Horticulture Lighting with LEDs

OS SSL | November 2016 | Regensburg

Light is OSRAM

Horticulture Lighting
What is horticulture lighting and how is it used?

- **Supplemental Lighting**
  To supplement natural daylight and raise grow light levels in order to enhance photosynthesis and thereby improve growth and quality of plants in greenhouses.

- **Photoperiodic Lighting**
  To control the light period by extending the natural day length with artificial light.

- **Cultivation without daylight**
  To totally replace daylight with artificial light for ultimate climate control.

Horticulture Lighting
What is horticulture lighting and how is it used?

Horticulture lighting is used to support, increase and enable the growth of plants by illuminating them with artificial light. LED Light is a very efficient way and upcoming solution for this application!

Top Lighting

Inter Lighting

Vertical Farming

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Green House Lighting with LEDs

Toplighting

Toplighting is currently used with conventional light sources. The plants are illuminated from the top similar sun light.
The high power consumption and the heat of HPS luminaires are also demanding a distance between the light source and the plants.

Interlighting

Interlighting is enabled by LEDs as a light source! In this case the lighting is in between the plants and leaves. This should reduce the shadowing of the leafs which may occur by top lighting. This increases the amount of light even on the lower leafs.
Unlike the hot HPS Luminaires, the comparatively low temperatures on the LED luminaire don't damage the plants.

Horticulture Lighting
How does light affect the plant growth?

• Light quantity

The amount of light affects the photosynthesis process in the plant. This process is a photochemical reaction within the chloroplasts of the plant cells in which CO2 is converted into carbohydrate under the influence of the light energy.

• Light quality regarding spectral composition of the light

The spectral composition of the different wavelength regions (blue, green, yellow, red, far red or invisible e.g. UV or IR) is important for the grows, shape, development and flowering (photomorphogenesis) of the plant. For the photosynthesis, the blue and red regions are most important.

• Light duration

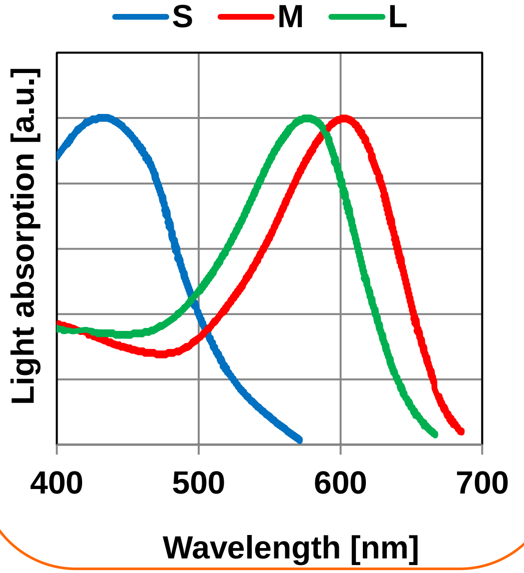
The timing / light duration which is also called photoperiod is mainly affecting the flowering of the plants. The flowering time can be influenced by controlling the photoperiod.

Source: [0];[18]

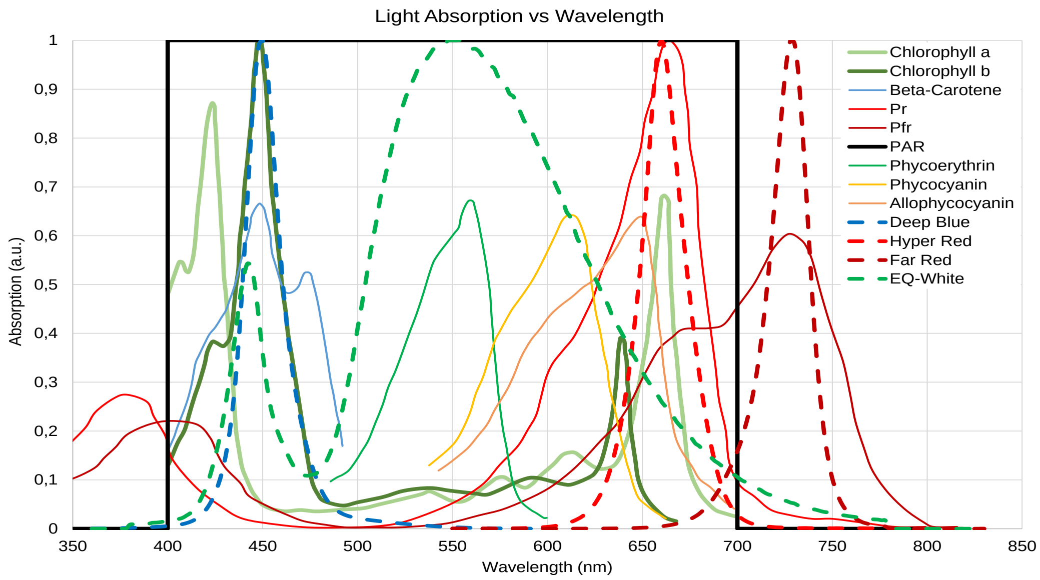
Difference in absorption curves for photochemical reactions between the human eye and plants

Light is generating a photochemical reaction. In our eye it is reacting with the photo receptor in different versions S, M and L. In plants, the light is reacting with Chlorophyll a and b.

Absorption curves of the human eye

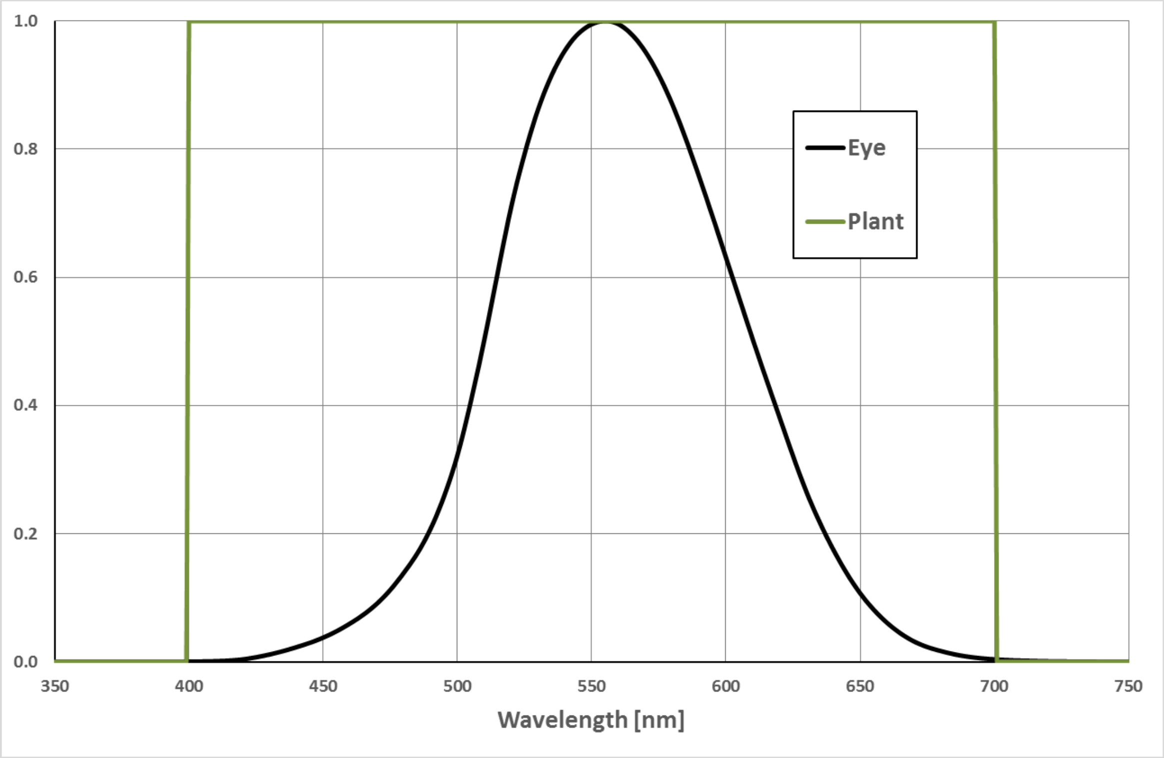


Absorption curves of plants



Different receptors – different units

	Human Eye	Plant
Amount of Light	Lumen **[lm]**	Micromol per second **[µmol/s]**
Efficacy	Lumen per Watt **[lm/W]**	Micromol per Joule **[µmol/J]**



