Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Canada

CGC 2017, Oct. 4

Smart Application of Lighting in Greenhouse Vegetable Production

Xiuming Hao, PhD

Harrow Research and Development Centre

Agriculture and Agri-Food Canada, Harrow, Ontario

Year-round vegetable production with lighting

1. Optimum crop production systems

- Need to change **cultivars**, **schedule**, **plant density**, **training system**, **climate control, fertigation, crop and pest management**

Large cultivar difference in response to lighting, especially in sweet peppers

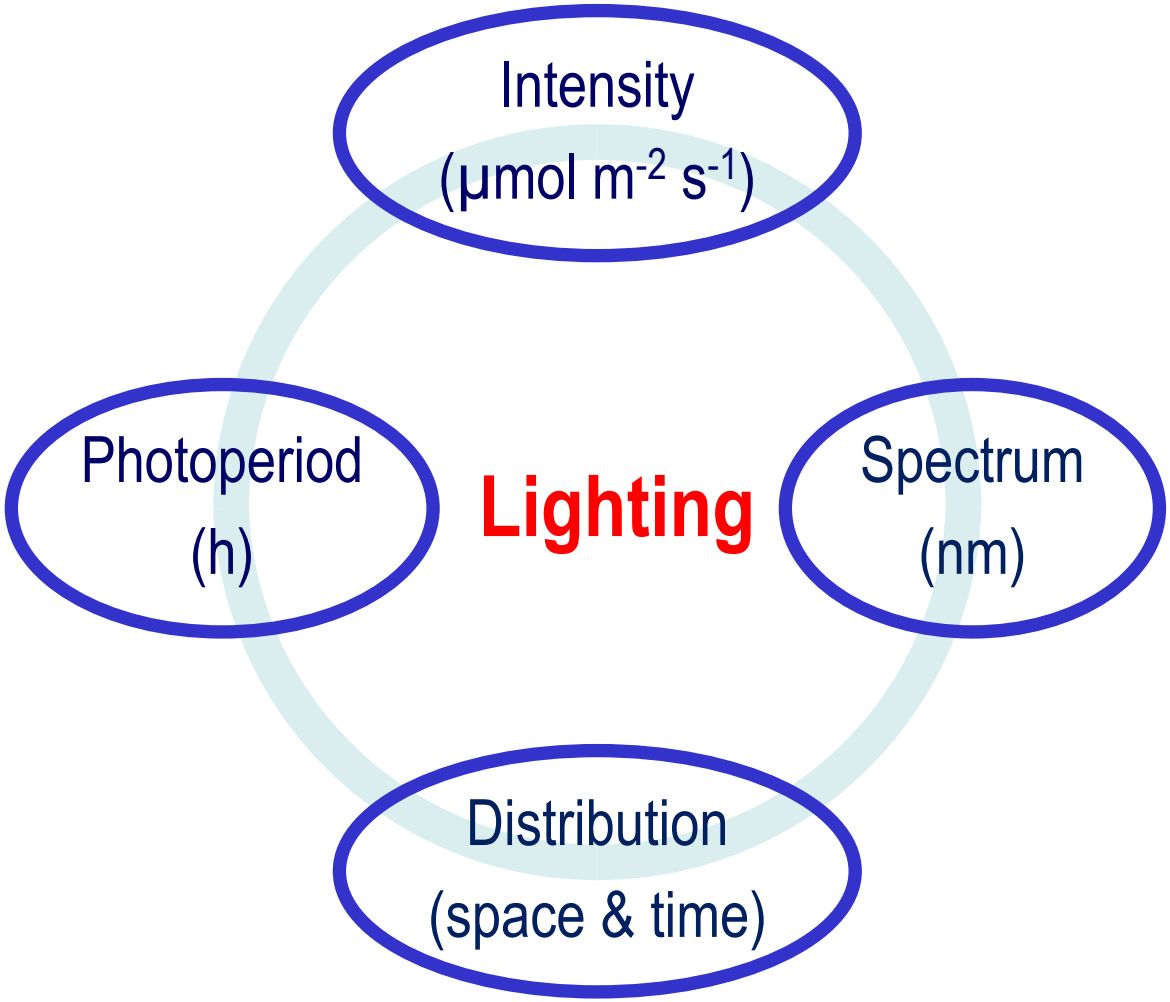
Year-round vegetable production with lighting

1. Optimum crop production systems

- **Schedule:** Planting in Sept. or Oct. so that the peak fruit harvesting period matches the period with high market price/shortage of produce.
- **Climate Control:** Optimum temperature and humidity are different from growing under ambient light; start CO_2 enrichment when the lighting system is on.
- **Fertigation:** Taking account of the supplemental lighting in irrigation control, the morning starts when the lighting system is on.
- Pest management and bee pollination need to be adjusted.

Year-round vegetable production with lighting

2. Supplemental Lighting Strategies



Supplemental Light Sources

- Photosynthesis (Assimilation light 400 – 700nm)
- Morphological response – Plant architecture, flowering
  - Red/Far-Red (Phytochrome)
  - UV-A and Blue (Crytochrome)
  - UV-B (UVR8)
- Secondary metabolism – Anthocyanins, phenolic compounds, anti-oxidants etc.
- Pest (insect and pathogen) control

