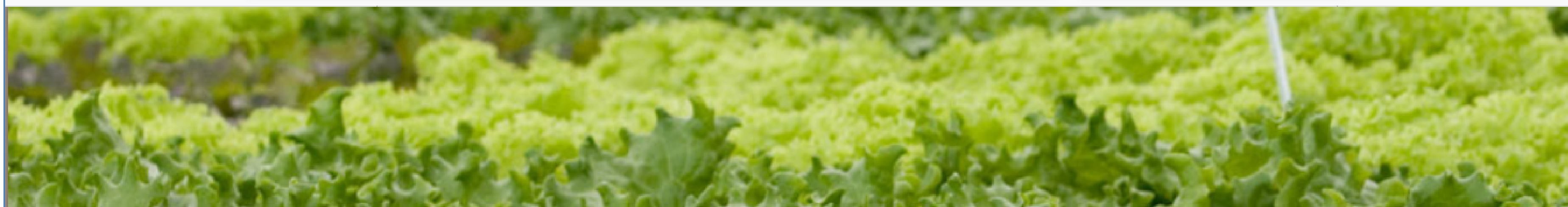

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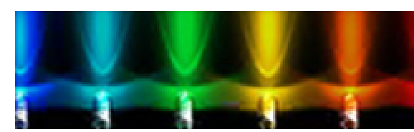
Cornell Controlled Environment Agriculture

Controlled Environment Agriculture or CEA facilities can range from the very low-tech such as row covers and high/low plastic covered tunnels, to fully automated glass greenhouses with computer controls. There have even been some CEA facilities on the international space station where astronauts have grown leafy greens both to eat and to advance scientific knowledge. The Cornell CEA program has worked with many different types of CEA facilities through the years. We developed a greenhouse hydroponic production method geared toward local food production. A prototype facility was built in Ithaca in the late 1990's and continues to function today producing more than 1000 heads of lettuce every day of the year. We continue to do research in the areas of supplemental lighting and commercial hydroponic vegetable production. Learn more about the CEA...

GLASE



The Greenhouse Lighting and Systems Engineering (GLASE) consortium is a public-private partnership led by Cornell University and Rensselaer Polytechnic Institute to integrate

GLASE
GREENHOUSE LIGHTING & SYSTEMS ENGINEERING

www.glase.org

Cornell
RPI LESA
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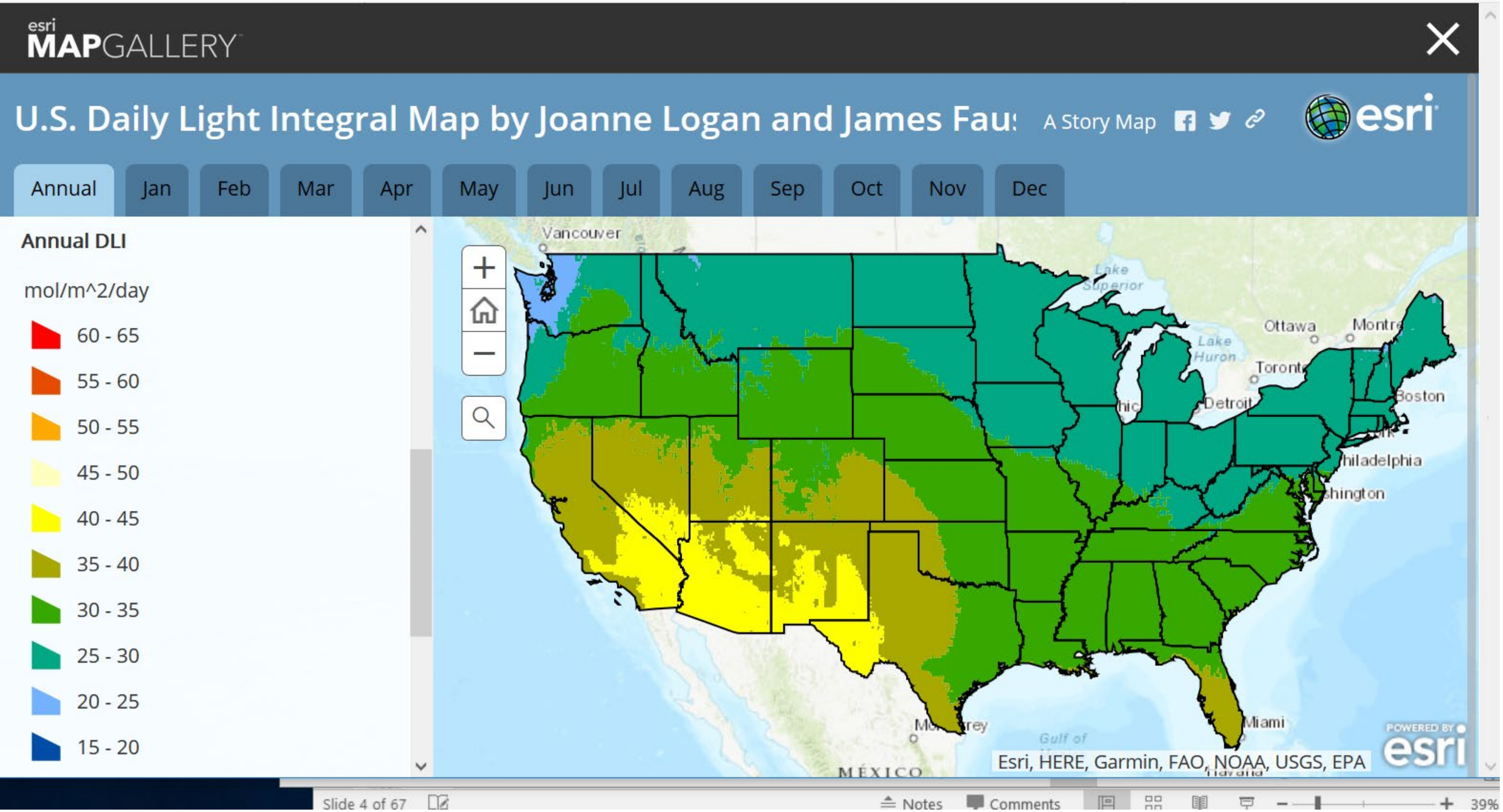
Outline

- How much light do you have?
- How much light do you need?
- Cost to buy/operate lights
- Lighting control