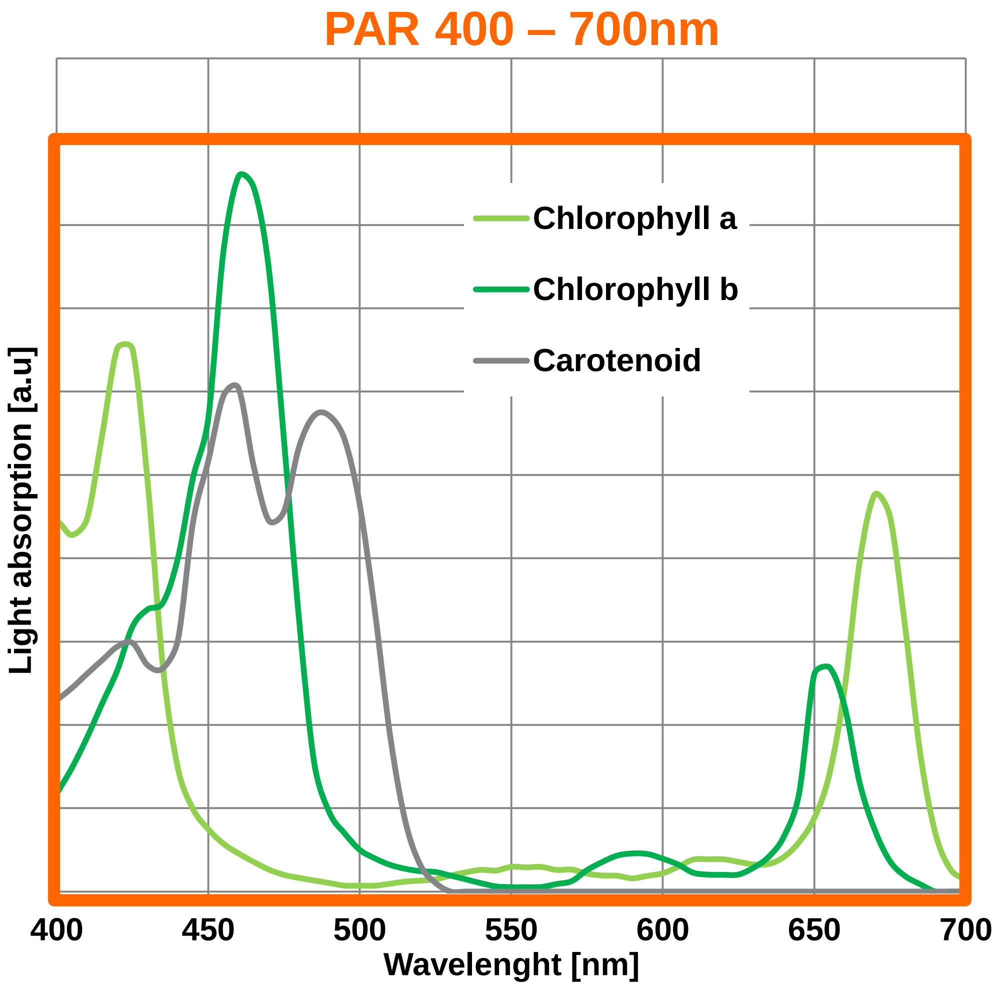
Photosynthetic efficiency is mainly driven by chlorophyll a and b

- **Chlorophyll a and b**

Mainly responsible for the photosynthesis and responsible for the definition of the area for the photosynthetically active radiation PAR.

•Carotenoid

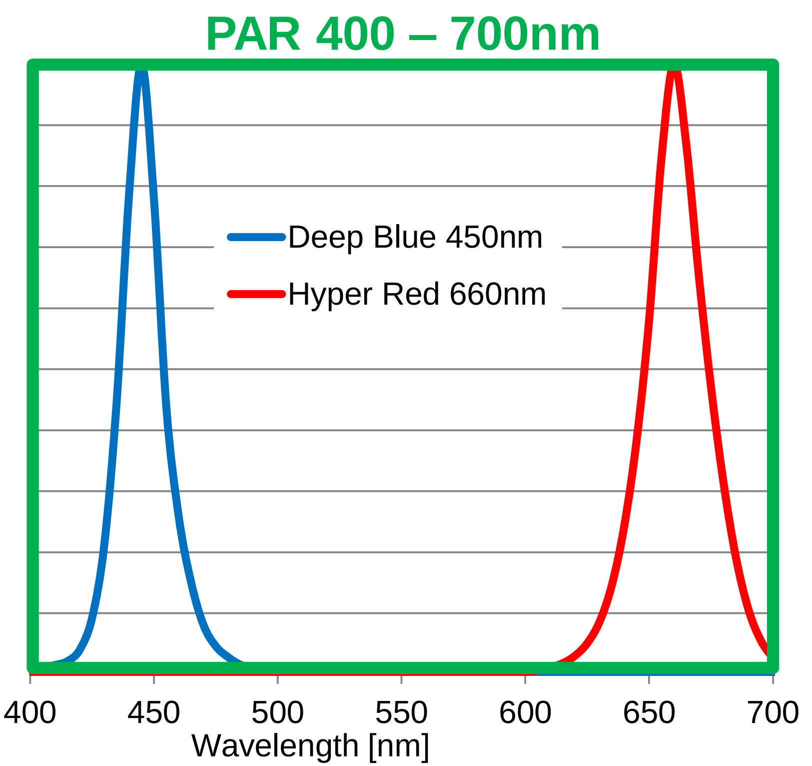
Further photosynthetic pigments also known as antenna pigments like carotenoids β-carotene, zeaxanthin, lycopene and lutein etc.