Incandescent

Plasma

Metal Halide

High Pressure Sodium

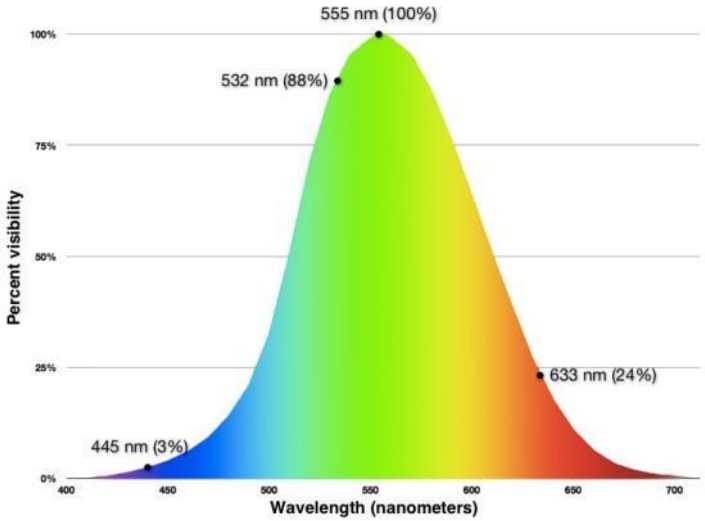
Fluorescent

Induction

LEDs

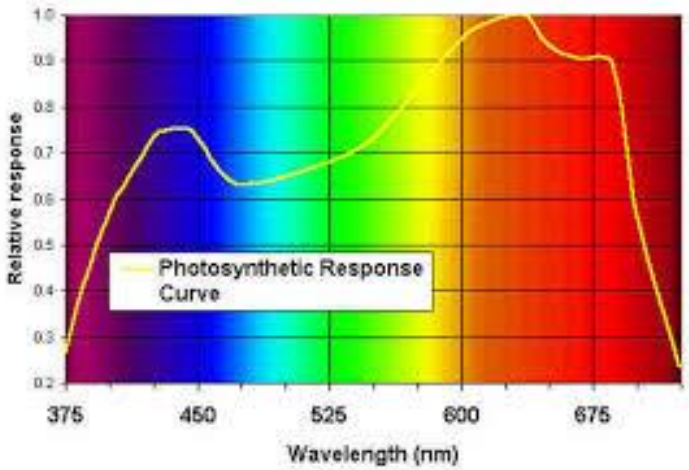
Human Photometric

•**Lumen** (**lm**) – A measure of total amount of weighted power of visible light based on human's eye sensitivity.
•**Lux** – A measure of luminous flux per unit area (lm m^{-2}).
•**Light Efficiency – Lumens/W**



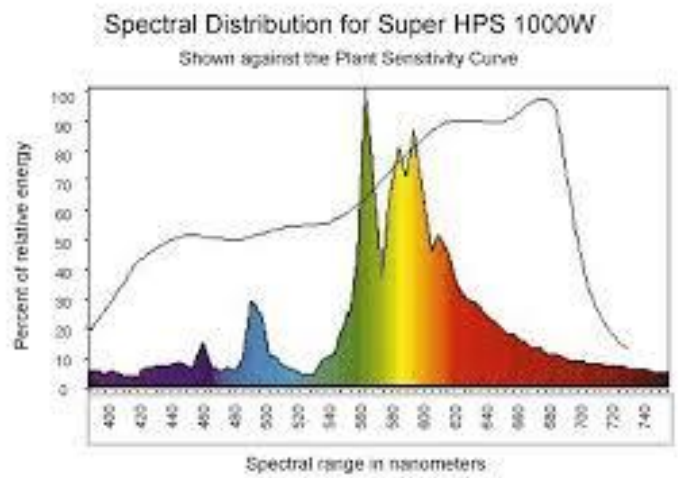
Plant Photometric

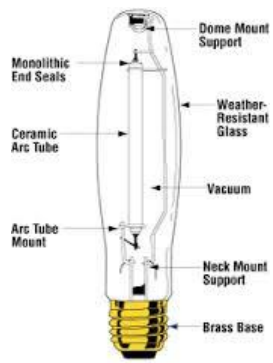
•**PAR** – Photosynthetically Active Radiation (400 to 700 nm).
•**PPF (Photosynthetic Photon Flux)** – A measure of number of PAR photon per unit of area per unit of time (µmol m^{-2} s^{-1}).
•**Light Efficiency: µmol/J**
or µmol/ W•S



Light Source - High Pressure Sodium Lamps (HPS)

- High temperature
- Broad spectrum
- "Hot" light
- Top lighting



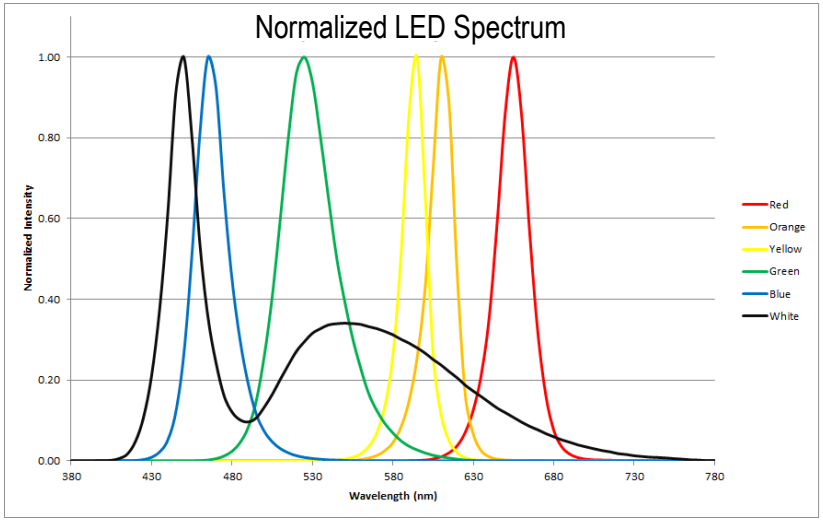


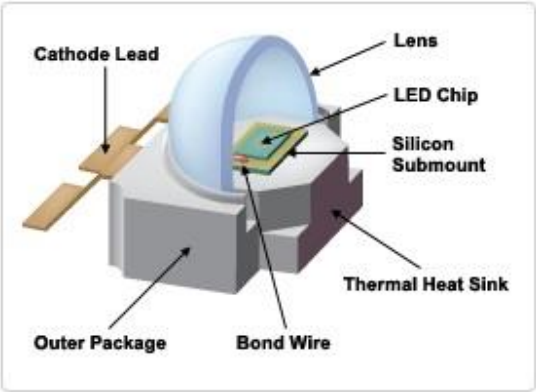
Fixture PAR efficiency (µmol/J)

