WINTER CROP LIGHTING & ITS APPLICATION IN ALBERTA GREENHOUSES

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Jan 18th, 2017

Saeid since 1998

OUTLINE

What is a light reaction in plants?

What is supplemental light?

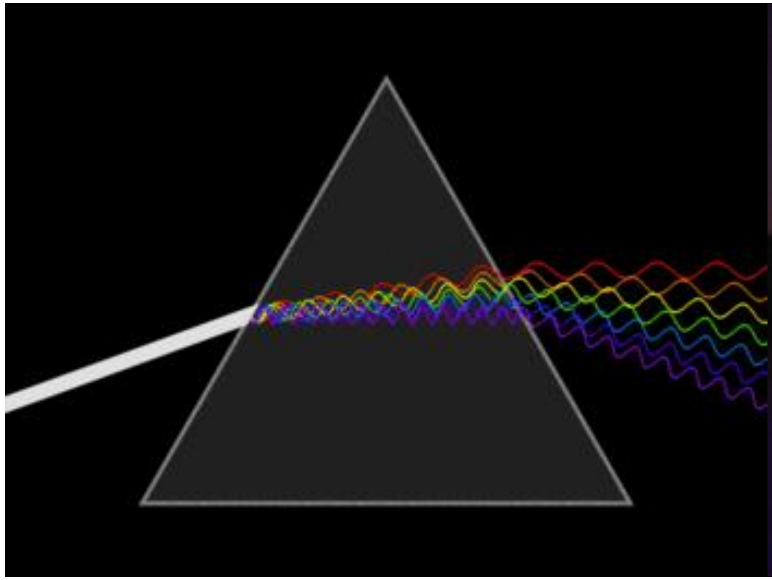
Applications of supplemental lighting

What is the appropriate lighting system for winter vegetable production?

A path to the development and commercialization of lighting systems

What are your desired results from this experiment?

What is Light ?



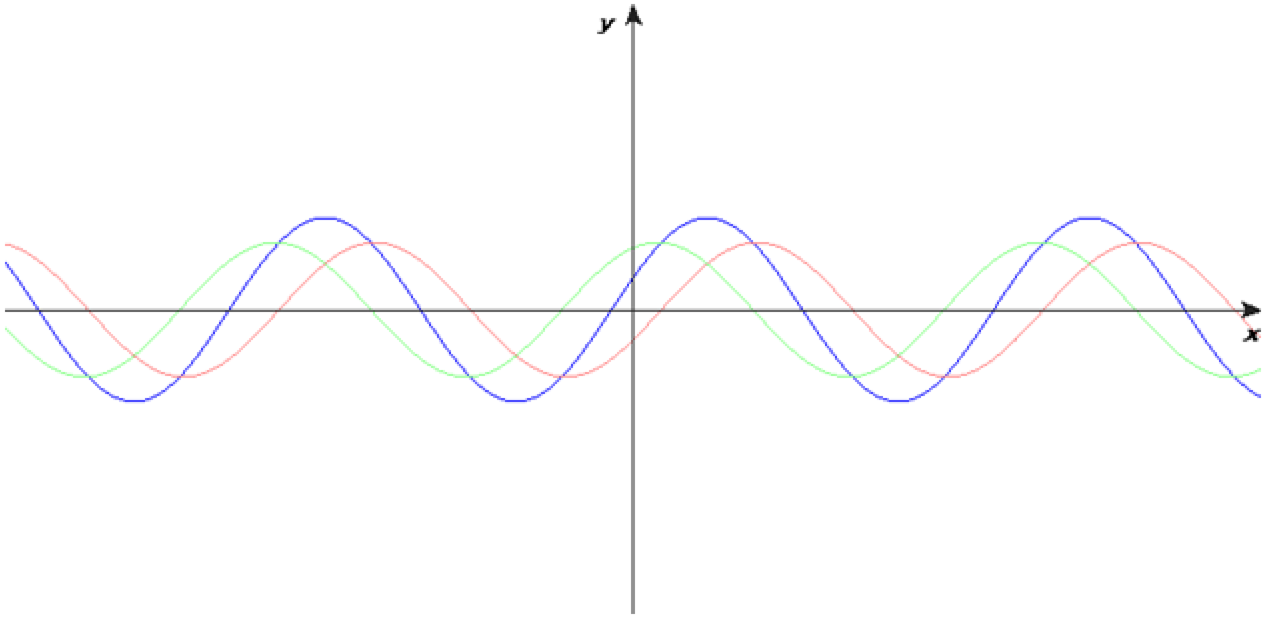
Visible part of Electro-Magnetic Radiation (EMR)

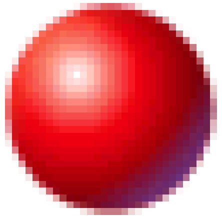
✓ It's a particle: carrying energy in the form of photons

✓ Travels as wave: It's energy varies by the wave length

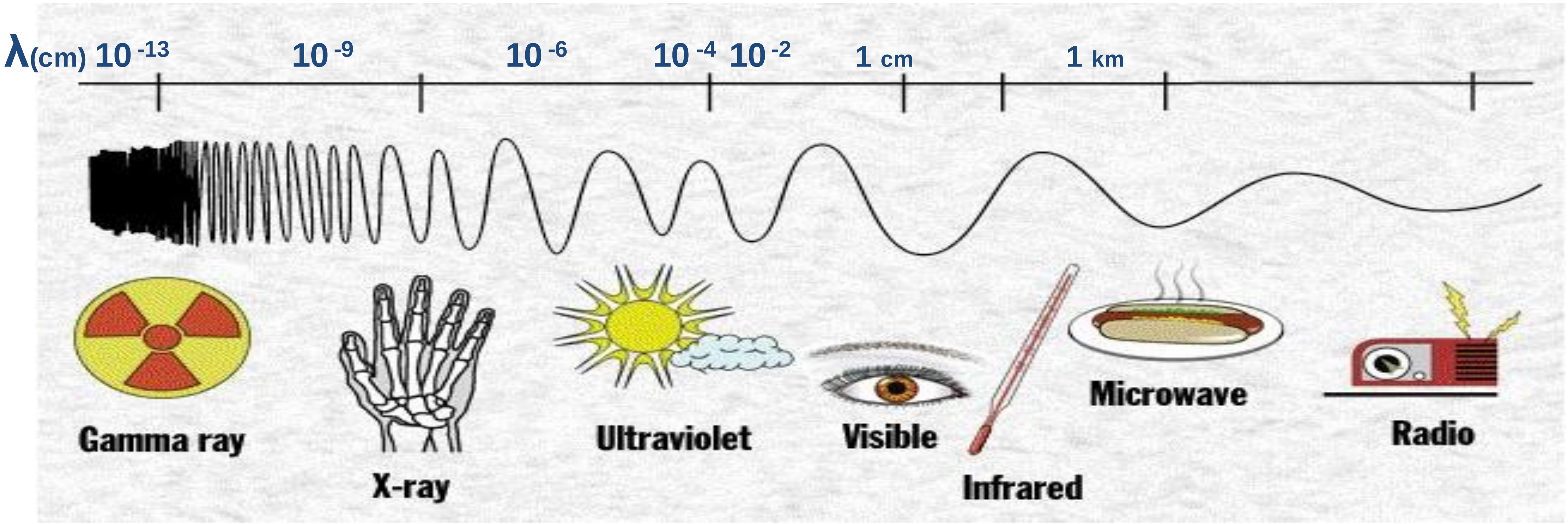
The “Dual Nature” of Light

Wave vs. Particle





Energy and Wavelength (λ)



The short wavelengths correspond to the higher energy

Measuring Light Quantity

- **Photometric Method**
- **Quantum Method**
- **Radiometric Method**

Photometric Method

- Based on the sensitivity of the human eye to detect electromagnetic radiation
- Very subjective
- Standard Unit = 1 foot candle (ftc)
    - Amount of light given off from 1 candle at a distance of 1 foot

Quantum Method

- **Measure of Photosynthetic Photon Flux (PPF) (400-700nm)**

- **Not measuring all λ of entire spectrum, it is measuring the amount of photosynthetic light**
- Standard Unit = mol (6.02 x 10^{23}) photons = μmol (6.02 x 10^{17}) photons
- **Regular way to measure light in the chambers /greenhouse because plants are "counting" photons that they absorb.**

» **Disadvantage**

We are not able to measure the intensity of light at particular wave length

Radiometric Method

- **Measures electromagnetic radiation in terms of total energy**

- Standard Unit = $W.m^{-2}$

- **Wavelengths function very differently on plant growth and development.**

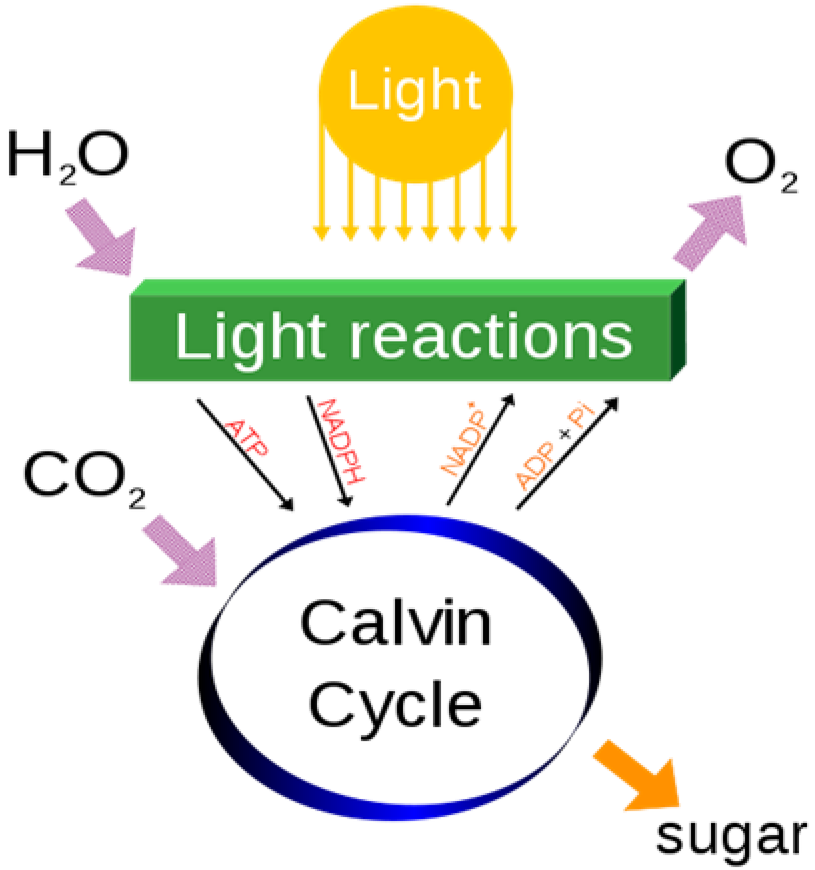
Light and plant growth

How much light is required for photosynthesis and the best yield?

