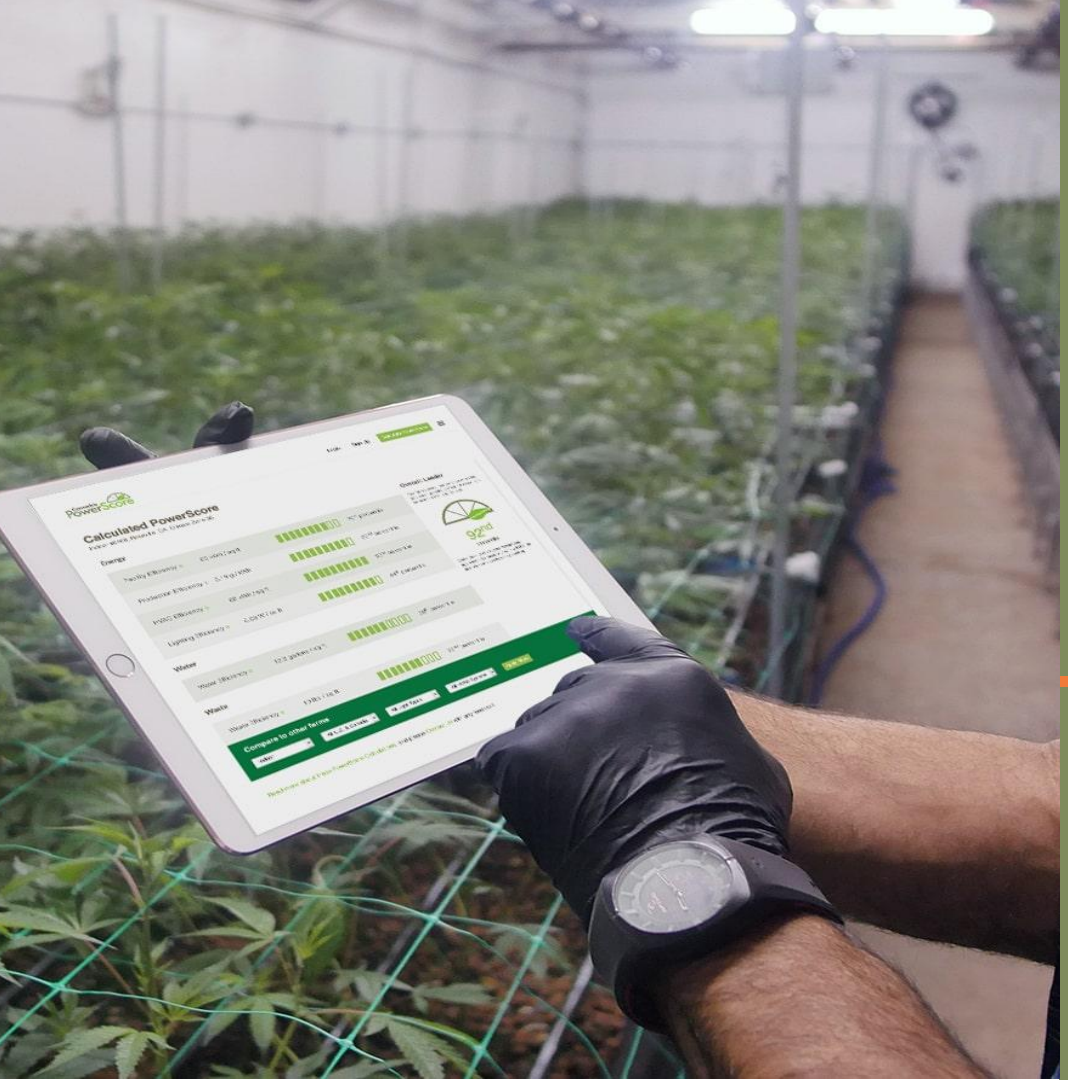


RESOURCE INNOVATION INSTITUTE

Efficient Yields
Best practices on energy, water efficiency, and productivity

Energy & Water Efficiency in Controlled Cannabis Cultivation

NYSERDA

Office of Cannabis Management

May 9, 2023

Agenda

Introduction & Purpose

Cannabis Science 101, part I

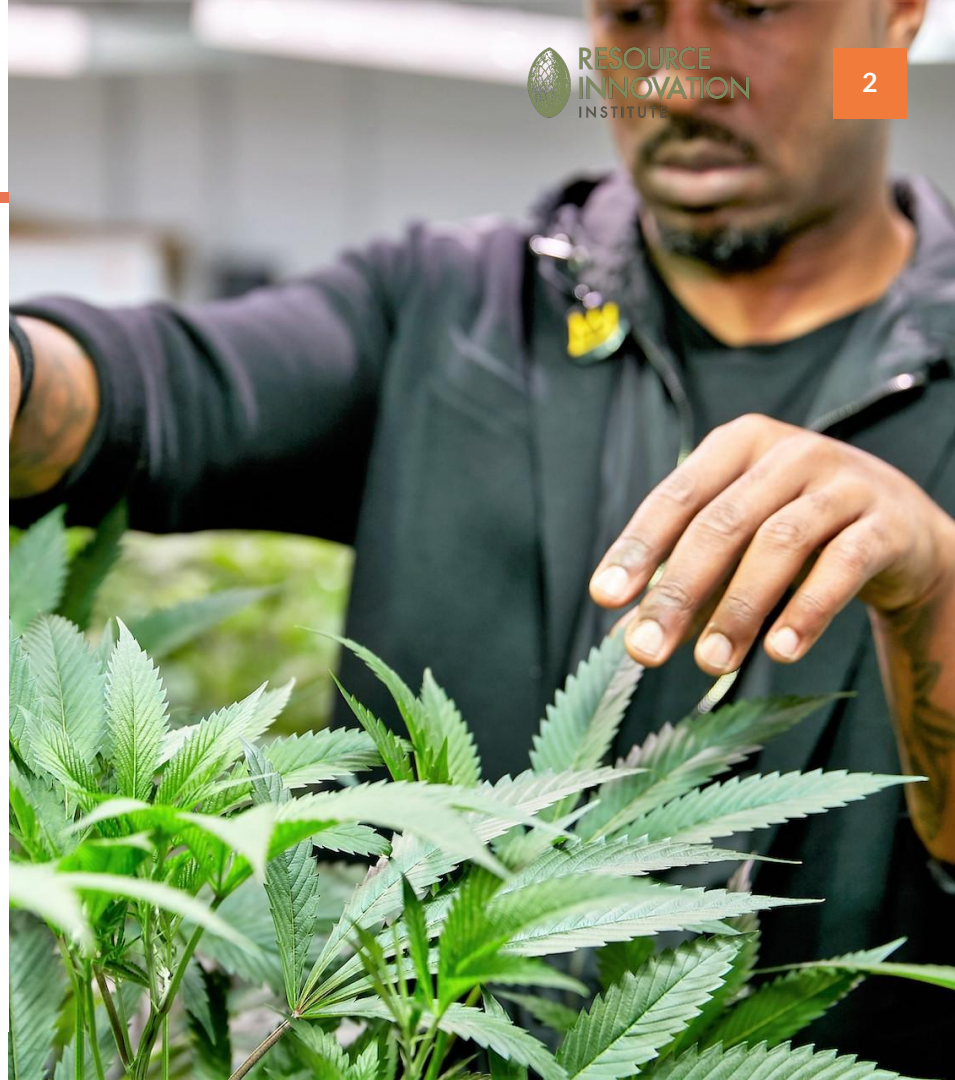
Lighting Considerations

Shade & Thermal Curtains

Water Quality & Sources

Resources

Q&A

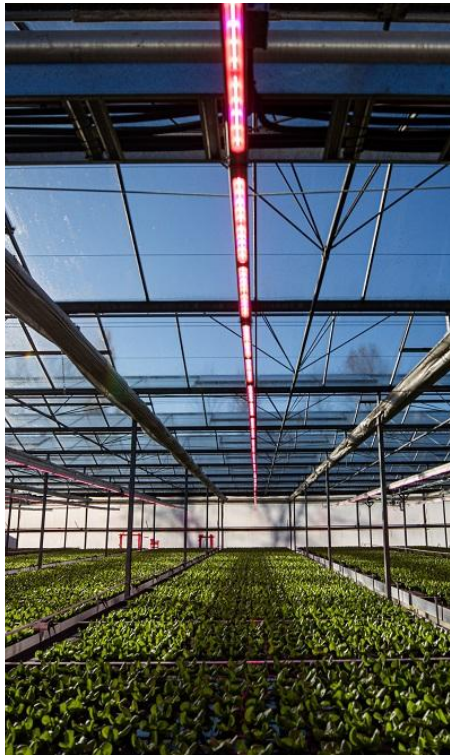


SECTION 01

INTRODUCTION

About RII

- Objective, data-driven, non-profit organization. USDA-funded.
- Founded 2016 in Portland, Oregon
- Form working groups from industry, government and academia to develop Best Practices Guides
- Webinars, workshops, articles for industry
- Benchmark growers production and resource efficiency with our Powerscore Platform


Our Network

INPUT from industry leaders and partners

RESOURCE INNOVATION INSTITUTE

EDUCATION and advocacy about best practices for growers

RII Industry Working Groups

- **Guides** development of standards and climate-smart methodology
- **Shapes** tools and resources to support Best Practices Guides
- **Advocates** for informed policies, incentives and regulations

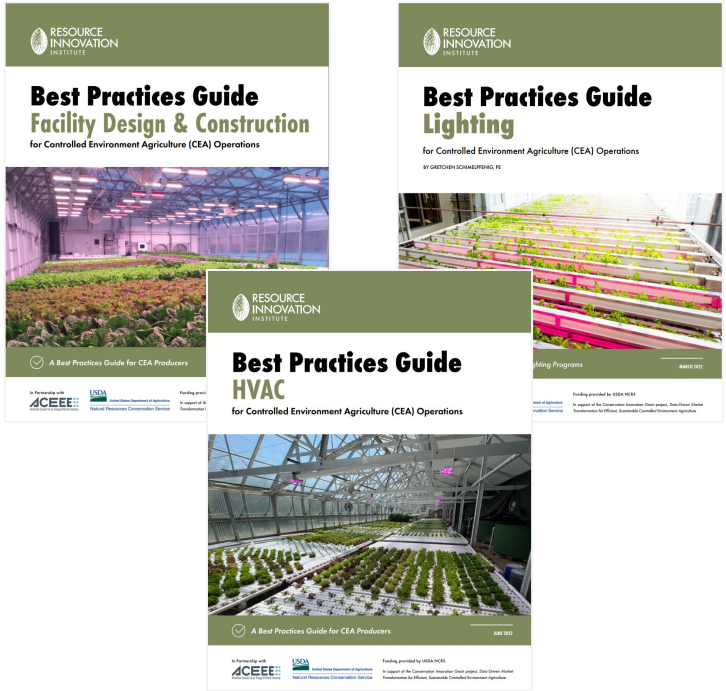
Equipment/Service providers: Become a Member!