Updated DLI maps

https://mapgallery.esri.com/map-detail/5b0f577674204e43b4a2329



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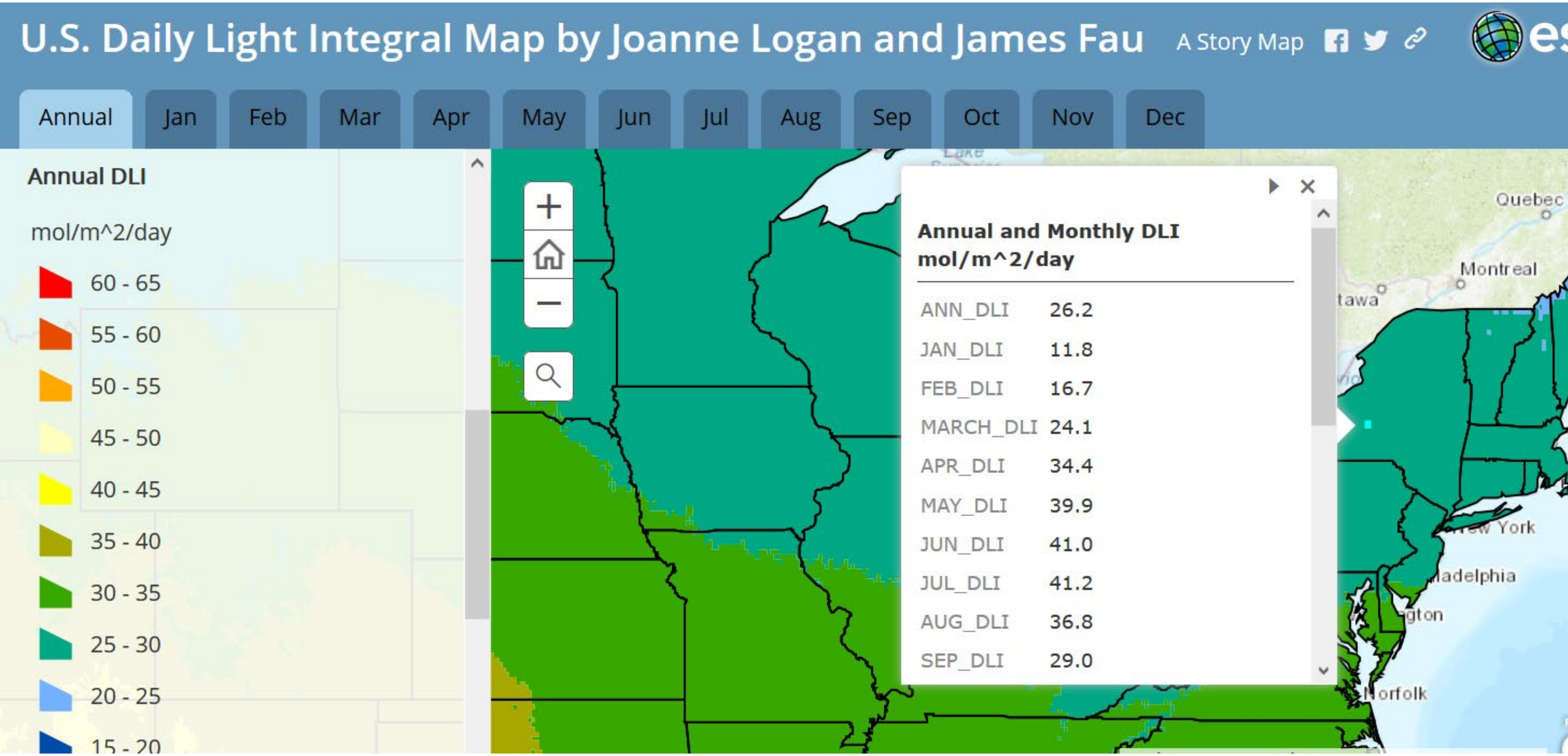
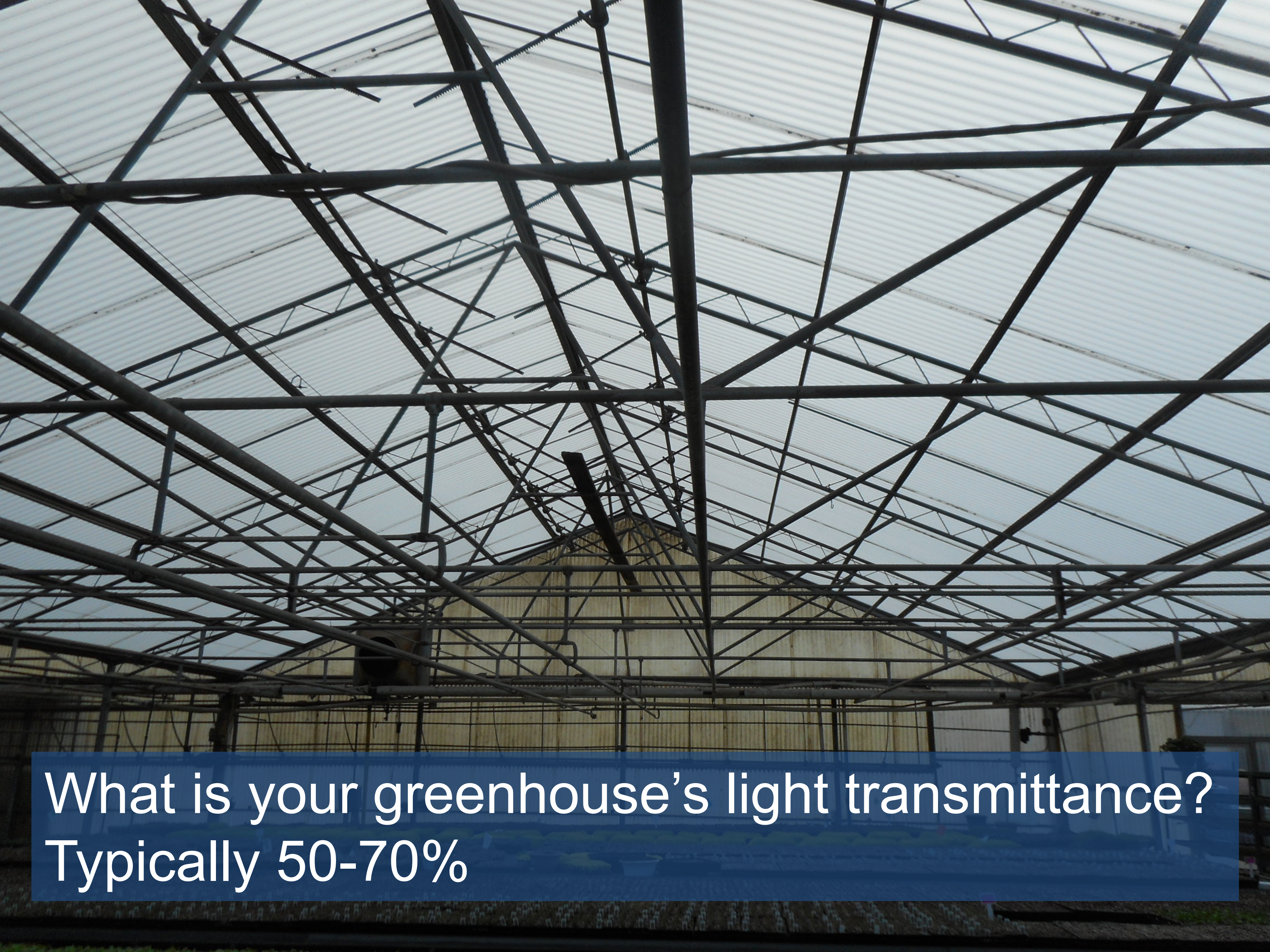




What is your greenhouse's light transmittance?
Typically 50-70%

Outline

- How much light do you have?
- How much light do you need?
- Cost to buy/operate lights
- Lighting control

How much light do you need?

Flower Crops

- Propagation of plugs and cuttings
  - 8-12 mol m^{-2} d^{-1} (after callus)
- Bedding plants
  - 10-12 mol m^{-2} d^{-1} (species dependent)
- Flowering potted plants
  - 10-12 mol m^{-2} d^{-1} (species dependent)
  - Phalaenopsis orchids (6), potted miniature roses (14)
- Install lighting capacity of 50-100 µmol m^{-2} s^{-1}

Table 2. DLI Requirements for Various Greenhouse Crops

Yellow	Minimum aceptable quality
Green	Good quality
Red	High quality

1=Requires ample water to perform well at high-light levels.
2=Requires cool or moderate temperatures to perform well at high-light levels.
3=Stock plants perform well under higher light levels than finished plants.

Species	Average Daily Light Integral (Moles/Day)														
	Greenhouse														
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Ferns (Pteris Adiantum)	Minimum	Good	High	High	High										
Maranta	Minimum	Good	High	High	High										
Phalaenopsis (orchid)	Minimum	Good	High	High	High										
Saintpaulia	Minimum	Good	High	High	High										
Spathiphyllum	Minimum	Good	High	High	High										
Forced hyacinth	Minimum	Good	High	High	High	High	High	High	High	High	High	High	High	High	High
Forced narcissus	Minimum	Good	High	High	High	High	High	High	High	High	High	High	High	High	High
Forced tulip	Minimum	Good	High	High	High	High	High	High	High	High	High	High	High	High	High
Aglaonema		Minimum	Good	High	High	High	High								
Bromeliads		Minimum	Good	High	High	High	High								
Caladium		Minimum	Good	High	High	High	High	High	High	High	High	High	High 1	High 1	High 1
Dieffenbachia		Minimum	Good	High	High	High	High								

Purdue Bulletin – Measuring daily light integral in the greenhouse

https://www.extension.purdue.edu/extmedia/HO/HO-238-W.pdf

Light intensity effects time to flower

Pansy grown for 3 weeks under different lamps

Increasing light intensity

DLI

8 10 12.5 16 19.5 23

How much light do you need?

Vegetables

- Within bounds: 1% more light → 1% more yield

- Lettuce and Herbs
  - 12-17 mol m^{-2} d^{-1}
  - For head lettuce
  - greater light → tipburn
  - Vertical airflow fans important
- Microgreens
  - 12 mol m^{-2} d^{-1}
- Install lighting capacity of 100-200+ µmol m^{-2} s^{-1}

