13th GLASE Industry Advisory Board Meeting

March 2023 - Quarter 1

29 CEA & Industry Members

NEXSEL For Best Results

Linde

Advanced Energy | ARTESYN

VERTAAG Vertical Automated Agriculture

EnSave

AeroFarms

THE POWER OF LIGHT ILLUMADYNE

intertek

nextlight

Plenty

RAYN GROWING SYSTEMS

signify

SOLLUM

BRIGHT FARMS

HYDROFARM

HORT AMERICAS

little leaf FARMS

WHEATFIELD GARDENS NIAGARA COUNTY, NY

SUSTAINABLEAQUAFARMS

SHENANDOAH GROWERS

TSRgrow

local bounti

DRAMM water Water Management for Horticulture

badia FARMS

AGILE SPECTRUM

The Chef's Garden

CORTEVA agriscience

P.L. LIGHT SYSTEMS

hoogendoorn growth management

RPI Research Updates

RPI Update for IAB Meeting March 2023

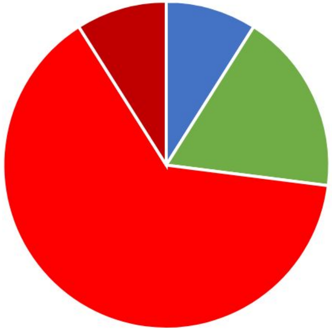
Elsebeth
Kolmos
Matt Goldman
Rick Neal

GLASE
GREENHOUSE LIGHTING
& SYSTEMS ENGINEERING

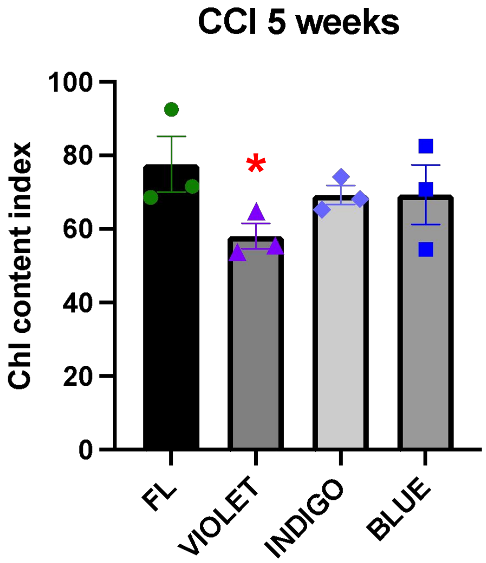
Rensselaer

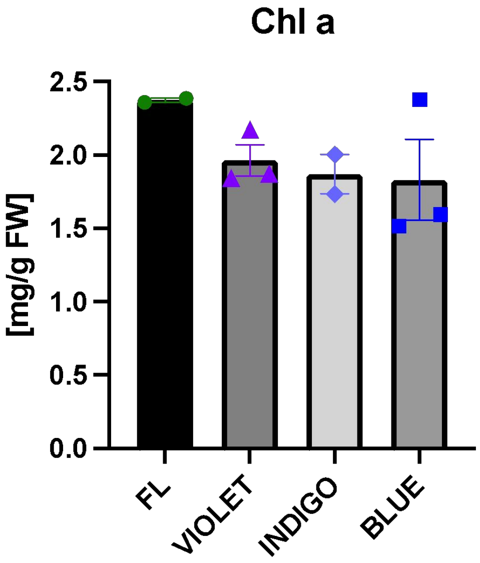
Experimental conditions

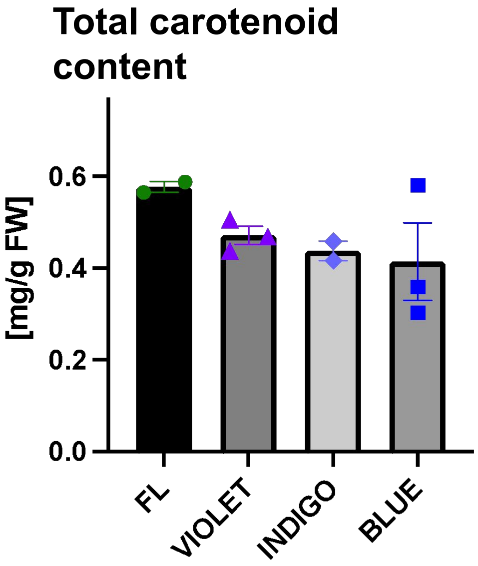
- Control light: Fluorescent, Philips T5
- LED light with different short wavelength light: **Violet** (400 nm), **Indigo** (420 nm), **Blue** (450 nm)
- Spectrum: 36 μmol/(m^2s) short wavelength, 72 μmol/(m^2s) **Green**, 256 μmol/(m^2s) **Red**, 36 μmol/(m^2s) **Far-red**
- Light intensity: 400 μmol/(m^2s)
- DLI: 23 mol/(m^2d)
- Long days (16 hours), 25°C/18°C
- Deep water reservoir with aeration
- 'Micro Tom' tomato (dwarf variety)
- Three replicated trials



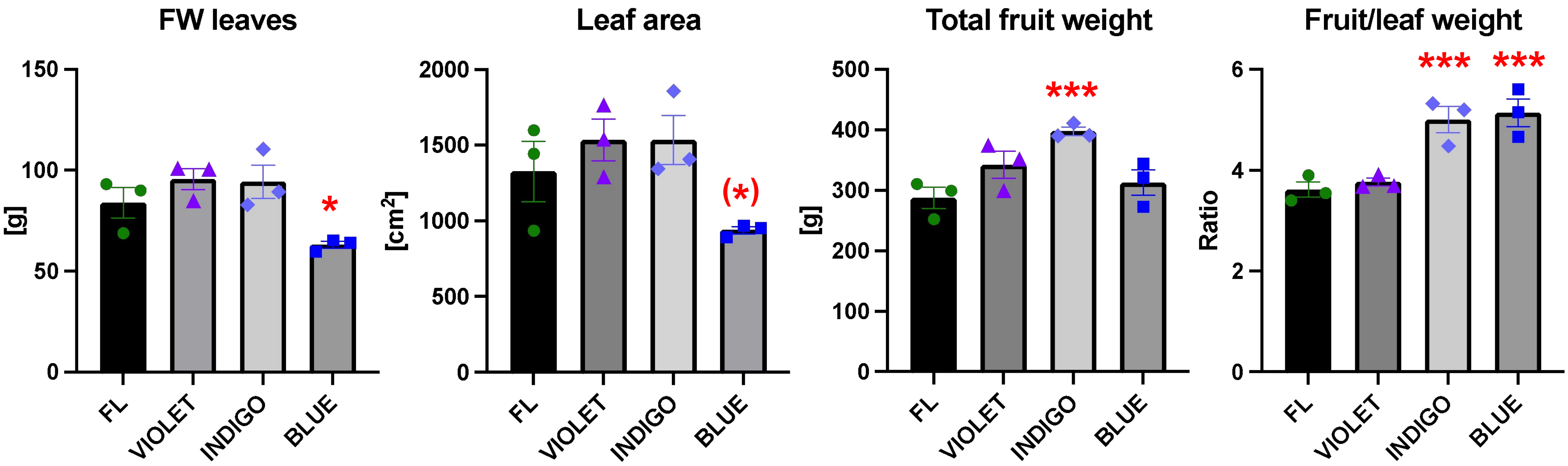
Leaf pigment analysis



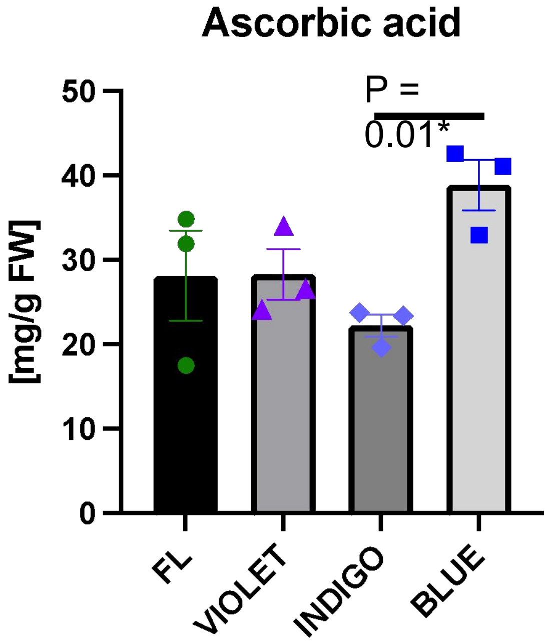




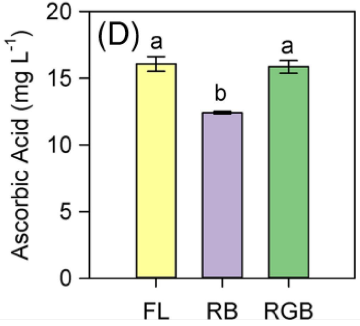
Some changes in plant biomass



Ascorbic acid (vitamin C) content is affected by blue light quality



		Light quality regimes		
Color	Wavelenght range	FL (Fluorescent)	RB (LED)	RGB (LED)
Violet	400-450 nm	7.0%	12.5%	15.5%
Blue	450-485 nm	5.8%	7.9%	11.1%
Cyan	485-500 nm	3.6%	0.3%	6.3%
Green	500-565 nm	26.1%	0.0%	15.6%
Yellow	565-590 nm	21.1%	0.7%	1.0%
Orange	590-625 nm	23.5%	42.8%	28.6%
Red	625-700 nm	10.0%	34.3%	20.4%
FR	700-800 nm	2.9%	1.5%	1.4%



Vitale et al. 2022

Preliminary conclusions

- Similar photosynthetic rate and chlorophyll fluorescence for all light conditions
- Low leaf chlorophyll for LED vs. FL
- High yield for INDIGO
- Low leaf area and biomass for BLUE
- High fruit/leaf ratio for INDIGO and BLUE
- Why the change in ascorbic acid for BLUE?
- Yet to be completed: total phenol content, antioxidant capacity, total flavonoid content, fruit acidity

GLASE
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& SYSTEMS ENGINEERING

Rutgers Research Updates

Five-minute Update

Tim Shelford, A.J. Both

12th GLASE Industrial Advisory Board Meeting

March 1, 2023

DesignLights Consortium

Proposed effective date: March 31, 2023

Technical Requirements for LED-Based Horticultural Lighting, Version 3.0

Key updates:

With a -5% allowance: 2.19 µmol/J

- New efficacy threshold: 2.3 µmol/J (35% higher than 1000 W DE HPS fixture)
- New reporting requirements: Intended use, dimensions, and image
- Requires dimming capability for certain AC-powered fixtures, all DC-powered products, & all replacement lamps (include control details)
- Introduces a surveillance testing policy (to be implemented in Q1 2024)

Check out their Qualified Products List (QPL) for horticultural lighting applications

- Measured LED fixture efficacies at Rutgers University*

Fixture	Type of cooling	Efficacy (µmol/J)
Illumitex PowerHarvest 10 Series W	fan cooled	1.71
Osram Zelion HL300 Grow Light	fan cooled	1.85
Fluence VYPR X Plus	passively cooled	2.02
Lemnis Oreon Grow Light 2.1	water cooled	2.08
Philips GreenPower LED Toplight	passively cooled	2.39
HortiLED TOP 2.0, Daylight spectrum	passively cooled	2.40 (2.55)**
GE Arize Element L1000	passively cooled	2.65
HortiLED TOP 2.0, RWMB spectrum	passively cooled	3.10 (3.25)**

*Shelford, T.J. and A.J. Both. 2021. On the technical performance characteristics of horticultural lamps. AgriEngineering 3:716-727. https://doi.org/10.3390/agriengineering3040046

** at 50% output

Cornell Research Updates

Impact of LEDs with dimmable lighting control compared to HPS supplemental lighting