Free Best Practices Guides

Collaboration by Industry Experts

Free guidance on efficient cultivation

- CEA Facility Design & Construction Best Practices, 2022
- CEA HVAC Best Practices, 2022
- Cannabis HVAC Best Practices, 2019
- CEA Lighting Best Practices, 2022
- Cannabis Lighting Best Practices, 2019



Purpose of Today's Workshop

- Help NY cannabis growers improve energy and water efficiency in greenhouse and indoor facilities

- Convey scientific insights and industry expertise directly to producers and find the best ways to translate them in the context of their locality

- Assist cannabis producers and their design and construction project partners, with what they need to know to stay competitive and comply with regulations

Efficient Yields
Best practices on energy, water efficiency, and productivity

Today's Experts

Rob Eddy

Jason Matlock

Paul Arena

Dane Sheldon

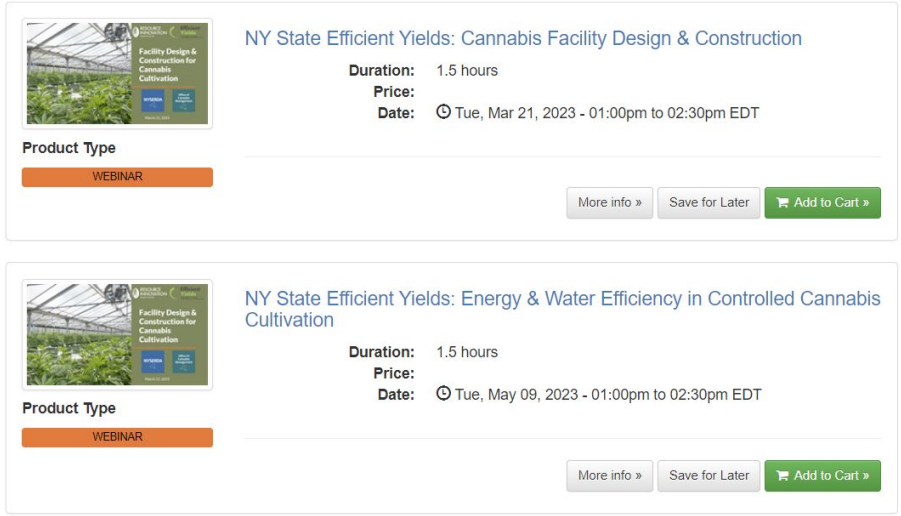
Access Your New York Virtual Classroom

Continue Learning Online

Free guidance on efficient cultivation

All live workshops are available for on-demand viewing!

- Recordings of live workshops
- Downloadable resources
- NY State program tools



Create an account at the NY Efficient Yields Classroom

SECTION 02

CANNABIS SCIENCE 101

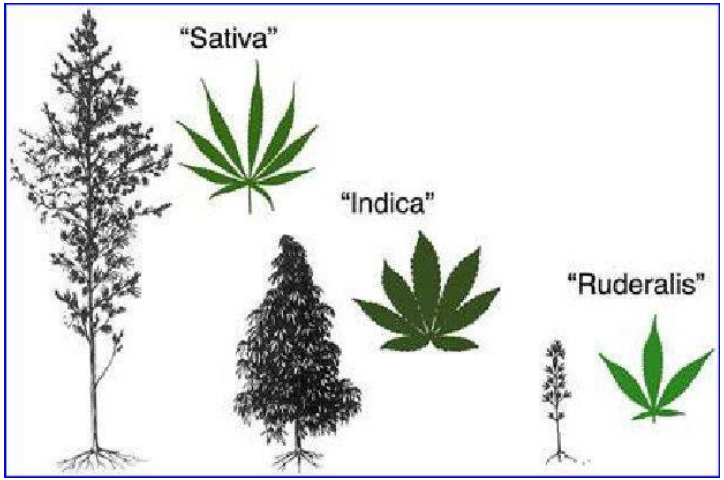
POLL ALERT!

What kind of facility are you cultivating in?

- Small indoor building
- Warehouse
- Standard, vented greenhouse
- Sealed, air-conditioned greenhouse
- Container farms or pods

Cannabis Plants

Botanically, *Cannabis sativa* is a dioecious flowering plant with three species subtypes: sativa, indica and ruderalis



McPartland, 2018

Noteworthy genetics:

-Production of secondary metabolites
-Production of lignin and cellulose
-Response to light

Pemberton, Co State Univ, 2017

TABLE 1

Development Stage	Propagation					Vegetative	Flowering
	Tissue Culture	Seed		Cutting			
	Fixed	Fixed	Photoacclimated	Fixed	Photoacclimated		
Light intensity (umols/m²/s)	60-80	150-250	150-350*	150-250	150 -350*	300-600	600+
CO_2 (ppm)	Lab	800	800	800	800	400-800	800-1400
Temperature (deg. F, day:night)	Lab	**68°F - 72°F***	**68°F - 72°F***	72°F - 80°F : 70°F - 78°F	75°F - 80°F : 70°F - 75°F	74°F - 84°F : 68°F - 76°F	68°F - 84°F : 68°F - 78°F
Relative Humidity (%)	Lab	> 85%	> 85%	> 85%	> 85%	55% - 75%	50 - 60%
VPD as calculated from T/RH ranges	Lab	Figure 6					
Leaf Temperature (deg. F)	Lab	73°F - 78°F	73°F - 78°F	73°F - 78°F	73°F - 78°F	75°F - 78°F	75°F - 78°F
Air speed (m/s)	Lab	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.8 - 1.2	0.8 - 1.2
EC (mS/cm)	Lab	0.3 - 0.7	0.3 - 0.7	0.3 - 0.7	0.3 - 0.7	1.0 - 2.0	1.5 - 2.6
Root Zone Temperature		75°F - 78°F	75°F - 78°F	73°F - 75°F	73°F - 75°F		
Nutrient ppm	There are important mineral ratios which need to be monitored. In many cases, growers have a different fertilizer regimen per stage of crop development. This strategy works for some, but is not generally recommended. You can be successful with having a baseline fertilizer mix which follows proper mineral ratios and rely on manipulation of EC during each stage to supplement nutrition concentration. More information can be found in the Nutrient section of this guide, and the pH chart and Mulder's Chart should be referenced in particular.						
pH							

Temperature for germination should be gradually increased throughout the seed development stage

Source: Fluence Cultivation Guide

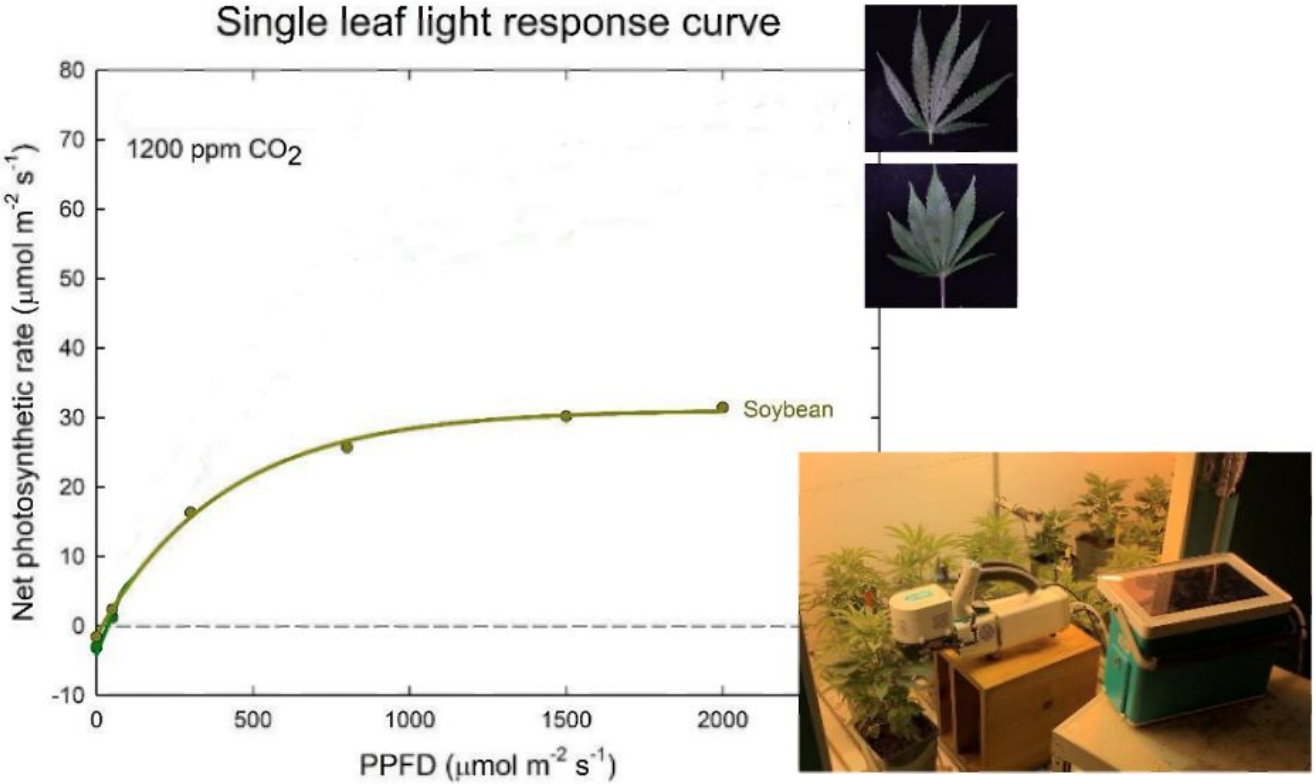
clade9
Las Vegas Strip

Flowers are where cannabinoids and terpenes are concentrated

Similar to cut flower production such as cut flower chrysanthemums!