Source: [18],[19]

Horticulture Lighting
450nm and 660nm provide the energy for the plant

The 450nm and the 660nm are providing the energy for the plant to life and grow. The amount of light is not measured in lumen but in amount of photons. The common unit in horticulture lighting is µmol/s in the range of 400-700 (photosynthetically active region)



Usually the customer will request for a certain photon flux level in µmol/s.
The values can be put in our horticulture calculator to derive the number of LEDs

Horticulture System Calculator

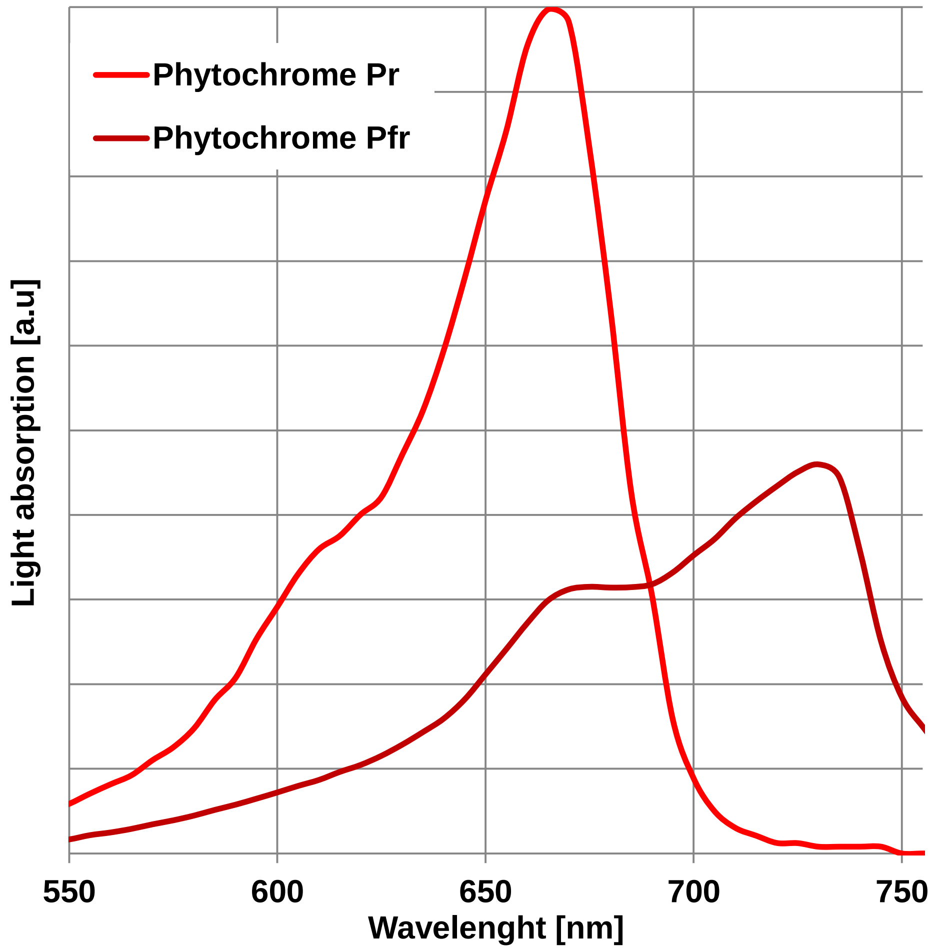
Photomorphogenic effects are mainly influenced by the phytochromes Pr and Pfr

• Phytochrome Pr and Pfr

The Phytochromes pr (red) and pfr (far red) are mainly influencing the germination, plant growth, leave building and flowering.

•Phytomorphogenic effects

The phytomorphogenic effects are controlled by applying a spectrum with a certain mix of 660nm and 730nm in order to stimulate the pr and pfr phytochromes.



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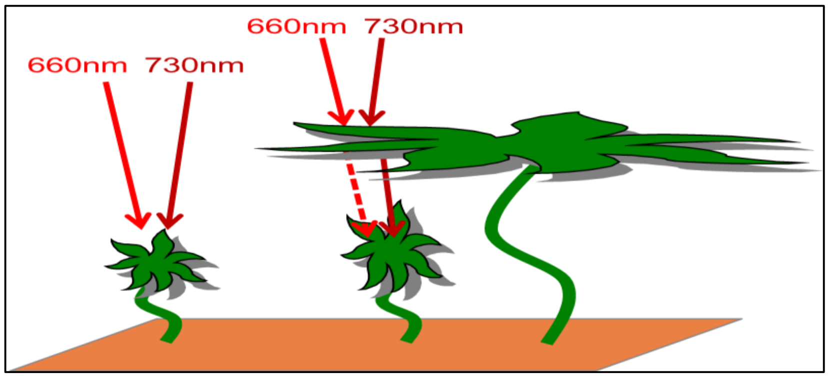
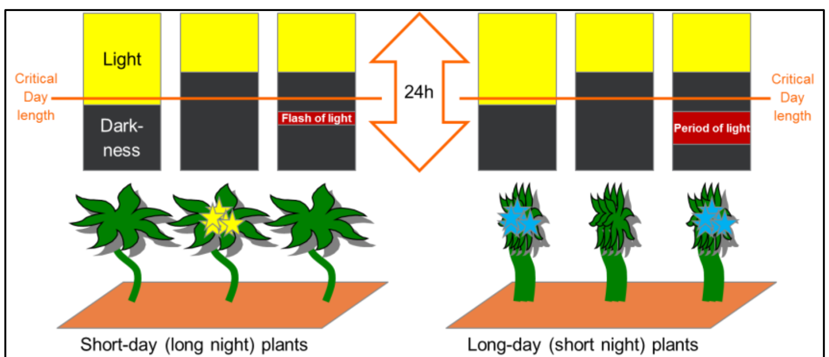
Horticulture Lighting - The 730nm is necessary to control the growth of the plant

The application of the 730nm is much more complicated and needs special knowledge by the grower. The 730nm LED should be in a separate string and dimmable in the luminaire.





The 730nm LEDs can be used to influence the length growth of the plant. Shining 730nm light on a plant makes the plant feel like being in the shadow of a bigger plant and triggers the “shade escape reaction” which means it grows very fast.

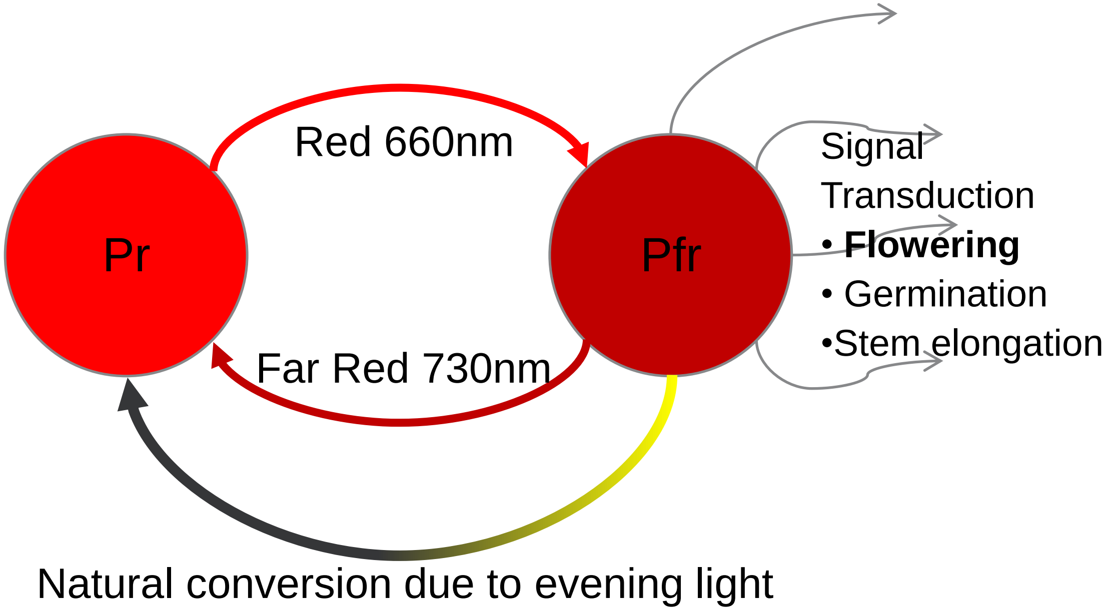
Another effect which can be influenced by the 730nm LEDs is the timing of blossoming of flowers. It can make the flowers blossom in winter time of even prevent the blossoming in summer time.