GLASE
GREENHOUSE LIGHTING & SYSTEMS ENGINEERING

Neil Mattson

Professor and Greenhouse Extension Specialist

nsm47@cornell.edu

Acknowledgements

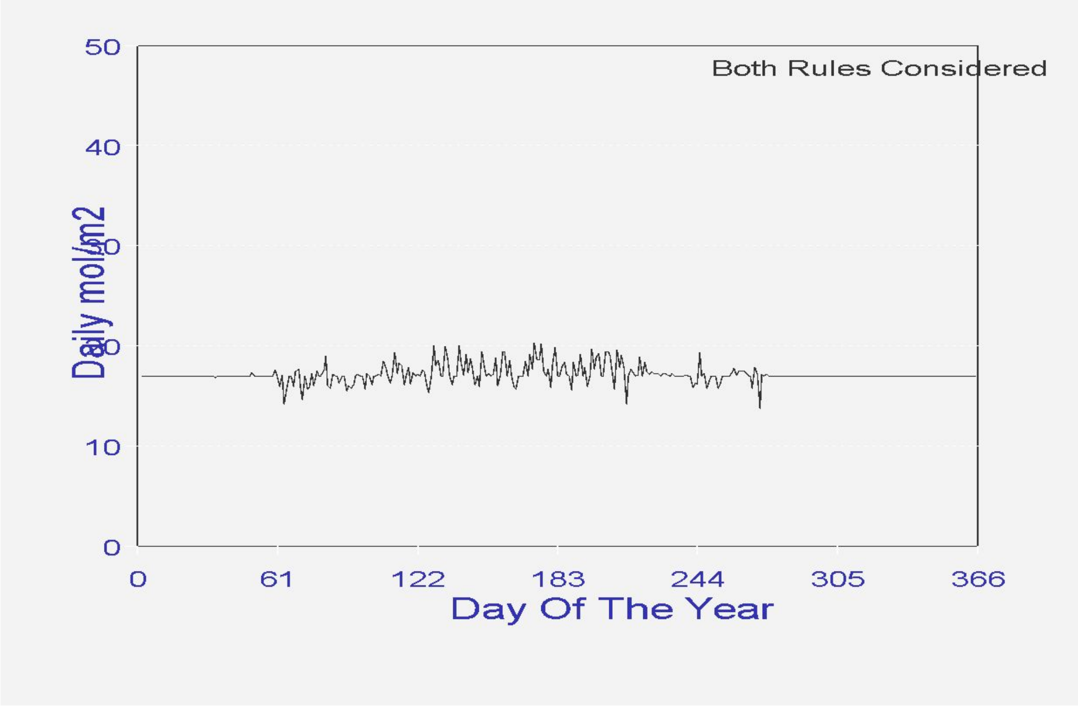
- Timothy Shelford
  - RT LASSI Algorithm development
- Melissa Cole
  - RT LASSI implementation
- Nick Kaczmar
  - Lettuce and tomato trials
- Chris Levine
  - Strawberry trials

TSRgrow™

Provided LED Fixtures

Background – LASSI

- LASSI: Light and shade system implementation
- Patented lighting control algorithm developed at Cornell in the 1990's for lettuce production
- Goals: Improve Daily Light Integral uniformity and shift lighting to cheaper off-peak periods



Albright, 2000

Background - LASSI

- Uses measured values of solar radiation to make predictions about the end of day natural DLI
- Delays supplemental lighting decisions until it predicts it must light to meet the DLI target
- Shifts supplemental lighting hours to the cheaper "off-peak" electricity pricing periods
- Uses shades to reduce incoming light during high light times of year
- Originally developed for use with HPS lights producing lettuce

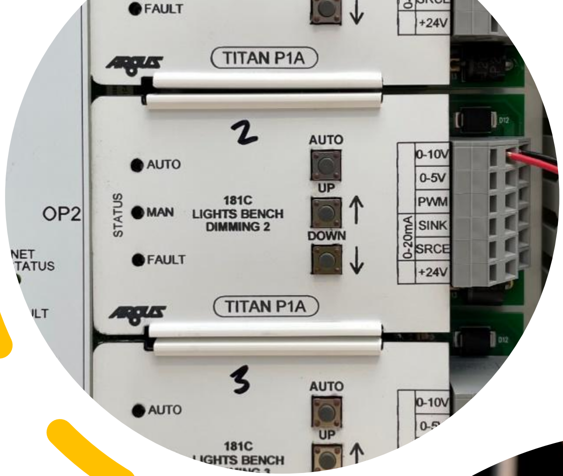
Slide: Tim Shelford, Cornell

Background – RT LASSI

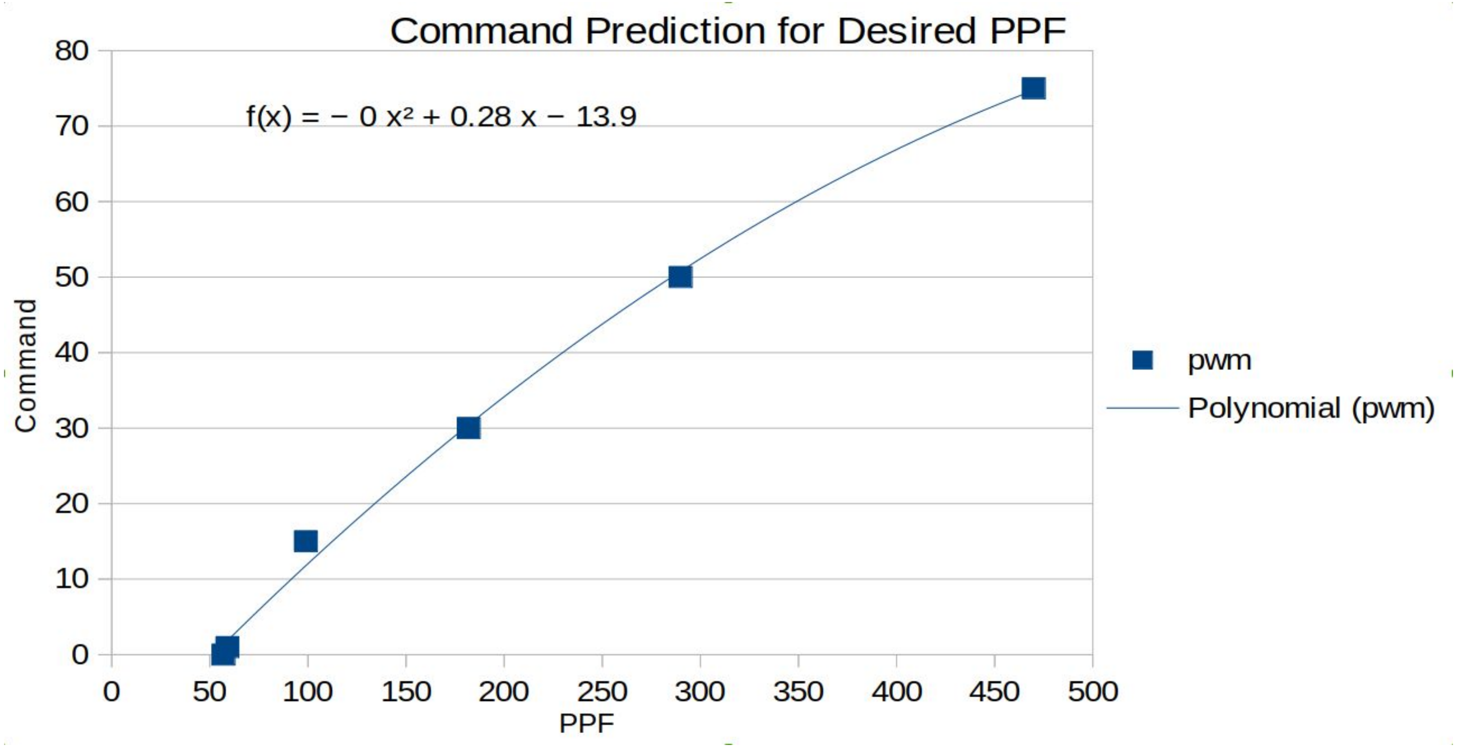
- GLASE objective: Developed a new control algorithm to take advantage of LED fixture capabilities:
- The ability of LED lights to dim and turn on/off rapidly
- "Real Time" makes decisions about what level to provide supplemental light on a much finer timescale (1 to 10 minutes) than original LASSI (hour timescale)
- Provides the ability to specify an upper bound for maximum PPFD (natural and supplemental) on a crop
- Can be used to spread out the lighting over the course of a lighting day

RT LASSI Implementation

- Two greenhouse sections at Cornell University installed TSR Grow LED (TG-600 HVR) fixtures
- Installed Argus P1A Dimming output modules
- RT-LASSI algorithm implemented on Arduino/Raspberry Pi system
  - Connected to quantum sensor at plant canopy height
  - Communicates with Argus through their Mod Bus to control light output (dimming) and shade curtain status



Calibration curve

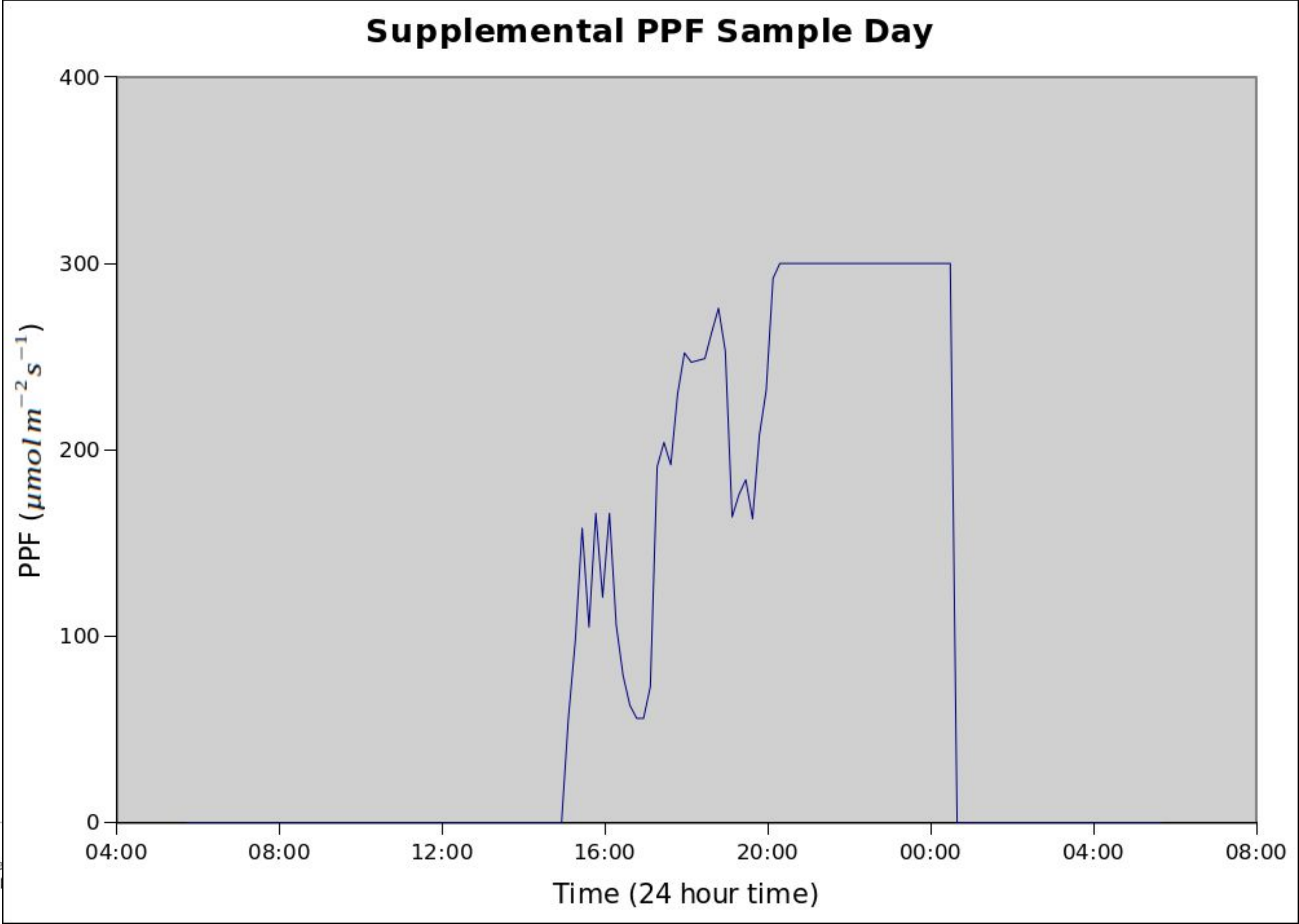


$$pwmCommand = (-0.00018) * x^2 + 0.2718x - 13.9 \text{where x is the desired PPF}$$

Figure: Melissa Cole, Cornell

Example day with RT-LASSI control

Note that afternoon supplemental light complements the sun to a target total PPF of 300 μmol·m^{-2}·s^{-1} while supplemental lighting after sunset is to the 300 μmol·m^{-2}·s^{-1} target.