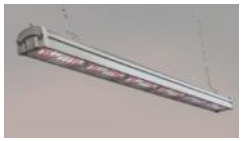
- 0.9-1.2 (Magnetic)
- 1.3-1.8 (Electronic)

Light Source - Light-Emitting Diode (LED)

- Low temperature
- Narrow spectrum
- Flexibility for spectral composition
- Little front heat radiation ("cold light")
- Back-end heat
- Inter-lighting or Top lighting
- Fixture PAR efficiency (µmol/J): 0.8-3.0

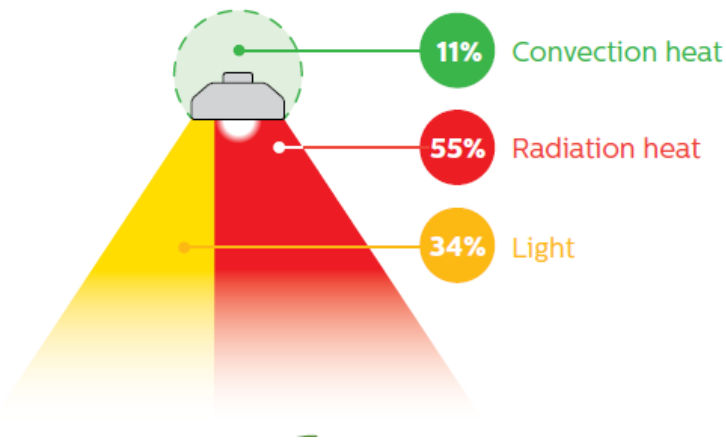




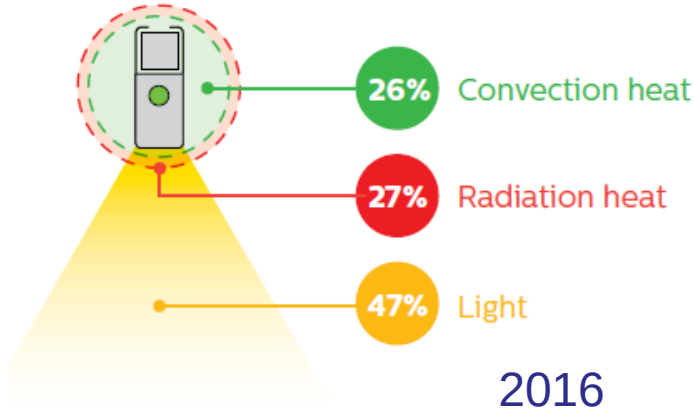


Energy distribution in light fixture output

HPS



LED



2016

- More radiation heat and higher canopy temperature in HPS
- Less radiation heat and lower canopy temperature in LEDs
- > 50% essential heating requirement can be met by the heat released from HPS at 200 µmol m^{-2} s^{-1} in SW Ontario.
- More heating required in production with LEDs (Dieleman *et al.*, 2016)

Heat energy cost using electricity*

Conversion of electricity price to price in heat unit

Electricity price ($/kWh)	Price in heat unit ($/GJ)
0.05	13.9
0.10	27.8
0.15	41.7

*. Each GJ equals to 277.8 kWh

- The best lighting system should convert more electricity to PAR.
- More economical to use fuels such as natural gas to heat the greenhouse, instead of heat from electricity.

Calculated LUE and EUE for Tomato cv. Komeett
(Jan. & Feb. 2013 was similar to Dec. 2012
using 1000W HPS, Harrow, AAFC)

Month	Lighting	PPFD ($\mu mol\ m^{-2}\ s^{-1}$)	LUE g/m^2 per $\mu mol\ m^{-2}\ s^{-1}$	EUE g/m^2 per W/m^2
Dec.	LED	73.4	16.4	31.4
	HPS	120	17.7	27.4
Mar.	LED	73.4	16.8	32.1
	HPS	120	3.5	5.4
Apr.	LED	73.4	8.8	16.8
	HPS	120	-15.4	-23.9
Total	LED	73.4	77.4	148.3
	HPS	120	37.1	57.2

Microclimate difference between HPS and LEDs affect cultivar selection /performance