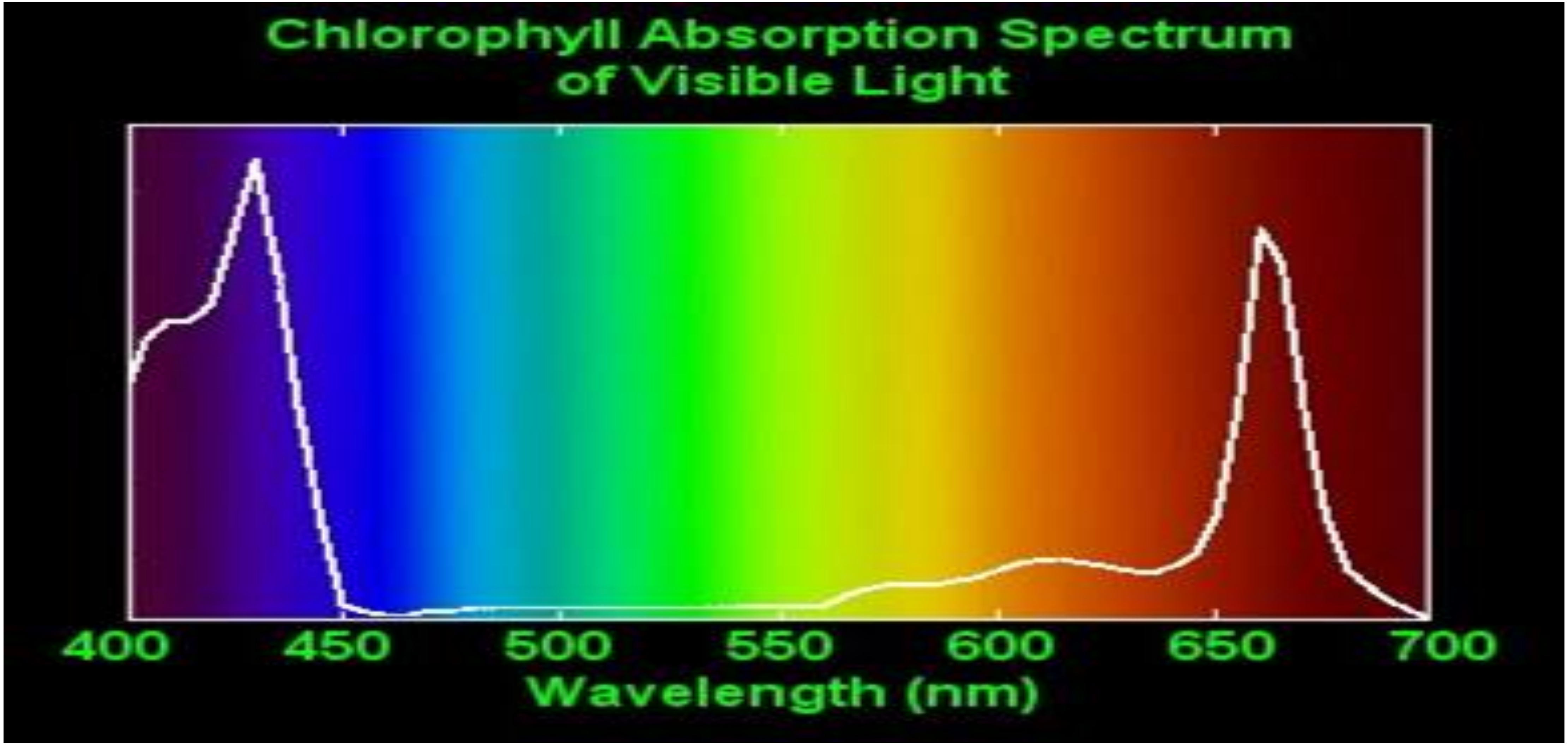
- **Quantity** (Intensity)
  – Photosynthesis e.g. biomass production

- **Quality** (Wavelength – Photoreceptors)
  – Photo-morphogenesis
  e.g. stem elongation, & flower induction

- **Duration**
  – Photoperiodism e.g. dormancy, flowering



Light Absorption by Chlorophyll

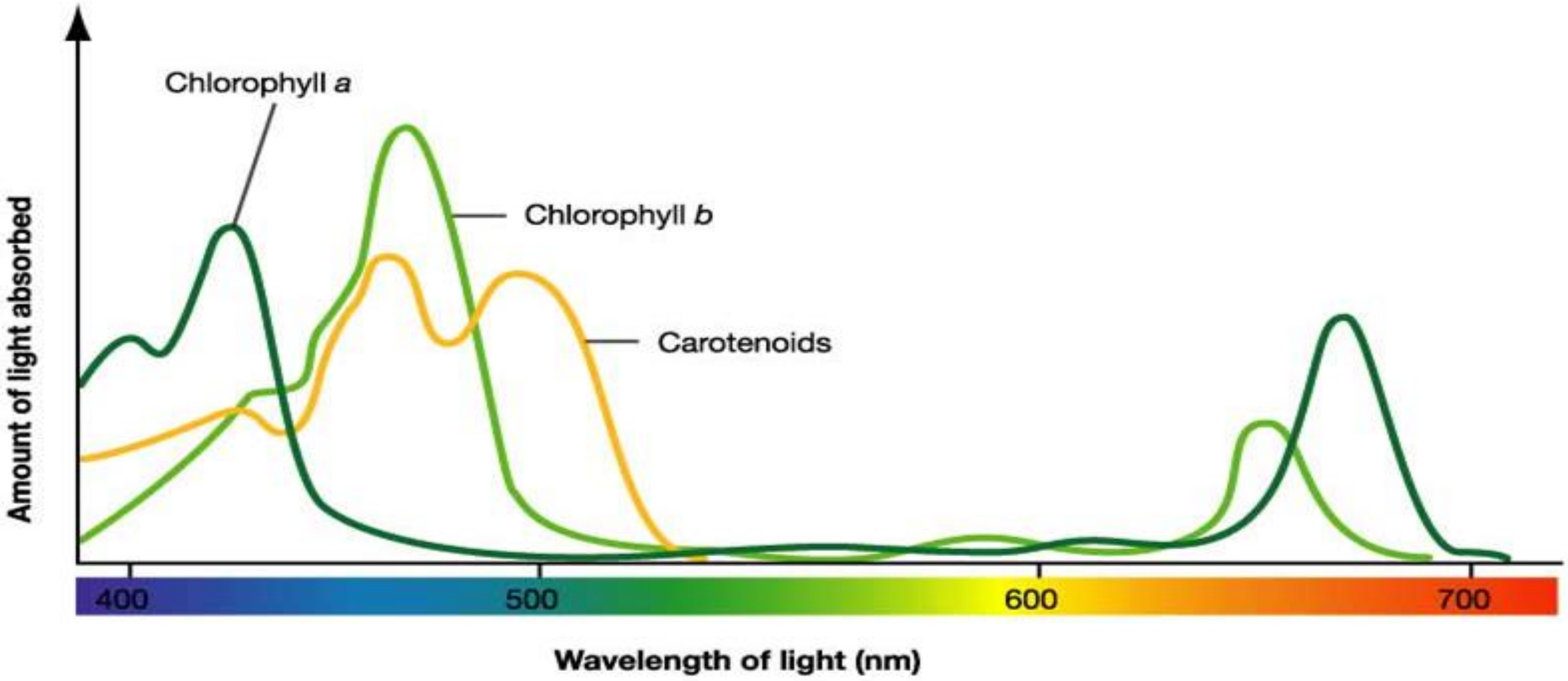


The action spectrum of photosynthesis take place from 400-450 & 600-700 nm, with the lower effect in the range of 600 - 650nm.

Light Absorption by Plant Pigments

Pigment	Light Absorbed	Light Reflected
Chlorophyll	Violet, Blue, Red	Green
Carotenoids	Blue	Yellow, Orange
Zanthophyll	Blue	Yellow, Orange
Melanin	Most Visible Light	Black
Anthocyanins	Blue, UV	Red
Phenolics	UV	

The Absorption Rate Of Visible Light By Chlorophylls



The action spectrum of photosynthesis take place from 400-500 & 650-700 nm, with the lower effect in the range of 600 - 650nm.

SUPPLEMENTAL LIGHT

Additional energy when there is a lack of natural light!!!!!

There is a variety of supplemental lighting sources:

- **HPS** (High Pressure Sodium)
- **LED** (Light-Emitting Diode) at high intensity
- **Intra-canopy LED**

- **Sustainable year round** vegetable production

Control your plant environment (**healthier plants**)

Supplemental lighting: **even in sunny winters of Southwest, US!!!**

Supplemental lighting:

- ✓ **Faster production**
- ✓ **Better yield**
- ✓ **Better flavour and quality**

Exist Light Spectrum in Current LEDs

Blue Light (400-500 nm)	Green (500-600 nm)	Red Light (600-710 nm)	Far red (710-850 nm)

Blue Light (400-500 nm)

- Better penetration in leaf tissue
- Stomata regulation
- Provide shorter internodes
- Thicker and darker leaves
- Increased root mass
- Flower induction
- Increase anthocyanin concentration

Red Light (600-710 nm)

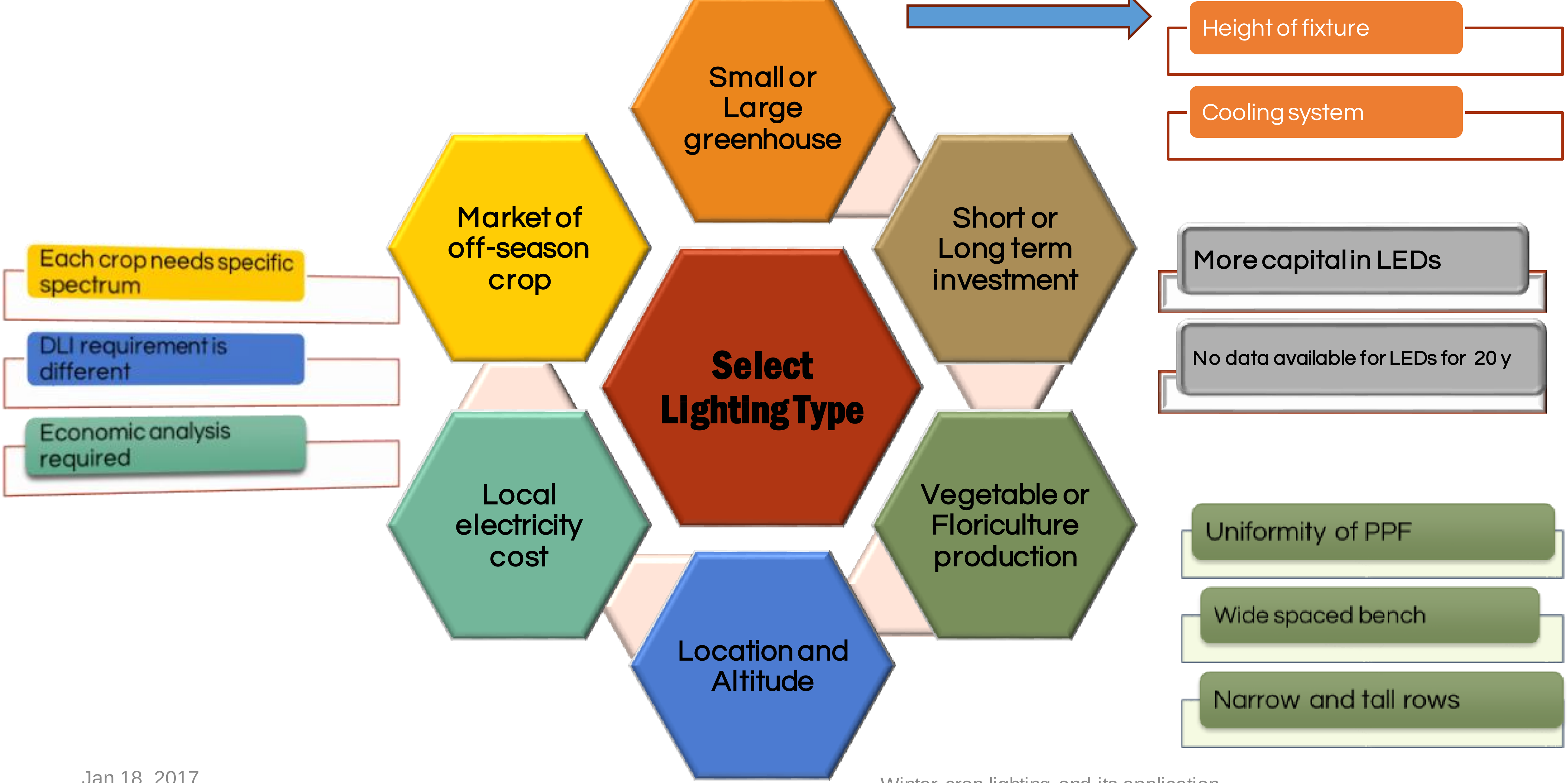
- More efficient at driving photosynthesis
- Light LEDs are less efficient in converting energy than Blue LEDs
- Stimulate root formation
- Enhance flowering in long day plants
- Increased branching in long day plants

Select the right LED lamps:

LED characteristics? & LED tips !!