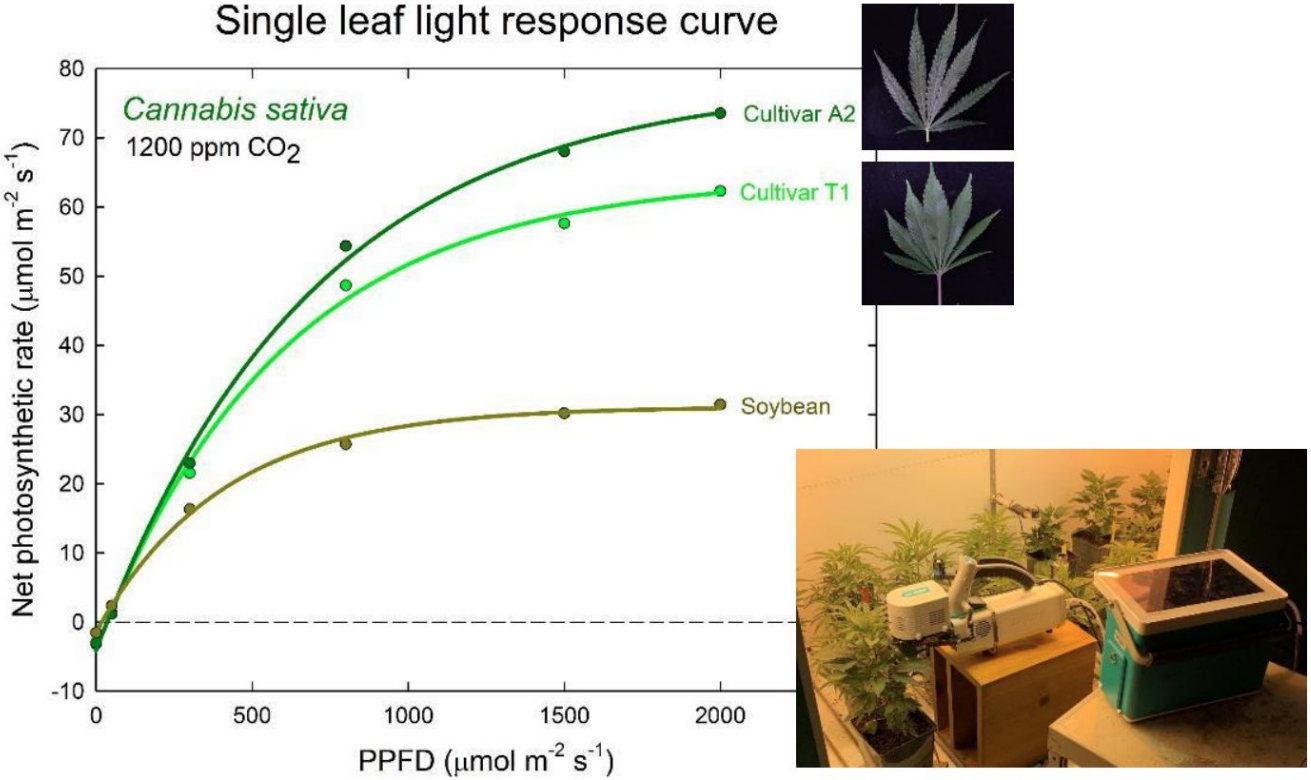

99 years ago…
plantingdiaries.com

Light Response



Bugbee, 2019

Light Response



Bugbee, 2019

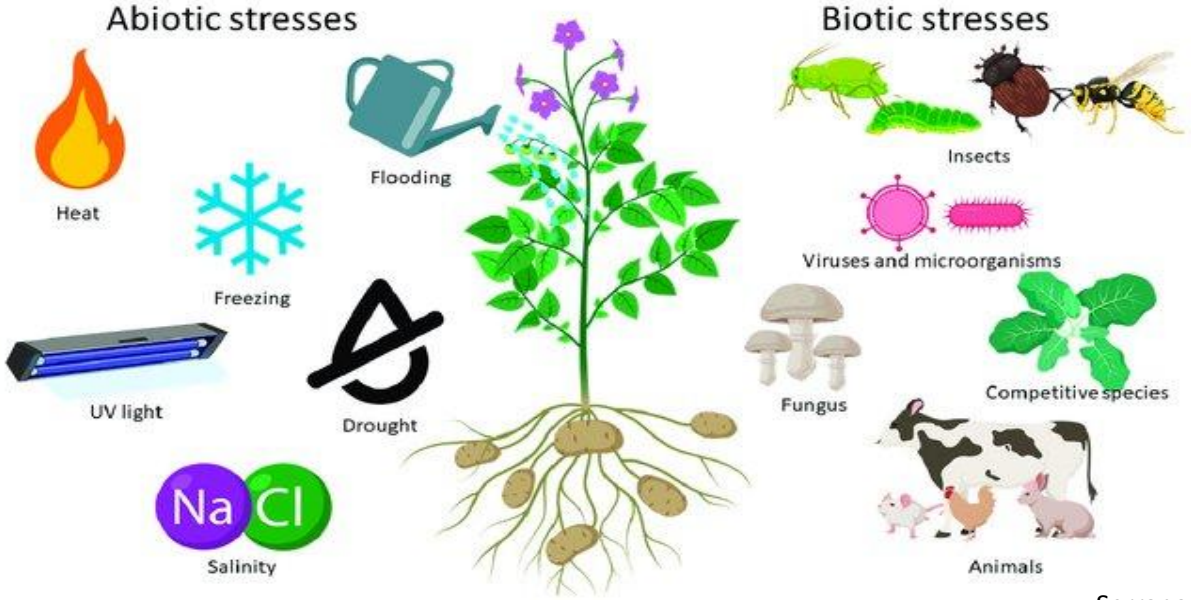
Yield Follows 1% Rule

- From vegetable industry: 1% increase light = 1% increase yield
- Change HPS, MH or fluorescent bulbs on a schedule
- Clean light reflectors, bulbs and LED diffusers if grimey or dusty
- Diffuse the sunlight in a greenhouse
- Consider intracanopy lighting for indoor grow rooms

Image credit: Plessey

Secondary Metabolites

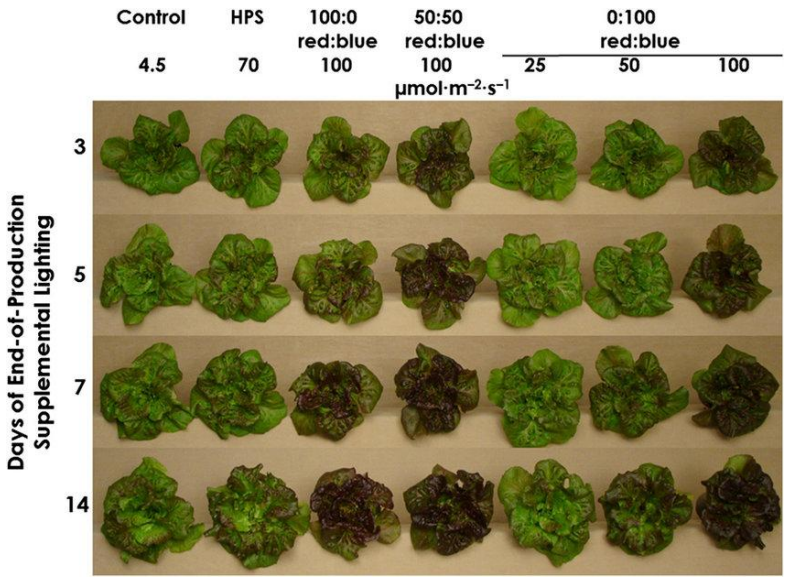
- What are primary metabolites? (Chlorophyll, DNA, sucrose, starch, etc.)
- Secondary metabolites are defense compounds



$$$

Serrano, et al., 2020

“Finishing Spectrums”



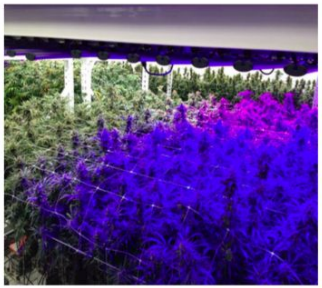
HortScience 50(5):676–684. 2015.

End-of-production Supplemental Lighting with Red and Blue Light-emitting Diodes (LEDs) Influences Red Pigmentation of Four Lettuce Varieties

W. Garrett Owen and Roberto G. Lopez[1,2]
Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN 47907-2010

MEDMEN RESEARCH & DEVELOPMENT

- Conducted during final 7 days of flower cycle
- Testing to enhance:
1. Anthocyanin – pigment responsible for purple coloration
2. Terpenes
3. THC
- Preliminary results promising, conducting more trials to gather larger data set



PHOTOx SUMMIT 2017 | SAN DIEGO 16

- *Source: Dr. Damian Solomon, Plant Geek Consulting, PhotoX Summit*

Controlled Drought Stress & Secondary Metabolites

HortScience 54(5):964–969. 2019. https://doi.org/10.21273/HORTSCI13510-18

Increasing Inflorescence Dry Weight and Cannabinoid Content in Medical Cannabis Using Controlled Drought Stress

Deron Caplan[1], Mike Dixon, and Youbin Zheng[2]
School of Environmental Sciences, University of Guelph, Guelph, Ontario, N1G 2W1, Canada

Drought **Increased:**

- THCA concentration by 12%
- CBDA concentration by 13%
- THCA yield by 43%
- CBDA yield by 47%
- THC yield by 50%
- CBD yield by 67%

One drought stress event applied on week 7 of flowering

POLL ALERT!

What kind of facility are you cultivating in?

Discuss Results

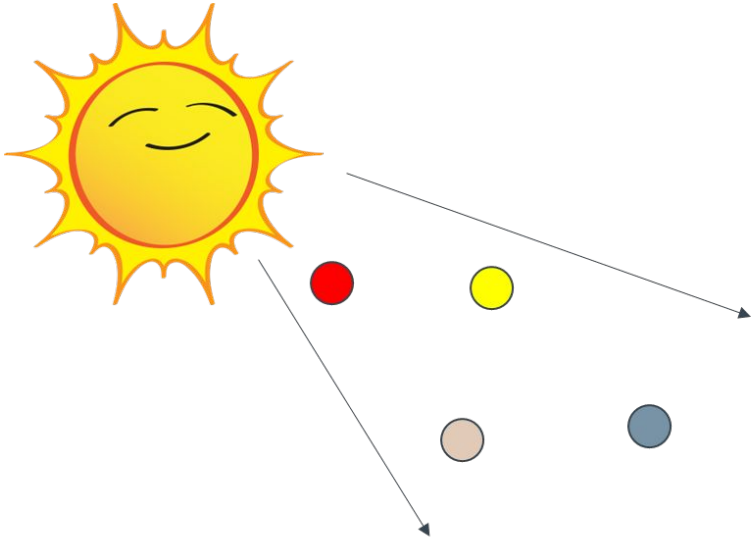
SECTION 03

LIGHTING CONSIDERATIONS

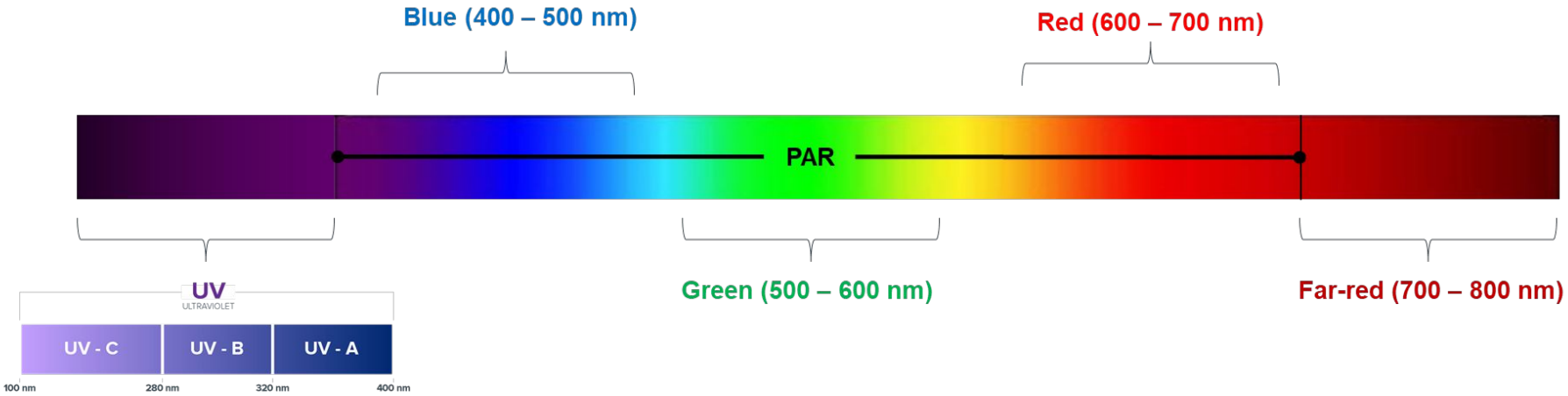
POLL ALERT!