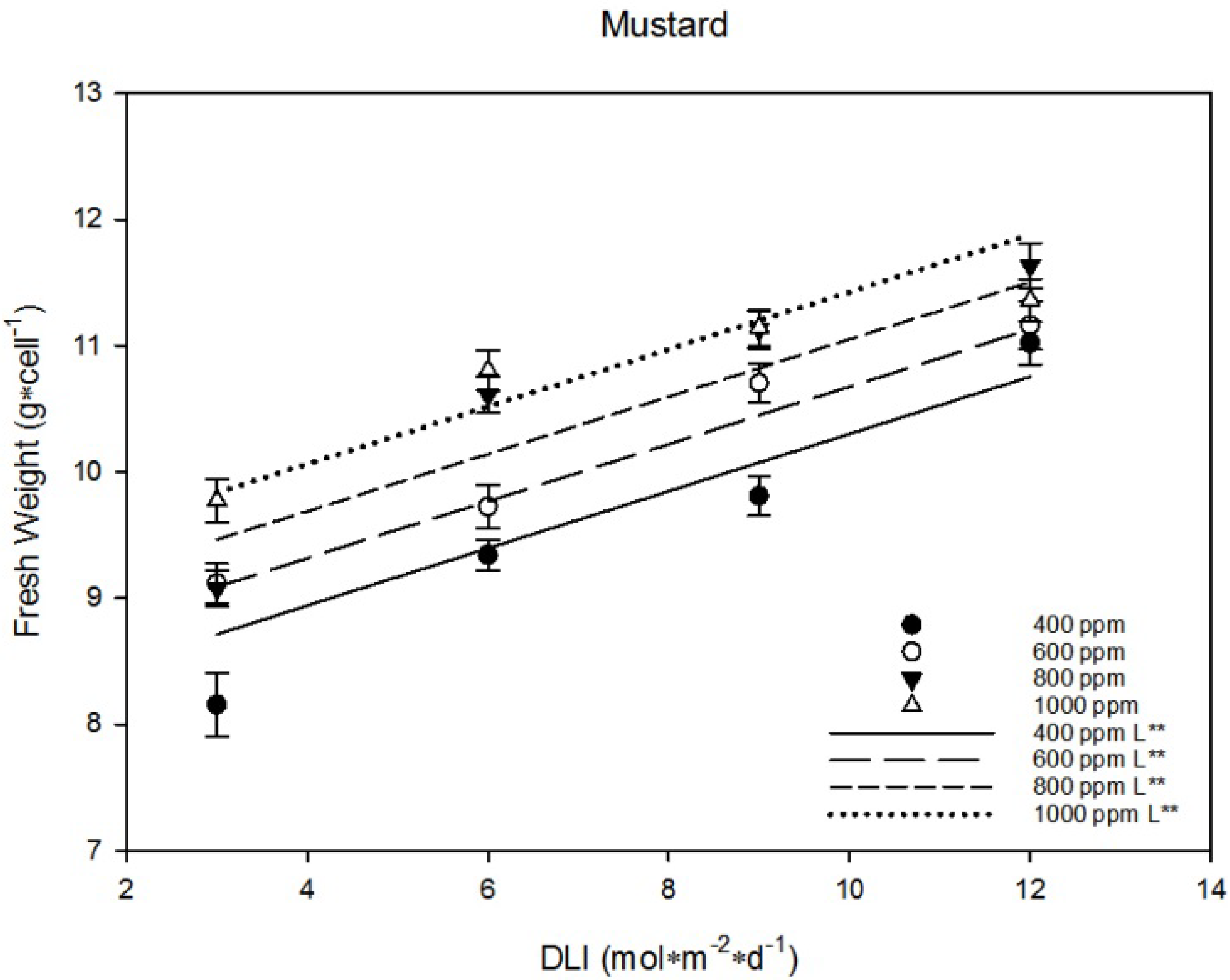
Lettuce and Light

- 17 mol m^{-2} d^{-1} target
  - Assumes good air flow (paddle fans)
- If > 17 mol m^{-2} d^{-1} for 3 days in a row → leaf tip burn
- If poor air flower or concerned about tip burn, set a lower target
- Days to harvest at:
  - 17 mol 35 days
  - 10 mol 60 days
  - 5 mol 119 days!

Low light →
Excessive stem elongation

Leaf Tip Burn (Calcium deficiency at high light)

Microgreens DLI and CO_2

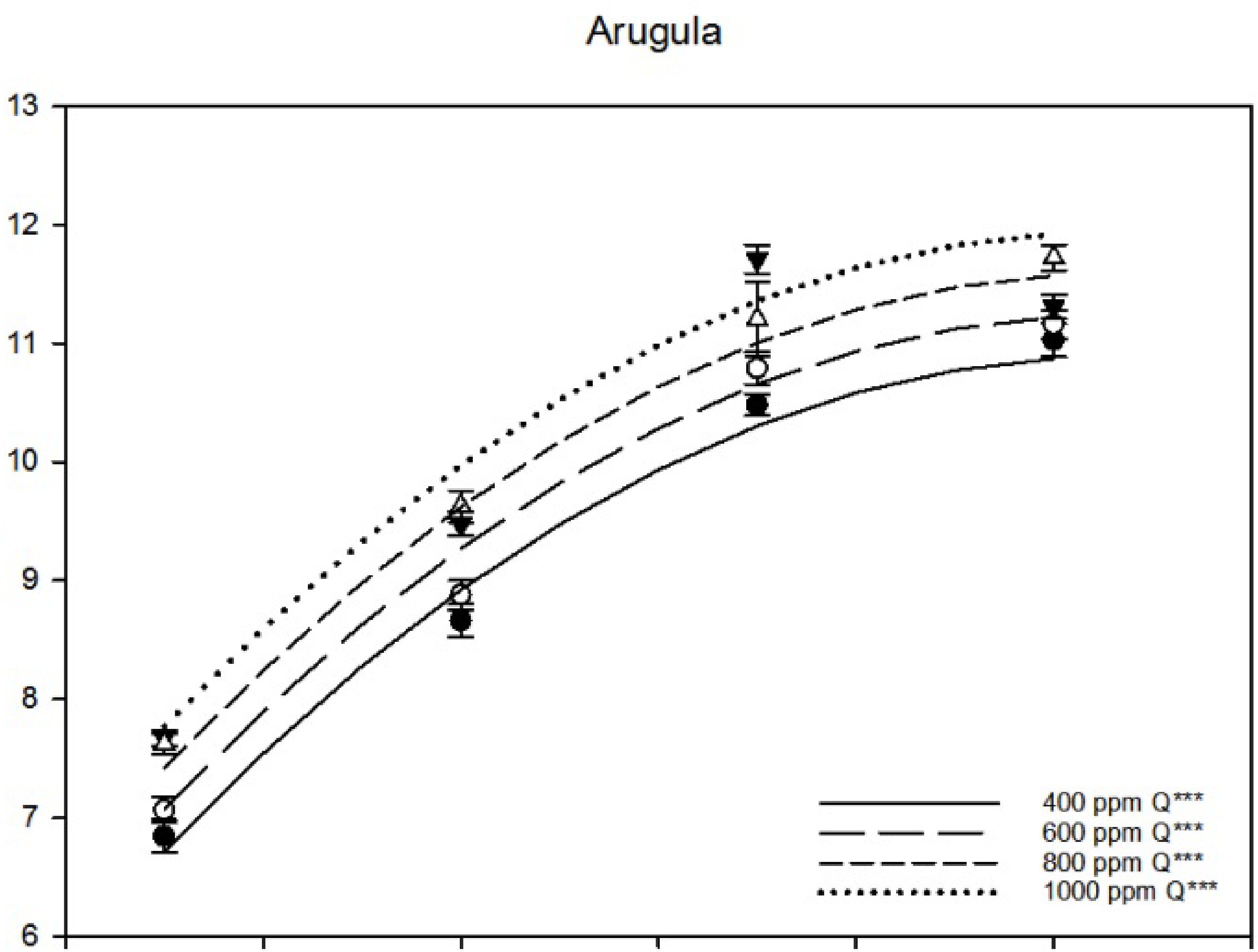


Mustard 'Garnet Giant'

Jonathan Allred, Cornell University

*Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

Microgreens DLI and CO_2



Arugula

Jonathan Allred, Cornell University

*Significance of linear (L) or quadratic (Q) regression: NS, *, **, *** denotes nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

How much light do you need?

Fruiting Crops

- Cucumber
  - 15 mol m^{-2} d^{-1} minimum, >30 mol m^{-2} d^{-1} optimum
- Tomato
  - 20 mol m^{-2} d^{-1} minimum, >30 mol m^{-2} d^{-1} optimum
- Sweet Pepper
  - 20 mol m^{-2} d^{-1} minimum, >30 mol m^{-2} d^{-1} optimum
- Strawberries
  - 17 mol m^{-2} d^{-1} minimum, >20 mol m^{-2} d^{-1} optimum
- Install lighting capacity of 100-200+ µmol m^{-2} s^{-1}

How much light do you need?

Fruiting Crops

- Require daily dark period of 4-6 hours
- Continuous light causes physiological disorders
  - Leaf chlorosis
  - Reduced plant size
  - Reduced yield
- Install lighting capacity of 100-200+ $\mu mol\ m^{-2}\ s^{-1}$

Strategies for determining target light intensity

(Target DLI - *Minimum ambient DLI) / Photoperiod

= Hourly LI $mol/m^2/hr$

Hourly LI X 1,000,000 μmol/mol / 3,600 s/hr

= Target PPFD $\mu mol/m^2/s$

*Minimum ambient DLI

- This could be the actual lowest DLI based on weather station data
- Lowest DLI except in the 10% most extreme cases
- Or based on monthly average calendar

Strategies for determining target light intensity

Example: **Tomato**, 18 hour photoperiod

Target DLI 20 mol/m^2/d, min. amb. DLI 5 mol/m^2/d

(Target DLI - *Minimum ambient DLI) / Photoperiod

= Hourly LI mol/m^2/hr

(20 mol/m^2/d – 5 mol/m^2/d / 18) = 0.83 mol/m^2/hr

(0.83 mol/m^2/hr) X (1,000,000 μmol/mol) / (3,600 s/hr) = 231 μmol/m^2/s


Outline
• How much light do you have?
• How much light do you need?
• Cost to buy/operate lights
• Lighting control

Considerations when choosing new lights

- **Wall-plug efficacy**
- **Initial cost ($/fixture x # of fixtures)**
- Lifespan (often reported to 70% output)
- Bulb replacement cost
- Installation cost
- Shading of fixture
- Uniformity of light plan
- Wavelength/Light quality?