Daily light integral

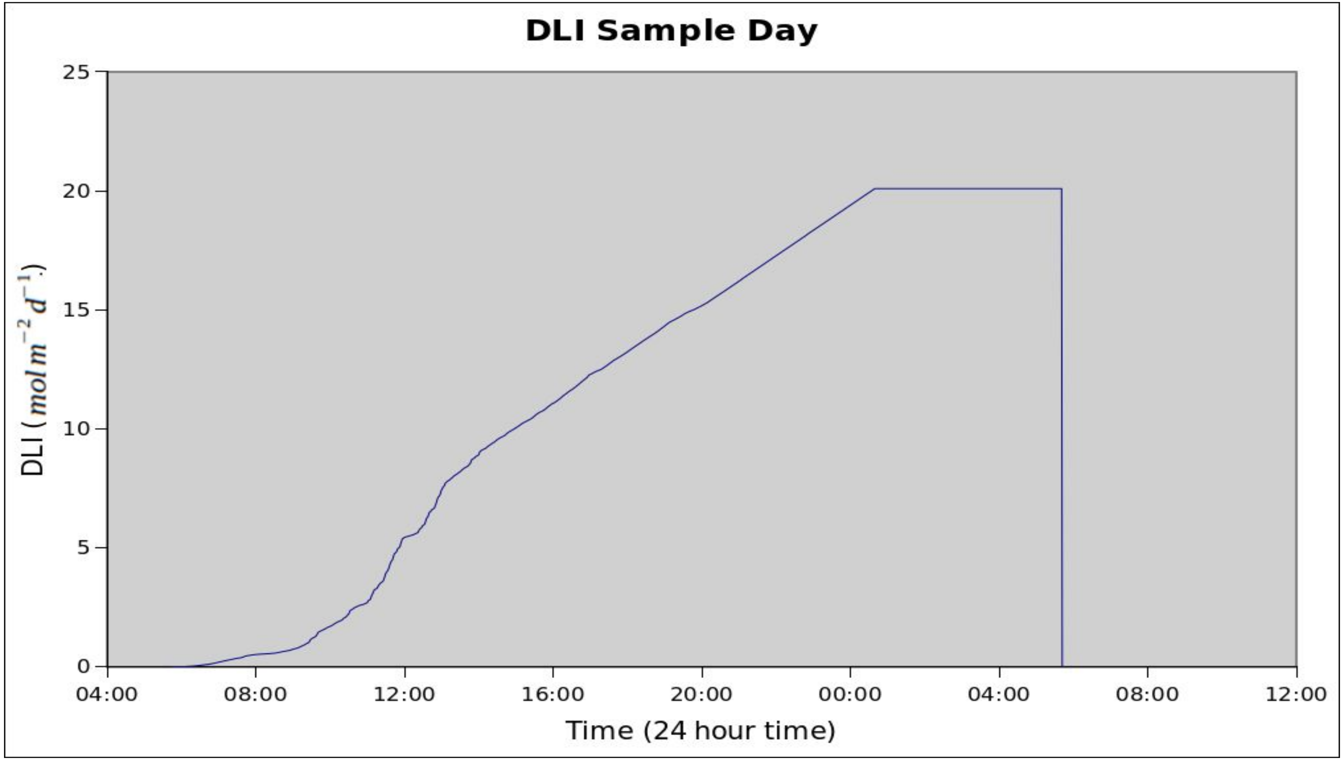


Figure: Melissa Cole, Cornell

RT-LASSI – Lettuce Objectives

- To determine the response of 3 sequential greenhouse-grown lettuce crops to:
    - RT-LASSI (10 min. interval) implemented with an LED lighting array
    - HPS fixtures (using standard 1-hour, on/off, non-dimmable LASSI) (control)

Lighting treatments

LED Treatment

- TSR Grow LED (TG-600 HVR) fixtures
- Efficacy 2.4 μmol/J
    - 33% less energy / mol than HPS
- Lighting control: RT-LASSI (10-minute dimming interval)

HPS Treatment

- PL Light HPS (1000 Watt electronic ballast)
- Efficacy 1.6 μmol/J
- Lighting control: LASSI (1-hour interval on/off) lighting

Light spectrum

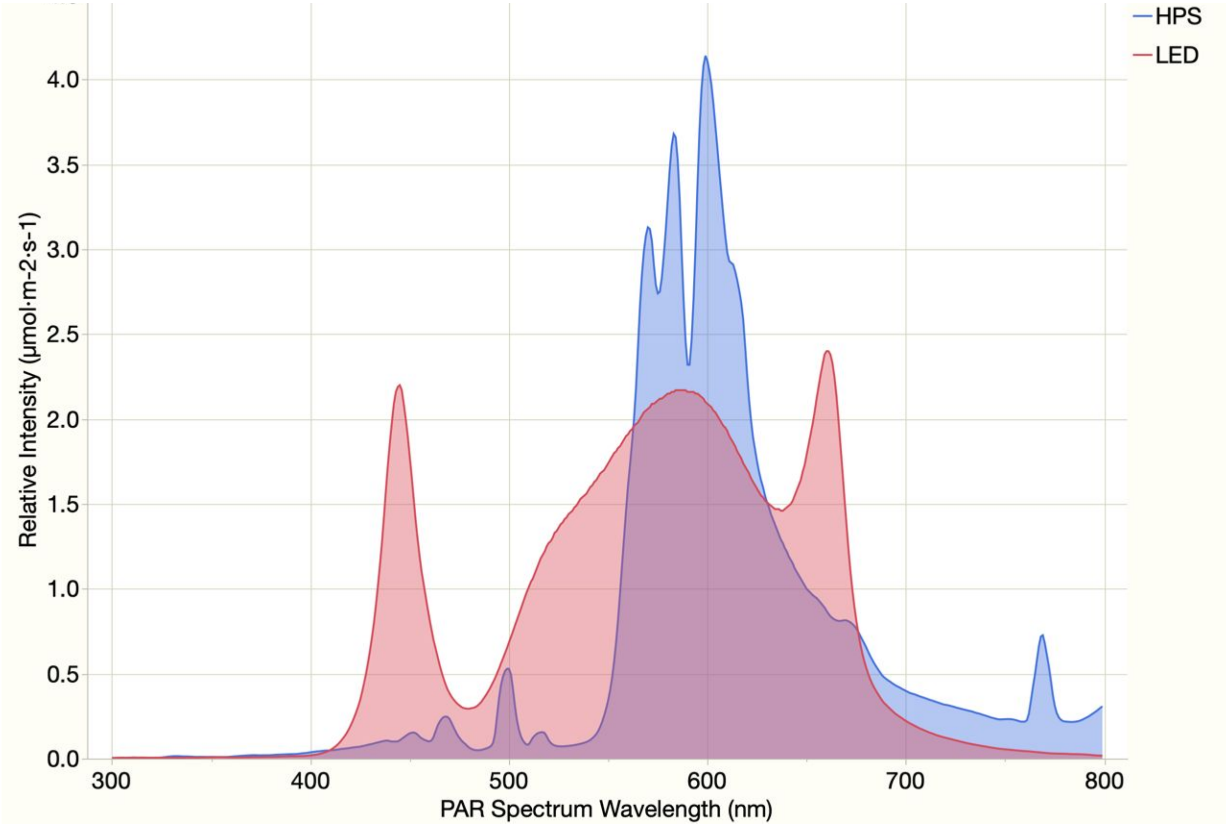


Figure: Jiaqi Xia and Chris Levine, Cornell

Methods

- Lighting treatments in adjacent greenhouses
- 2 Lettuce varieties used in trial
  - ‘Rex’ Butterhead
  - ‘Rouxai’ Oakleaf
- 200 seeds of each germinated in 1” rockwool cubes
  - Fertilized daily with 150ppm N 15-5-15
- Moved into greenhouse hydroponic flood tables after 14 days
- Nutrient solution consisted of:
  - Calcium Nitrate 15-0-0 (2.84 g/gallon)
  - Jack’s 5-12-26 (2.84 g/gallon)
  - EC 1.8-2.0
  - pH 5.6-6.0
- Plants harvested after 21 days, total of 35 days per growth cycle

Experimental Design

- Each flood table (4’ x 8’) was divided into 8 floats, each containing 8 plants
- Each light treatment was set up as a randomized complete block design
    - Each table was considered a single rep
    - Each float was considered a single block containing 8 plants of a single varieity
    - Position of each float was randomized within each table
- 64 plants per table, 32 of each variety
- 3 flood tables per lighting treatment per crop cycle
    - 192 plants total per lighting treatment
    - 96 of each variety in each lighting treatment
- 3 replicate crop cycles