Knowledge Check: Compared to field crop production in summer, a greenhouse…

- Has about the same insect and disease problems
- Has less insect and disease problems
- Has more insect and disease problems



- White Light emitted by the sun is composed of discrete packets of energy called photons that move like a wave
- The color and energy content of a photon is reflected in its wavelength
- Photons with wavelengths in the range of 400 – 700 nanometer make up the **P**hotosynthetically **A**ctive **R**adiation (PAR) spectrum, which closely matches the visible spectrum as well



(PPFD): *How Hard is it Raining?*

Quantity (Photons) → **$\mu mol \cdot m^{-2} \cdot s^{-1}$** ← Time

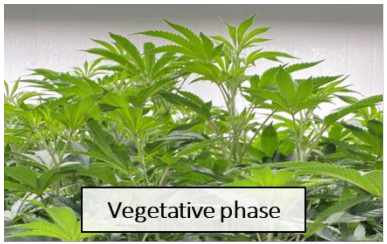
Area

(DLI): *How Much did it Rain?*

Quantity (Photons) → **$mol \cdot m^{-2} \cdot day^{-1}$** ← Time

Area

3 – 5 DLI
(50 – 80 PPFD)



26 – 38 DLI
(400 – 600 PPFD)

38 – 65 DLI
(900 – 1500 PPFD)

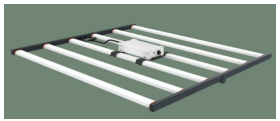
Efficacy: *How Much Energy Used?*

Quantity (Photons) → **$\mu mol \cdot joule^{-1}$** ← Energy

Legacy Lighting (HPS + CMH)

0.80 – 1.90 µmol·j^{-1}

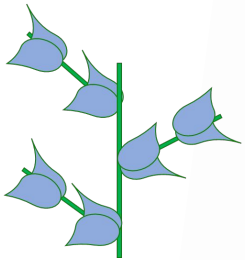
Modern LED Lighting



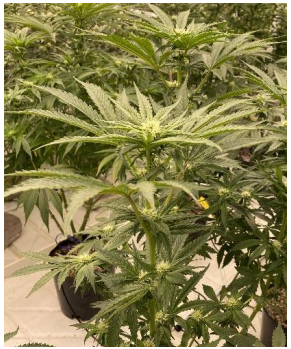
1.90 – 3.80 µmol·j^{-1}

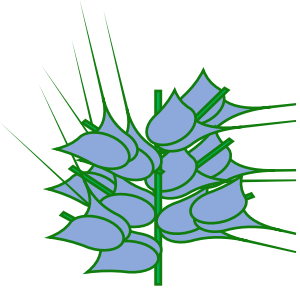
Light Affects Yield and Quality: Primary Economic Drivers

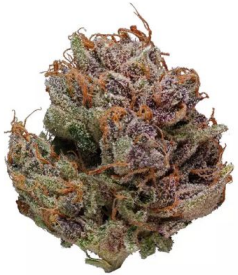
Low Light



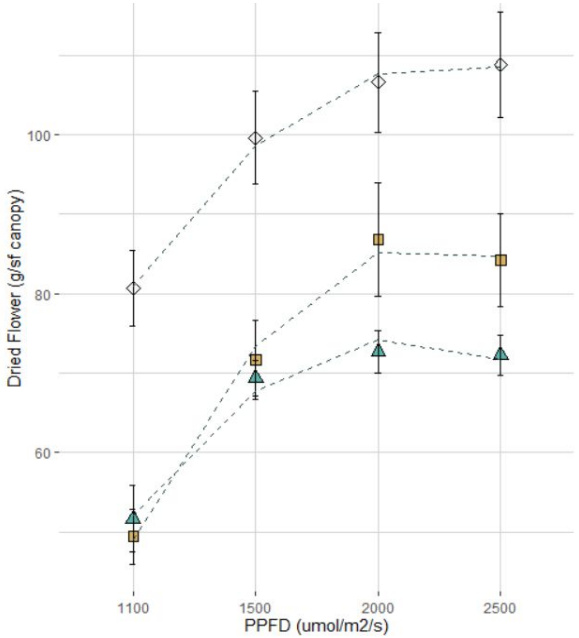
High Light







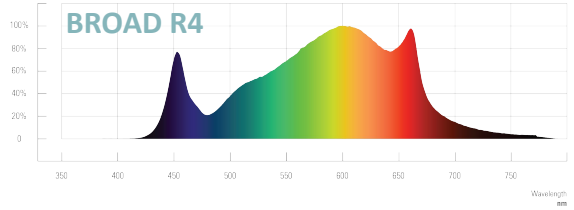
No Practical Limit to Cannabis Light Tolerance under Optimized Conditions

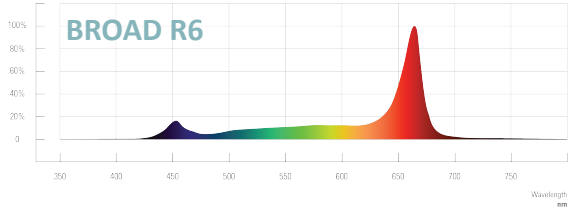


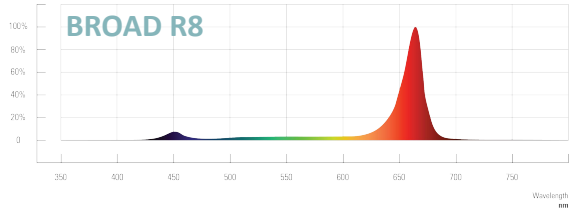
Spectral Quality Affects Total Light Output

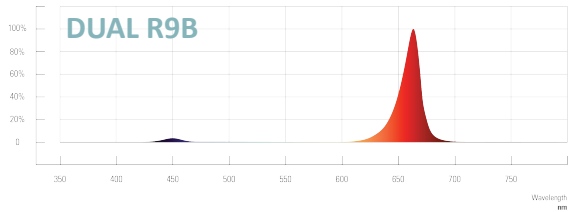
- More energy is required to produce blue photons than red photons
- A Red Shifted Spectrum will affect Fixture Efficacy
  - More light output for the same wattage
  - Less energy for the same light output

Red Fraction	µmol·J^{-1}
40 %	2.7
60 %	3.0
80 %	3.2
90 %	3.6









Spectral Quality Also Affects Plant Development

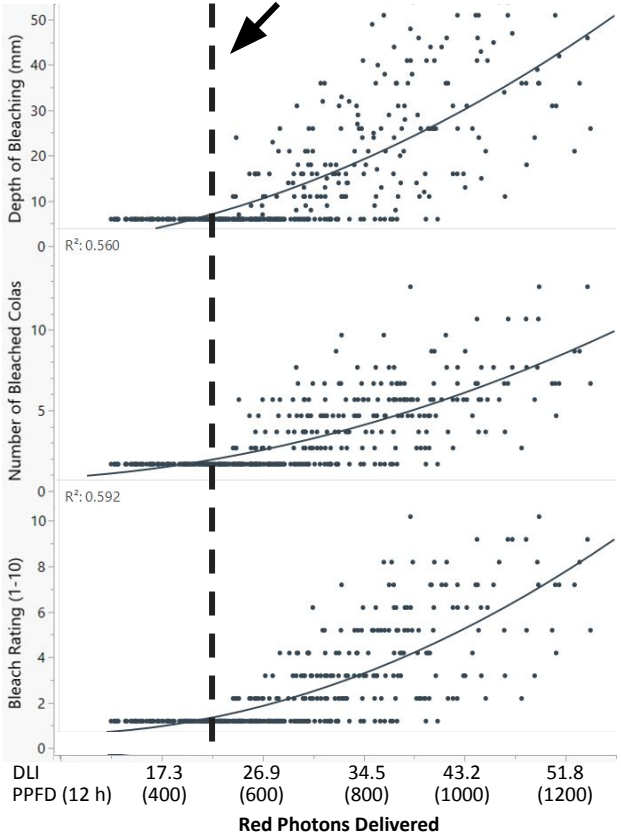
Red Light DLI over 21.5 $mol \cdot m^2 \cdot day^{-1}$ created risk of photobleaching in Fluence Study

Total Photon Flux Affects Maximum Red Fraction

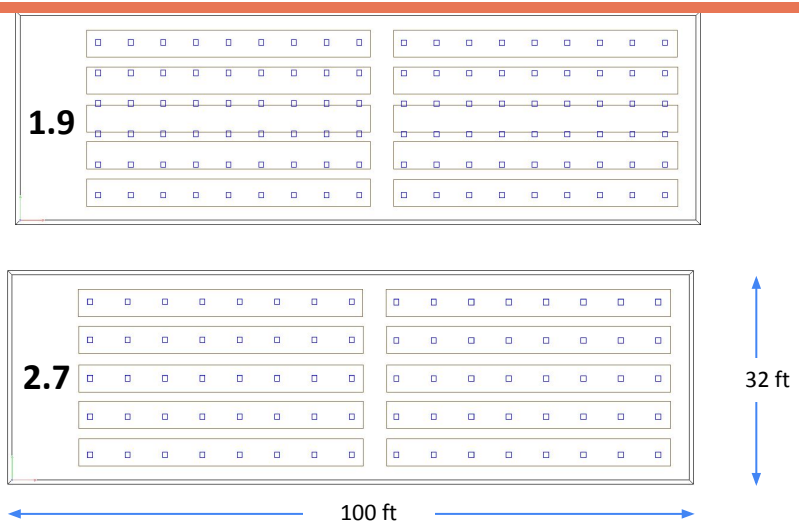
Greenhouses must account for natural light contributions