Lamp Life L70 (to 70% output)

Fluorescent	10,000 hours
Metal Halide	20,000 hours
High Pressure Sodium	30,000 hours
LED	50,000 hours

- Bulbs can be replaced for fluorescent/HID but not for LED
- May make economical sense to replace bulbs/lights before L70 is reached

Highest measured efficacies (so far)

Lamp type	Power consumption (W)	PAR flux (µmol/s)	PAR efficacy (µmol/J)	PAR efficacy (mol/kWh)
INC	102.4	32.8	0.32	1.15
CFL	61.4	54.6	0.89	3.20
LED (INC replacement)	17.2	23.9	1.39	5.00
HPS (single ended)	700	1,092	1.56	5.62
HPS (double ended)	1,234	1,962	1.59	5.72
LED (bar)	214	511	2.39	8.60

A.J. Both Rutgers University

Comparing Efficacy of Greenhouse Lighting Fixtures

- Neil Mattson, David de Villiers, Lou Albright, Cornell University
- A.J. Both, Rutgers University

nyserda

Energy. Innovation. Solutions.

Fixture	Power (Watts)	Par Flux / Light Output (µmol/s)	Wall-plug Efficacy (mol/kWh)	Cost ($ / fixture)
PAR Source 1000W DE HPS	1077	1712	5.72	$407
Gavita Pro 600W SE HPS	700	1092	5.62	$294
Heliospectra LX602-G LED (100% on R/W/B)	649	772	4.27	$1,849
Illumitex PowerHarvest W 10 Series LED	510	872	6.16	$1,299
LumiGrow Pro 650™ LED (100% on R/W/B)	566	764	4.86	$1,369
Philips GreenPower LED Toplighting DR/B – Med. B	216	516	8.60	$500

Fixtures from 2016
Cost data, from online July 2016.
Always check with supplier for current cost and bulk pricing.

How much area can one fixture light?

Calculating by dividing light output (μmol/s) by target instantaneous light (μmol m^{-2} s^{-1})

Example: PAR Source/Agrosun DE 1000 W

- Light output: 1712 μmol/s
- Target: 200 μmol m^{-2} s^{-1}

1712 / 200 = 8.56 m^2

→ 92 ft^2

Also consider mounting height and light pattern

Fixture	Par Flux / Light Output (µmol/s)	Square feet coverage
PAR Source 1000W DE HPS	1712	92
Gavita Pro 600W SE HPS	1092	59
Heliospectra LX602-G LED (100% on R/W/B)	772	42
Illumitex PowerHarvest W 10 Series LED	872	47
LumiGrow Pro 650™ LED (100% on R/W/B)	764	41
Philips GreenPower LED Toplighting DR/B – Med. B	516	28

Electricity cost for 1 fixture per year

(Power (Watts) x hours on per year) / 1000
= kWh / year

Example: (1077 W x 2592 hrs) / 1000
= 2,791 kWh / year

2,791 kWh/yr x $0.105 (cost of kWh)
= $293 / yr electricity

Electricity cost per square foot

Annual electricity cost for 1 fixture divided by number of square feet lit

Example:PAR Source/Agrosun DE 1000 W

- Electricity cost $293 / yr
- Square feet lit 92 ft^2

$293 / 92 = $3.18 / ft^2 / yr

Neil's calculator: fixtures needed and electricity costs

	A	B	C	D	E	F	G
1	**LAMPS NEEDED CALCULATOR**						
2	estimating lamp needs for greenhouse space						
3	© Neil Mattson, Cornell University 4/23/15						
4							
5	Fill in yellow highlighted boxes						
6	200	Target instantaneous light intensity (µmol/m2/s PAR)					
7	872	Lamp output (µmol/s) fill in from table in Lamps tab					
8	43560	Area to light (square feet)					
9	6.16	Efficacy of lamp (mol/kWh) fill in from table in Lamps tab					
10	10%	percent light lost from edge effects					
11	7.1	hours that lights are on per day (0-24)					
12	$0.105	cost of electricity ($/kWh)					

Lamps on for 2592 hrs/yr

10% loss from edge effects

Target light: 200 µmol m^{-2} s^{-1}

Illumitex PowerHarvest 10 Series W fixture

Neil's calculator: fixtures needed and electricity costs

	A	B	C	D	E	F	G	H
13								
14	**Calculations** (don't modify these boxes)							
15	**4,047**	Square meters to light (note 1 square meter = 10.7639 square feet)						
16	**510**	Lamp power consumption (W)						
17	**929**	Lamps needed without edge effects						
18	**1,033**	Lamps needed with edge effects						
19	**5**	Daily light integral (mol/m2/day PAR)						
20	**1,364,237**	kWh of electricity to light this many lamps for the given number of hours						
21	**$143,245**	electricty cost ($/area in cell A8/yr)						
22	**$3.29**	electricity cost ($/sf/yr)						
23								
24	*Note* placement of lamps should be determined by a lighting professional to optimize							

Available at: http://cea.cals.cornell.edu/

Lighting 1 acre greenhouse

Fixture	Fixtures to light 1 acre	Cost of fixtures ($)	Fixture cost ($/sf)
PAR Source 1000W DE HPS	473	$192,511	$4.42
Gavita Pro 600W SE HPS	742	$218,148	$5.01
Heliospectra LX602-G LED (100% on R/W/B)	1,049	$1,939,601	$44.53
Illumitex PowerHarvest W 10 Series LED	929	$1,206,771	$27.70
LumiGrow Pro 650™ LED (100% on R/W/B)	1,060	$1,451,140	$33.31
Philips GreenPower LED Toplighting DR/B – Med. B	1,569	$784,500	$18.01

Fixtures from 2016

Lamps on for 2592 hrs/yr Target light: 200 μmol m^{-2} s^{-1}

Lighting 1 acre greenhouse

Fixture	kWh electricity (1 yr.)	Electricity cost (1 yr.)	Electricity cost ($/sf)
PAR Source 1000W DE HPS	1,320,965	$138,701	$3.18
Gavita Pro 600W SE HPS	1,345,067	$141,232	$3.24
Heliospectra LX602-G LED (100% on R/W/B)	1,769,370	$185,784	$4.27
Illumitex PowerHarvest W 10 Series LED	1,226,889	$128,823	$2.96
LumiGrow Pro 650™ LED (100% on R/W/B)	1,554,593	$163,232	$3.75
Philips GreenPower LED Toplighting DR/B – Med. B	878,270	$92,218	$2.12

Fixtures from 2016

Lamps on for 2592 hrs/yr   Target light: 200 µmol m^{-2} s^{-1}

e-gro.org → Alerts → Edibles

by Neil Mattson
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How Many Light Fixtures Do I Need?

Thinking of adding or upgrading supplemental lights in your greenhouse? This alert will walk you through estimating how many light fixtures you need and their electricity cost.