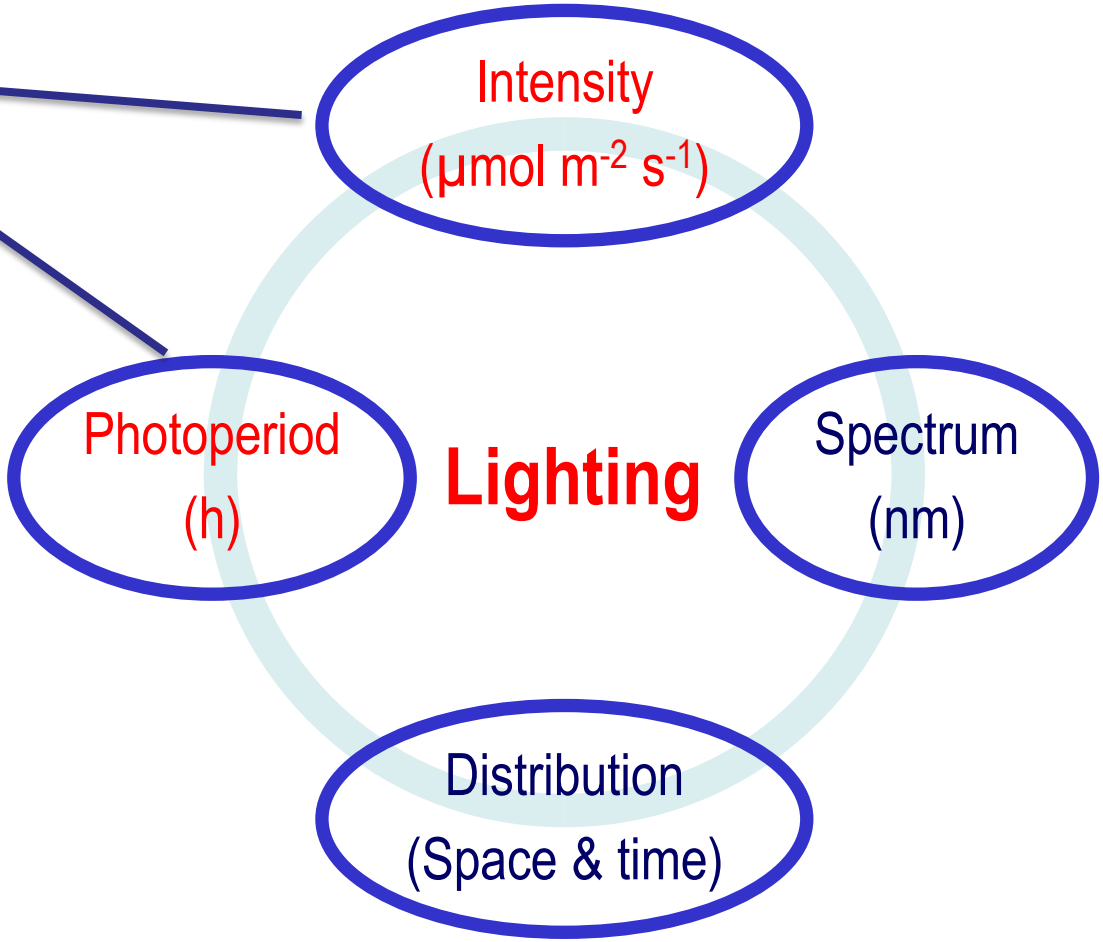
- **HPS: senesced faster in generative cultivars.**
- **LEDs: able to maintain plant vigour in generative cultivars but slower early fruit production in vigorous cultivars.**