Recommend <50% Supplemental Red Light for Market Flower Production when Total Supplemental Flux exceeds 500 PPFD

Incidence of Photobleaching under Red Gradient Light with White Light Background



Efficient Lighting Technologies Are Part of a Holistic Approach to Greenhouse Design



Efficacy	PPFD	DLI	Coverage	Power Density
$\mu mol \cdot J^{-1}$	$\mu mol \cdot m^{-1} \cdot s^{-1}$	$mol \cdot m^{-2} \cdot day^{-1}$	Sq. ft.	$W \cdot$ Sq. Ft^{-1}
1.9	+ 750	+ 32.4	20.2	49.5
2.3	+ 750	+ 32.4	24.3	41.2
2.7	+ 750	+ 32.4	27.3	36.6

Lower Power Consumption:

- 20-40% Reduction in Electrical Use and Heat Output
- Reduced Demand for Cooling And Primary Power Decreases Project CAPEX
- Less Heat Stress During Summer Months

Fewer Fixtures for Same Light Target:

- Lower Install Costs
  - Hanging
  - Electrical Infrastructure
- Less Natural Light Blockage

Dimming Control:

- Reduced Peak Demand Charges
- Integration into Climate Control Systems
  - Heat Management
  - DLI Predictions
  - Photo Acclimation

Knowledge Check: Compared to field crop production in summer, a greenhouse…

- ~~Has about the same insect and disease problems~~
- ~~Has less insect and disease problems~~
- Has more insect and disease problems

SECTION 04

SHADE & THERMAL CURTAINS

POLL ALERT!

What is your focus for the upcoming year within your cultivation practices?

- I’m just starting out!
- Saving Energy
- Temperature control
- Humidity control
- Light control


Blackout & Light Deprivation
Diffusive Shading & Cooling
A climate solution for every grower

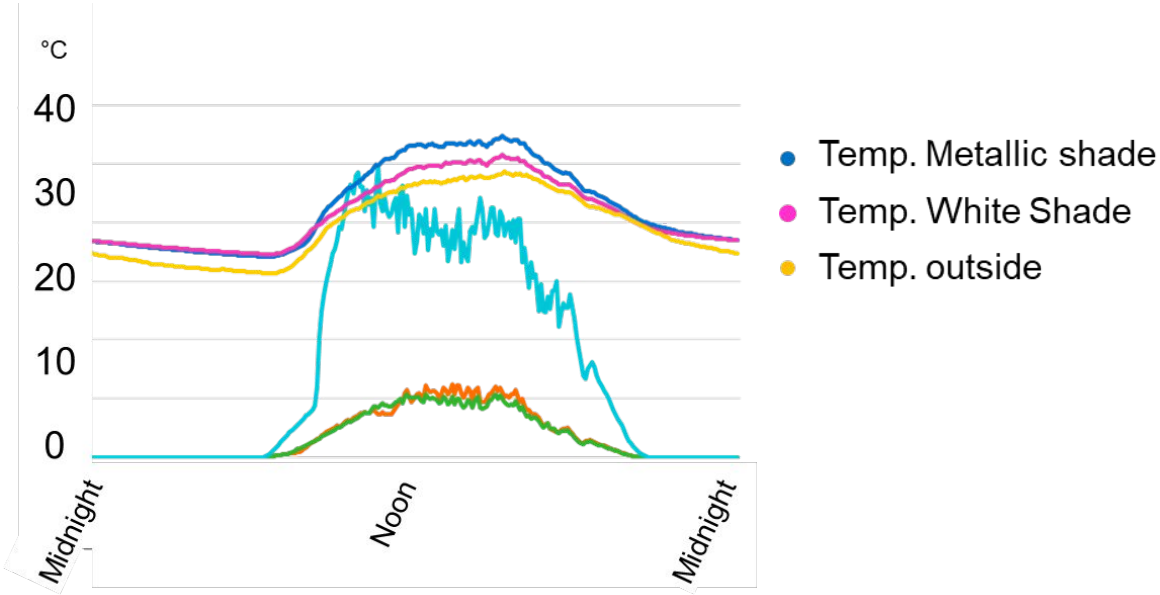
Benefits of Shade and Light Diffusing Screens

- Shading screens can help control light and temperature levels, providing an overall cooler environment for both the plants, as well as the greenhouse employees.
- Diffusive white strips scatter sunlight to reach deeper and more evenly throughout the crop.
- Leads to stronger, healthier plants and accelerated production.
- Consistent bud sizes, thanks to uniform light spread

White strips vs Aluminum strips in Shade Screens

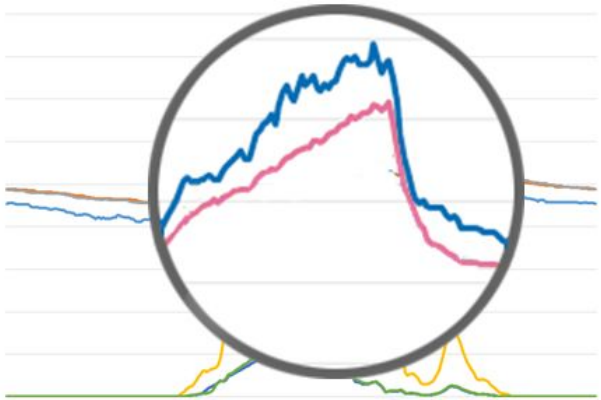
Every Degree Counts:

Reduce Average & Peak Temperatures



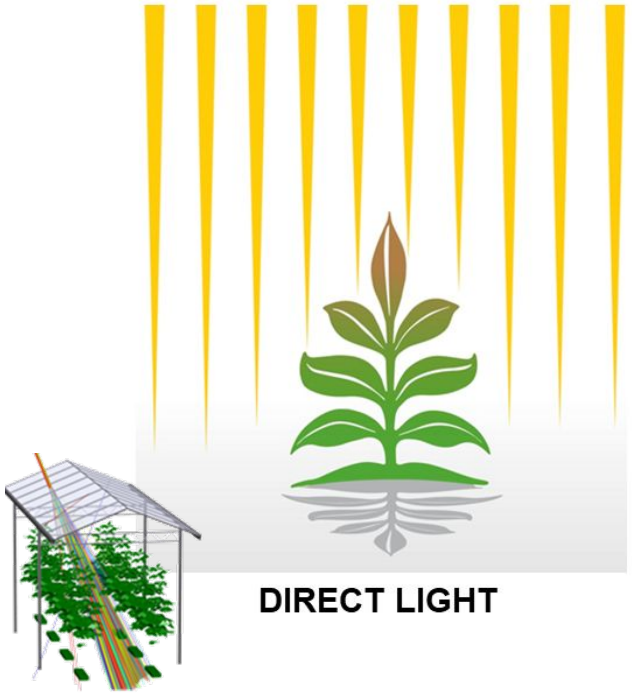
Brite Leaf Citrus Nursery, Lake Panasoffkee FL, US
Average PAR and temperatures, June 2015.

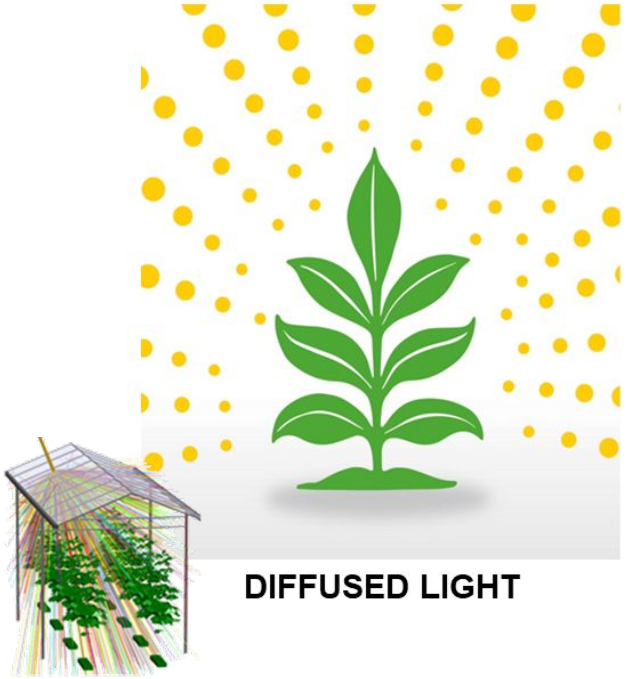
5°C LOWER
peak temperatures!*



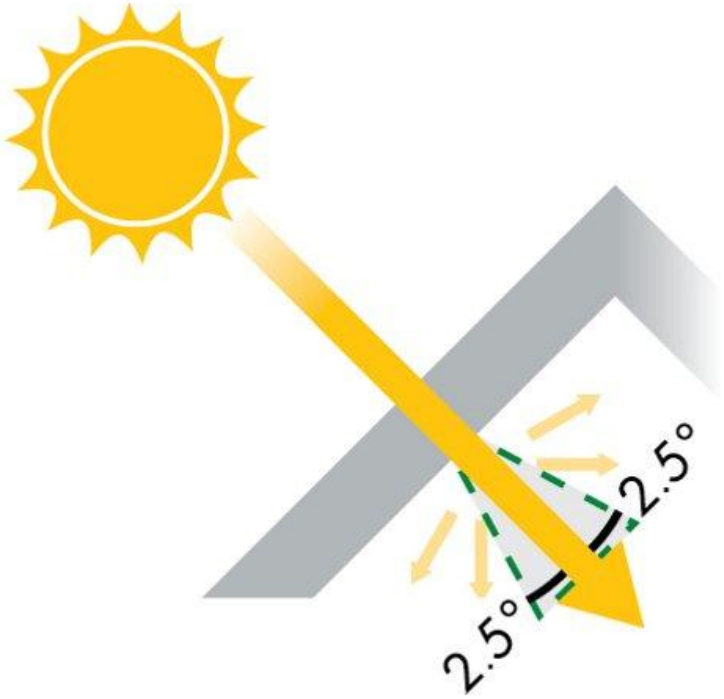
* July 6, 2015

What is Diffused Light?