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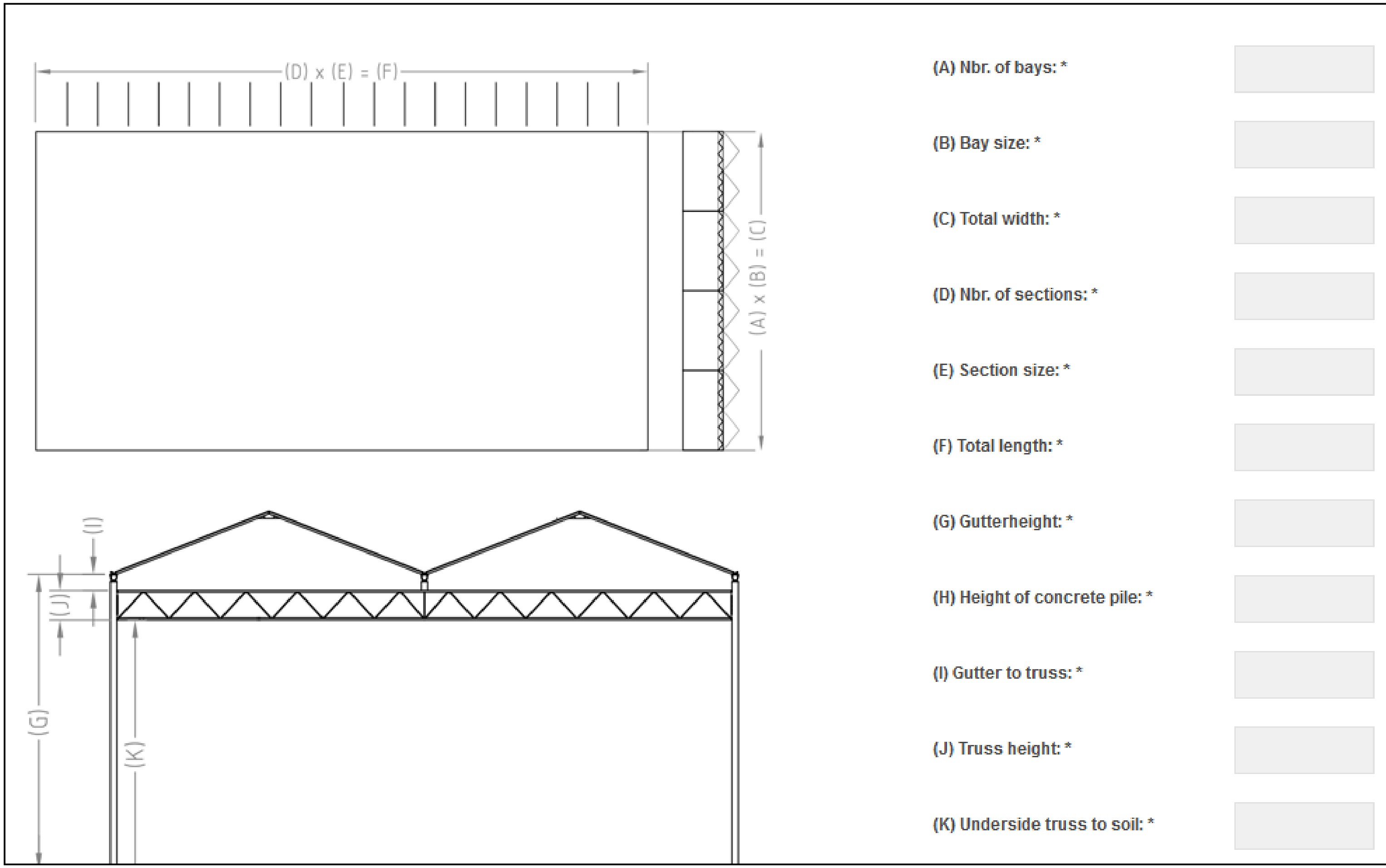
Greenhouse lighting plan from lighting professionals



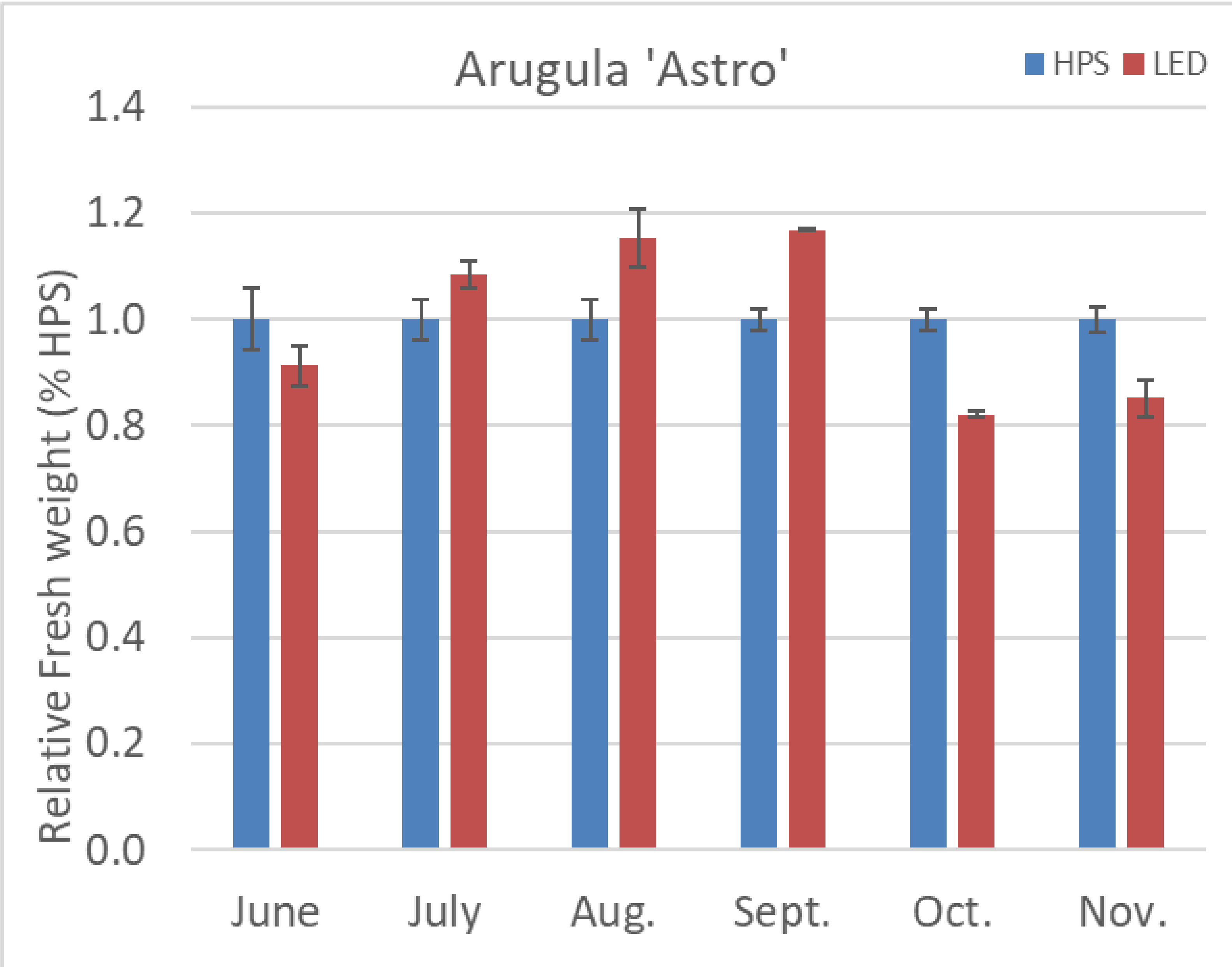
Example: www.pllight.com

Performance of baby leaf greens under HPS vs. LED during a 1-year period

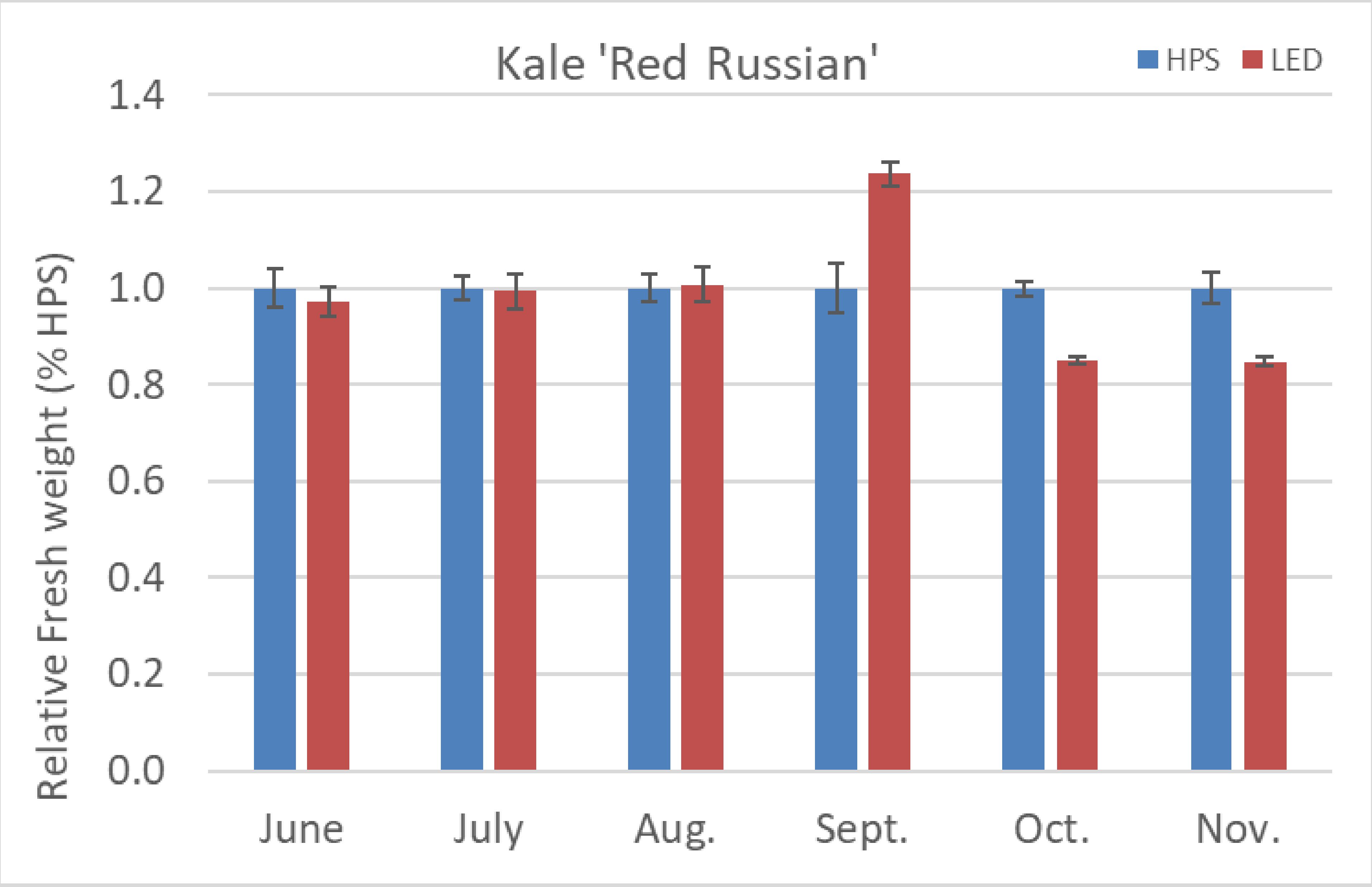
- **LED**: Philips GreenPower LED toplighting model 9290-009-799, Deep Red/Blue
- **HPS**: Gavita Pro 6/750 FLEX
- Greenhouse with supplemental light to 17 $mol \cdot m^{-2} \cdot d^{-1}$
- Arugula, kale, lettuce
  - Ca. 17 day crop cycle