- Higher energy efficiency to convert electricity to the photons (e.g. HPS 1.58 vs. LED 2.39 which is based on current technology and can be improved to 3.0)
- Narrow bands of spectrum and their ratio
- Tunable and dimmable
- Provide specific wavelength for photosynthesis, photoperiod, morphology, and second metabolites

Light Fixture Specification:



For 3 minutes!

APPROPRIATE LIGHTING FOR WINTER CROPS

LED Tips:

Suitable for use in intra-lighting applications due to lower operating temperature.

Place your LED lamp close to leaf surface; SAVE ENERGY!

Manage the color of fruit, leaf and flower of your plants by adjusting the spectrum!!

New intra-canopy LED technology; (advantages/ disadvantages)

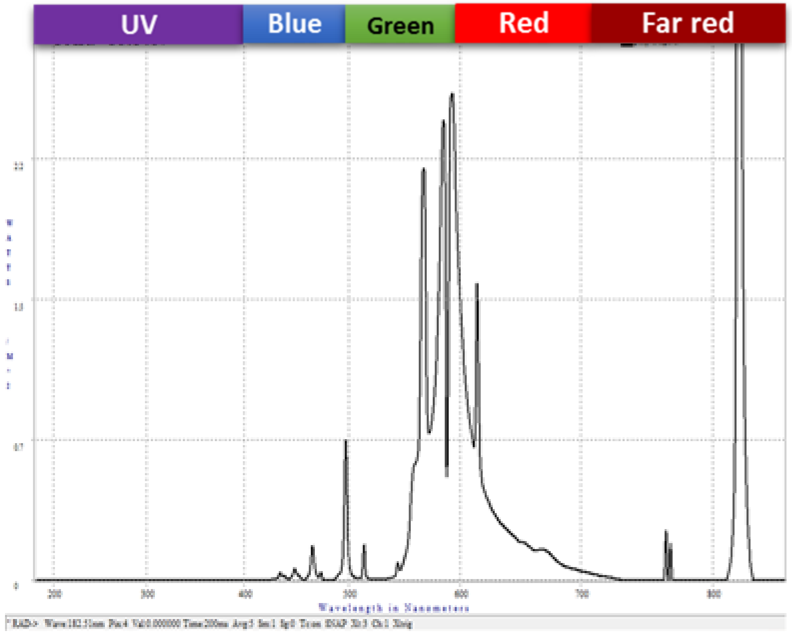
Ready for commercial production???

Or needs more consideration???

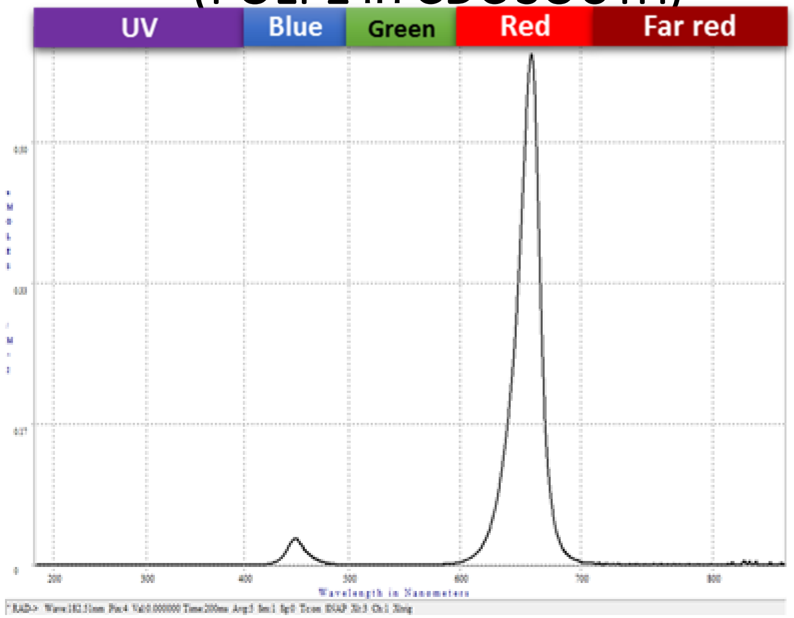
LED lamps, an efficient alternative to the current (HPS) supplemental lighting technology?

LIGHT QUALITY and Intensity of LED and HPS in Our Trial

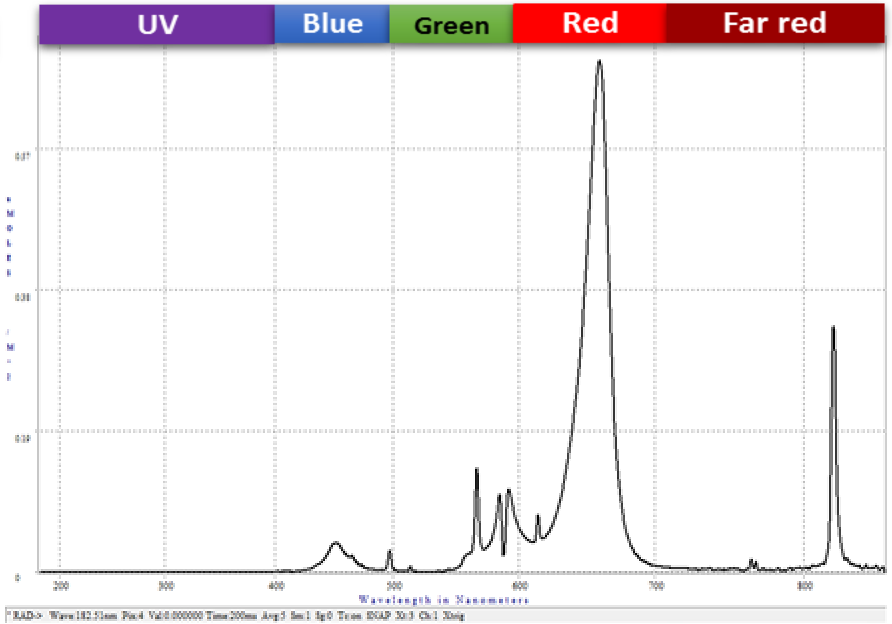
(POLY 1 in CDC SOUTH)



HPS



Intra-Canopy-LED



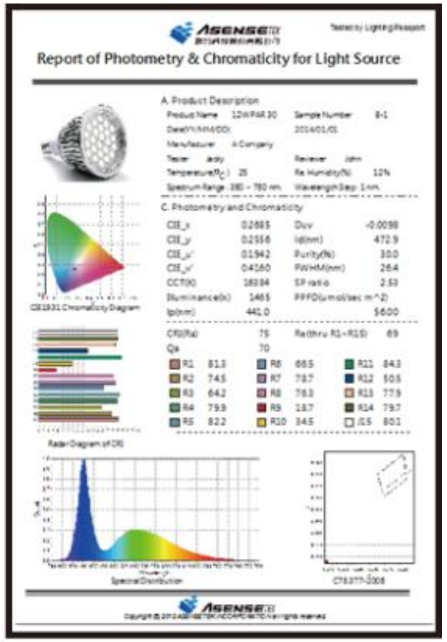
HPS plus Intra-Canopy-LED

PPF ($\mu mol \cdot m^{-2} \cdot s^{-1}$) supplied by light sources	HPS (600 W)	Intra – Canopy LED (140 W)	HPS plus Intra-Canopy-LED
At the mid canopy close to leaves	20 - 25	40 - 60	45 - 60
At the top canopy close to head of the plant	100 - 120	15	105 - 125

METRICS FOR PLANT LIGHTING MEASUREMENT

Photosynthetically Active Radiation

(PAR; 400-700 nm)



Photosynthetic Photon Flux

(PPF; $\mu mol \cdot m^{-2} \cdot s^{-1}$)

Daily Light Integral

(DLI; $mol \cdot m^{-2} \cdot d^{-1}$) refers to the amount of light received in 1 day in 1 m^{-2}

DAILY LIGHT INTEGRALS (DLI)

Effect of light is not cumulative!!!

- DLI provided by supplemental lighting <u>should</u> fill the **deficiency** of solar radiation (make a daily balanced) as well as the specific plant light requirements.

WHY SHOULD I MEASURE DLI IN MY GREENHOUSE?

DLI affects plant quantity(density), photosynthetic rate (biomass) and plant growth (yield)

DLI a key factor for:

- Adjust plant density (the most significant factor)
- Shade curtains (deploy or stow)
- Whitewash (apply or remove)
- Hanging basket density (increase or decrease)

DO I NEED **SUPPLEMENTAL LIGHTING** OR NOT? IF NEEDED, HOW MANY MOL $M^{-2}D^{-1}$?

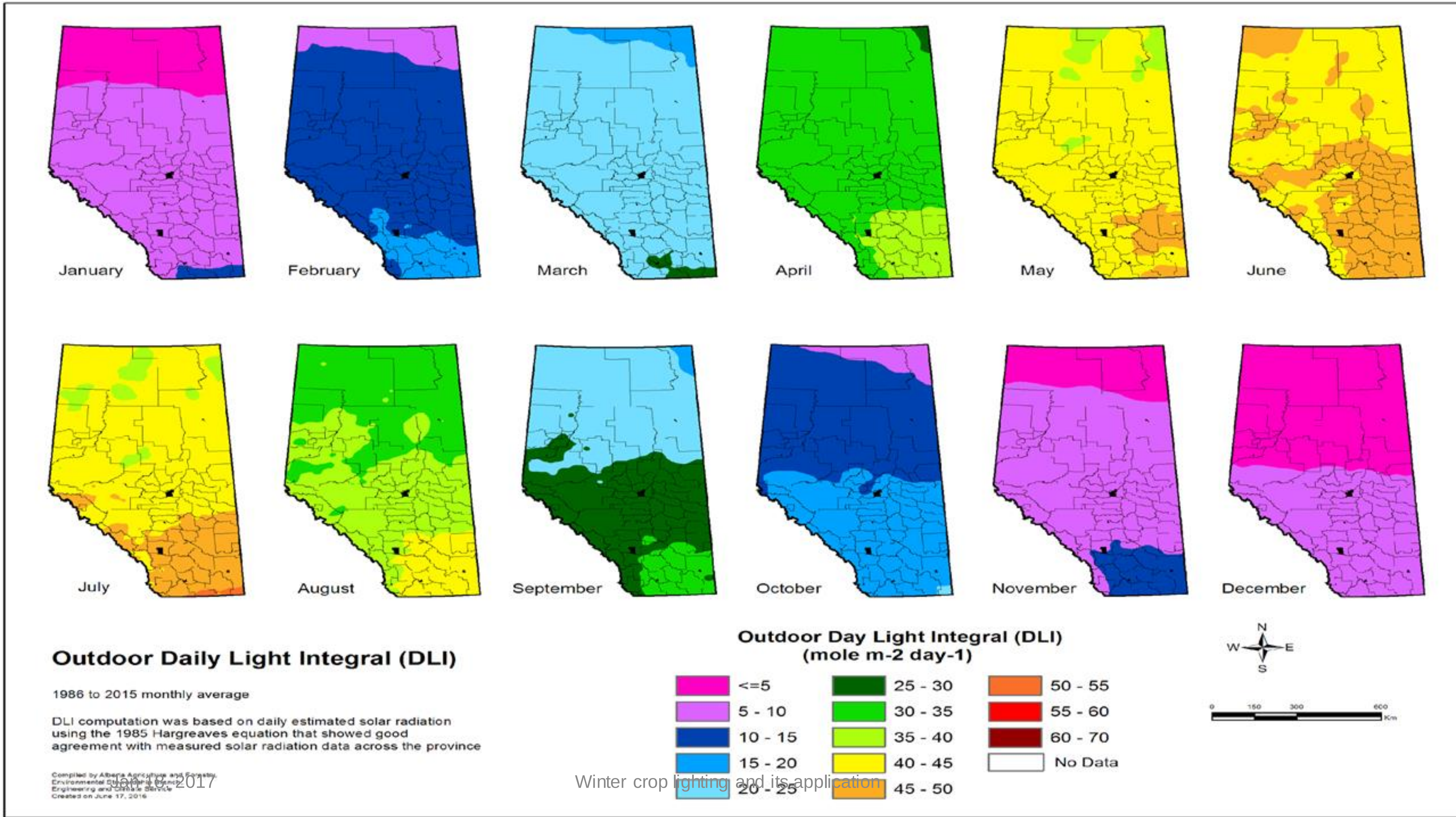
What is the sufficient DLI for my plant?