HPS

LED

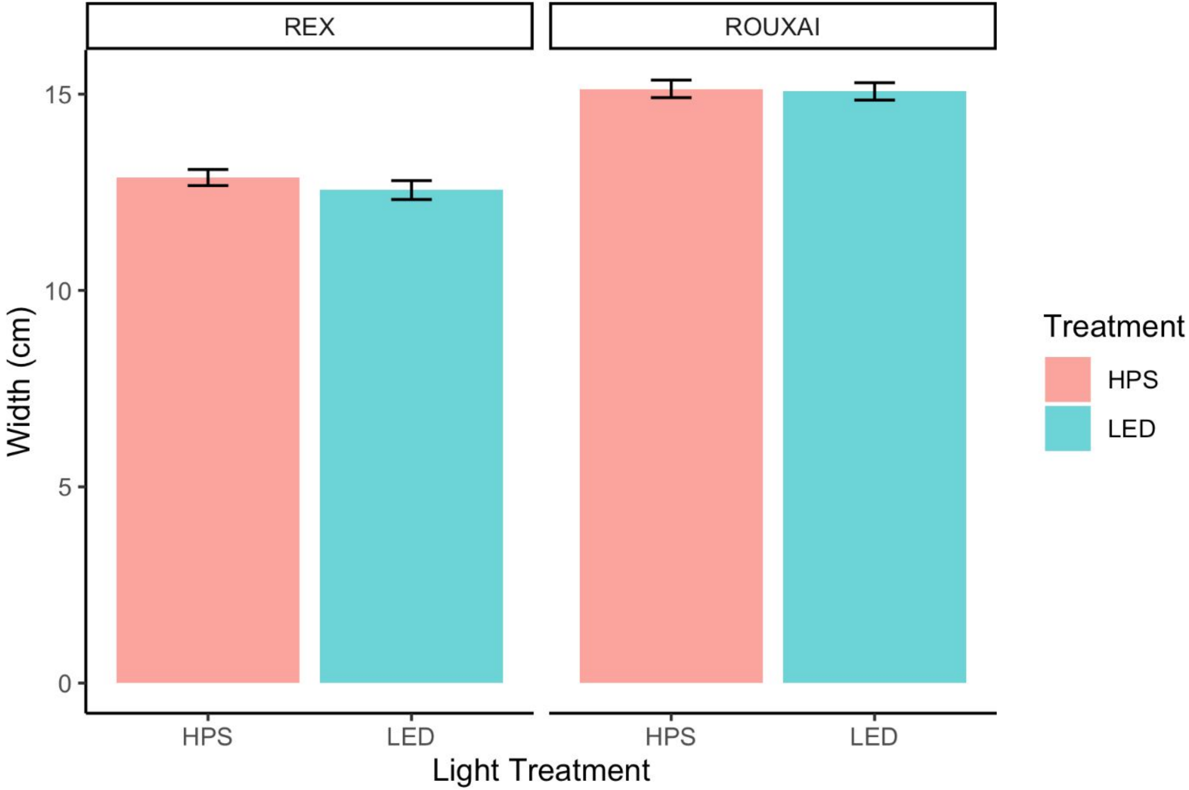
LED

HPS

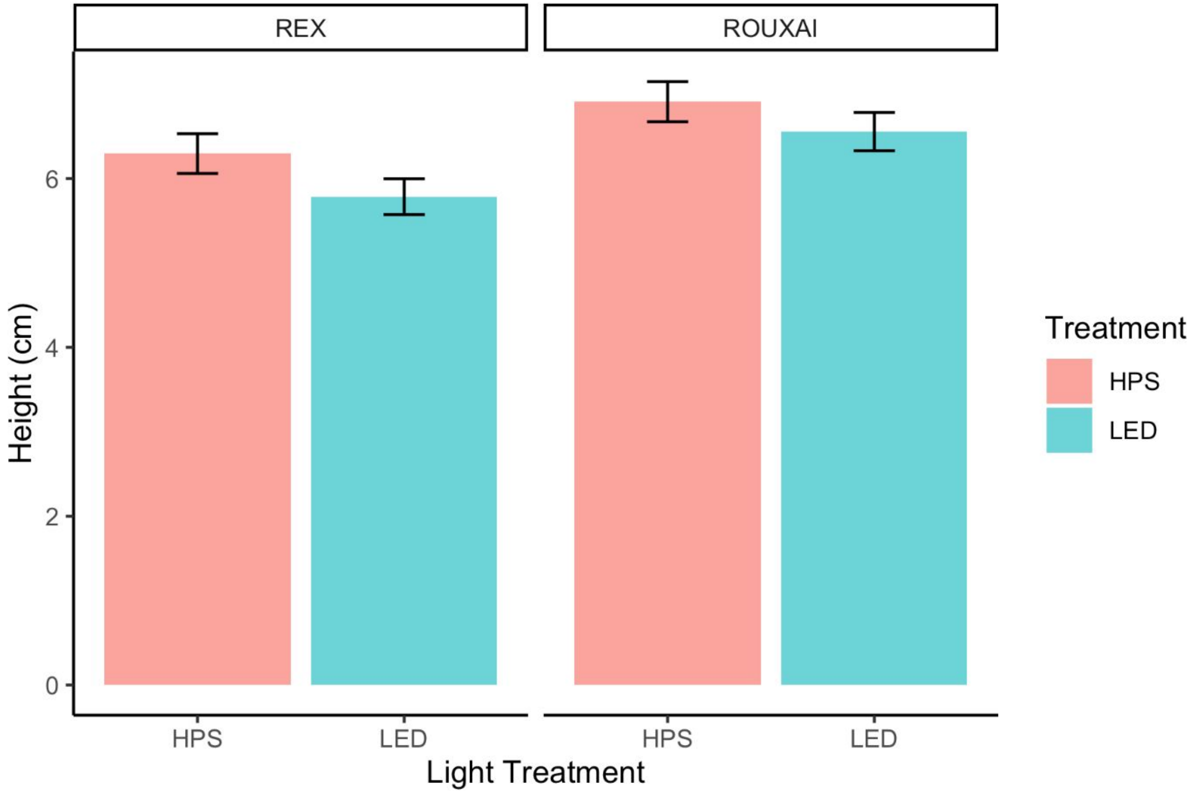
LED

HPS

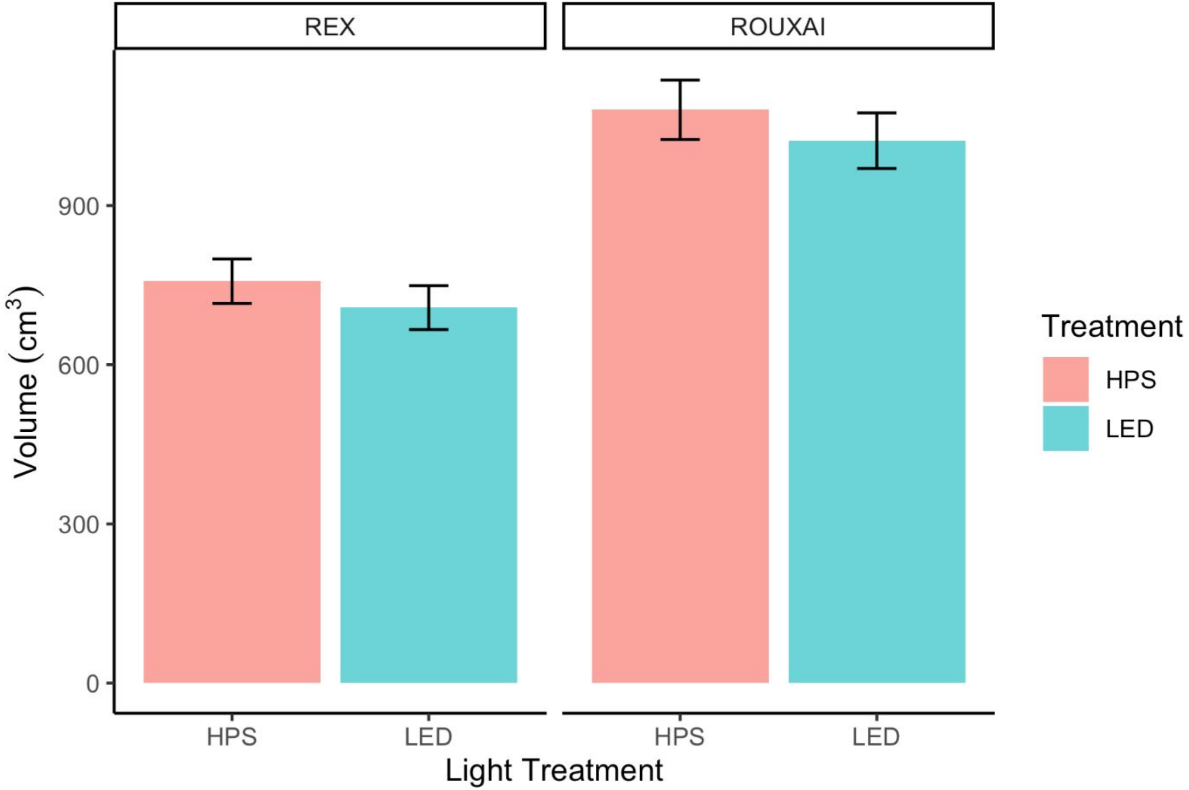
Total Width


REX
ROUXAI
15
10
5
0
Width (cm)
HPS
LED
HPS
LED
Light Treatment
Treatment
HPS
LED