Kale Harbick, David de Villiers, Jonathan Allred, Neil Mattson

Preliminary results



Preliminary results



Outline

- How much light do you have?
- How much light do you need?
- Cost to buy/operate lights
- Lighting control

Consistent DLI = consistent growth

- Why is consistency important?
  - Growers
    - Predictable yields
    - Sales contracts
    - Predictable labor
  - Research
    - Reproducibility

Light Control Strategies for photosynthetic light

- Time clock
- Instantaneous thresholds light/shade
- Target daily light integral

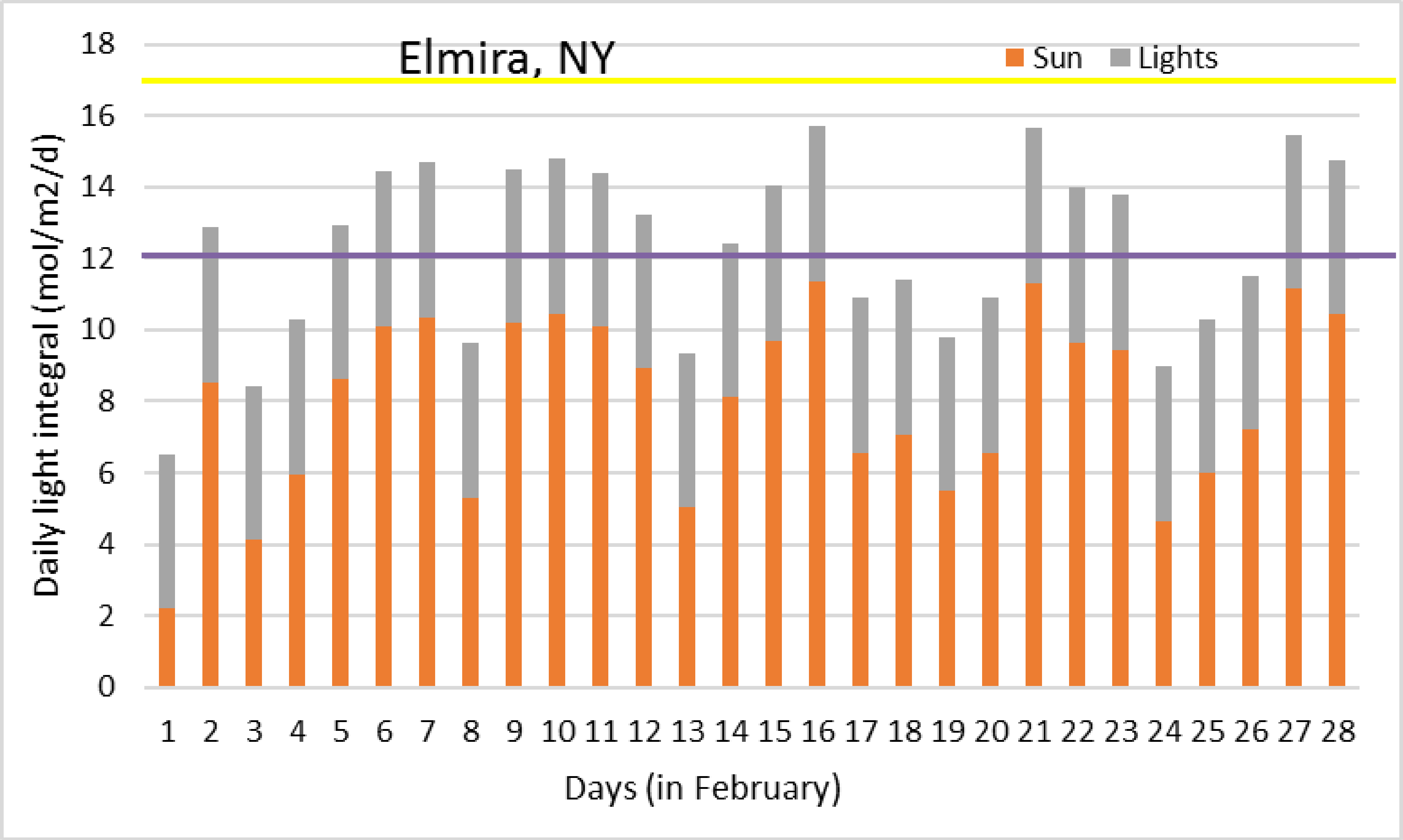
Time clock

- Lights on for set time each day, often from:
  - October–March (North)
  - November-February (South)

- Manually turn off during “sunny” days?

Example

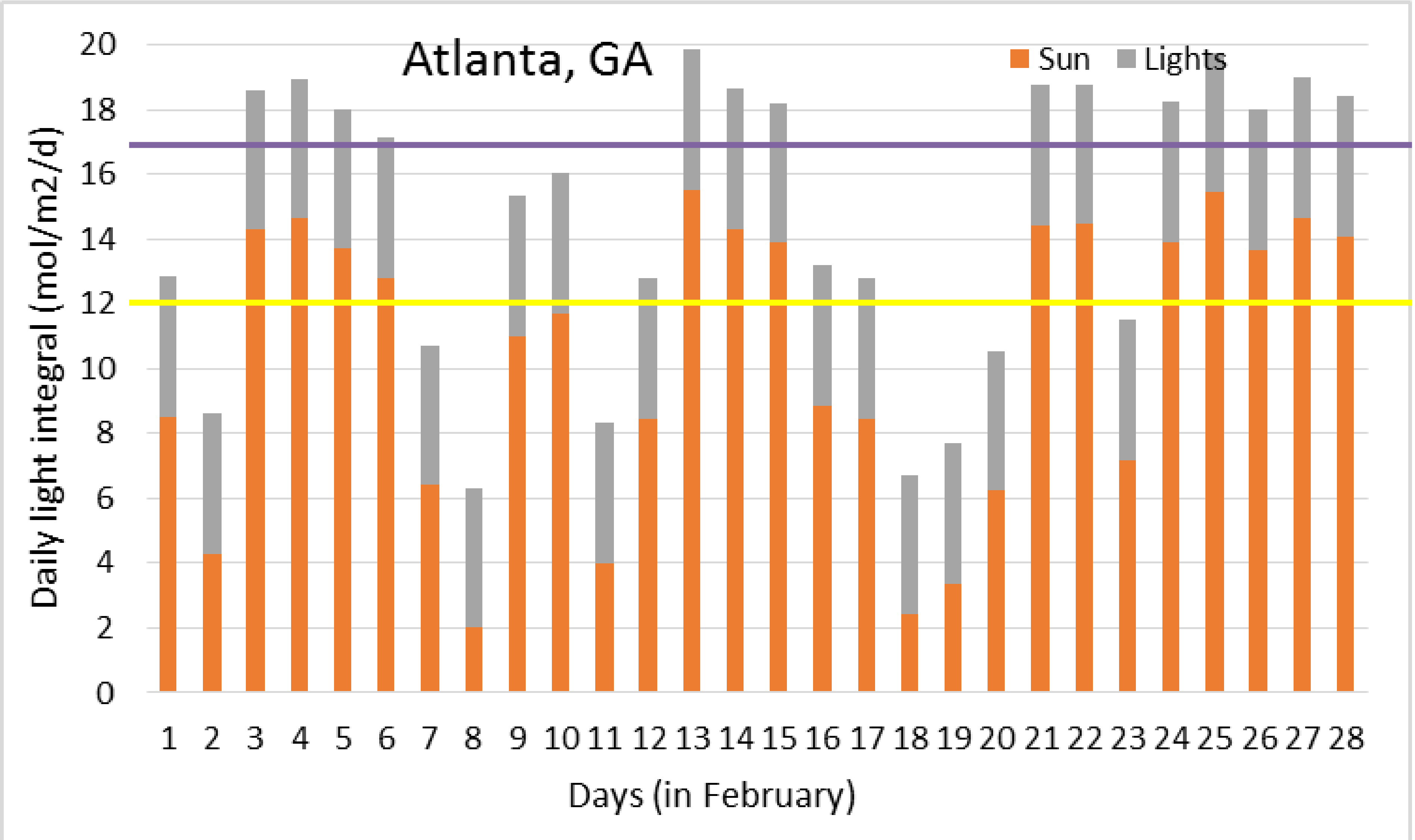
- Lights on 12 hours/day (6am-10am, 4pm-12am)
- 100 µmol m^{-2} s^{-1} x 12 hrs → 4.32 mol m^{-2} d^{-1}