E.g. 18-h light with >185 µmol $m^{-2} s^{-1}$ PPF over the canopy (DLI > 12 mole $m^{-2}d^{-1}$)

Mini and Max DLI examples from the literature (Runkle 2011**):**

- DLI =12 moles $m^{-2}d^{-1}$: the minimum inside GH target light level to **grow fruit vegetables**.
  DLI =10 moles $m^{-2}d^{-1}$: the minimum inside GH target light level to **grow** leafy vegetables**.**
  DLI = 2-4 moles $m^{-2}d^{-1}$ average in Netherlands during the winter time within a glass greenhouse (assuming 50% glazing reduction).

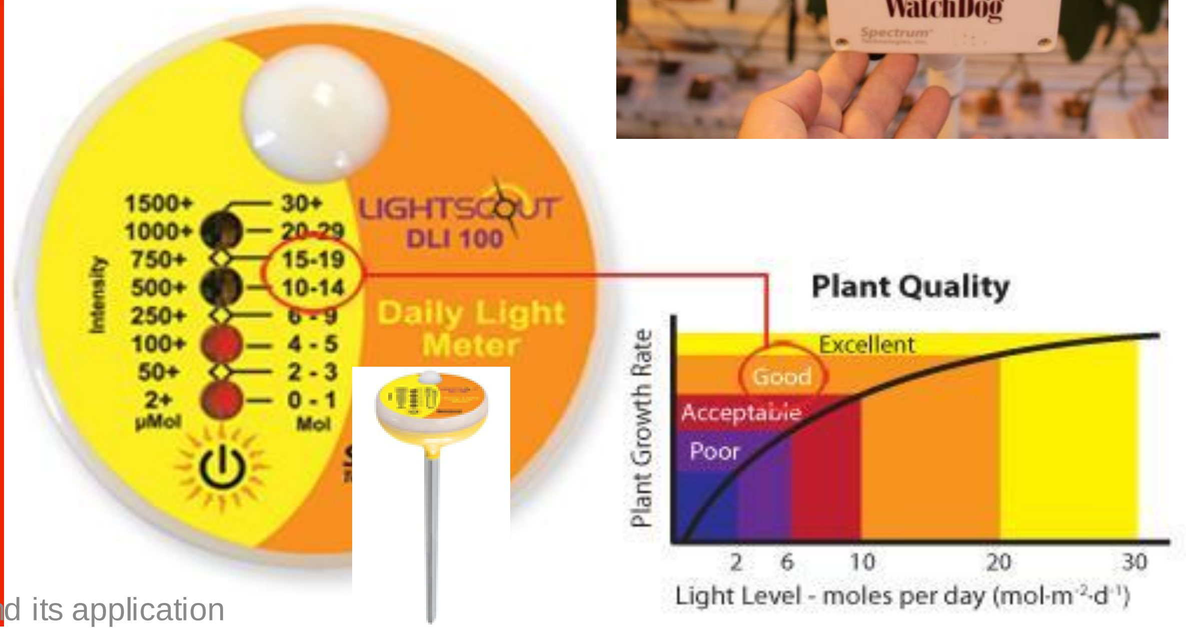
- The maximum DLI we can receive indoors is about **30** mol m^{-2} d^{-1} on a cloudless day in the summer.
- On a dark winter day in the northern Alberta, the indoor DLI could be less than **3** mol m-^{2}d^{-1}

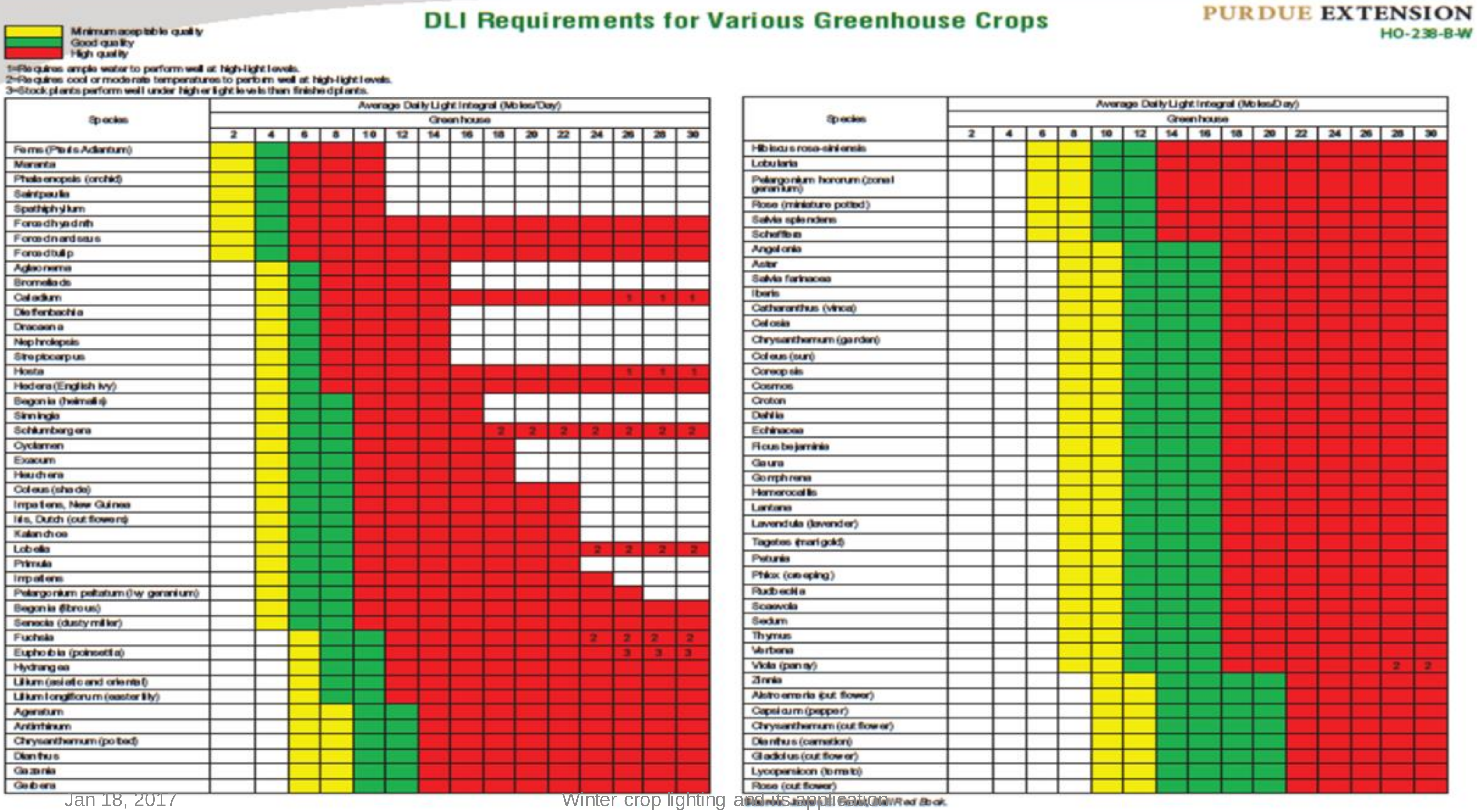

January
February
March
April
May
June
July
August
September
October
November
December
Outdoor Daily Light Integral (DLI)
1986 to 2015 monthly average
DLI computation was based on daily estimated solar radiation using the 1985 Hargreaves equation that showed good agreement with measured solar radiation data across the province
Outdoor Day Light Integral (DLI) (mole m-2 day-1)
<=5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
50 - 55
55 - 60
60 - 70
No Data
N
W
E
S

HOW DO I MEASURE DLI IN MY GREENHOUSE?

Using DLI meter:

Easiest way to get an estimate of existing light quantity close by my plants.




DLI Requirements for Various Greenhouse Crops
PURDUE EXTENSION
HO-238-B-W
Minimum acceptable quality
Good quality
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)
Maranta
Phalaenopsis (orchid)
Saintpaulia
Spathiphyllum
Forced hyacinth
Forced narcissus
Forced tulip
Aglaonema
Bromeliads
Caladium
Dieffenbachia
Dracaena
Nephrolepsis
Streptocarpus
Hosta
Hedera (English ivy)
Begonia (heimalis)
Sinningia
Schlumbergera
Cyclamen
Exacum
Heuchera
Coleus (shade)
Impatiens, New Guinea
Iris, Dutch (cut flowers)
Kalanchoe
Lobelia
Primula
Impatiens
Pelargonium peltatum (ivy geranium)
Begonia (fibrous)
Senecio (dusty miller)
Fuchsia
Euphorbia (poinsettia)
Hydrangea
Lilium (asiatic and oriental)
Lilium longiflorum (easter lily)
Ageratum
Antirrhinum
Chrysanthemum (potted)
Dianthus
Gazania
Gerbera
Hibiscus rosa-sinensis
Lobularia
Pelargonium hororum (zonal geranium)
Rose (miniature potted)
Salvia splendens
Schefflera
Angelonia
Aster
Salvia farinacea
Iberis
Catharanthus (vinca)
Celosia
Chrysanthemum (garden)
Coleus (sun)
Coreopsis
Cosmos
Croton
Dahlia
Echinacea
Ficus benjaminia
Gaura
Gomphrena
Hemerocallis
Lantana
Lavandula (lavender)
Tagetes (marigold)
Petunia
Phlox (creeping)
Rudbeckia
Scaevola
Sedum
Thymus
Verbena
Viola (pansy)
Zinnia
Alstroemeria (cut flower)
Capsicum (pepper)
Chrysanthemum (cut flower)
Dianthus (carnation)
Gladiolus (cut flower)
Lycopersicon (tomato)
Rose (cut flower)

LIGHT PROJECT GOALS (in progress):

- **Adjust LED light quality and quantity** for commercial varieties of cucumbers and tomatoes in Alberta greenhouses.
- **Compare LED** with the conventional **HPS** lighting (side-by-side).

  - Test new fixture designs (**ICL**) and application methods.