Special potential of LEDs in floriculture lighting

Traditionally ornamental plants are of high economic importance. The Red and Far-Red light mediates the conversion of phytochromes which can control the triggers for flowering.

Illumination with 730nm:

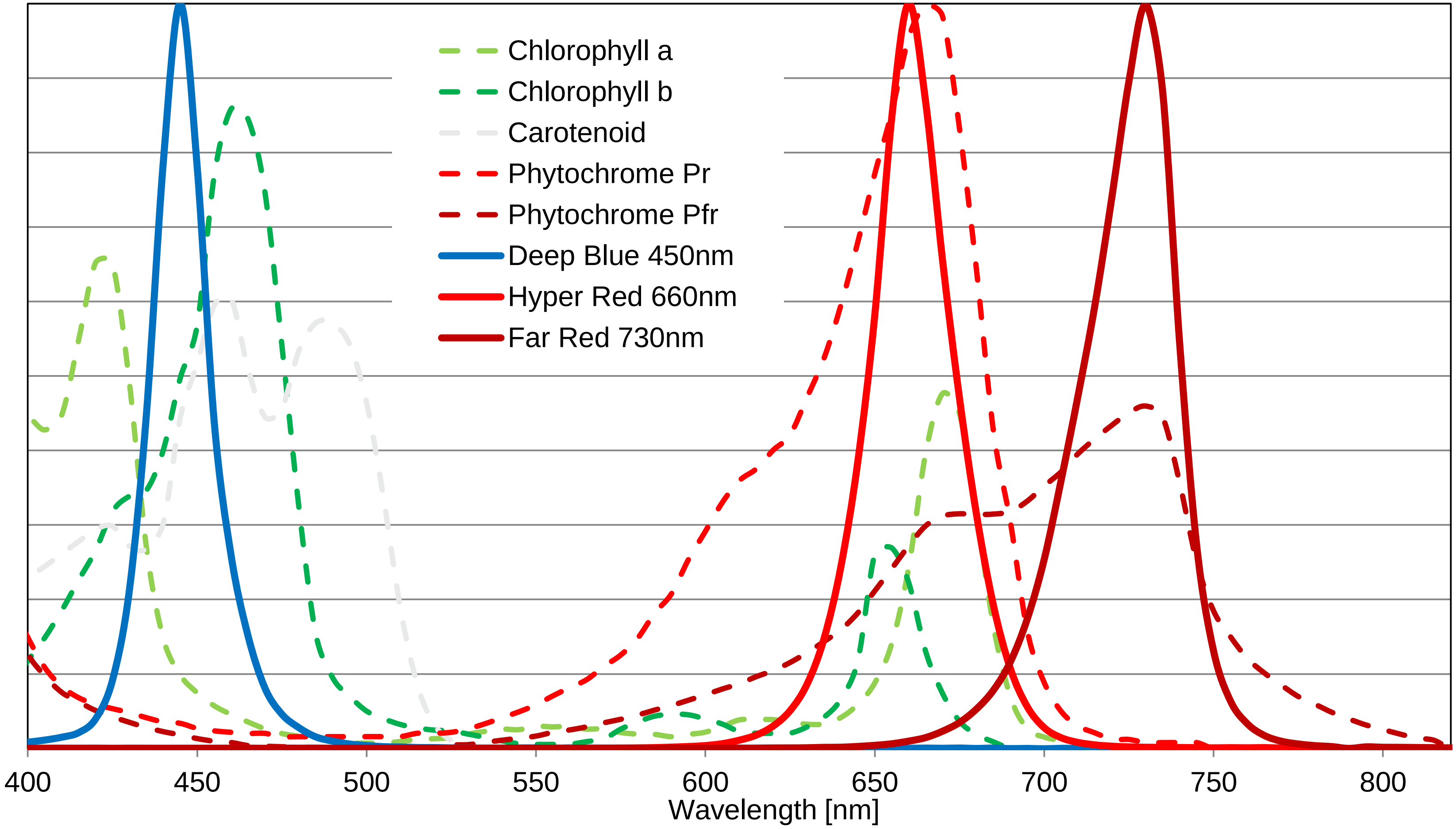
The cycle from Pr to Pfr is initiated by red light of 660nm which represents daylight. During the night time, the Pfr is converted back to Pr. This back conversion can also be actively be influenced by 730nm far red light.
This enables a perfect control of the flowering timing independent of the seasons.



Source: [0]

Therefore we are focusing in horticulture lighting on the 450nm, 660nm and 730nm LEDs

All three important wavelength are available in the same LED package:



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The incumbent –
High-Pressure Sodium (HPS) lamps

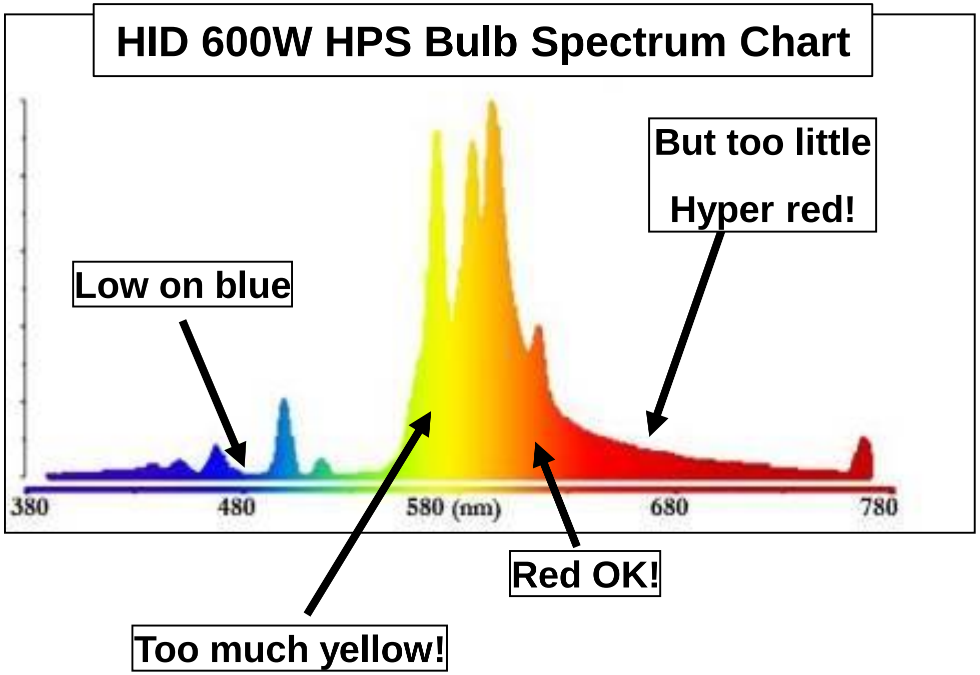
Today‘s widely used High-Pressure Sodium lamps produce over 100 lm/W, but over a wide wavelength range