Supplemental Lighting Strategies

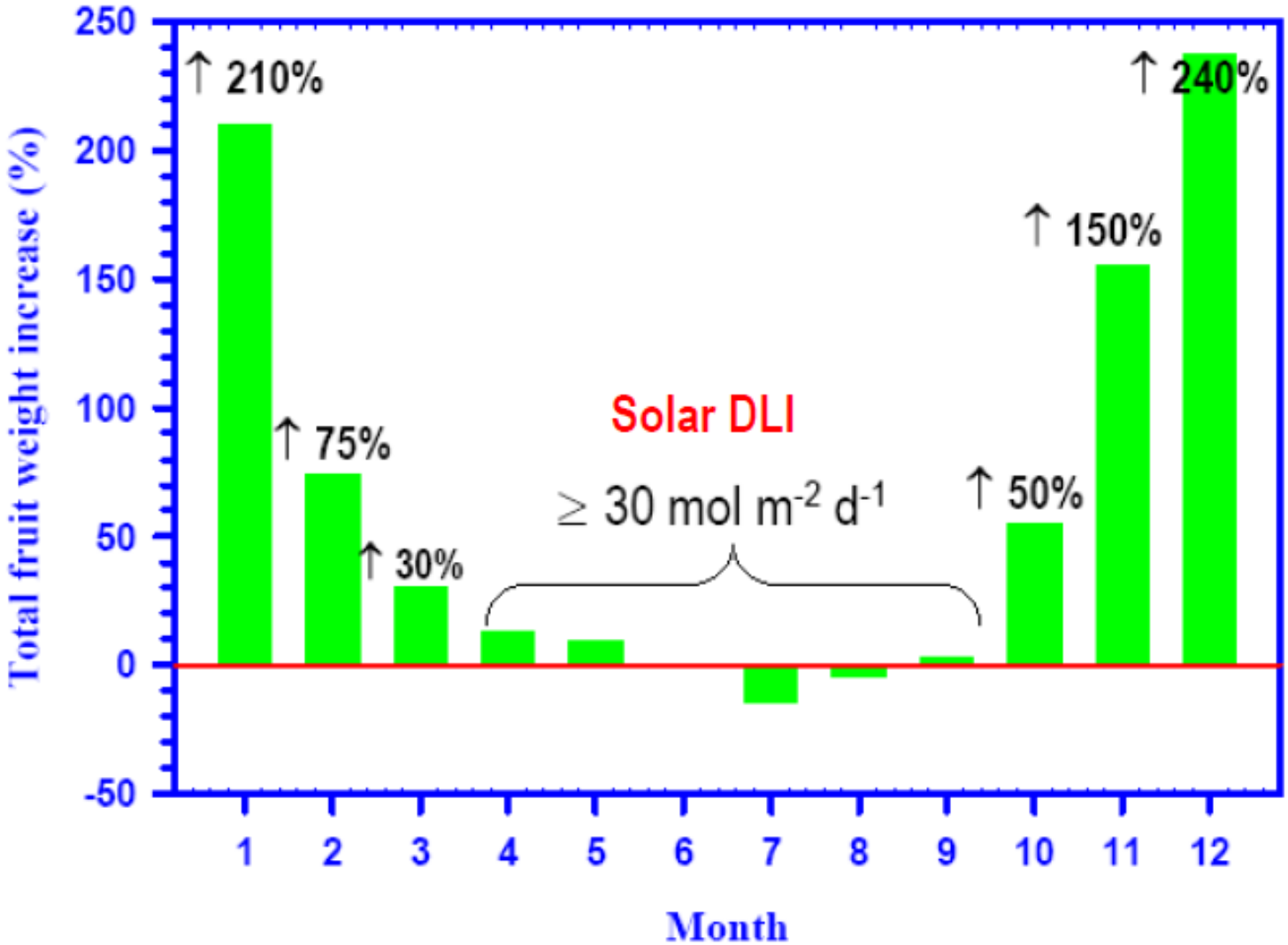
Daily Light Integral

Economical analysis

- Yield and quality increase
- Produce market price
- Electricity price
- Natural gas price
- Light fixture, installation & maintenance costs
- Interest rate on capital
- Labor, fertilizer and water costs etc.



Monthly marketable fruit yield increase with 188 µmol m^{-2} s^{-1} HPS lighting in long English cucumbers – AAFC, Harrow, ON (2006)



Light requirement (Intensity and Photoperiod)

Species	Cucumber	Tomato	Sweet pepper
DLI (mol m^{-2} d^{-1})	≤30	≤30	≤12 ?
Intensity (μmol m^{-2} s^{-1})*	100-300	125-250	100-200
Photoperiod (h)	**16-20h**	**16-18h**	**13-20h**

*. Varying with cultivars and local climate – High light intensity at places with lower sunlight and temperature.

- Practical intensity for tomato and cucumber is about 200μmol m^{-2} s^{-1} in Ontario, vary with cultivars.

- Using low light intensity and long photoperiod is a more economical way to achieve target **DLI**

- If photoperiod is > 17 hours
  - Leaf chlorosis
  - Reduced or no further yield increase

Circadian rhythm

Phytochrome interacting factor

Level 1 Level 2 Level 3 Level 4 Level 5

Level 0

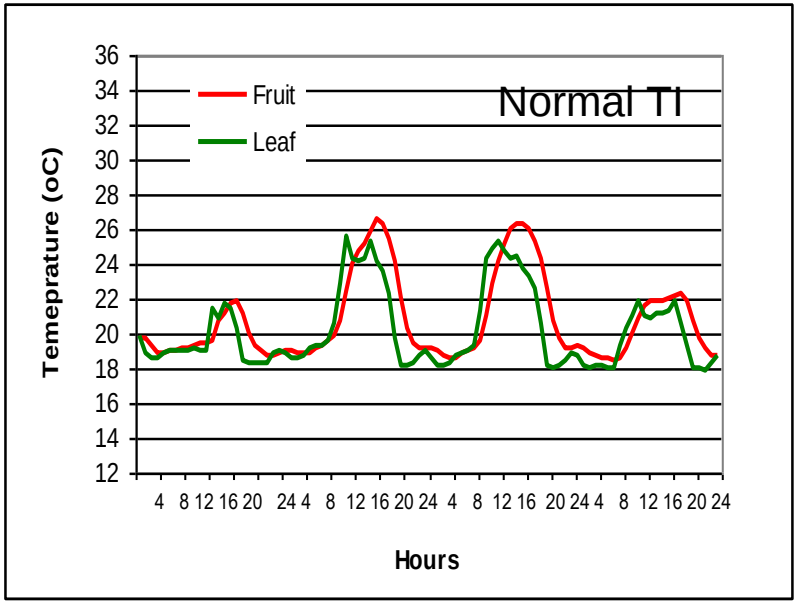
Level 1

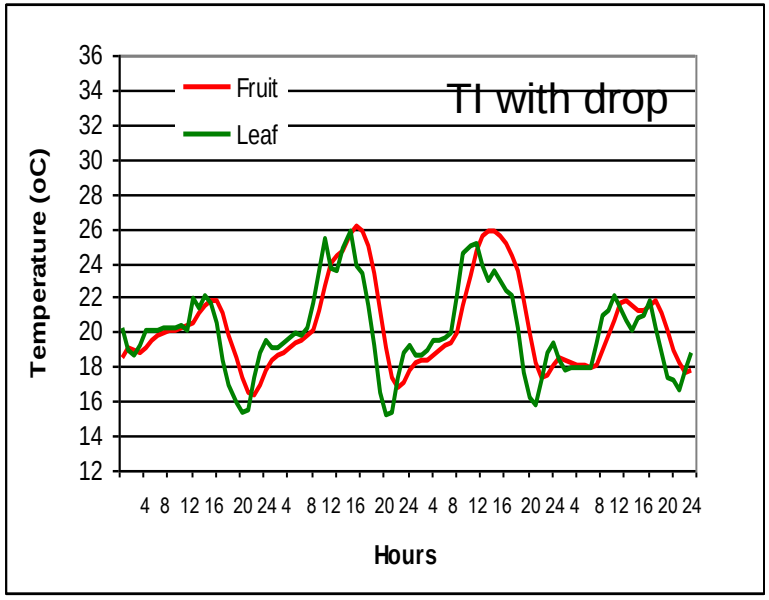
Level 2

Level 3

Dynamic Temperature Integration (TI) with a pre-night temperature drop

- Higher fruit T (relative to leaf), higher early fruit yield and less energy use in tomatoes – promoted biomass partitioning to fruit (Zhang and Hao, 2010, HortSci.).