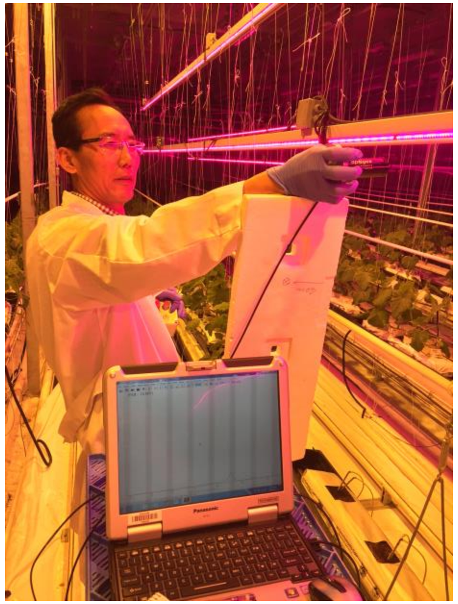
  - Illustrate the effect of light source on **energy use efficiency** and **yield improvements.**

  - Determine the effect of lighting treatments on **leaves' edema and fruit quality**.

  - Compare the **cost-effectiveness** of ICL-LEDs with over head lighting (OHL)-HPS/LEDs.

Comparing energy consumption between LED and HPS supplemental lighting, evidence are scarce and confusing !!!

- HSP lamps consume **40%** greater electricity than LEDs to achieve the same PPF over the canopy when they are used in small scales (Nelson & Bugbee 2014).
- When simulated for a commercial greenhouse with 800 m^2, HPS was shown to be **44%** energy-saving than LED lighting.
- We try to address this controversy in a large-scale commercial greenhouse **under Alberta climatic condition.**



Material and Methods

RCBD design (4 replication)

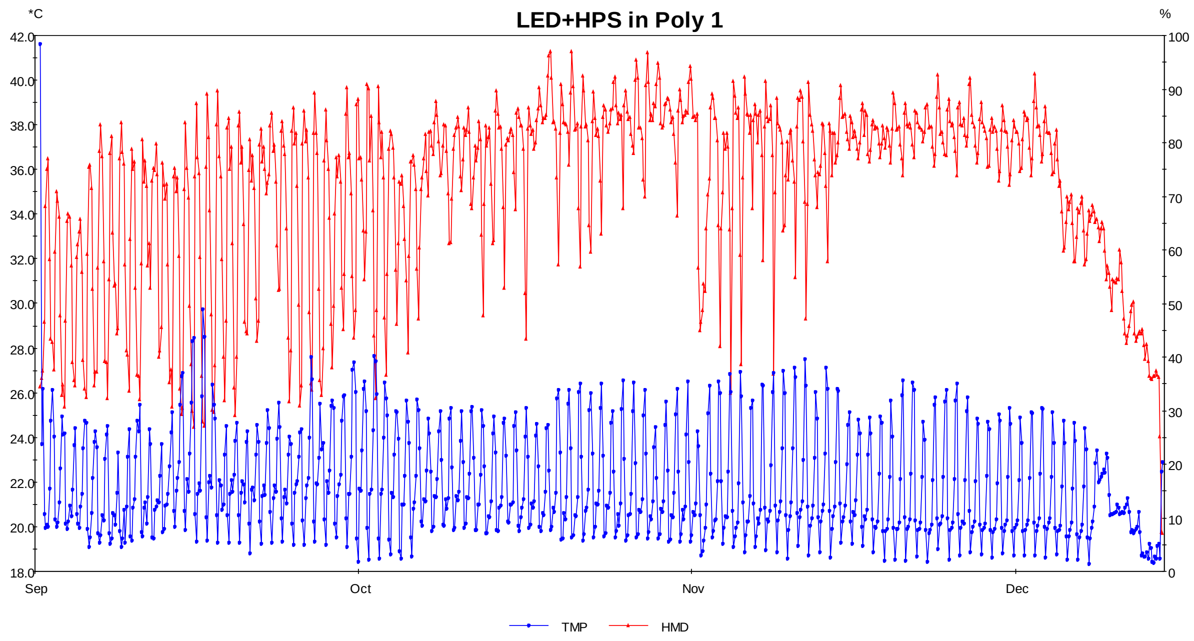
4 treatments (Sunlight; HPS; LEDs in two layers; HPS + LEDs in two layers)

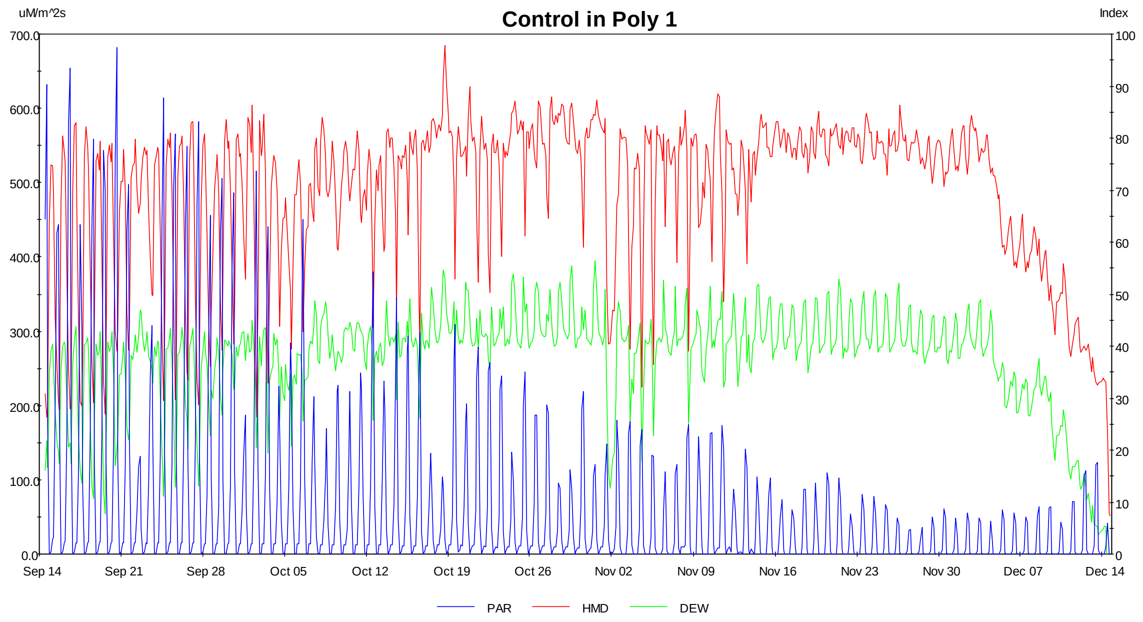
HPS (120 µmolm^{-2}s^{-1}), **LED** (60 µmolm^{-2}s^{-1})

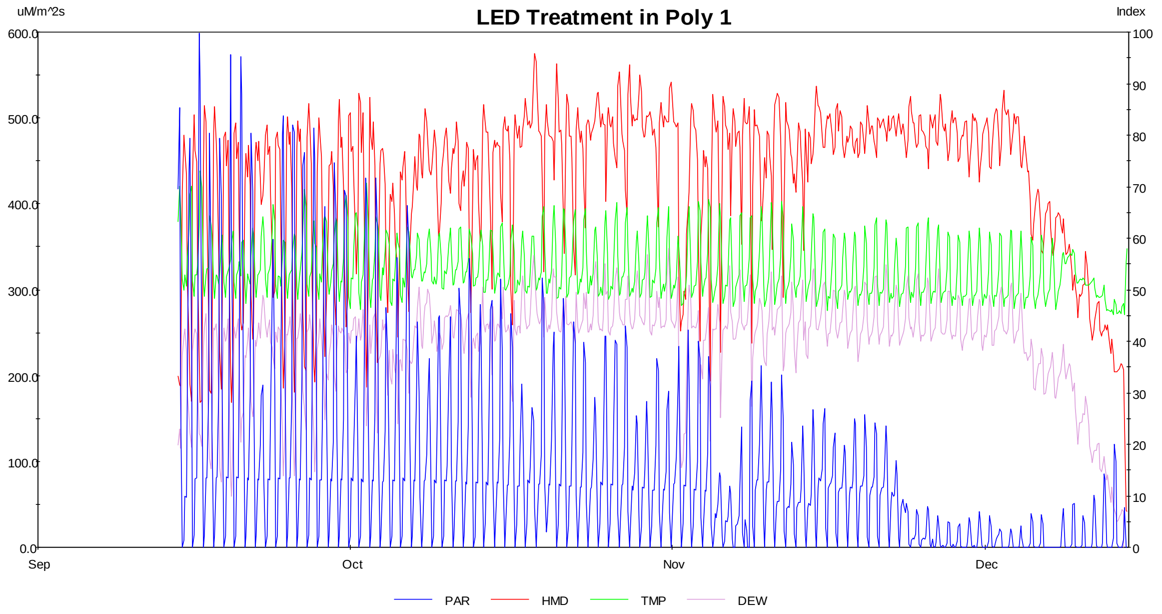
Cucumber *var.* BonBon (Sept – Dec & Jan – April)

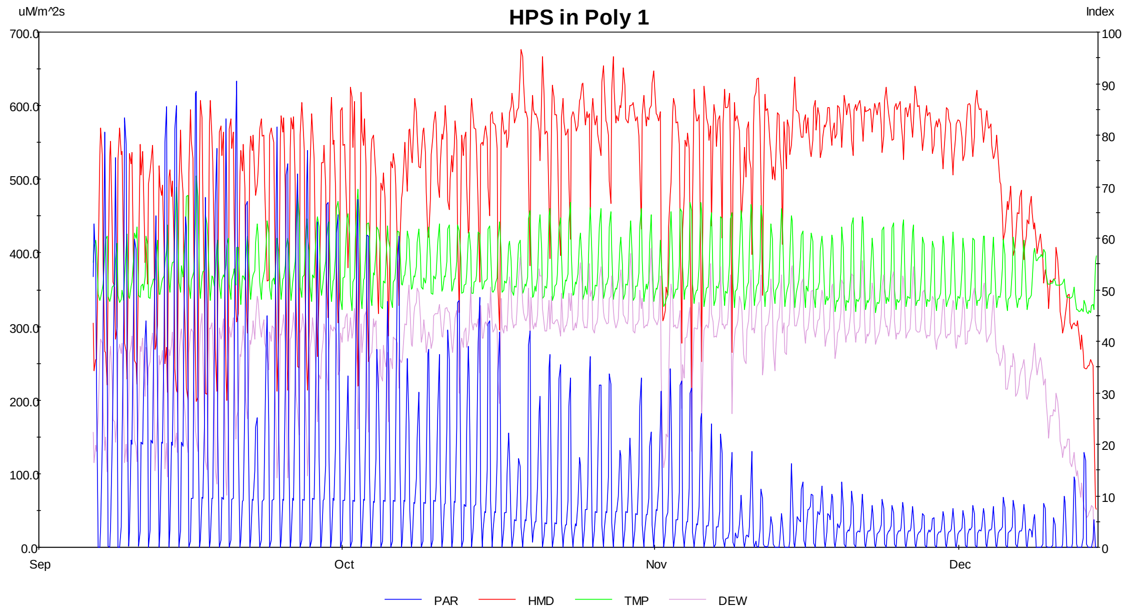
18-hours supplemental lighting photo-period