Efficacy in Lumen per Watt is misleading, since plants don‘t have eyes

Typical lifetime is (only) ~8000h

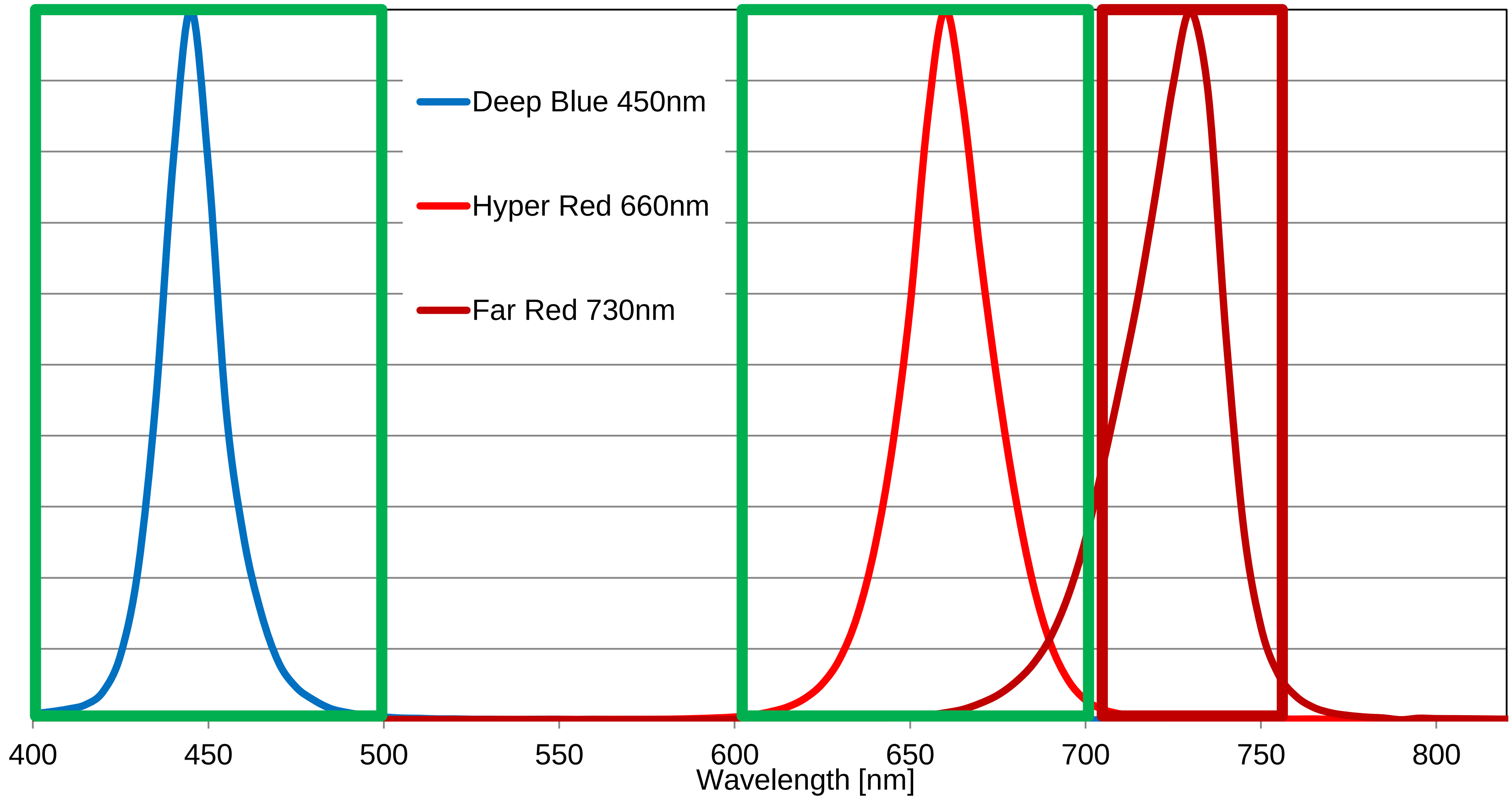
Takes minutes to reach full power

Large lamps are most cost efficient

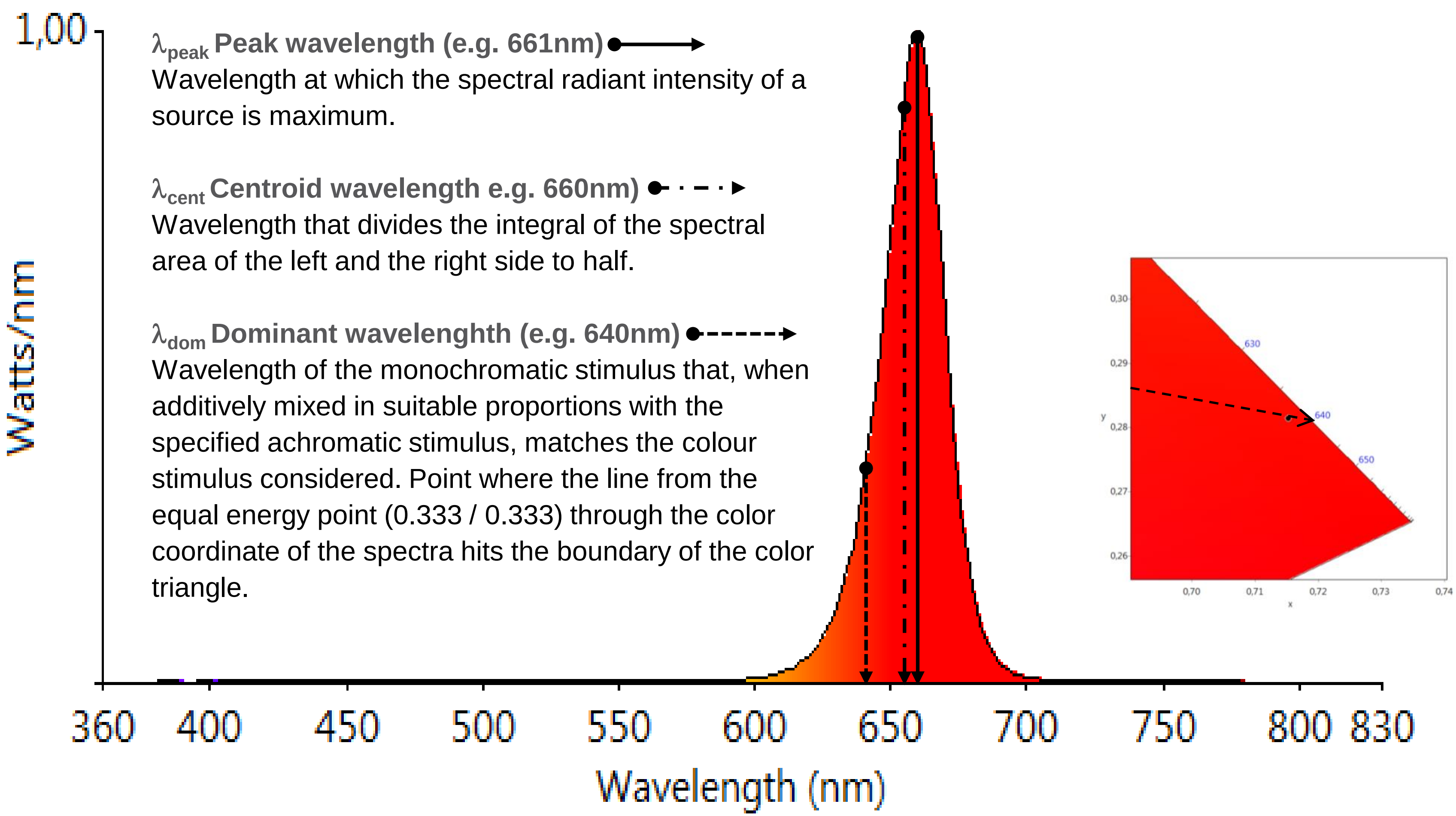


Horticulture Lighting - What are the LEDs and colors used for horticulture lighting?