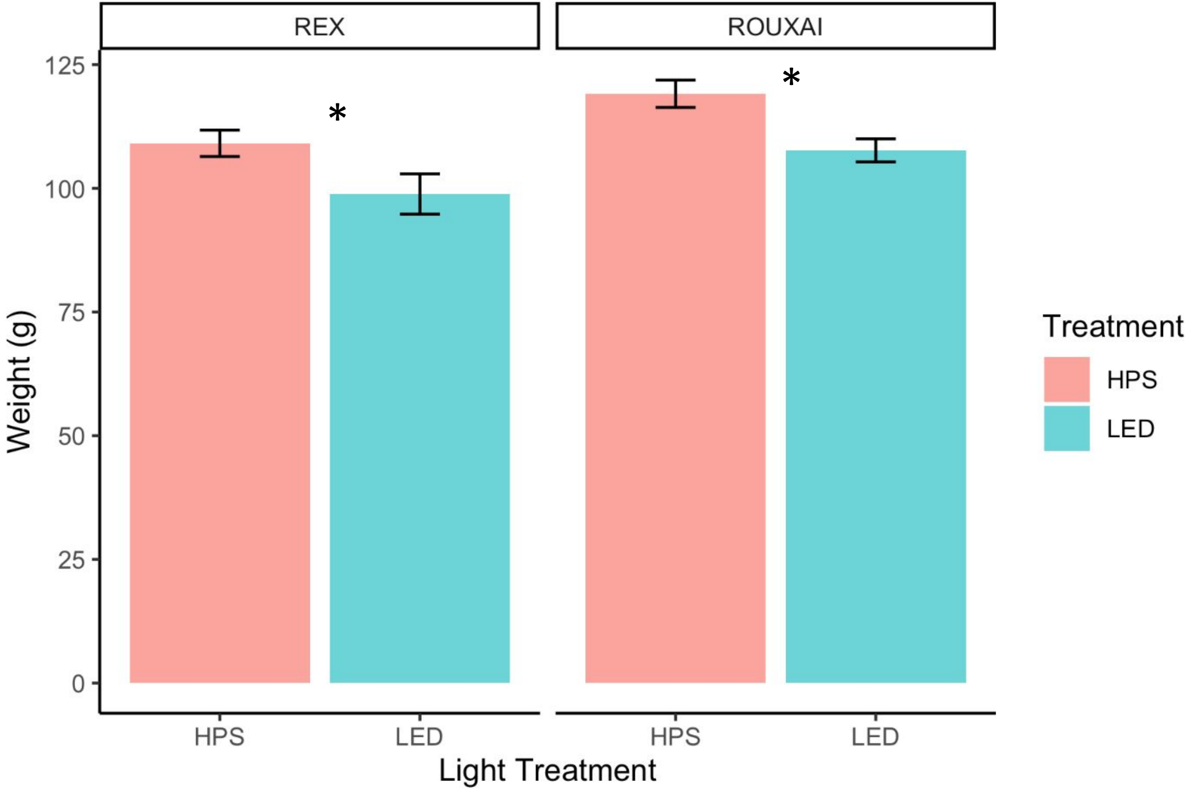
Total Height



Total Volume



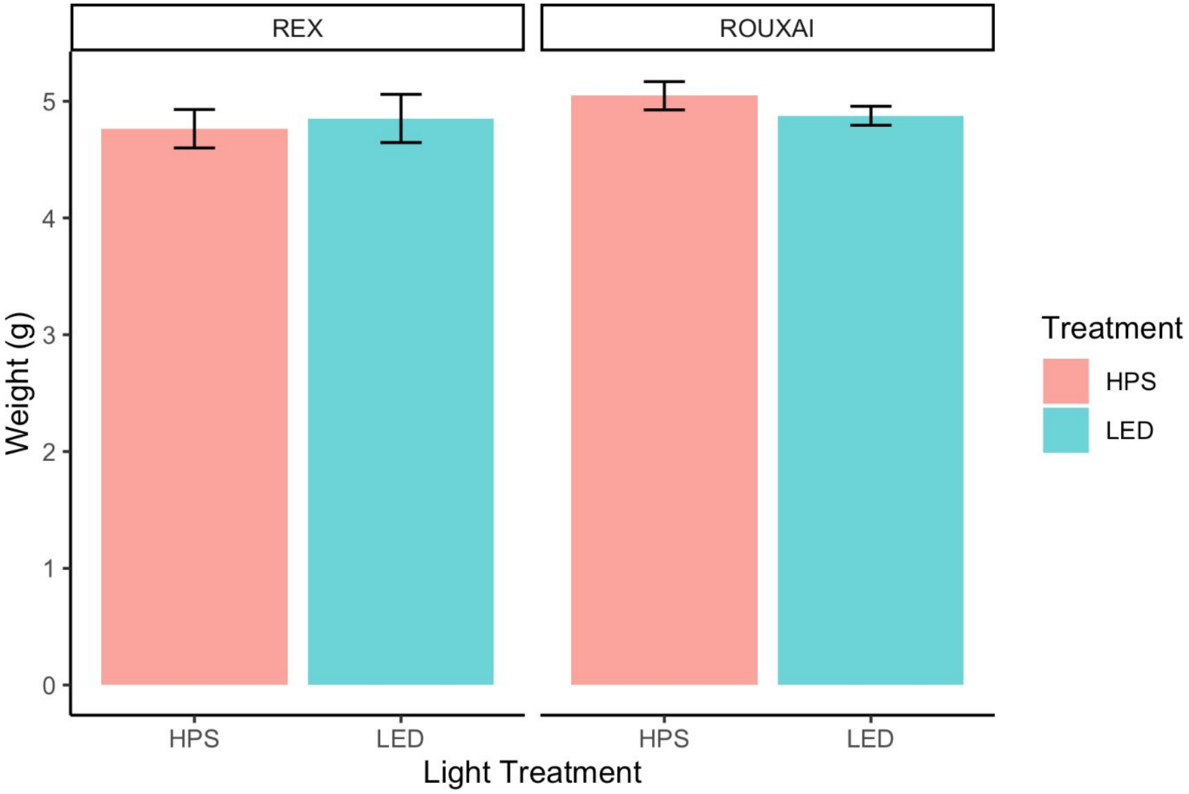
Total Harvest Fresh Weight



CornellCALS and Life Sciences

* Indicates significant difference at p ≤ 0.05

Total Harvest Dry Weight



Summary lettuce

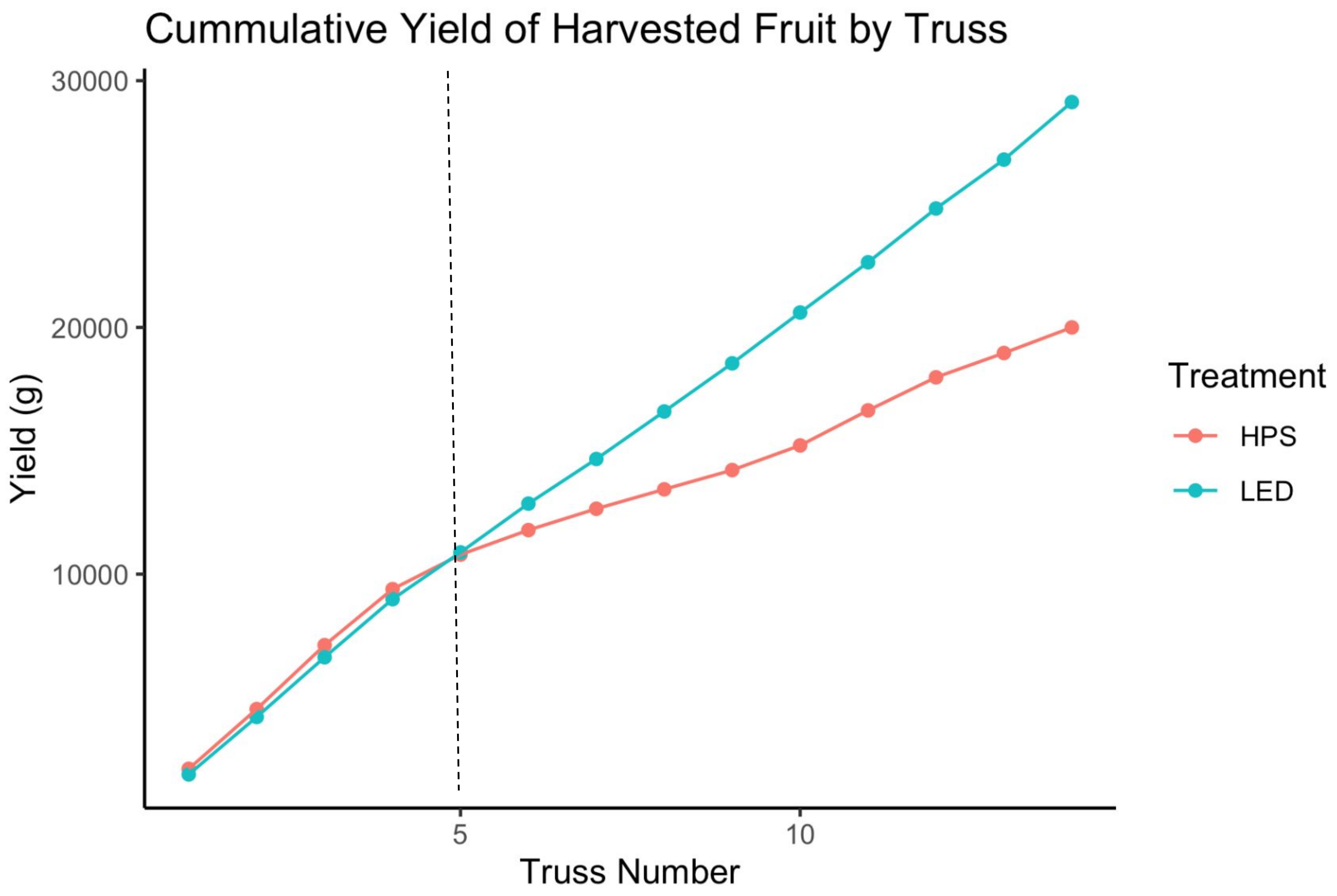
- Some subtle differences in lettuce morphology (shape) were noted including increased height and volume under HPS
- HPS fixtures lead to greater plant fresh weight than LEDs
    - LED lettuce had the same dry weight as HPS, thus HPS fixtures had greater water content
- We speculate differences in plant size/shape may be due to either far-red light impacts or infra-red leaf temperature impacts of HPS
- Overall, implementation of RT-LASSI with LED lighting provided an estimated 33% savings in electricity over HPS fixtures

RT-LASSI Tomatoes

Nick Kaczmar, Research support specialist
Neil Mattson, Professor

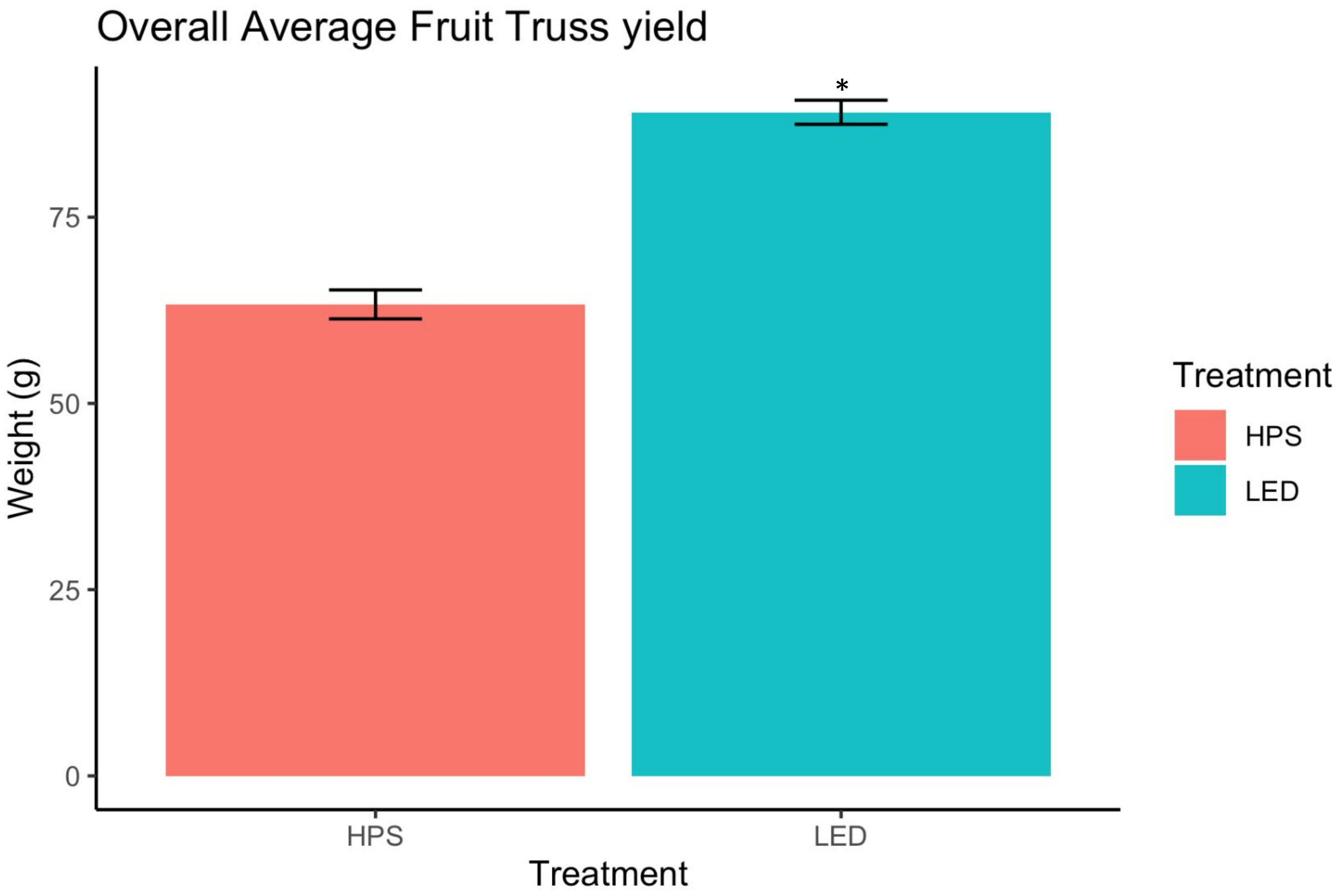
Methods

- Lighting treatments in adjacent greenhouses
    - TSR Grow LEDs controlled by RT-LASSI to 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ with a 25 $mol \cdot m^{-2} \cdot d^{-1}$ target
    - PL Light High pressure sodium (HPS) fixtures controlled by LASSI hourly on/off with a 25 $mol \cdot m^{-2} \cdot d^{-1}$ target
- Climate Set points
    - Day 74F
    - Night 66F
- Light Treatments- RT LASSI started on 7/15/2022 and continued for 3 months