Temperature Drop X Long Photoperiod – 2013-2017

Conducted in 8 greenhouse compartments each with 50 m^2 growing area from Oct. 2013 to Mar. 2017, 2 winters on tomatoes, one winter on sweet peppers, and one winter on cucumbers.

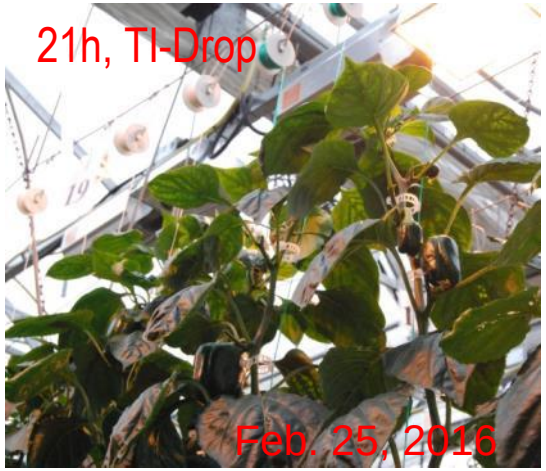
Air temperature set-points at 2 photoperiods with 2 TI regimes for the tomato experiments in winters 2013/14 and 2014/15*

Photo	TI	Heating set-points (ºC) during 4 periods in a day				24 h Avg.
		1	2	3	4	
16/17h	Reg.	00:00-8:00 20	10:00-15:00 21	17:00-22:00 19	22:00-23:00 19	19.98
16/17h	Drop	00:00-8:00 21.5	10:00-15:00 22.4	17:30-20:30 13.5	22:00-23:00 20.1	19.97
19/20h	Reg.	00:00-8:00 20	10:00-15:00 20.6	17:00-20:00 19	21:00-24:00 20	19.99
19/20h	Drop	00:00-8:00 21.5	10:00-15:00 22.2	17:30-20:30 13.5	22:00-23:00 20.8	19.98

*. The set-points ramped linearly between the periods in a day.

- **The set-points during the dropping period were 15.5ºC and 12.5ºC for sweet peppers and cucumbers, respectively.**

Pre-night Temperature Drop Improved Responses to Long Photoperiods



- Dynamic TI with a pre-night temperature drop reduced leaf chlorosis on tomatoes and sweet peppers but not on cucumbers.
- Long photoperiods improved fruit yield on tomatoes, cucumbers, and sweet peppers in early production period.
- Pre-night temperature drop improved fruit yield on tomatoes, cucumbers, and in late production on sweet peppers (10-30%) at long photoperiods.
- Dynamic TI with a pre-night temperature drop reduced energy use during cold months.

Dynamic TI with a pre-night temperature drop is an energy efficient temperature control strategy to improve response of greenhouse fruiting vegetables to long periods of lighting.

Supplemental Lighting Strategies

Intensity
($\mu mol\ m^{-2}\ s^{-1}$)

Photoperiod
(h)

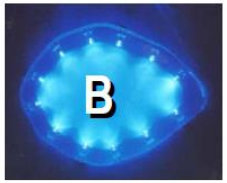
Lighting

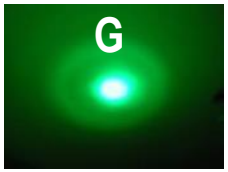
Spectrum
(nm)

Distribution
(space & time)

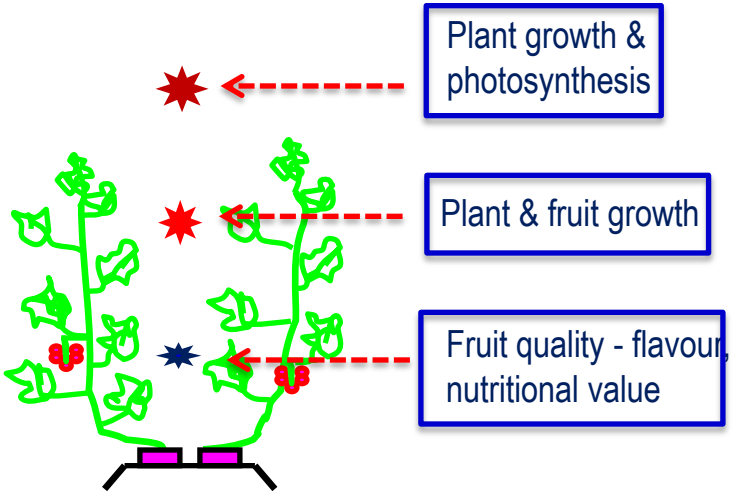
Optimizing vertical light spectral distribution to improve both fruit yield and nutritional value (anti-oxidants)

Different spectra of light trigger different growth processes





Optimized vertical profile



Effects of overhead LED schedule and intra-canopy LED lighting on fruit production of tomato cv. Foronti* (Winter 2016)

Overhead LED	Intra-canopy LED	Total fruit	
		Num. (plant^{-1})	Wt. (kg plant^{-1})
Red:blue:white 76:16:8 All the time	Red	30.4 a	5.46 ab
	Blue	30.0 a	5.74 a
	UV-A	28.7 b	5.27 b
	White	29.6 ab	5.56 ab
100% red Oct to Dec, 2015 Red:blue:white 67:22:11 Dec, 2015 to Feb, 2016 100% red After Feb. 2016.	Red	30.5 a	5.89 a
	Blue	30.6 a	5.83 a
	UV-A	29.1 b	5.42 b
	White	30.7 a	5.63 ab

Effects of overhead and inter-light LED spectrum on fruit yield of sweet pepper cv. Redwing (Winter 2017)

Overhead	Interlight	Yield (kg m^{-2})	Fruit size (g)
	Control	15.53 b	236.2
100% RED	Red	15.03 b	222.7
	Blue	14.70 b	218.4
	White	**17.77 a**	231.1
	Control	15.85 b	227.8
R:B:W 76:16:8	Red	16.31 b	225.8
	Blue	16.56 ab	239.6
	White	**17.38 a**	239.2
Overhead		0.40	0.49
INTER		0.02	0.66
OH*INTER		0.23	0.13

Cucumber grown under strong HPS light

- Leaf deformation
- Reduced leaf size
- Short internode

Sweet pepper grown under strong HPS light

- Very compact
- Short internode

Far-red light to improve plant growth and fruit production

Winter 2014/15 : Beefsteak tomato cv. Foronti grafted on Stallone, planted on Nov 26, 2014 at 2.8 heads m^{-2}.