Light data is from a typical meteorological year (TMY)

70% light transmission

Purple line: target DLI lettuce; Yellow line: target DLI many floriculture crops



Light data is from a typical meteorological year (TMY)

70% light transmission

Purple line: target DLI lettuce; Yellow line: target DLI many floriculture crops

Time clock

- Pros
  - No light sensors or computer control required

- Cons
  - No control over DLI
  - Over light (wasted energy)
  - Under light (reduced yield/quality)
  - Difficult for crop scheduling

Instantaneous thresholds for light and shade

- Computer control system
- Light sensor
  - Location?
    - Should be inside at plant canopy height

Example

< 200 μmol m^{-2} s^{-1} for 10 mins → Lights on

> 300 μmol m^{-2} s^{-1} for 10 mins → Lights off

> 600 μmol m^{-2} s^{-1} for 10 mins → Shade closed

Continue light in evening until DLI target met

Instantaneous thresholds for light and shade

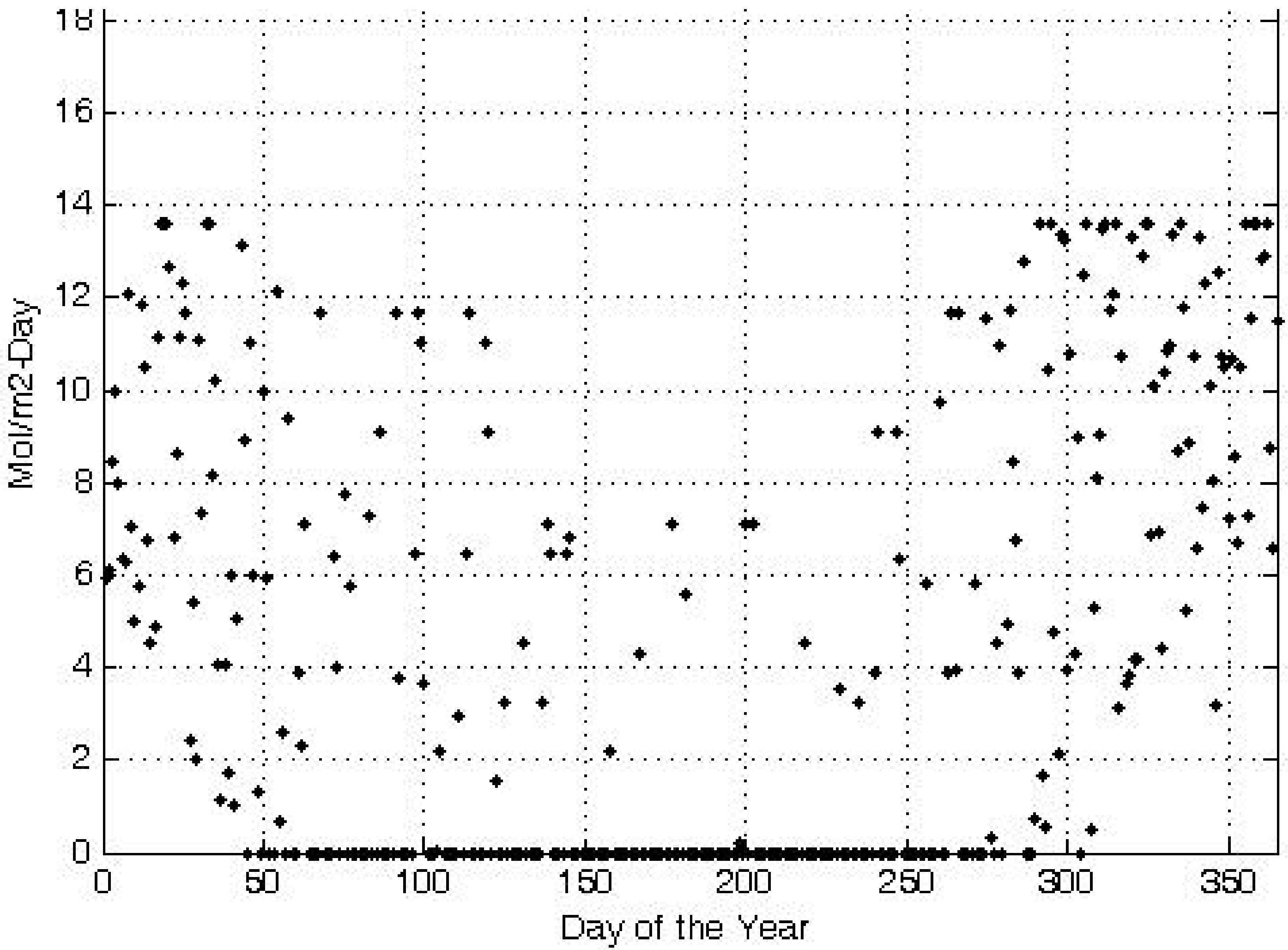
- Pros
  - Target daily light integral can be met
  - Allows consistent crop scheduling
- Cons
  - May have excess light costs from times when over-lit or over-shaded

Target Daily Light Integral

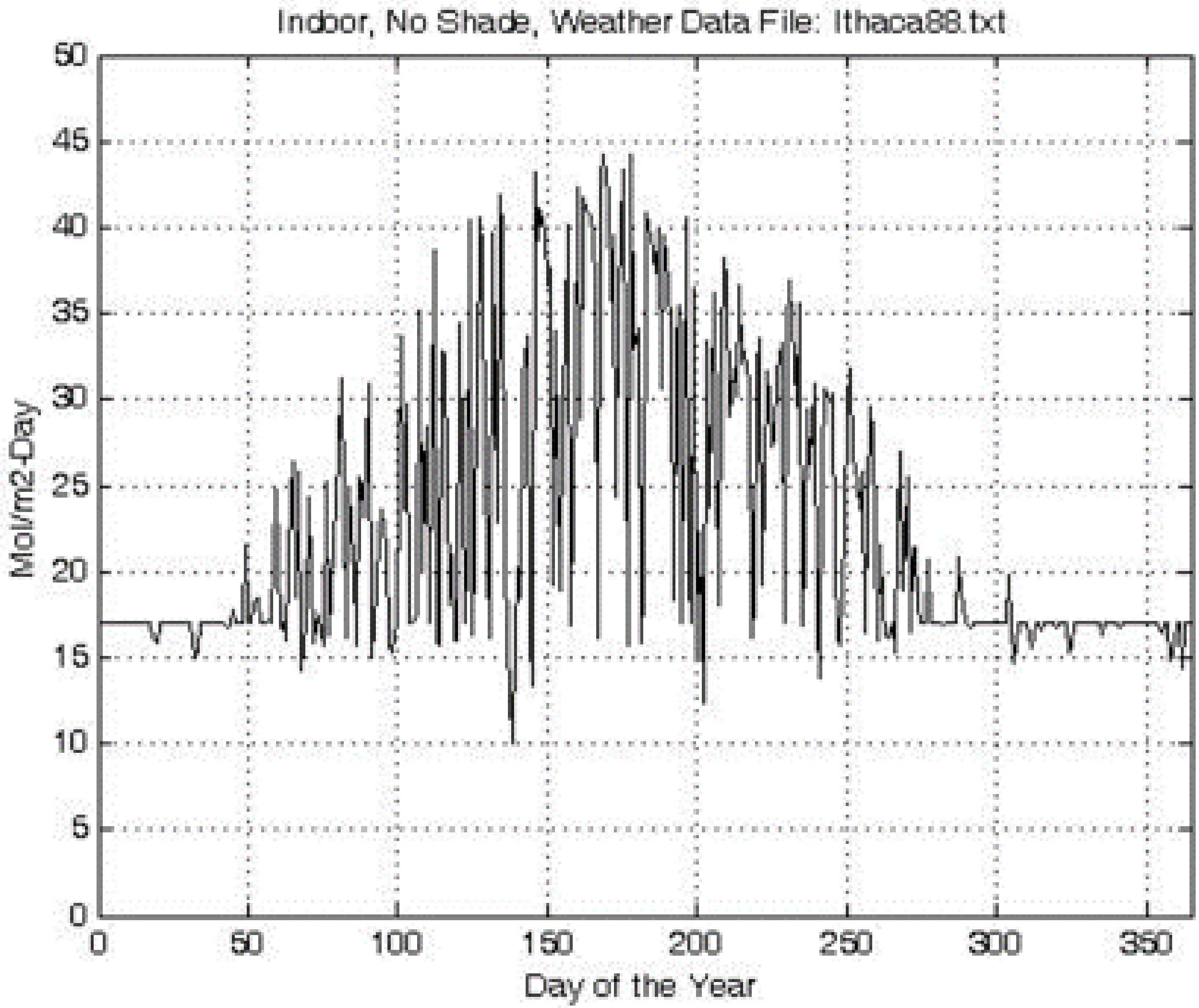
- Light and Shade System Implementation (LASSI)
- Lou Albright, Cornell University