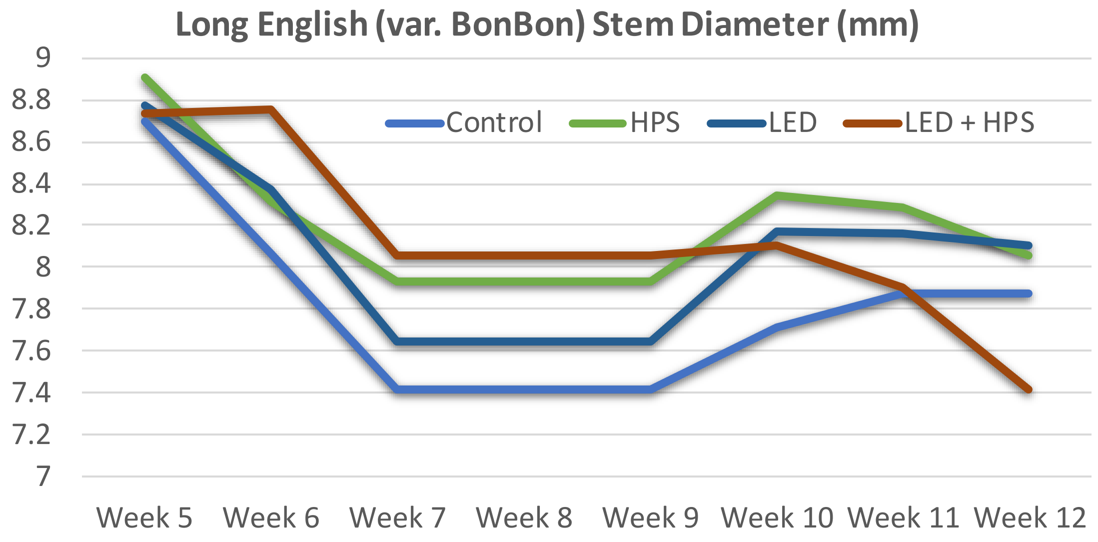
Shut down light over 300 (**save energy**)

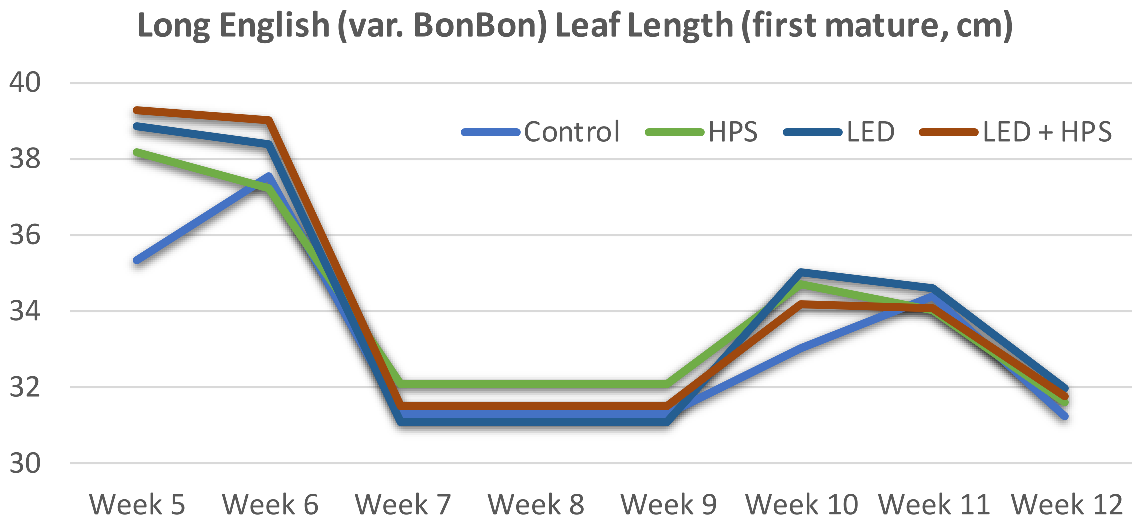

LED+HPS in Poly 1
*C
%
42.0
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
100
90
80
70
60
50
40
30
20
10
0
Sep
Oct
Nov
Dec
TMP
HMD

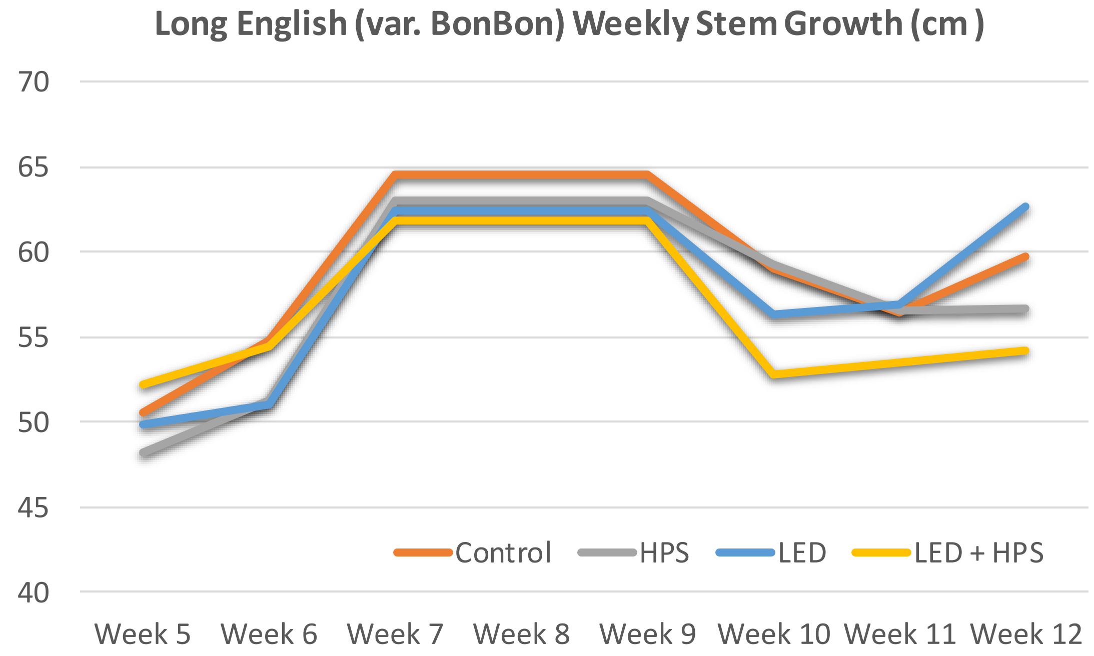

Control in Poly 1
uM/m^2s
Index
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
100
90
80
70
60
50
40
30
20
10
0
Sep 14
Sep 21
Sep 28
Oct 05
Oct 12
Oct 19
Oct 26
Nov 02
Nov 09
Nov 16
Nov 23
Nov 30
Dec 07
Dec 14
PAR
HMD
DEW

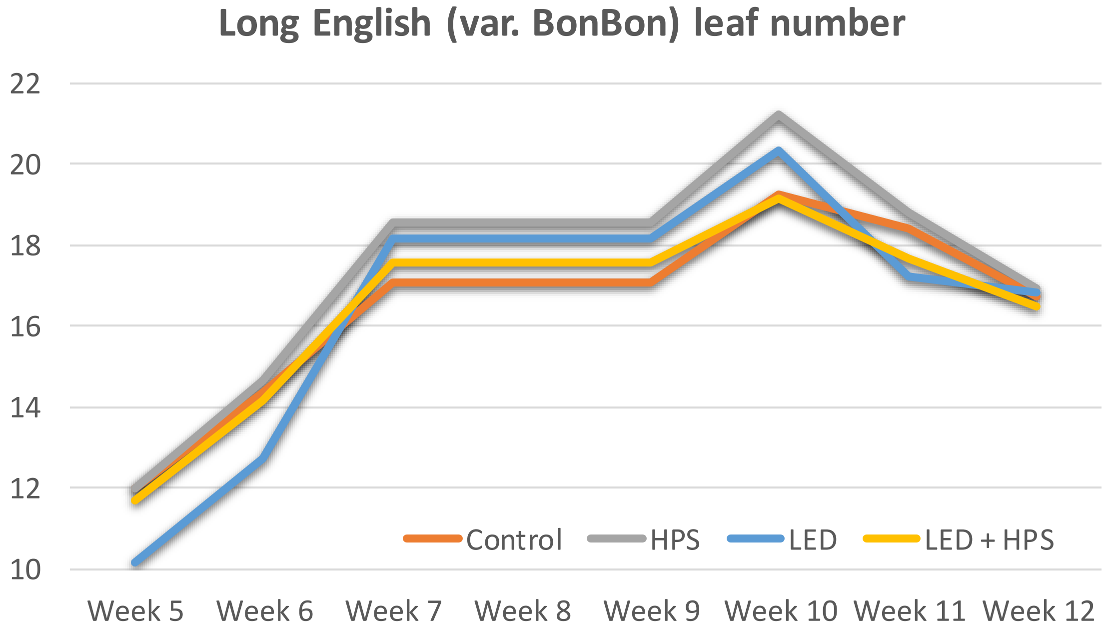

LED Treatment in Poly 1
uM/m^2s
Index
600.0
500.0
400.0
300.0
200.0
100.0
0.0
100
90
80
70
60
50
40
30
20
10
0
Sep
Oct
Nov
Dec
PAR
HMD
TMP
DEW

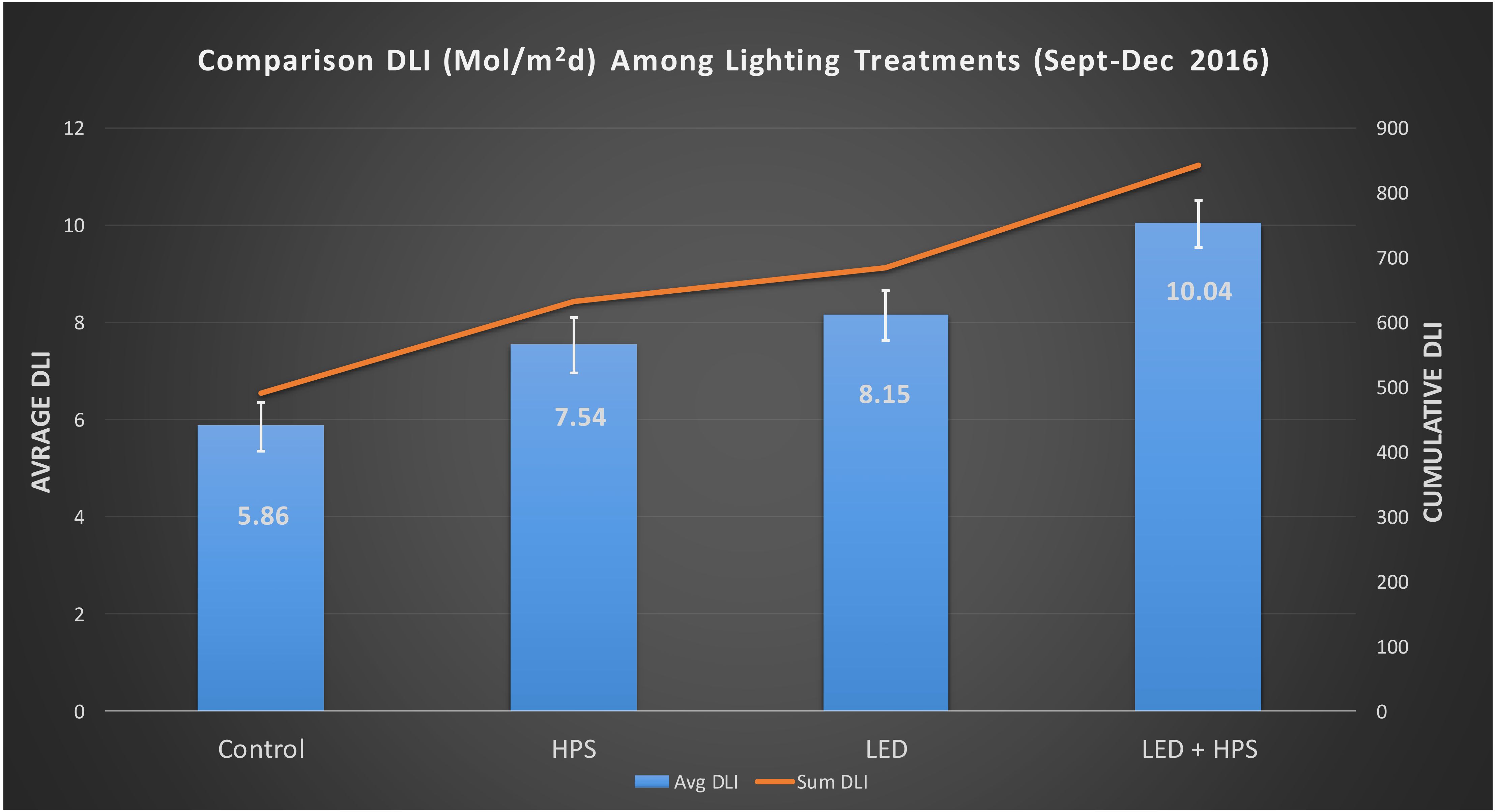

HPS in Poly 1
uM/m^2s
Index
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
100
90
80
70
60
50
40
30
20
10
0
Sep
Oct
Nov
Dec
PAR
HMD
TMP
DEW