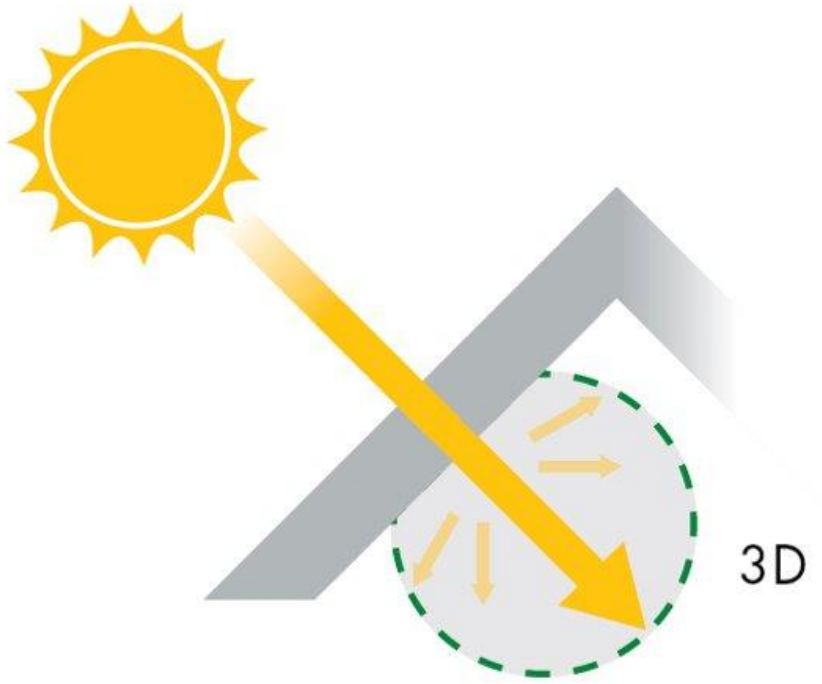




HAZE

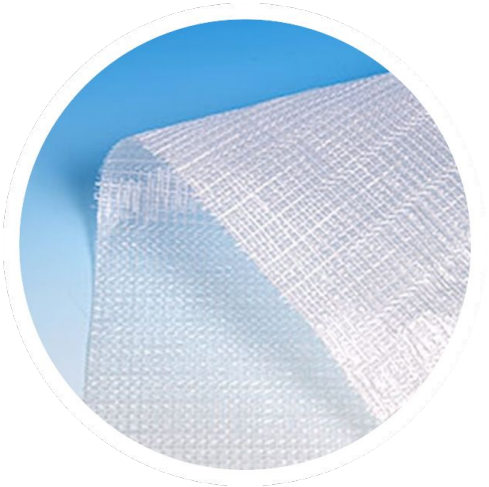


HORTISCATTER

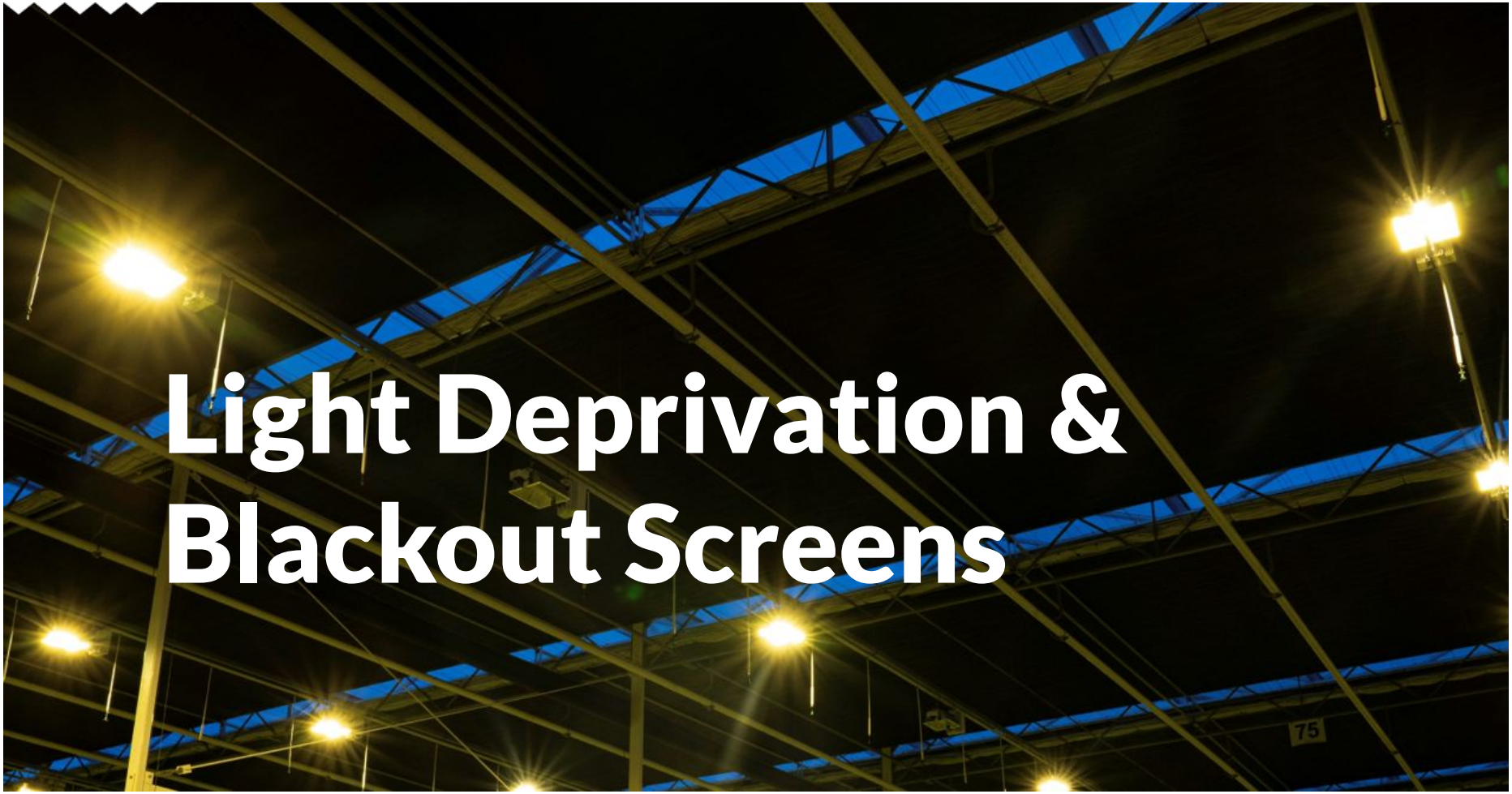


Equal Light Spread

Harmony 2047 FR



Even light diffusion decreases shadows and increases overall light in contact with the crop



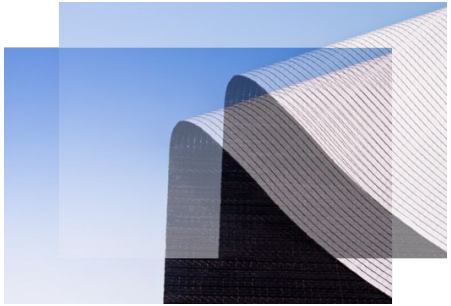
Light Deprivation & Blackout Screens

Light Deprivation

Single, double, or triple layer blackout

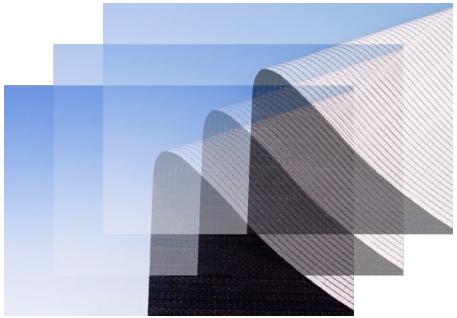
Single layer

No flowering



Double layer

Flowering

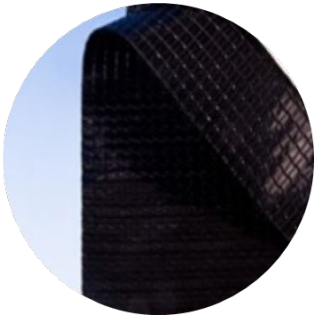


Triple layer

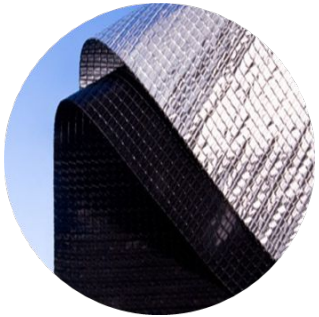
Flowering

Layer Configurations - Twice as Versatile

Double and triple layer options offer complete versatility for your climate needs



Black layers **absorb and restrict** Interior light and sunlight



Aluminum upper layer options **save the most energy** at night

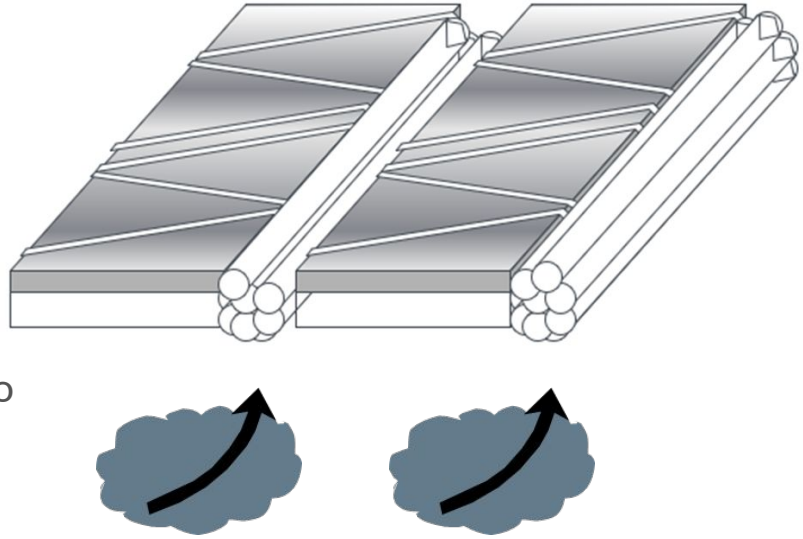
White reflective upper layers **maximize cooling** in hot, sunny weather