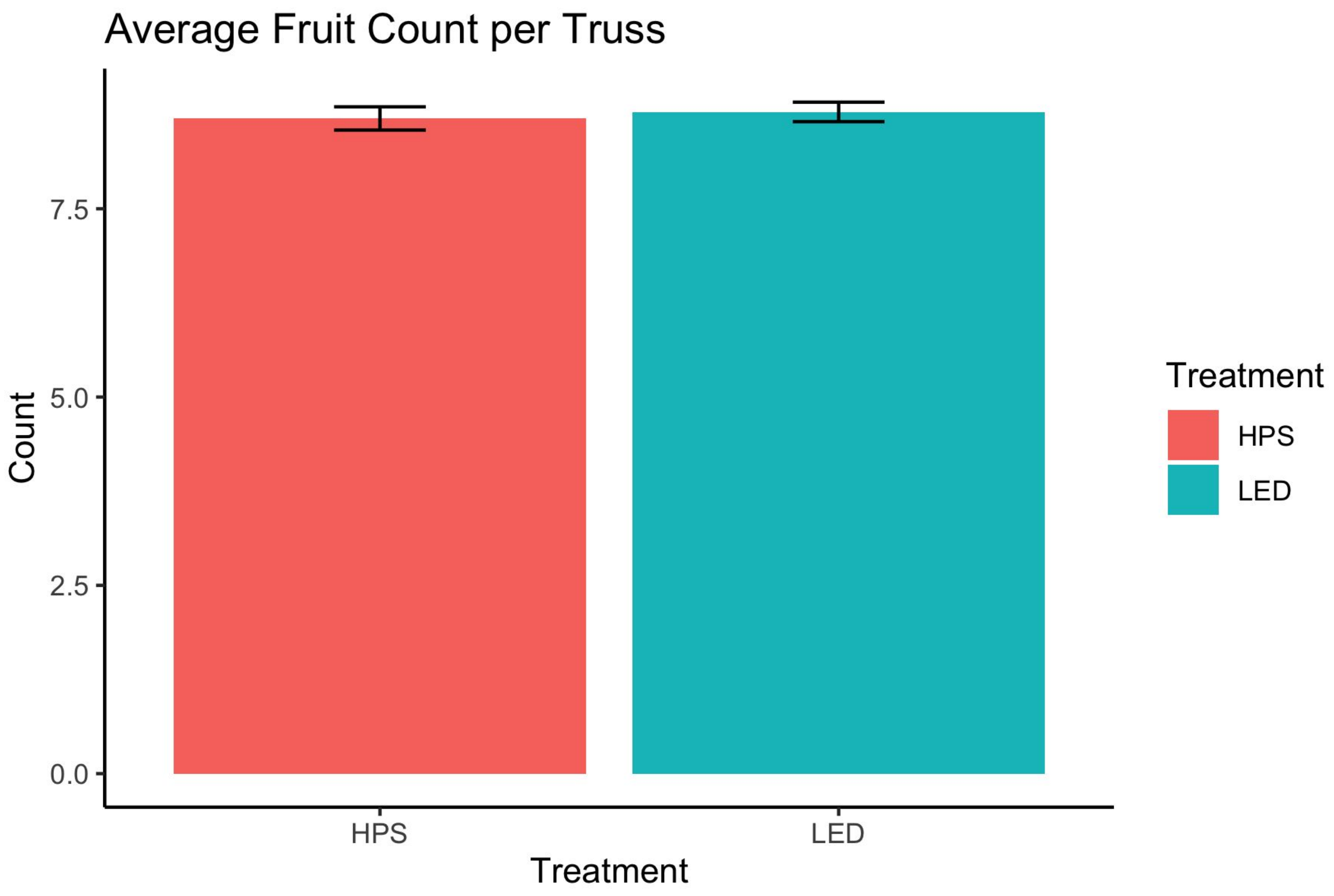


---- Start of Light treatments

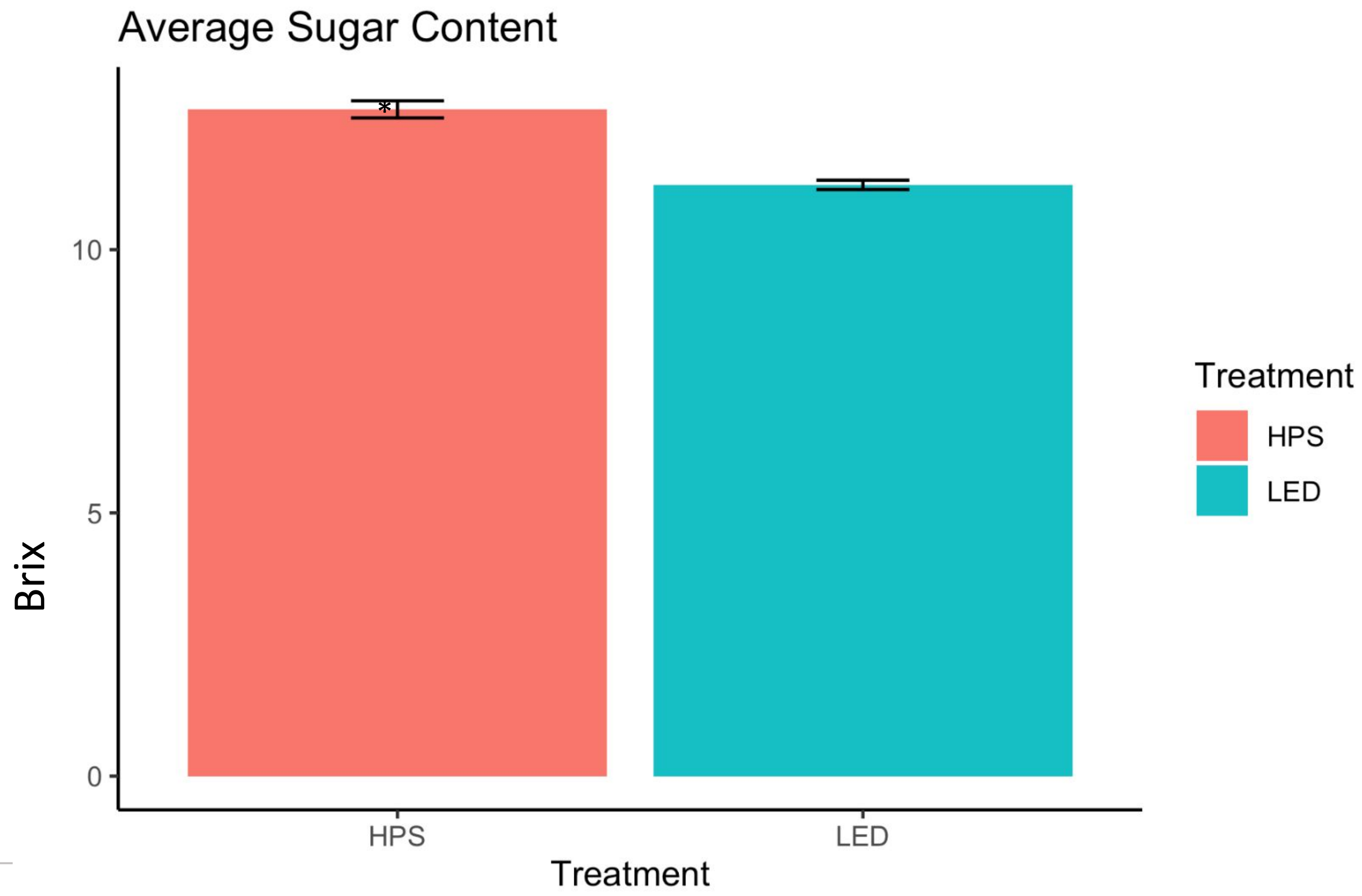
Cornell



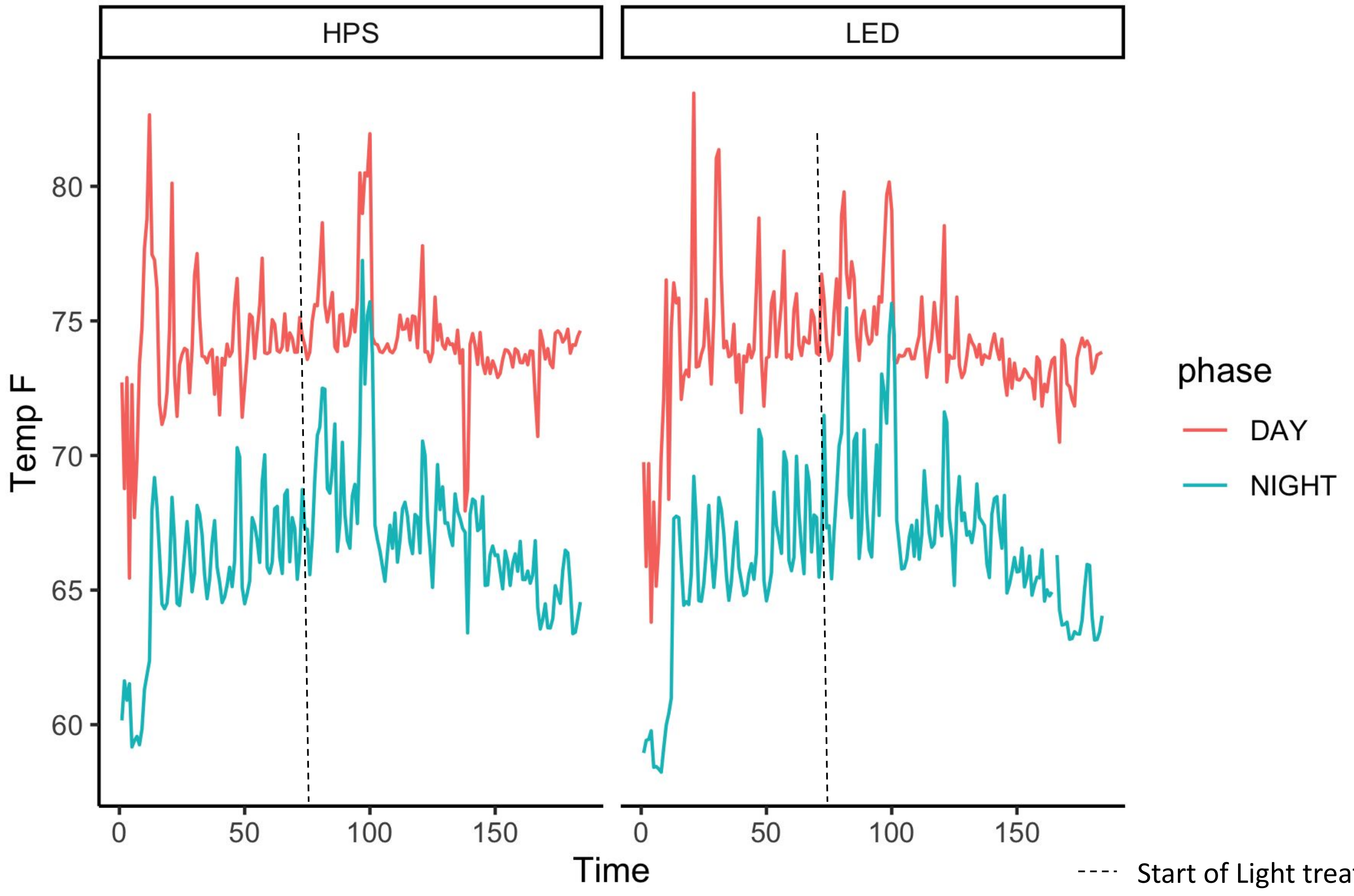
* Indicates significant difference at p ≤ 0.05


Average Fruit Count per Truss
Count
7.5
5.0
2.5
0.0
HPS
LED
Treatment
Treatment
HPS
LED

Cornell



* Indicates significant difference at $p \leq 0.05$



---- Start of Light treatments

Cornell

Summary tomatoes

- RT-LASSI with LED lighting led to about a 30% greater tomato yield vs. HPS
  - This was associated with increased fruit size but not increased fruit number (or increased truss, i.e. flower cluster number)
- Brix (soluble sugar content) of HPS grown fruit was higher than RT-LASSI with LED lighting
- Plant yield and Brix responses may be due to impact of HPS on plant temperature (due to long wave radiation), however air temperature was very similar between both treatments
- Implementation of RT-LASSI with LED lighting led to a ca. 33% electricity savings while delivering the same daily light integral as HPS

RT-LASSI Strawberry Report

Neil Mattson, Professor and Chris Levine, M.S. Student

Methods

- Two cultivars of day-neutral strawberries: ‘Cabrillo’ and ‘Albion’
- Strawberry runners of each cultivar were propagated and subsequently transplanted into 11-L troughs (with 4 plants per trough)
- Troughs were moved into respective greenhouse with lighting treatments on February 24 for establishment to fruiting
- On April 20 lighting treatments were initiated
- Fruiting yield data was collected for 3 months and ceased on July 20
- Within each greenhouse (lighting treatment) there were 3 replicate blocks (rows) each containing 4 troughs of ‘Albion’ and 4 troughs of ‘Cabrillo’ (24 troughs per greenhouse)
- Spacing (accounting for aisles) was 1 plant per square foot

Methods

- Lighting treatments in adjacent greenhouses
  - TSR Grow LEDs controlled by RT-LASSI to 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ with a 20 $mol \cdot m^{-2} \cdot d^{-1}$ target
  - PL Light High pressure sodium (HPS) fixtures controlled by LASSI hourly on/off with a 20 $mol \cdot m^{-2} \cdot d^{-1}$ target
- Climate Set points
  - Day 72F
  - Night 57F
- Maintenance
  - Old leaves and runners were removed weekly

Data Collection

Data collected weekly for 14 weeks on:

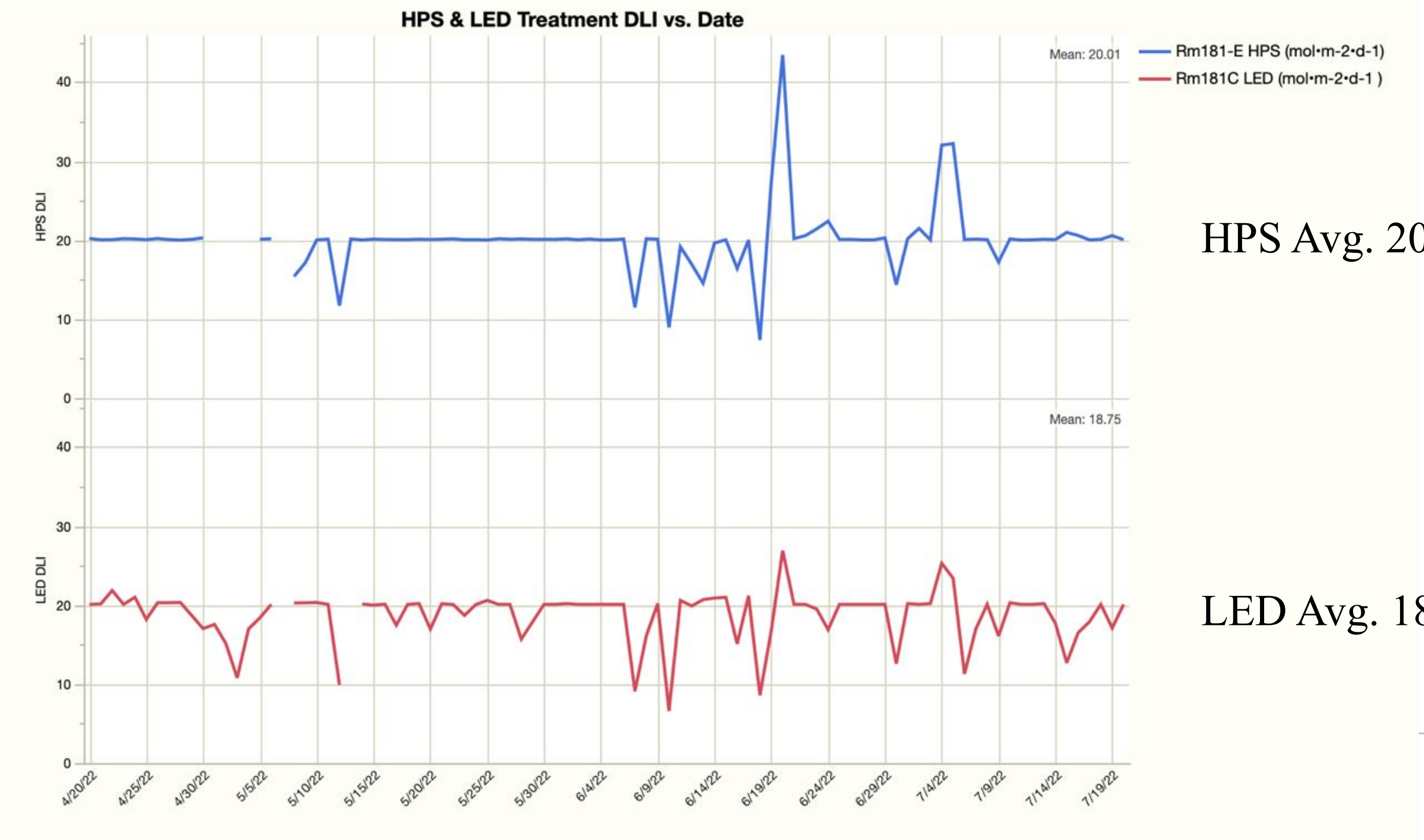
- Total berry yield (g/plant)
- Marketable berry yield (g/plant)
    - 90% red, no size distortions
- Fruit number

During last month of experiment

- Brix (soluble sugar content)
- Titratable acidity
- Brix to acidity ratio


JM EAGLE

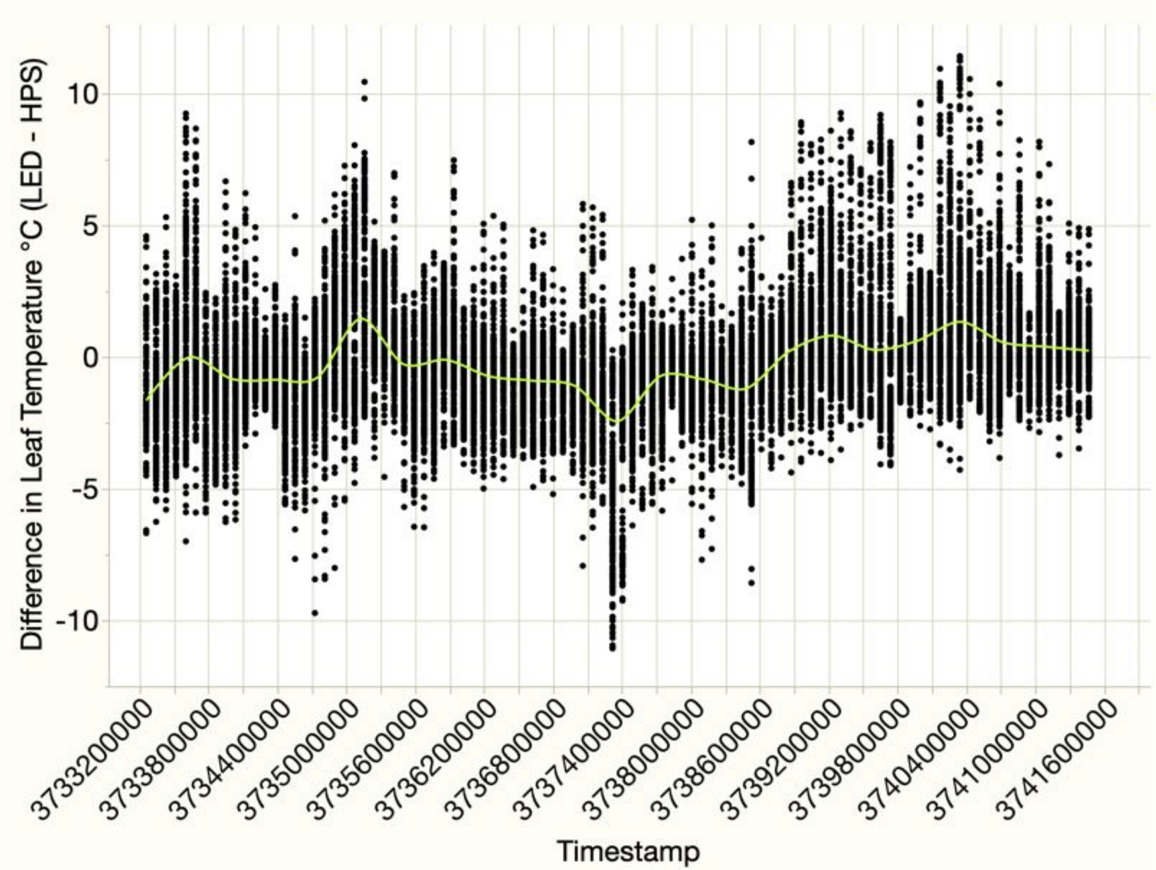
Daily light integral



HPS Avg. 20.01 mol•m^{-2}•d^{-1}

LED Avg. 18.75 mol•m^{-2}•d^{-1}

An infra-red radiometer connected next to a datalogger was placed in each greenhouse to measure leaf temperature for each lighting treatment

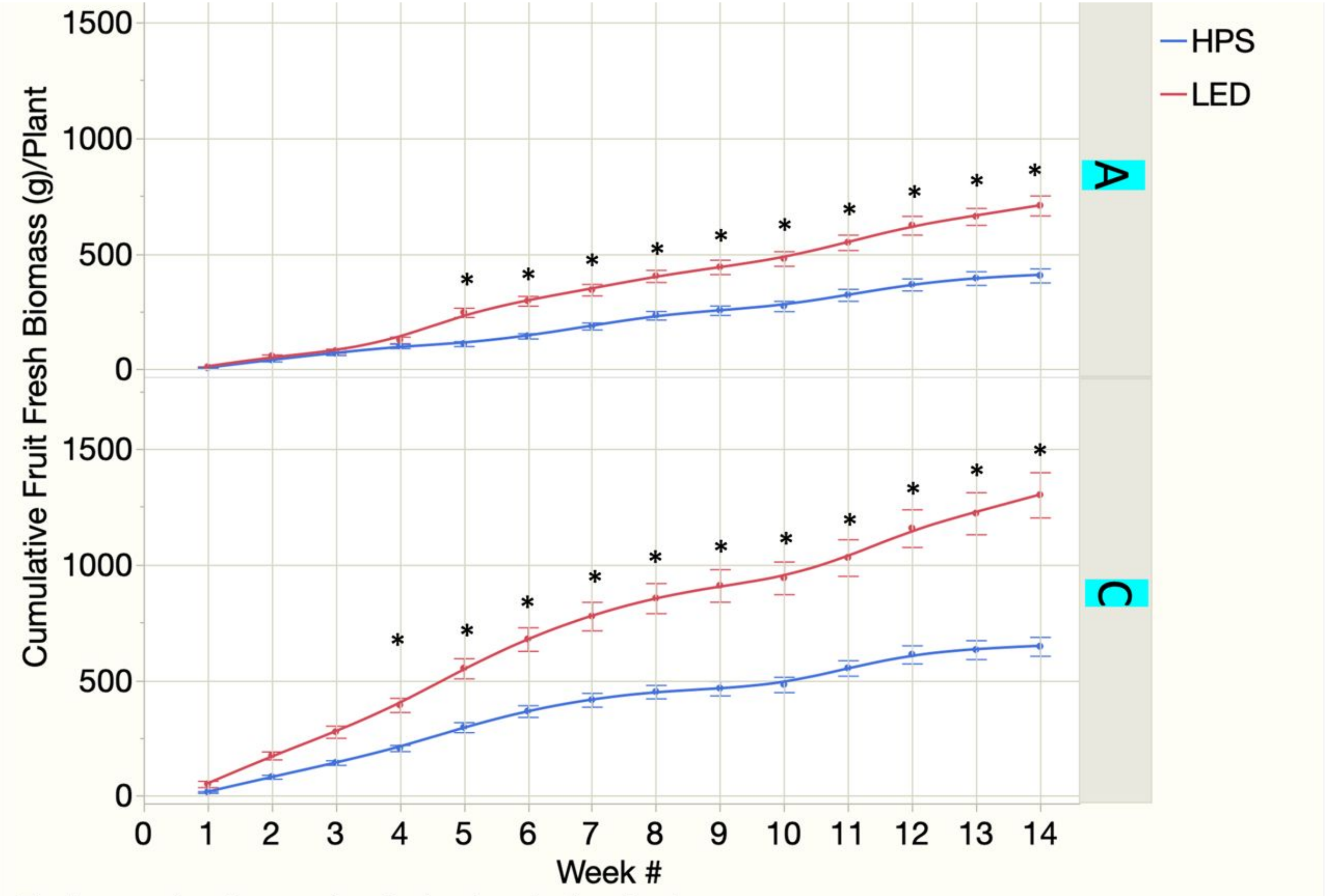


Difference in leaf temperature by treatment (daily average is yellow line)