Long English (var. BonBon) Stem Diameter (mm)
Control
HPS
LED
LED + HPS
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12

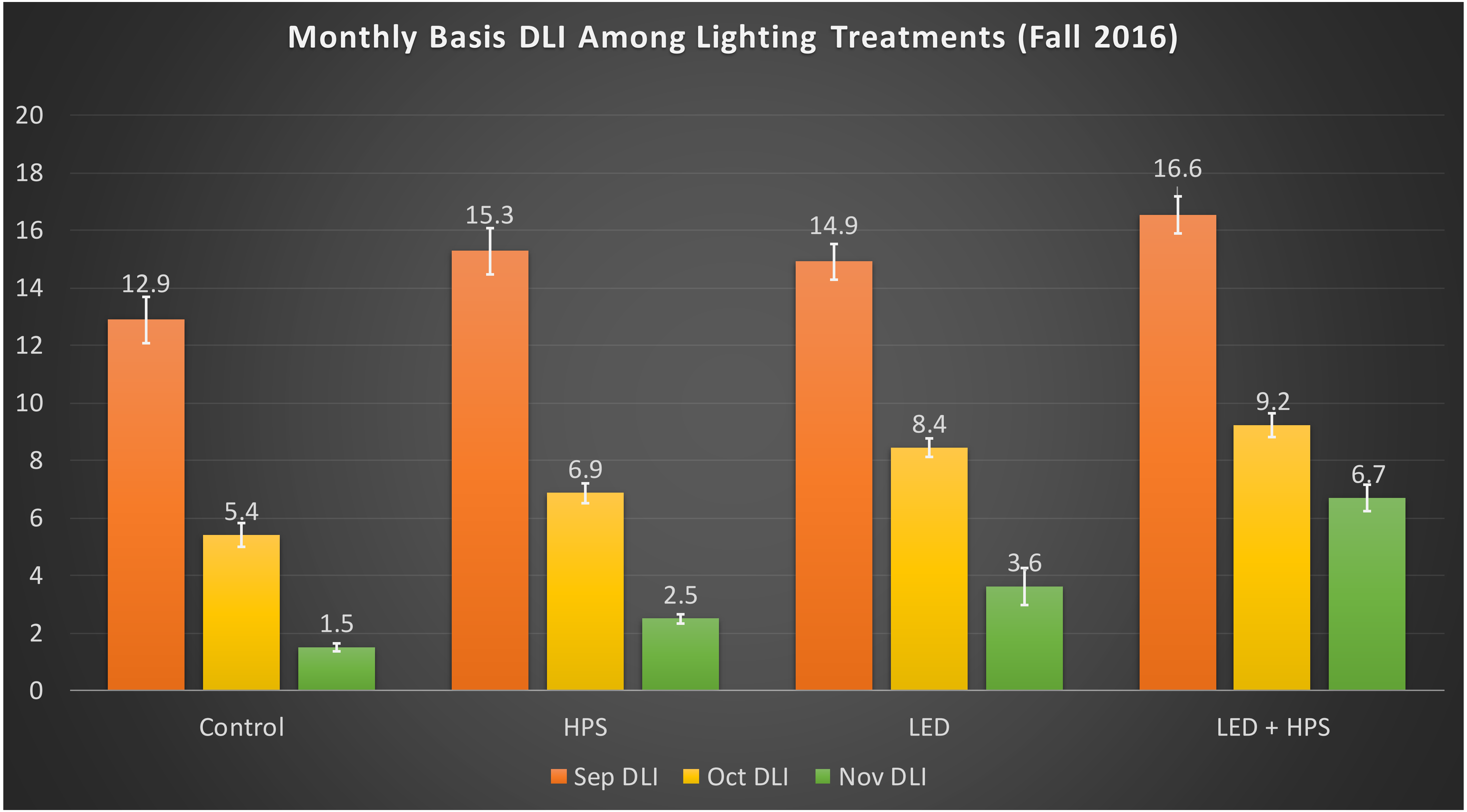

Long English (var. BonBon) Leaf Length (first mature, cm)
Control
HPS
LED
LED + HPS
40
38
36
34
32
30
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12


Long English (var. BonBon) Weekly Stem Growth (cm)
70
65
60
55
50
45
40
Control
HPS
LED
LED + HPS
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12


Long English (var. BonBon) leaf number
22
20
18
16
14
12
10
Control
HPS
LED
LED + HPS
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12

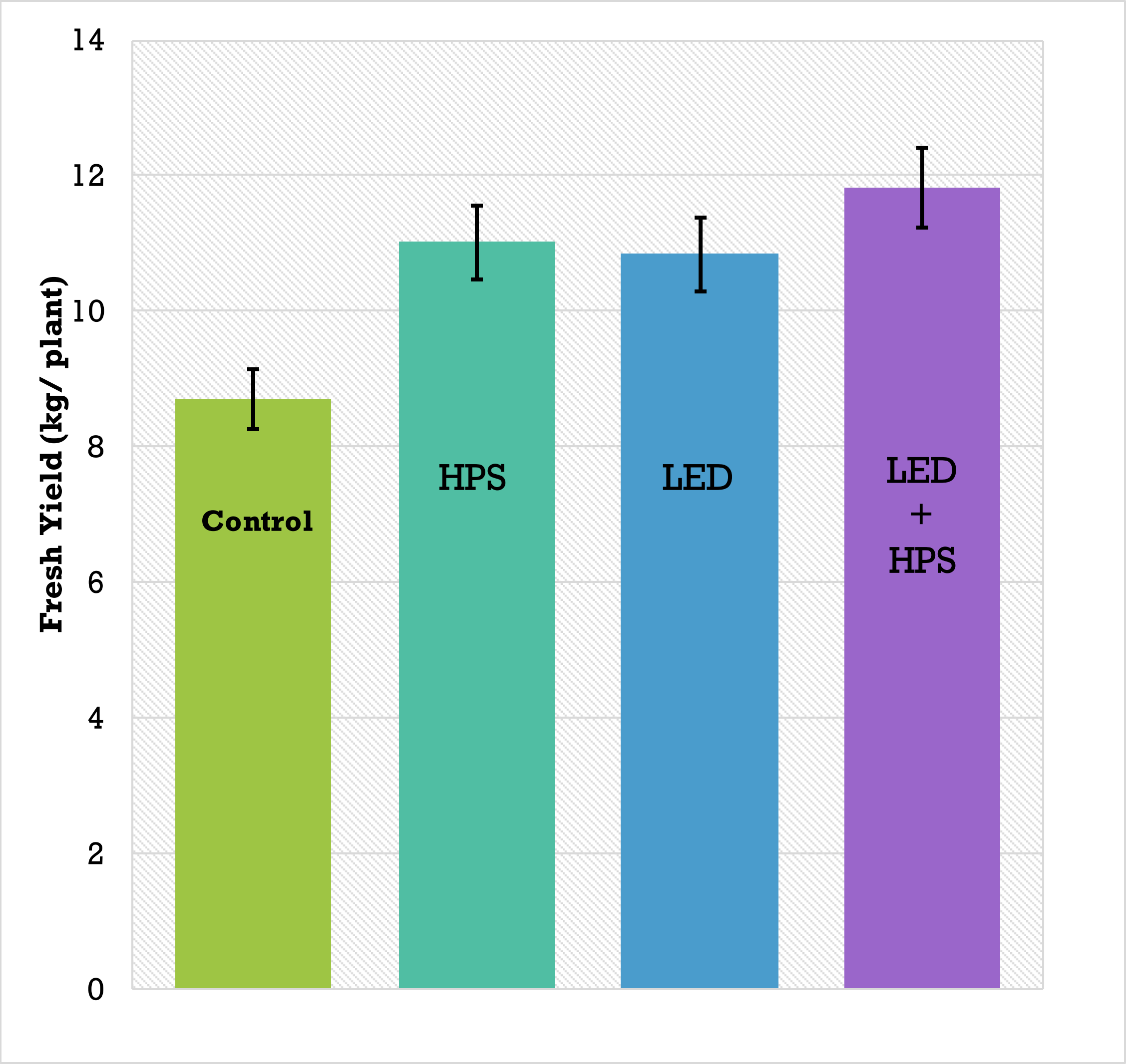


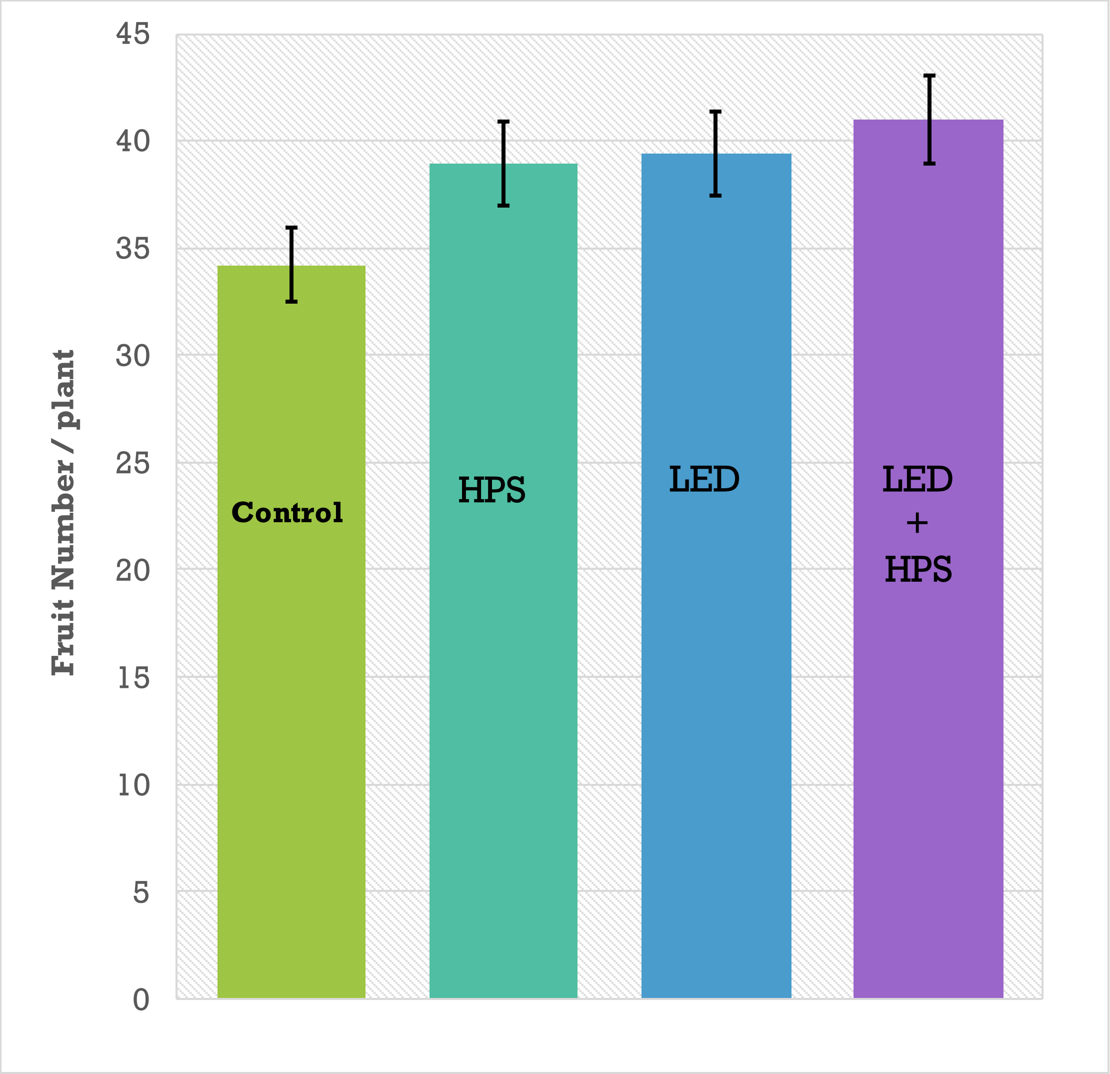
Error bars indicated Standard Error ($p < 0.05$)