White bottom layer **reflects and intensifies** supplemental lighting

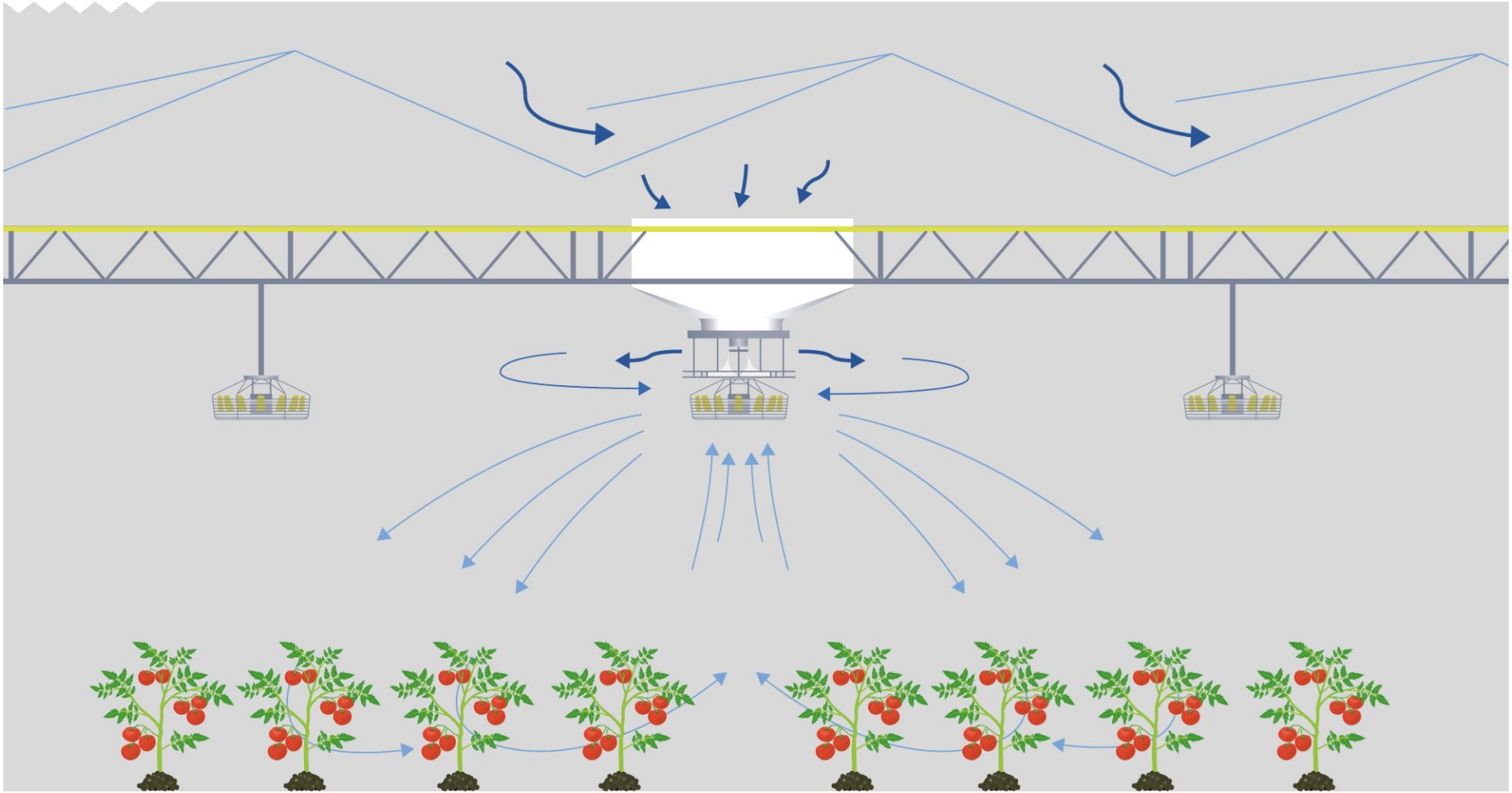
Managing Humidity Under Blackout Light Deprivation Screens

Humidity should always be carefully managed!

- Selecting a "breathable screen“ that allows water vapor to pass through is key for preventing moisture buildup and extreme spikes in humidity levels – minimizing plant diseases such as botrytis.
- "But I can't gap a screen that needs to stay closed to control my crop's photoperiod!"
- What other methods of dehumidification can I use to control their humidity under blackout?



humidity transport via yarns



Energy Calculator

- Specific to each grower's operation
- A vital resource when applying for a rebate with your local utility
- Extra insight into your operational costs
- Additional insight into the specifics of your climate when requested

ANNUAL SUMMARY

Scenario names	No Screen	Single Energy Screen	PARperfect
Screen 1	-	HARMONY_2047_FR	OBSCURA_9950_FR_W
Screen 2	-	-	HARMONY_2047_FR
Screen 3	-	-	-
Vertical 1	-	OBSCURA_10070_R_FR_W	OBSCURA_10070_R_FR_W
Vertical 2	-	-	-
Energy consumpt. (m3 gas)	3 497 792	2 431 799	2 085 115
m3 gas/m²	94.60	65.77	56.39
Energy expenditure	979 382	680 904	583 832
US Dollars/m²	26.5	18.4	15.8
Energy saving (%)	-	30%	40%
Investment	-	443 700	739 500
US Dollars/m²	-	12.00	20.00
Return on investment (year)	-	1.5	1.9

POLL ALERT!

What is your focus for the upcoming year within your cultivation practices?

Discuss Results

SECTION 05

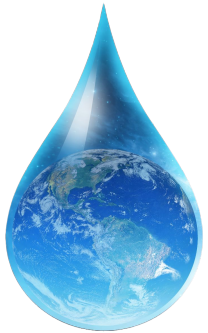
WATER QUALITY & SOURCES

Knowledge Check:

Some greenhouse curtains can be used for both shading in the day and retaining heat at night.

- TRUE
- FALSE

The Why Behind Water Efficiency



- Market pushing for ***faster, cheaper, greener***
- In terms of water usage and pollution prevention, CEA has a leg up on traditional agricultural methods given inherent control and potential for recapture and reuse
- Only about 3% of the water on earth is fresh 0.5% is accessible
- In 2022, world population hit 8 billion people all relying on this limited resource
- In short, water is one of our most precious resources and should be conserved wherever possible

Objective of a Facility Water Management Strategy:

Identify opportunities to economically reduce, reuse and recycle

Water Management 101

High level overview of considerations for optimizing water management at your facility

- Focus on the basics
  - Reliable source of irrigation feed water
  - Manage wastewater generated
  - Achieve this as efficiently as possible (cost and resource intensity)

Key Message:

Whether building a new facility or retrofitting an existing structure, taking the time to consider water usage, waste water generation and opportunities for recovery and / or reclamation at the outset will avoid costly modifications or missed opportunities down the line

Wate Jargon and Common Contaminants

- **Total Suspended Solids (TSS):**

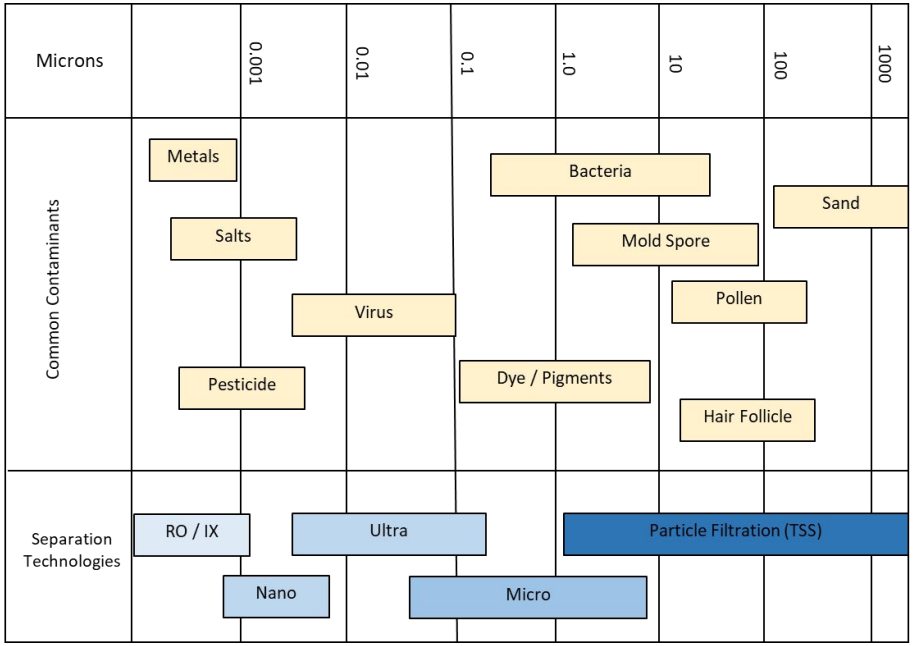
  Suspended particles in water >2micron

- **Total Dissolved Solids (TDS):**

  Dissolved organic and inorganic constituents present in water

- **Colony Forming Units (CFU):**

  Microbial organisms present in water



Irrigation Feed Water

- Require thousands to tens of thousands of gallons of water each and every day
- Quality dependent on:
  - Source (municipal, well, rain, other)
  - Location
  - Seasonal Variability

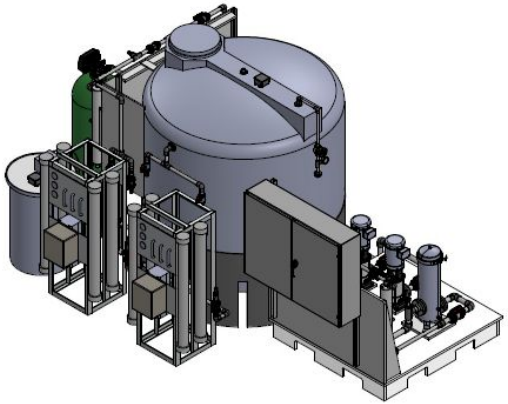
epa.gov/waterlabnetwork

Key Takeaway:

These variables, along with cultivator preferences and staffing capabilities, should be utilized to determine the system(s) required to reliably provide desired water quality and volume

Considerations in System Design

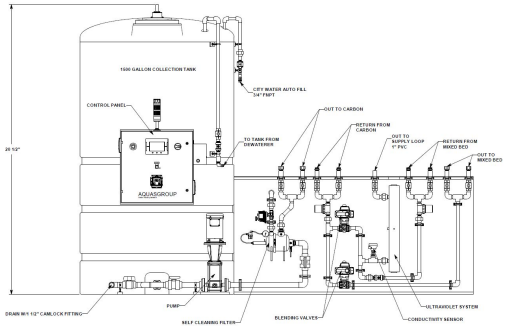
- Depending on water source reliability, on site storage may be beneficial
- Avoid stagnation in storage tanks and distribution piping as this supports microbial growth
- Size any treatment system with some margin for error and room for future growth
- If considering RO, pre-treatment and conditioning is critical to system performance and membrane longevity



Note - RO feed water temperature is critical to performance. Efficiency generally based on 70°F water

Key Considerations:

- There is no one size fits all approach to system design
- Water purification systems, if required, should be based off of quantifiable specifications
- Quality and volume specifications will drive capital and ongoing operational costs as well as PM
- ***Spend the time from the start as water systems can be a significant investment and ongoing cost***



Wastewater Management

- Waste Streams will be generated at your facility from the following sources:
  - HVAC condensate
  - Irrigation leachate
  - Periodic flushing / washdown / sanitizations
  - Water purification byproducts i.e. RO reject
  - Other
- Plan for management will depend on location, existing infrastructure, regulations and company objectives
- NY State's proposed regulations request plans for water efficiency and waste minimization under Environmental Plan Requirements described in Section 125.1

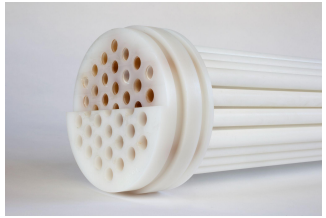
Key Considerations:

- How might I manage waste? - Sewer, Surface / Ground, Collect & Haul
- What might each require? - POTW effluent limits, SPDES Permit, Costs
- How may I reduce or even eliminate waste water generated at my facility through reuse and reclamation?