HPS Avg. 20.6 °C

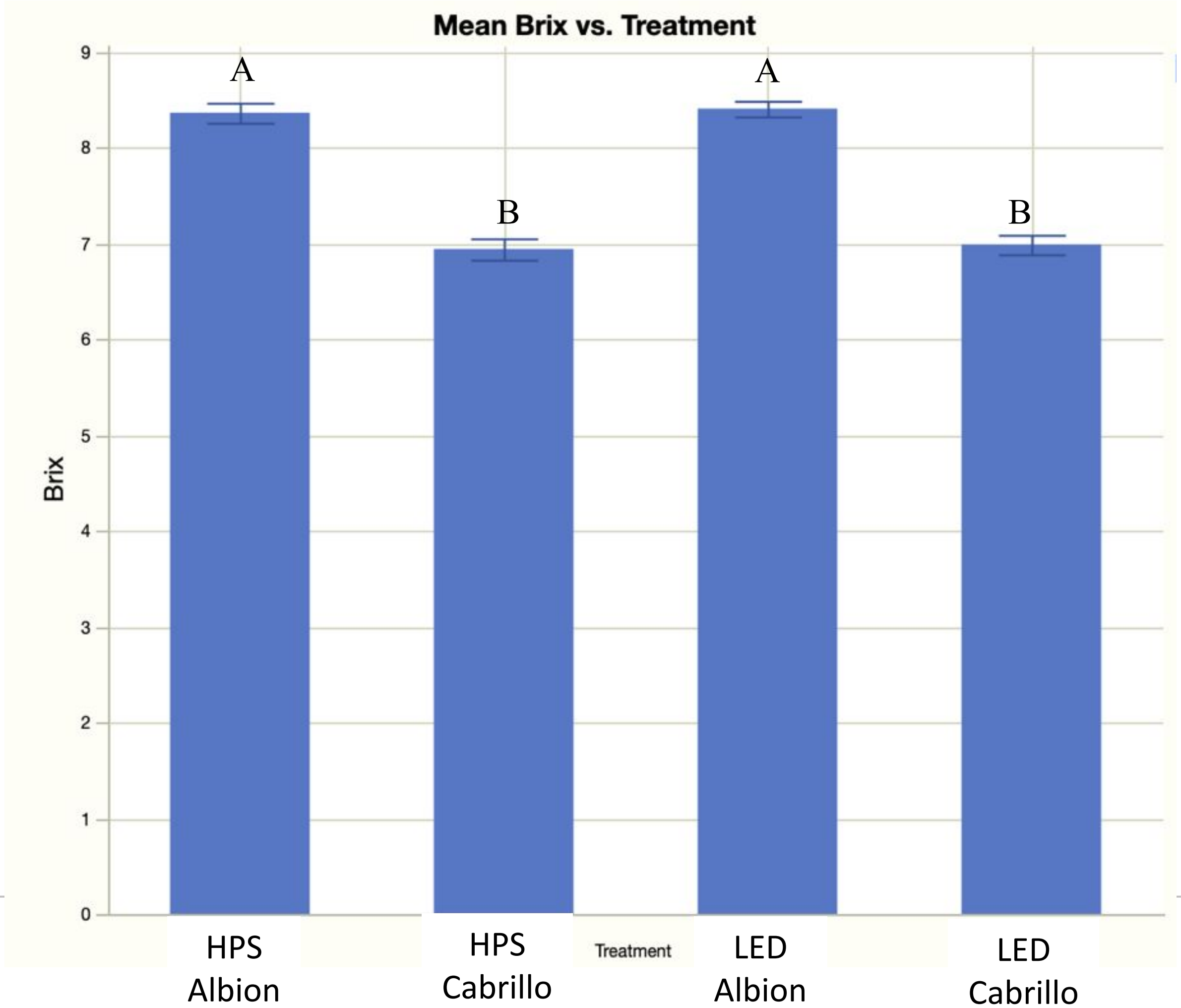
LED Avg. 20.4 °C

Cumulative berry weight per plant

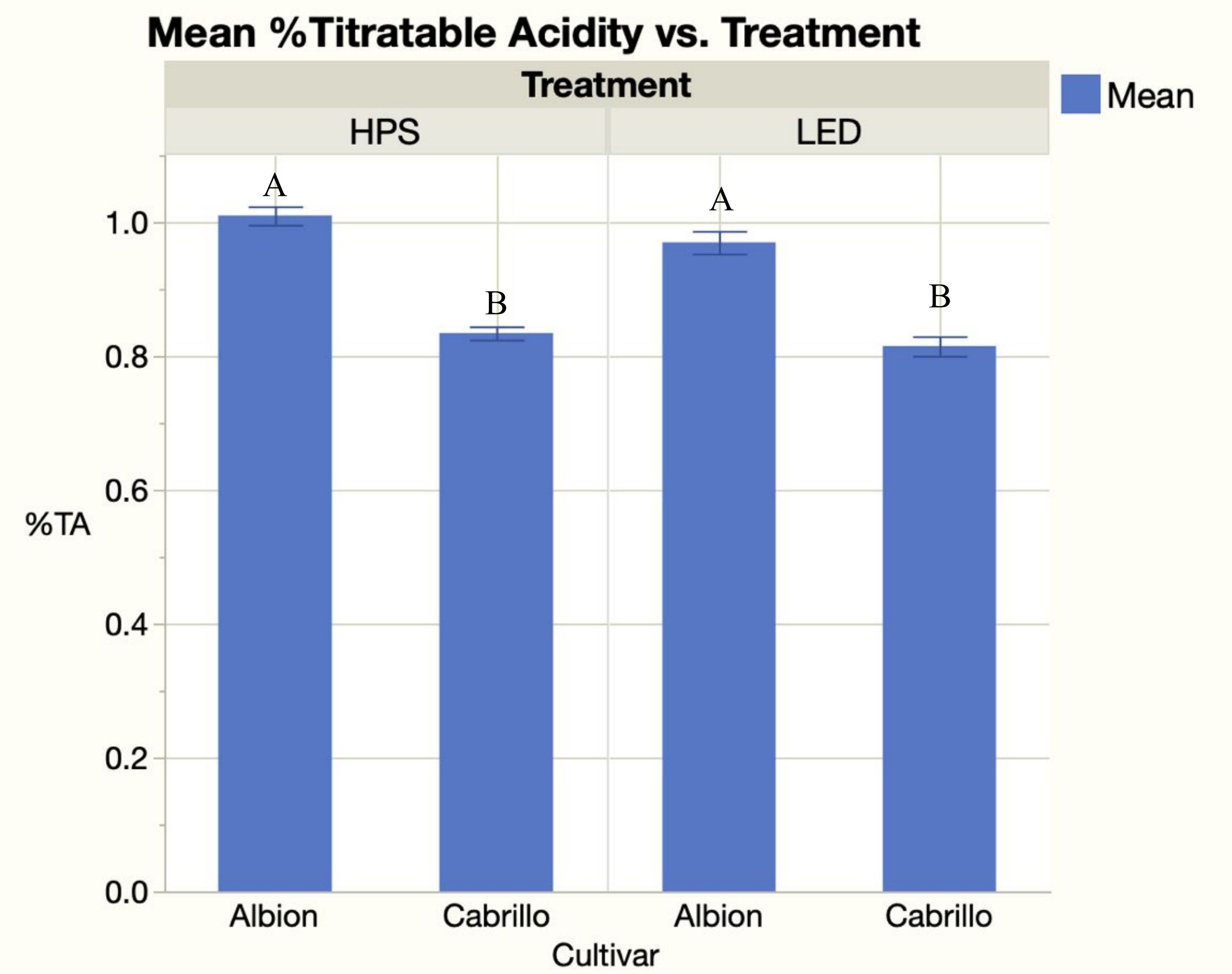


Brix, i.e. soluble sugar content

Higher is better



Titratable acidity (lower is better)



Summary strawberries

- For both 'Cabrillo' and 'Albion' RT-LASSI with LED lighting led to about a 45% greater strawberry yield vs. HPS
  - May be due to LED light spectrum or the dimming strategy (complementing the sun to achieve a target instantaneous light intensity)
- Brix and titratable acidity were not impacted by lighting treatment but were affected by cultivar (Albion was greater than Cabrillo)
- Implementation of RT-LASSI with LED lighting led to a 45% greater berry yield and 33% electricity savings as compared to HPS with LASSI

Thank you! Questions?

GLASE
GREENHOUSE LIGHTING & SYSTEMS ENGINEERING

Neil Mattson
Professor and Greenhouse Extension Specialist
nsm47@cornell.edu

GLASE Updates & Discussion

GLASE in 2022

- Webinars
  - 8 webinars
  - 627 live attendees
  - 1043 on-demand views
- GLASE Annual Summit
  - 60 attendees
  - IAB Meeting
  - Conference & greenhouse tours
- Climate Control Short Course
  - 250 registrants
  - 20 speakers
  - 6 modules
  - 12 hours of certified content

GLASE Products available for Members

	2018	2019	2020	2021	2022
Products developed	0	2	2	2	4
Services developed (cumulative)	0	2	4	4	5
Products variations tested in pilot systems	0	0	1	0	3
Intellectual Properties	0	2	2	1	0

Products

- New LED modules for indoor cultivation (2019)
- Remote fluorescence detection system (2019)
- CO2 LASSI Software for greenhouse energy modeling applications (2020)
- CO2 LASSI Software for the control of light and CO2 in greenhouses (2020)
- Spectral Acquisition System (2020)
- Greenhouse light fixtures (2021)
- DAM LASSI Model Software (2021)
- Real Time LASSI Model software (2022)
- Real Time LASSI Physical Application (2022)
- CO2 Real Time LASSI Model software (2022)
- Ventilation and CO2 optimization Model software (2022)

Services

- Complementary light analyses at Intertek (2019/20/21/22)
- Light analyses at Rutgers (2019/20/21/22)
- CEA Database and Benchmark Tool (2021/22)
- On Line LASSI (2021/22)
- CEA Open Data Base (2022)

Product variation tested in Greenhouses

- LASSI (2020)
- CO2 LASSI (2022)
- Real time LASSI (2022)
- Real time CO2 LASSI (2022)

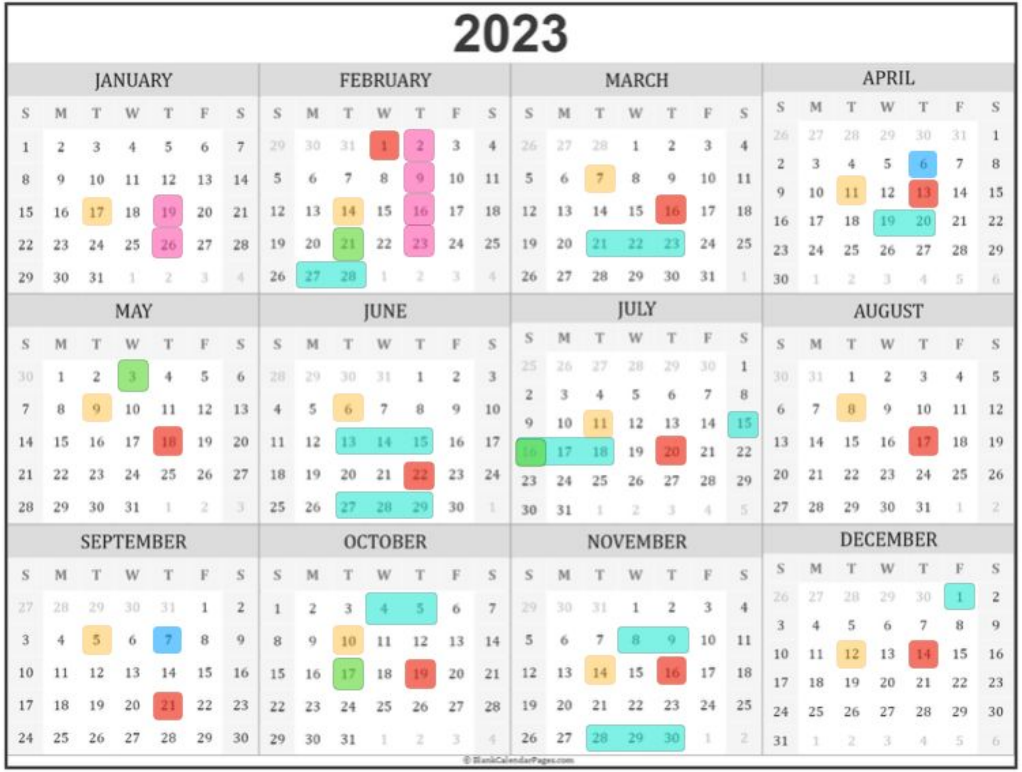
Intellectual Properties

- New LED modules for indoor cultivation (2019)
- Remote fluorescence detection system (2019)
- Software for using CO2 LASSI in greenhouse energy modeling applications (2020)
- Software for using CO2 LASSI for the control of light and CO2 in greenhouses (2020)
- DAM LASSI Model Software (2021)

2023 Agenda

- IAB Meetings *(2 virtual, 2 in-person)*
- Webinars *(virtual)*
- SAB Meetings *(virtual)*
- Newsletter *(virtual)*
- Short Course *(virtual)*
- GLASE Summit (*TBA - in person)*
- Industry Events *(in person)*

- Indoor AgCon, Las Vegas, NV (Feb 27-28)
- Green Tech Americas (Mar 21-23)
- NCERA-101, Davis, CA (Apr 19-21)
- Green Tech Amsterdam (Jun 13 - 15)
- Advancing CEA on Land & Space, Toledo, OH (June 27-29)
- Cultivate 23, Columbus, OH (Jul 15-18)
- Canadian Greenhouse Conference, Niagara (Oct 4-5)
- NE Greenhouse Conference, Boxboro MA (Nov 8-9)
- MJ Biz, Las Vegas, NV (Nov 28-Dec 1)



GLASE at Cultivate 2023

- July 15-18, Columbus OH
- GLASE Booth: 1013 (Sun-Tues)
- In-person IAB meeting

GLASE 2023 Summit

- Fall 2023 (October)
- Ontario, Canada
- Exploring partnerships
- In-person IAB meeting

Greenhouse Benchmark

- 10 applications processed
- 1st report completed
- 70 greenhouses to go

LASSI Implementation

- USDA NYS SCBG
- 6 facilities
- 8 implementations
- 12 months data analyses

Executive Director Search & GLASE Moving Forward

- Final 3 candidates - news soon