The typical wavelength used for horticulture lighting are 450nm and 660nm. For the control of the plants 730nm are used



One spectrum and three different definitions of the wavelength



λ_{peak} Peak wavelength (e.g. 661nm)
Wavelength at which the spectral radiant intensity of a source is maximum.

λ_{cent} Centroid wavelength e.g. 660nm)
Wavelength that divides the integral of the spectral area of the left and the right side to half.

λ_{dom} Dominant wavelenghth (e.g. 640nm)
Wavelength of the monochromatic stimulus that, when additively mixed in suitable proportions with the specified achromatic stimulus, matches the colour stimulus considered. Point where the line from the equal energy point (0.333 / 0.333) through the color coordinate of the spectra hits the boundary of the color triangle.

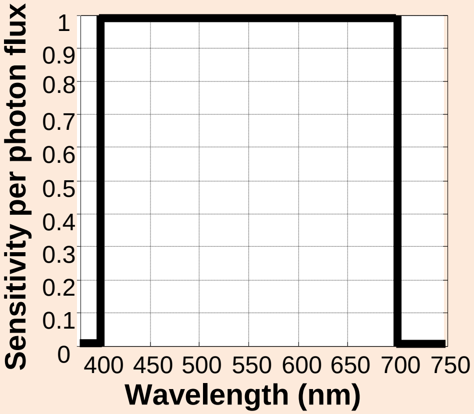
Background Knowledge
Photon counting

Today’s method of weighing the spectrum is not really adequate

Situation today

- The whole spectrum is weighed equally by counting the photons in the photosynthetically active region (PAR)

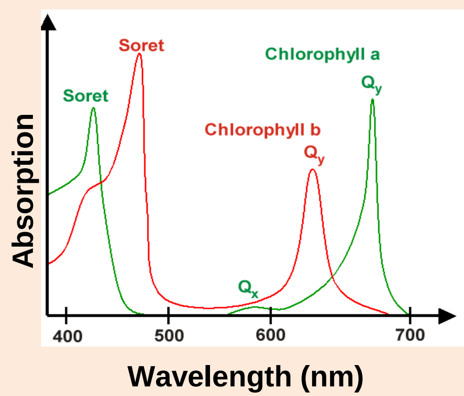
PAR sensitivity curve



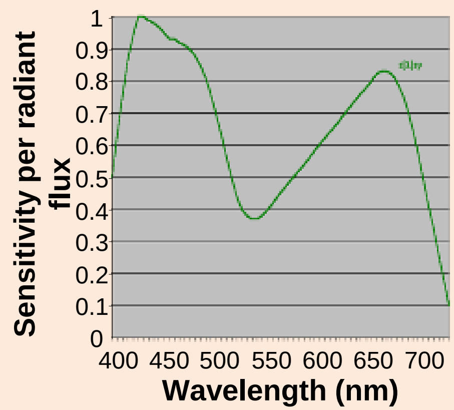
More realistic approach

- Weighing the emission spectrum of the light source with plants' spectral sensitivity curve (“plm/W”)
- This curve is derived from the chlorophyll absorption spectrum taking into account internal energy transfer processes of the plant / leaves

Chlorophyll absorption spectrum



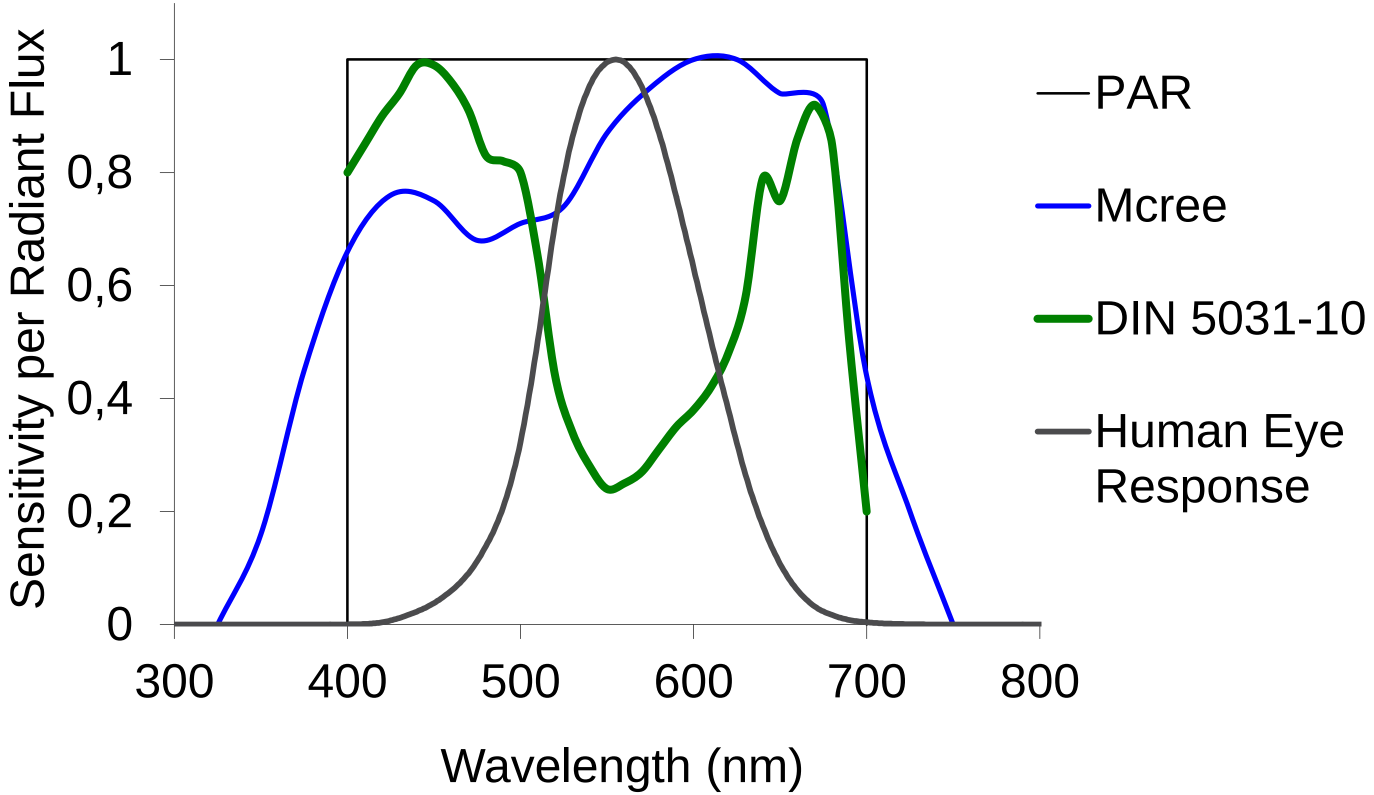
Plant sensitivity curve (DIN)*



* DIN 5031-10

Background Knowledge
Photon counting

Today's method of weighing the spectrum is not really adequate



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Effect of the different wavelength regions on plants

Different regions of the wavelength in the illumination spectrum have different effects on the plants:

Wavelength range [nm]	Photosyntesis	Further Effects	Further Effects	Further effects
200 – 280		Harmful		
280 – 315		Harmful		
315 – 380				
380 – 400	Yes			
400 – 520	Yes	Vegetative growth		
520 – 610	Some	Vegetative growth		
610 – 720	Yes	Vegetative growth	Flowering	Budding
720 – 1000		Germination	Leaf building and growth	Flowering
> 1000		Converted to heat		

Source: [0]

What are typical µmol/s.m² values for horticulture lighting?