Error bars indicated Standard Error ($p < 0.05$)

Cucumber (*var.* Bonbon) Fresh Yield and Fruit Number Under Different Lighting Treatments Jan – April 2016 under poly house in CDC South

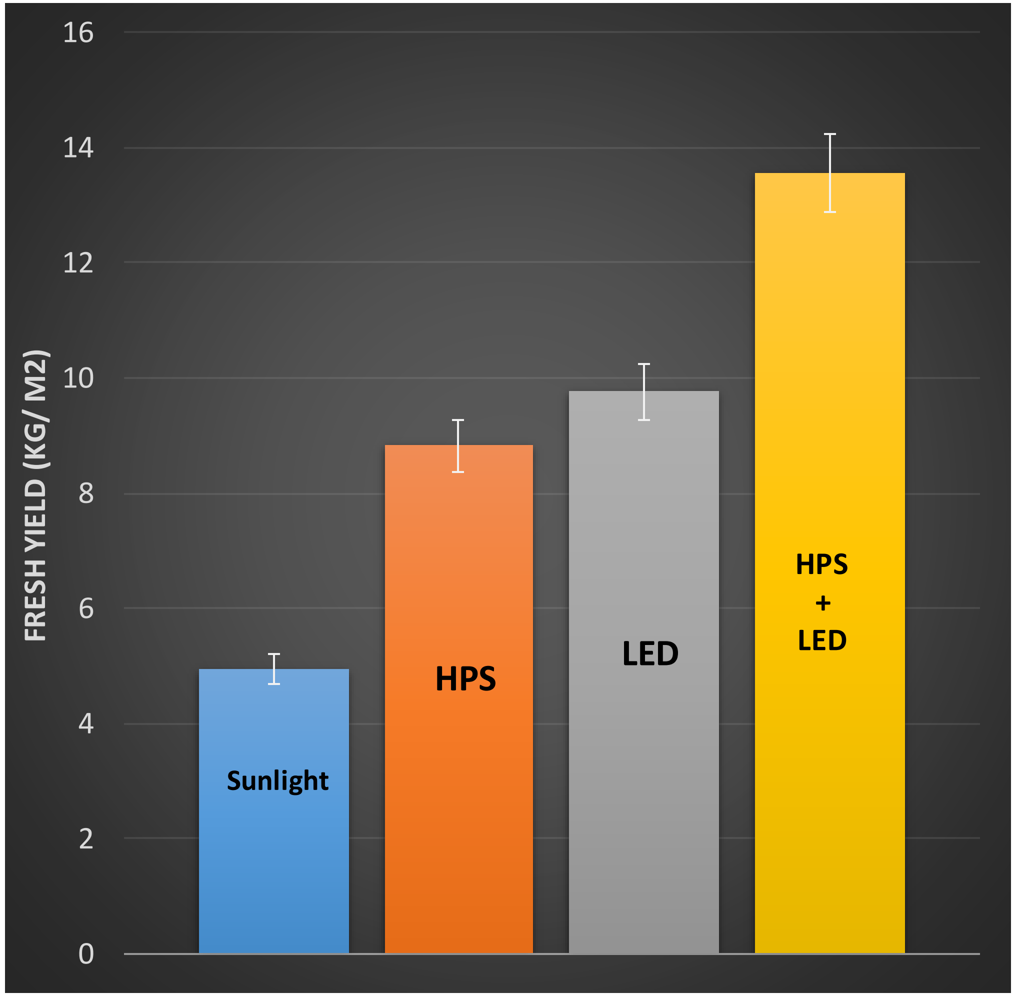


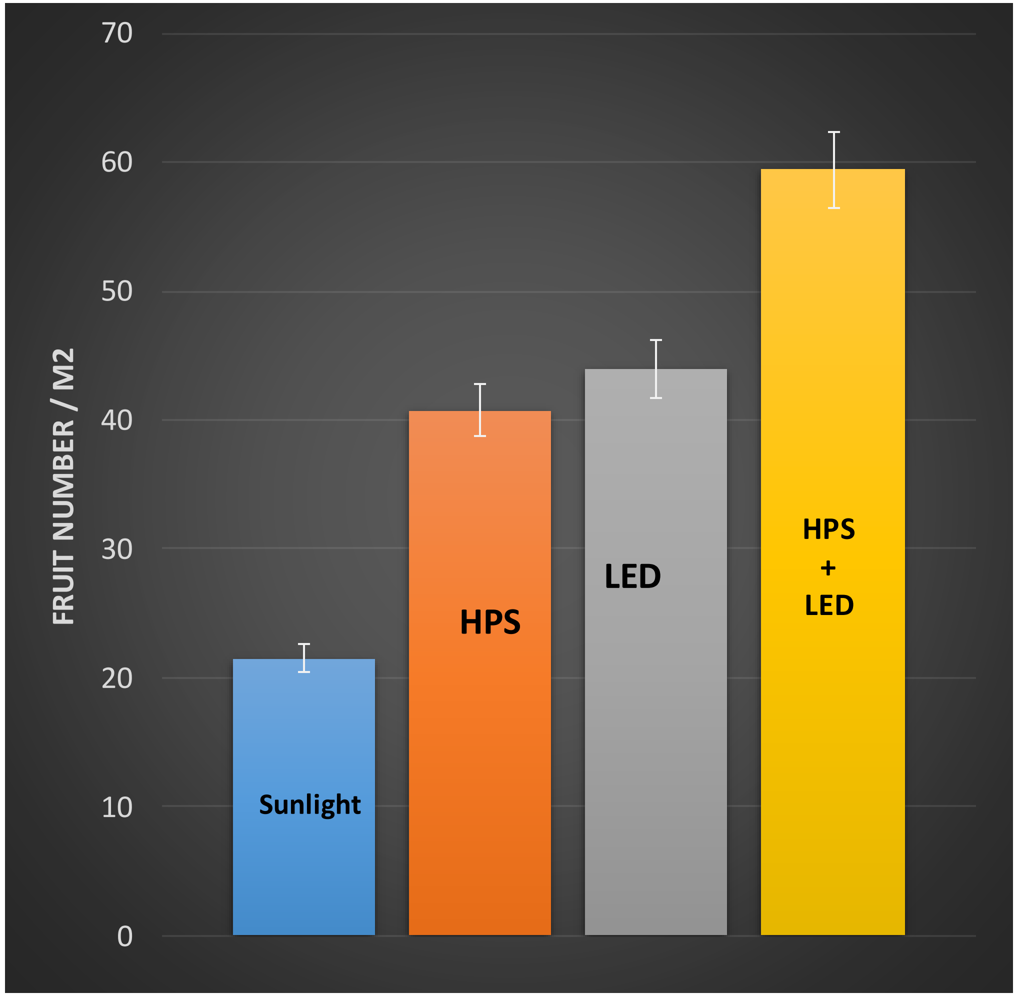


Error bars indicated Standard Error ($p < 0.05$)

Cucumber (*var.* Bonbon) Fresh Yield and Fruit Number Under Different Lighting Treatments

Sept – Dec 2016 under poly house in CDC South





Error bars indicated Standard Error ($p < 0.05$)

Economic Analysis: LED vs. HPS for Long English cucumber (*var.* BonBon)

Emmanuel Anum Laate, Senior Crop Economist, emmanuel.laate@gov.ab.ca, (780) 422-4054

KEY Assumptions:

1) Life expectancy of HPS and LED lamp = 10,000 and 25,000 hours respectively.
2) Life expectancy of HPS and LED fixtures = 10 years
3) Number of hours lamp was operated in a year measured as 2,376 h
4) Number of growing seasons (crops) in a year when light will be used = 2
5) HPS lamp replacement and disposal fees were $25 and $30 for new lamp
6) The electricity cost ($/kW-h) was taken as $ 0.05/kW-h
7) Interest cost was adjusted for inflation.

Method of Analysis

Analyzed only incremental costs and returns.

- Essentially a partial budget analysis; all other cost items were assumed to be the same.

Costs

- Investment
- Lamp replacement
- Interest
- Electricity

Returns

- Additional Production relative to Control which has no supplemental lighting

costs

	HPS ONLY	TWO LED	HPS + TWO LED
AREA UNDER LIGHT (SQ. M.)	**80**	**80**	**80**
Fixture number	20	40	60
Total cost per fixture	$226	$261.4	$487.4
Total cost of fixtures	$4,520	$10,456	$14,976
Installation cost (assumed 30% of fixture cost)	$1,356	$3,137	$4,493
Lamp replacement cost (2.4 times in 10 y)	$2,095	$0	$2,095
Total investment cost (fixture + lamp replacement)	**$7,971**	**$13,593**	**$21,564**
Interest costs (10 years, adjusted for inflation)	$1,652	$2,362	$4,013
Total capital cost (fixture + lamp replacement + interest)	$11,157	$15,955	$27,112
Capital costs/year	**$1,116**	**$1,596**	**$2,711**
Capital costs/m2	$116.95	$199.43	$316.38
Total electricity cost ($/year)	$1,148	$670	$1,817
Electricity cost ($/m2)	$14.35	$8.37	$22.72

RETURNS

	HPS ONLY	TWO LED	HPS + TWO LED
AREA UNDER LIGHT (SQ. M.)	**80**	**80**	**80**
Additional Fresh Yield (kg/m2)	7.3	7.8	13.5
Total Incremental Production (kg)	584	622	1,080
Average Selling Price ($/kg)	$3.69	$3.69	$3.69
Total incremental sales/year	**$2,151**	**$2,291**	**$3,980**
Total incremental sales ($/m2)	$26.88	$28.64	$49.75

Economic indicators

	HPS only	Two LED	HPS + Two LED
Benefit Cost Ratio (BCR)	1.03	1.00	0.91
Net Present Value (NPV)	$547	$93	-$3,726
Total cost per kg of produce	$3.57	$3.64	$4.03
Electricity cost per kg of produce	$1.97	$1.08	$1.68

The results show that using both HPS only or Two LEDs for supplementary lighting is financially feasible.

Conclusion:

- LED inter lighting shows potential and cost-effectiveness feasibility of crop productivity improvement.
- Winter Inter Canopy lighting significantly improves greenhouse profitability by:

1. Crop yield
2. Energy saving
3. Off season product price
4. Create jobs

- With supplemental lights, growers need to practice Best Crop Management through adjusting irrigation, nutrients, temperature, ventilation (RH%), CO_2 level, even IPM programs in tune.
- Update information for future business decisions such as investment, commercialization, and strategic direction on greenhouse lighting system in Alberta is required.

ACKNOWLEDGMENT:

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Mark Lefsrud (University of McGill)

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Zengguang Guang Pan and Shannon Petersen (CDC South)

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ACIDF
Alberta Crop Industry Development Fund Ltd.

Growing Forward 2
A federal-provincial-territorial initiative