Winter 2015/16 : Mini-cucumber cv. Pickwell, planted on Oct. 5, 2015 at 3.3 plants m^{-2}.




Winter 2016/17 : Sweet pepper cv. Redwing, planted on Oct. 20, 2016 at 7 stems m^{-2}.



Fruit yield (kg stem^{-1}) of tomato cv. Foronti (Jan. 23 to Apr. 20, 2015).

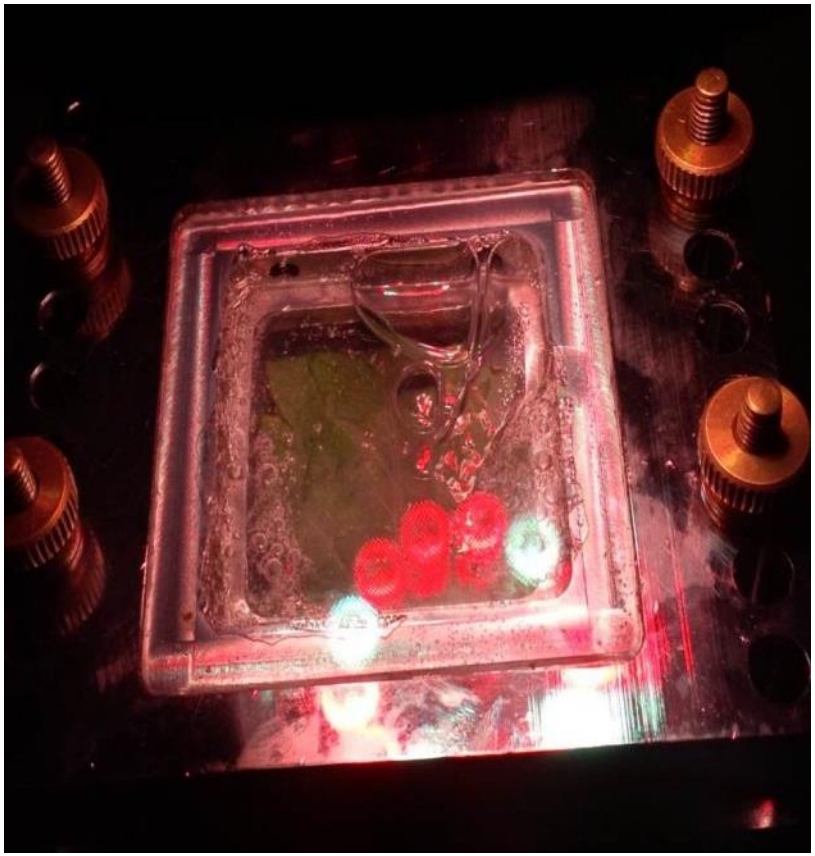
Far-red (µmol m^{-2} s^{-1})	First month	Second month	Third month	Total
0	**2.2**	2.3	3.3	**7.9**
8	**2.4**	2.5	3.6	**8.6**
16	**2.5**	2.4	3.4	**8.3**
24	**2.5**	2.5	3.3	**8.3**
Statistical test[1]	*	ns	ns	*

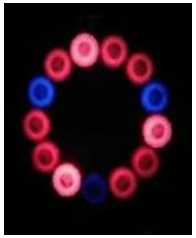
[1] Significance of statistical test from ANOVA: * $p < 0.05$; ns $p > 0.05$.