Opportunities for Reclamation

- HVAC Condensate
  - High quality source
  - Control for pH, metals , microbial growth and volatiles picked up through air handling systems
- Irrigation Leachate
  - Interesting for reuse but more complex
  - Reuse, reclaim i.e. treat or hybrid approach
  - Control for nutrient levels / stacking, microbial growth, solids
- Process Water - periodic flushes, sanitizations, washdowns)
  - Needs to be segregated
  - Do not want what is in water going back out to plants
  - Treatment required
- RO Reject
  - Concentrated waste stream with limited options for recovery - distillation a potential

Technology Overview



- **Removal of Suspended Solids (TSS):**
  - Standard filtration (bag, depth, multi-media, backwashable)
  - Microfiltration and Ultrafiltration membrane
- **Removal of Dissolved Solids (TDS):**
  - Ion Exchange (IX) Resins
  - Nanofiltration and Reverse Osmosis membrane
  - Distillation
- **Biological Control / Disinfection:**
  - Ultra, Nano or RO membrane with appropriate upfront treatment
  - UV and Ozone
- **Chlorine / Chloramine / PFAS / PFOS:**
  - Granular Activated Carbon aka GAC
- **Evaporation / Vacuum Distillation:**
  - Important tool for waste streams not suitable for other technologies
  - Vacuum distillation far more attractive from efficiency and sustainability perspective

Summary

- No one size fits all approach
- Allocate time / resources at the outset to set yourself up for success
- Sustainable water practices can also be commercially advantageous
- Water systems do require oversight and preventative maintenance
- Consider in-house capability and partner with a company that provides ongoing service and support
- In addition to capital cost, discuss and consider ongoing operational costs and required maintenance
- Don’t violate the KISS principle
    - Quality
    - Reliability
    - Efficiency (capital and resource)

Knowledge Check:

Some greenhouse curtains can be used for both shading in the day and retaining heat at night.

- TRUE
- ~~FALSE~~

SECTION 09

RESOURCES

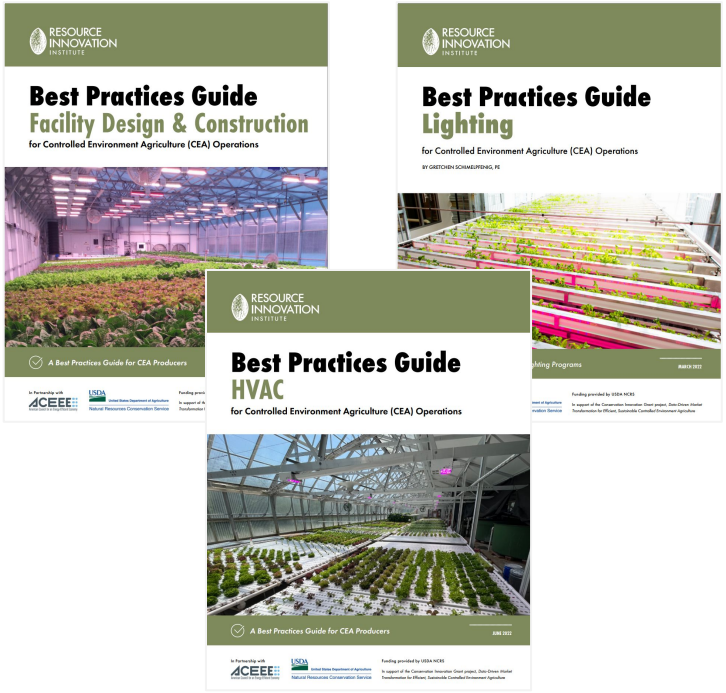
Free Best Practices Guides & Workshop Recordings

Collaboration by Industry Experts

Free guidance on efficient cultivation

- CEA Facility Design & Construction Best Practices, 2022
- CEA HVAC Best Practices, 2022
- Cannabis HVAC Best Practices, 2019
- CEA Lighting Best Practices, 2022
- Cannabis Lighting Best Practices, 2019

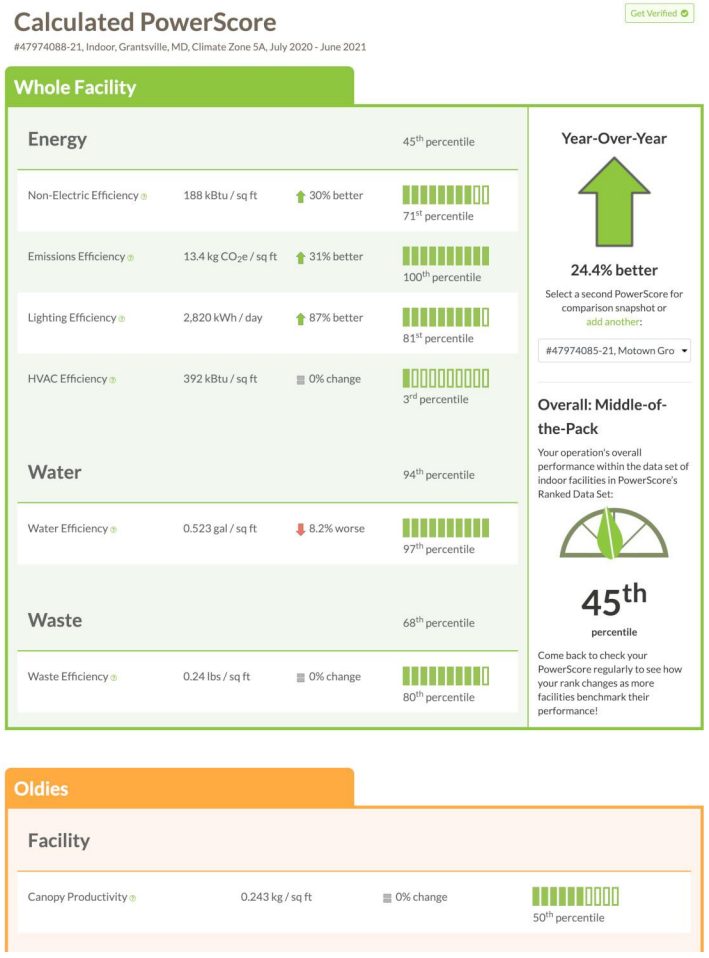
More at catalog.resourceinnovation.org



Start Collecting Data: Benchmarking

What data should you collect?

- Energy consumption
  - All fuel types
- Water consumption
- Water quality
- Production
- Use controls & automation systems to improve data collection
  - Improve understanding of subsystems



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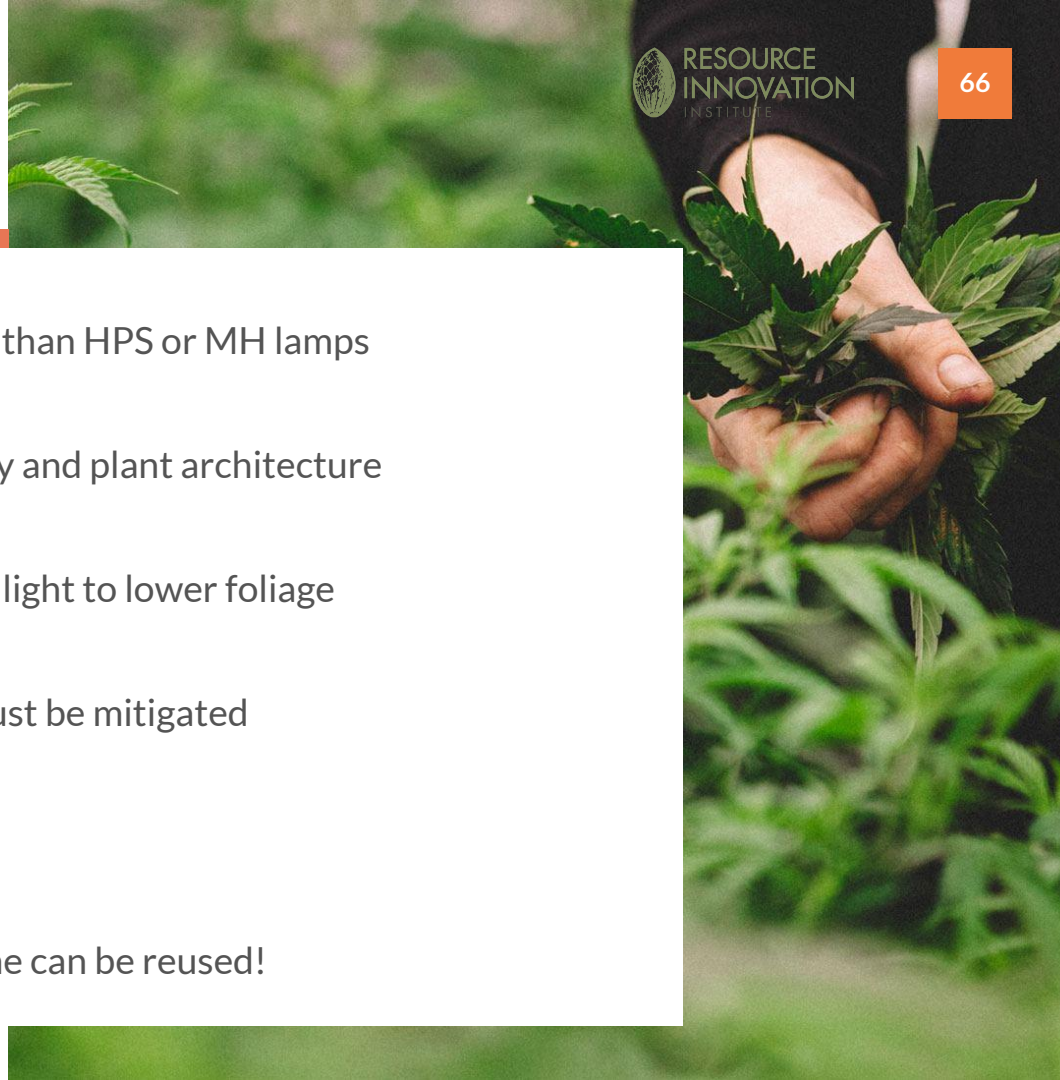
Actionable Takeaways

- LED lighting is more than twice as efficient than HPS or MH lamps
- Lighting impacts flower yield, flower quality and plant architecture
- Diffused light increases yield by increasing light to lower foliage
- Excess humidity under light deprivation must be mitigated
- Water must not be allowed to stagnate
- Plan for multiple wastewater streams–some can be reused!



SECTION 10

Q & A

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