- Predicts natural light accumulation based on first few hours after sunrise
  - Lights on if predicted sunlight is insufficient
  - Deploys shades if predicted sunlight is too much
- Light/shade decisions made at ½ hour time steps
  - Delays shading when possible to avoid over shading
  - Lighting to take advantage of nighttime off-peak electricity rates when possible

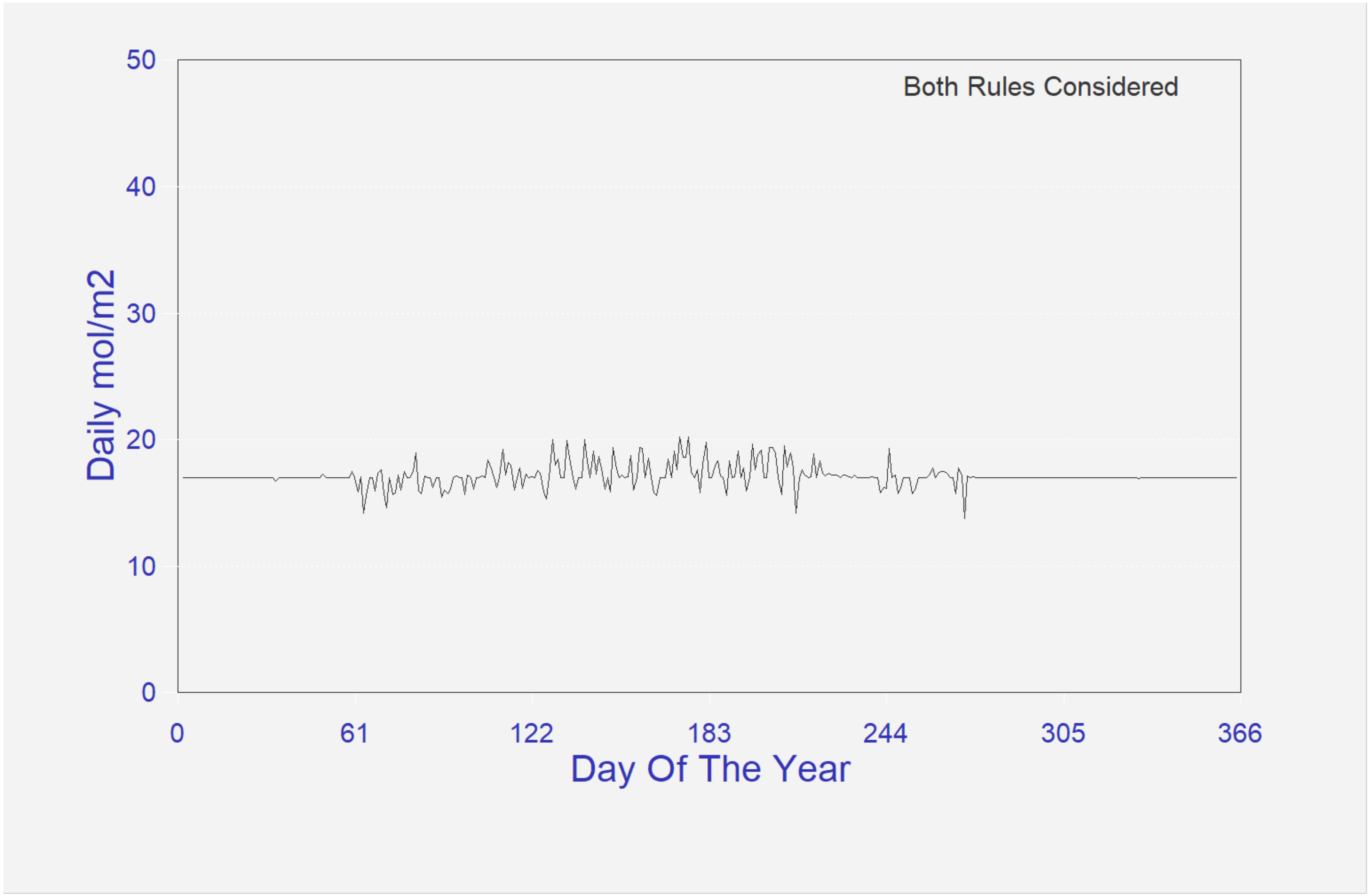
Daily supplemental light



DLI without moveable shade



LASSI



Supplemental light + moveable shade curtains

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An ASABE Meeting Presentation
DOI: 10.13031/aim.20162460478
Paper Number: 162460478

Electrical savings comparison of supplemental lighting control systems in greenhouse environments

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Written for presentation at the
2016 ASABE Annual International Meeting
Sponsored by ASABE
Orlando, Florida
July 17-20, 2016

ABSTRACT. *Greenhouse vegetable production can be optimized by properly controlling the conditions in the growing environment. Supplemental light and shade systems in a CEA greenhouse are typically controlled using manual control or time-clock control. Previous work describes a Light and Shade System Implementation (LASSI) that controls lighting to a consistent daily light integral (DLI) of*

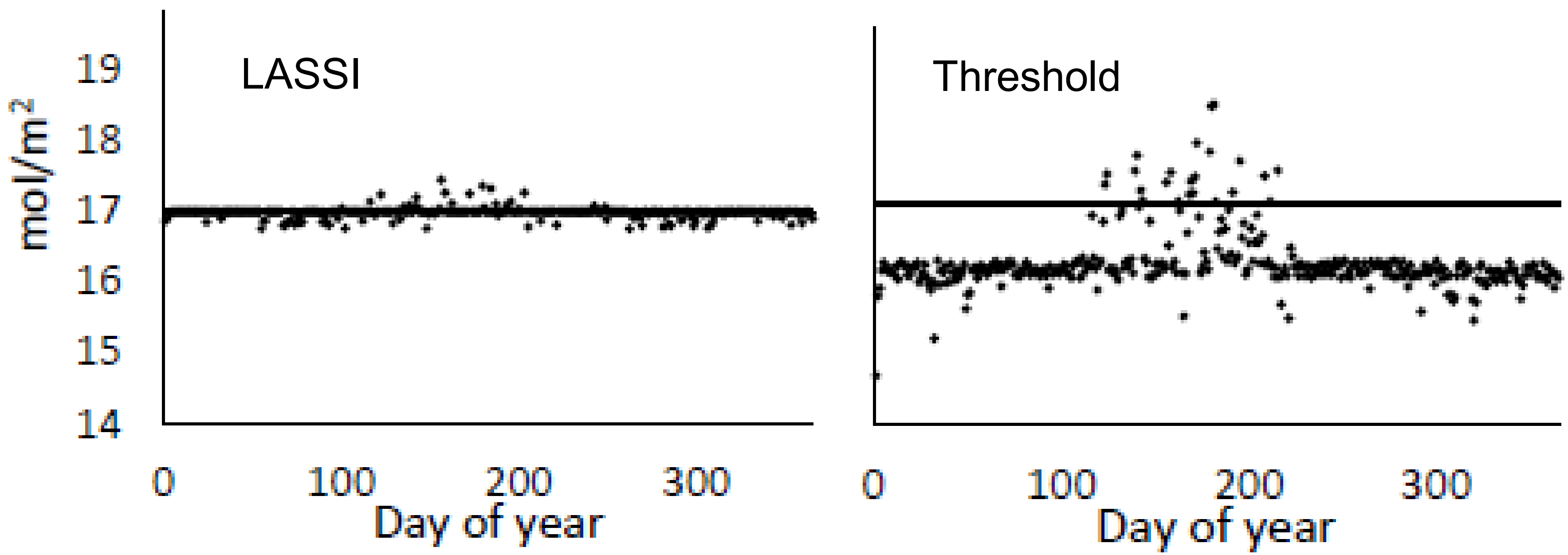
Lighting Energy Savings

City	Electricity Savings LASSI vs. Threshold		
	Lettuce (17 mol/m²/d)	Tomato (25 mol/m²/d)	Floriculture (12 mol/m²/d)
Elmira, NY	24%	20%	28%
Helena	28%	27%	39%
Minneapolis	28%	27%	38%
Phoenix	56%	39%	69%

Data from Harbick et al., 2016

Why? Ex: controller performance MSP

- Threshold control has more aggressive shading and does not anticipate sunlight
  → ↑ use of supplemental lighting
- Threshold control → DLIs above/below target



Questions?

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