What light level for what type of crop?			
Plant	**min µmol/s.m²**	**max µmol/s.m²**	**typical µmol/s.m²**
Tomato	170	200	185
Pepper	70	130	100
Cucumber	100	200	150

What light level for what potted plant?			
Plant	**min µmol/s.m²**	**max µmol/s.m²**	**typical µmol/s.m²**
Orchid/Phalaenopsis	80	130	105
Dendrobium	130	260	195
Bromelia	40	60	50
Anthurium	60	80	70
Kalanchoë	60	105	82,5
Potted chrysanthemum	40	60	50
Potted rose	40	60	50
Geranium	40	60	50
Orchid/Phalaenopsis	80	130	105

What light level for what cut flower?			
Plant	**min µmol/s.m²**	**max µmol/s.m²**	**typical µmol/s.m²**
Chrysanthemum	105	130	117,5
Rose	170	200	185
Lily	80	100	90
Lisianthus	170	200	185
Alstroemeria	60	105	82,5
Anthurium / Orchid – cut	80	105	92,5
Freesia	70	105	87,5
Gerbera	80	105	92,5
Tulip	25	40	32,5

Source: http://www.hortilux.nl/light-technology

Effect of red light around 660nm on physiology of vegetables

Plant	Radiation source	Effect on plant physiology	Reference
Indian mustard (*Brassica juncea L.)* Basil (*Ocimum gratissimum L.)*	Red (660 and 635 nm) LEDs with blue (460 nm)	Delay in plant transition to flowering as compared to 460 nm + 635 nm LED combination	[38]
Cabbage (*Brassica olearacea var. capitata L.)*	Red (660 nm) LEDs	Increased anthocyanin content	[33]
Baby leaf lettuce (*Lactuca sativa L. cv.* Red Cross)	Red (658 nm) LEDs	Phenolics concentration increased by 6%	[7]
Tomato (*Lycopersicum esculentum L. cv.* MomotaroNatsumi)	Red (660 nm) LEDs	Increased tomato yield	[39]
Kale plants (*Brassica olearacea L. cv* Winterbor)	Red (640 nm) LEDs (pretreatment with cool white light fluorescent lamp)	Lutein and chlorophyll a, b accumulation increased	[36]
White mustard (*Sinapsis alba),* Spinach (*Spinacia oleracea), Green* onions (*Allium cepa)*	Red (638 nm) LEDs with HPS lamp (90 µmol m^{-2} S^{-1}), total PPF (photosynthetic photon flux) maintained at 300 µmol m^{-2} S^{-1}	Increased vitamin C content in mustard, spinach and green onions	[41]
Lettuce (*Lactuca sativa)* Green onions (*Allium cepa L.)*	Red (638 nm) LEDs and natural illumination	Reduction of nitrate content	[40]

Source: [0]

Effect of red light around 660nm on physiology of vegetables

Plant	Radiation source	Effect on plant physiology	Reference
Green baby leaf lettuce (*Lactuca sativa L.)*	Red (638 nm) LEDs (210 μmol m^{-2} S^{-1}) with HPS lamp (300 μmol m^{-2} S^{-1})	Total phenolics (28.5%), tocopherols (33.5%), sugars (52.5%), and antioxidant capacity (14.5%) increased but vitamin C content decreased	[42]
Red leaf, green leaf and light green leaf lettuces (*Lactuca sativa L.)*	Red (638 nm) LEDs (300 μmol m^{-2} S^{-1}) with HPS lamp (90 μmol m^{-2} S^{-1})	Nitrate concentration in light green leaf lettuce (12.5%) increase but decreased in red (56.2%) and green (20.0%) leaf lettuce	[43]
Green leaf 'Lolo Bionda' and red leaf 'Lola Rosa' lettuces (*Lactuca sativa L.)*	Red (638 nm) LEDs (170 μmol m^{-2} S^{-1}) with HPS lamp (130 μmol m^{-2} S^{-1})	Total phenolics and α-tocopherol content increased	[44]
Sweet pepper (*Capsicum annuum* L.)	Red (660 nm) and farred (735 nm) LEDs, total PPF maintained at 300 μmol m^{-2} S^{-1}	Addition of far-red light increased plant height with higher stem biomass	[34]
Red leaf lettuce 'Outeredgeous' (*Lactuca sativa L.)*	Red (640 nm, 300 μmol m^{-2} S^{-1}) and farred (730 nm, 20 μmol m^{-2} S^{-1}) LEDs.	Total biomass increased butanthocyanin and antioxidant capacity decreased	[30]

Source: [0]

Effect of red light around 660nm on physiology of vegetables

Plant	Radiation source	Effect on plant physiology	Reference
Red leaf lettuce ‘Outeredgeous’ (*Lactuca sativa L.)*	Red (640 nm, 270 μmol m^{-2} S^{-1}) LEDs with blue (440 nm, 30 μmol m^{-2} S^{-1}) LEDs	Anthocyanin content, antioxidant potential and total leaf area increased	[30]
Tomato seedlings ‘Reiyo’	Red (660 nm) and blue (450 nm) in different ratios	Higher Blue/Red ratio (1:0) caused reduction in stem length	[16]

Source: [0]

Effect of blue light around 450nm on physiology of vegetables

Plant	Radiation source	Effect on plant physiology	Reference
Cherry tomato seedling	Blue LEDs in combination with red and green LEDs, total PPF maintained at 300 µmol m^{-2} S^{-1}	Net photosynthesis and stomatal number per mm^2 increased	[39]
Seedlings of cabbage (*Brassica olearacea*var. *capitata L.)*	Blue (470 nm, 50 µmol m^{-2} S^{-1}) LEDs alone	Higher chlorophyll content and promoted petiole elongation	[33]
Chinese cabbage (*Brassica camprestis* L.)	Blue (460 nm, 11% of total radiation) LEDs with red (660 nm) LEDs, total PPF maintained at 80 µmol m^{-2} S^{-1}	Concentration of vitamin C and chlorophyll was increase due to blue LEDs applicatio	[32]
Baby leaf lettuce 'Red Cross' (*Lactuca sativa* L.)	Blue (476 nm, 130 µmol m^{-2} S^{-1}) LEDs	Anthocyanin (31%) and carotenoids (12%) increased	[7]
Cucumber 'Bodega' (*Cucumis sativus)* and tomato 'Trust' (*Lycopersicon esculentum)*	Blue (455 nm, 7-16 µmol m^{-2} S^{-1}) LEDs with HPS lamp (400-520 µmol m^{-2} S^{-1})	Application of blue LED light with HPS increased total biomass but reduced fruit yield	[45]
Transplant of cucumber 'Mandy F1'	Blue (455 and 470 nm, 15 µmol m^{-2} S^{-1}) with HPS lamp (90 µmol m^{-2} S^{-1})	Application of 455 nm resulted in slower growth and development while 470 nm resulted in increased leaf area, fresh and dry biomass	[46]

Source: [0]