Far-red light to improve plant growth and fruit production

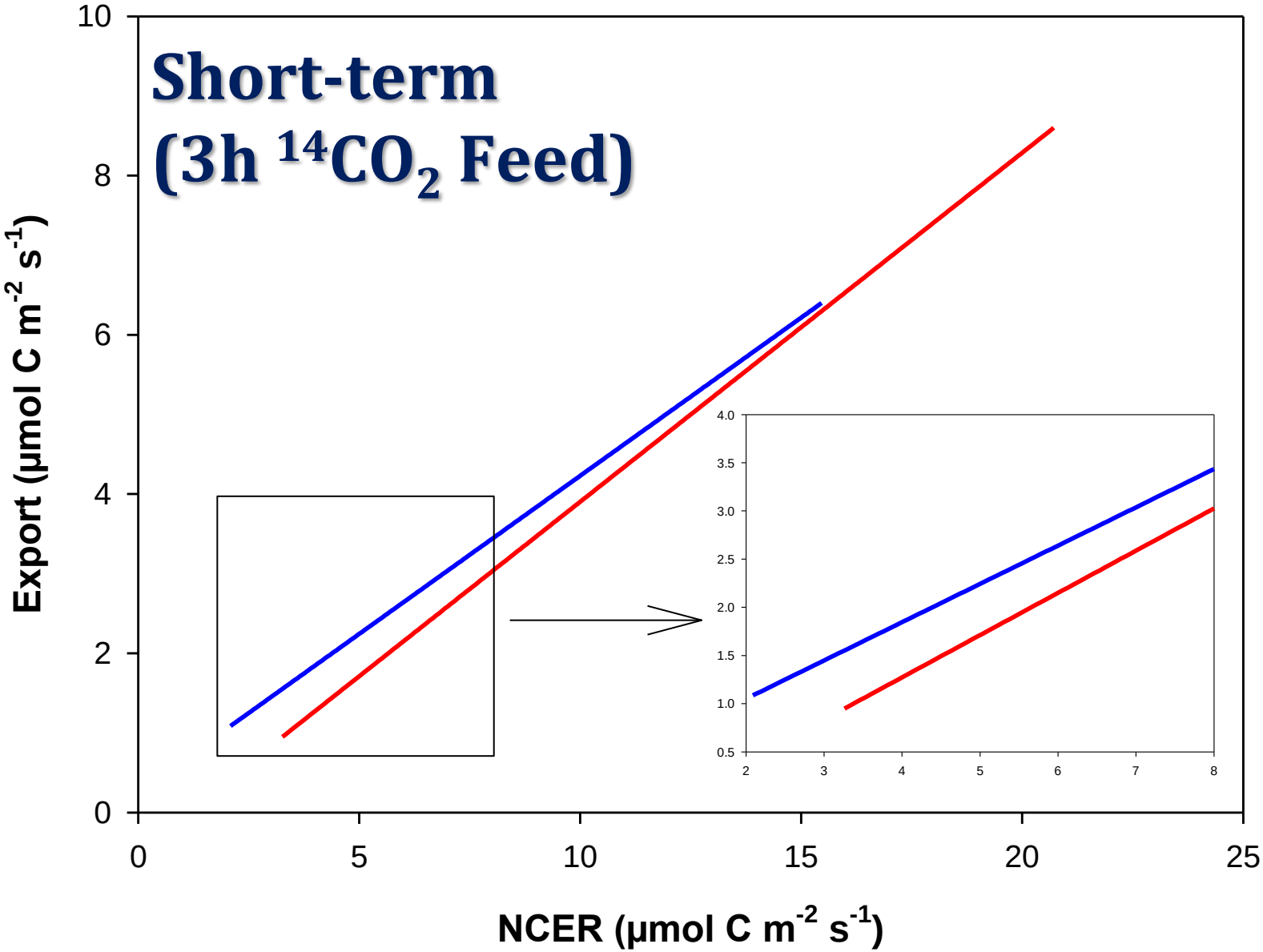
- Low dose of far-red light is beneficial in early stage of fruit production of greenhouse tomatoes and sweet peppers grown under HPS lighting but not for cucumbers.
- The increased plant height and more light capture might have contributed to the higher early yield under far-red light.

Wavelength Specific LED Lighting on Carbon Fixation, Export, and Partitioning (J. Lanoue, 2017, University of Guelph)

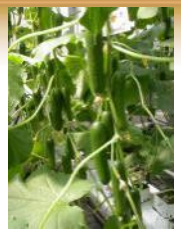




J. Lanoue, 2017, University of Guelph

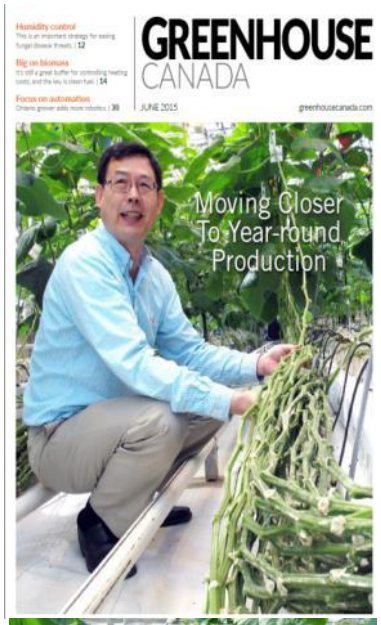


Summary



- New cultivars, climate control, fertigation and crop management strategy are required for production with lighting.
- Supplemental light not only affects light conditions but also energy balance and plant microclimate.
- A proper pre-night temperature drop can improve the response of tomatoes, cucumbers and sweet peppers to long photoperiods of lighting.
- Small dose of far-red light is beneficial in early fruit production for tomatoes and sweet peppers but not for cucumbers.
- The optimized vertical light distribution regimes varies with species and can be developed for improving both fruit yield and quality.
- LED light recipe to increase translocation of photo-assimilate to fruit can be developed to improve fruit yield.

Sustainable year-round, high quality, and pesticide-free mini-cucumber production system



New system

- 2 crops/year
- 60Kg/m^2 (Oct-Mar)
- No diseases
- Pesticide free
- 50Kg/m^2 (Apr-Sept)

Traditional system

- 4 crops/year
- 15Kg/m^2 per crop
- High replanting costs
- Severe powdery mildew

Sustainable year-round high quality sweet pepper production system
(Promising but not there yet)

- Planted in early Oct. 2015
- Ended in Mid-Apr. 2016
- Could extend to Sept. with a tall greenhouse
- 21 kg/m^2 (best treatment)

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

ONTARIO GREENHOUSE VEGETABLE GROWERS naturally Fresh inside

Acknowledgement

The research has been funded/supported by Ontario Greenhouse Vegetable Growers, AAFC GF I & II, AgriInnovation and Peer-Review Programs.

The professional and technical support of Mr. Shalin Khosla, Drs. Rong Cao, Guang Wen and Xiaobin Guo, Prof. Bernard Grodzinski, Mr. Jason Lanoue, Ms. Celeste Little, Yun Zhang, and Mr. JingMing Zheng, many co-op students, and greenhouse workers are greatly appreciated.