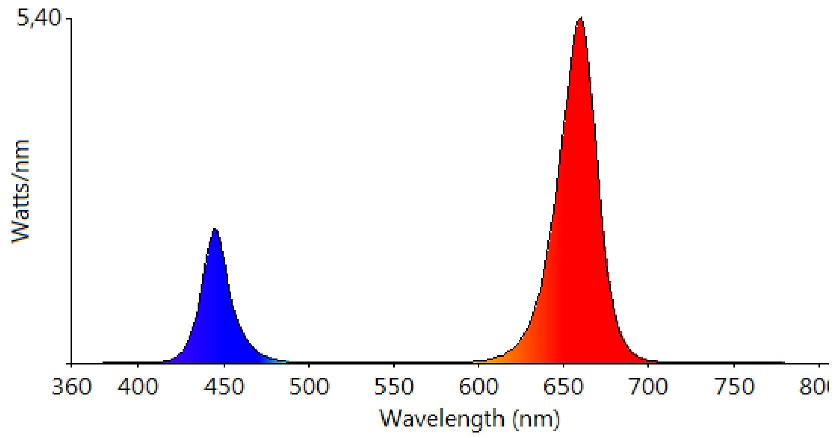
Effect of green light around 520nm on physiology of vegetables

Plant	Radiation source	Effect on plant physiology	Reference
Red leaf lettuce (*Lactuca sativa L. cv* Banchu Red Fire)	Green 510, 520 and 530 nm LEDs were used, and total PPF was 100, 200 and 300 µmol m^{-2} S^{-1} respectively	Green LEDs with high PPF (300 µmol m^{-2} S^{-1}) was the most effective to enhance lettuce growth	[37]
Transplant of cucumber 'Mandy F1'	Green (505 and 530 nm, 15 µmol m^{-2} S^{-1}) LEDs with HPS lamp (90 µmol m^{-2} S^{-1})	505 and 530 nm both resulted in increased leaf area, fresh and dry weight	[46]
Red leaf lettuce (*Lactuca sativa L. cv* Banchu Red Fire)	Green 510, 520 and 530 nm LEDs were used, and total PPF was 100, 200 and 300 µmol m^{-2} S^{-1} respectively	Green LEDs with high PPF (300 µmol m^{-2} S^{-1}) was the most effective to enhance lettuce growth	[37]
Tomato 'Magnus F1' Sweet pepper 'Reda' Cucumber	Green (505 and 530 nm, 15 µmol m^{-2} S^{-1}) LEDs with HPSlamp(90 µmol m^{-2} S^{-1})	530 nm showed positive effect on development and photosynthetic pigment accumulation in cucumber only while 505 nm caused increase in leaf area, fresh and dry biomass in tomato and sweet pepper	[47]
Transplant of cucumber 'Mandy F1' **Source: [0]**	Green (505 and 530 nm, 15 µmol m^{-2} S^{-1}) LEDs with HPS lamp (90 µmol m^{-2} S^{-1})	505 and 530 nm both resulted in increased leaf area, fresh and dry weight	[46]

Horticulture Lighting
Example LED light ratios for different purposes

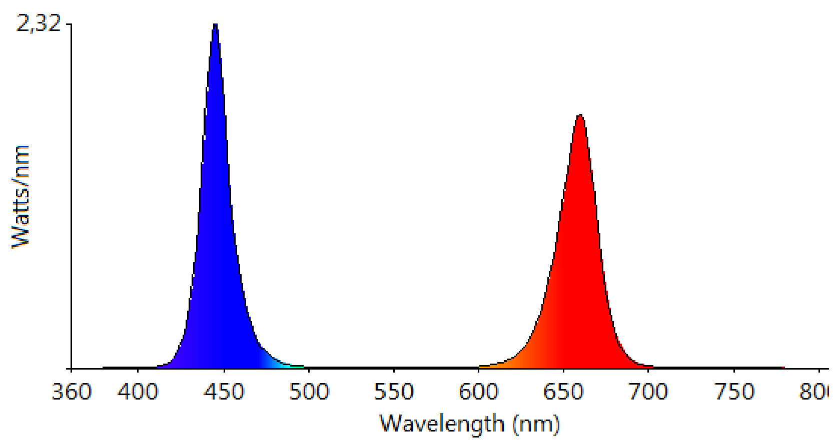
General purpose – high efficiency		
Type	Wavelength	mW Ratio
GD Cxxx	450nm	23%
GH Cxxx	660nm	77%

The highest efficacy of µmol/J from the spectrum can be achieved by using the 660nm Red LEDs combined with some 450nm Blue LEDs to maintain a reasonable ratio between the wavelengths



Vegetative Growth		
Type	Wavelength	mW Ratio
GD Cxxx	450nm	50%
GH Cxxx	660nm	50%

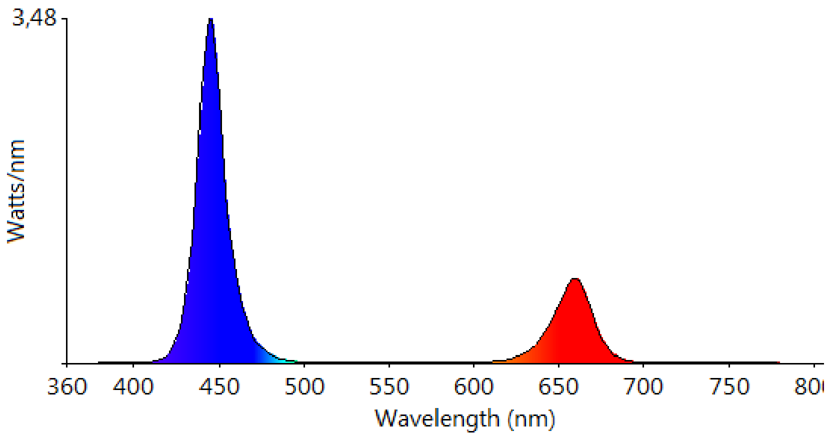
Especially for growth of the leafy green vegetable plants the vegetative growth ratio is used to achieve fastest growth where visible assessment of plant health is not important



Source: http://www.illumitex.com/illumitex-leds/surexi-horticulture-leds/

Horticulture Lighting
Example LED light ratios for different purposes

Best for seedlings		
Type	Wavelength	mW Ratio
GD Cxxx	450nm	75%
GH Cxxx	660nm	25%
A high blue content in the spectrum is recommended for growth of the seedlings.		

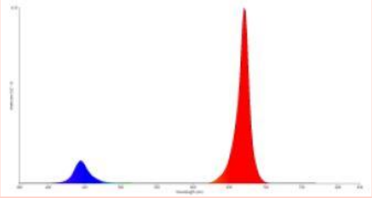
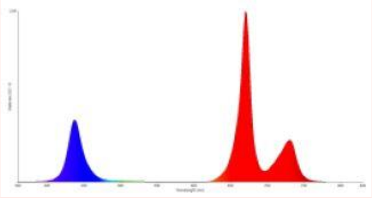
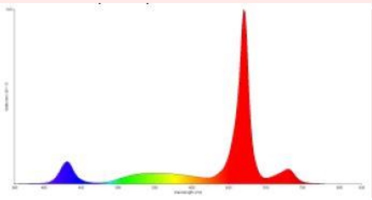


Source: http://www.illumitex.com/illumitex-leds/surexi-horticulture-leds/

Horticulture Lighting
Example LED light ratios for different purposes

Actual Studies:

- More kind of wavelegth may be needed by plants, not only red and blue

Color Combination	Works For	
Blue + Red	Leafy greens such as lettuce	
Blue + Red + Far Red	Far Red as a „Good-night-kiss“ for phytochrome processes	
Blue + Red + Yellow + Green	Flowering plants where biomass is the goal	
Green	Needed for leafs to get their green color	

Thank you.

Products

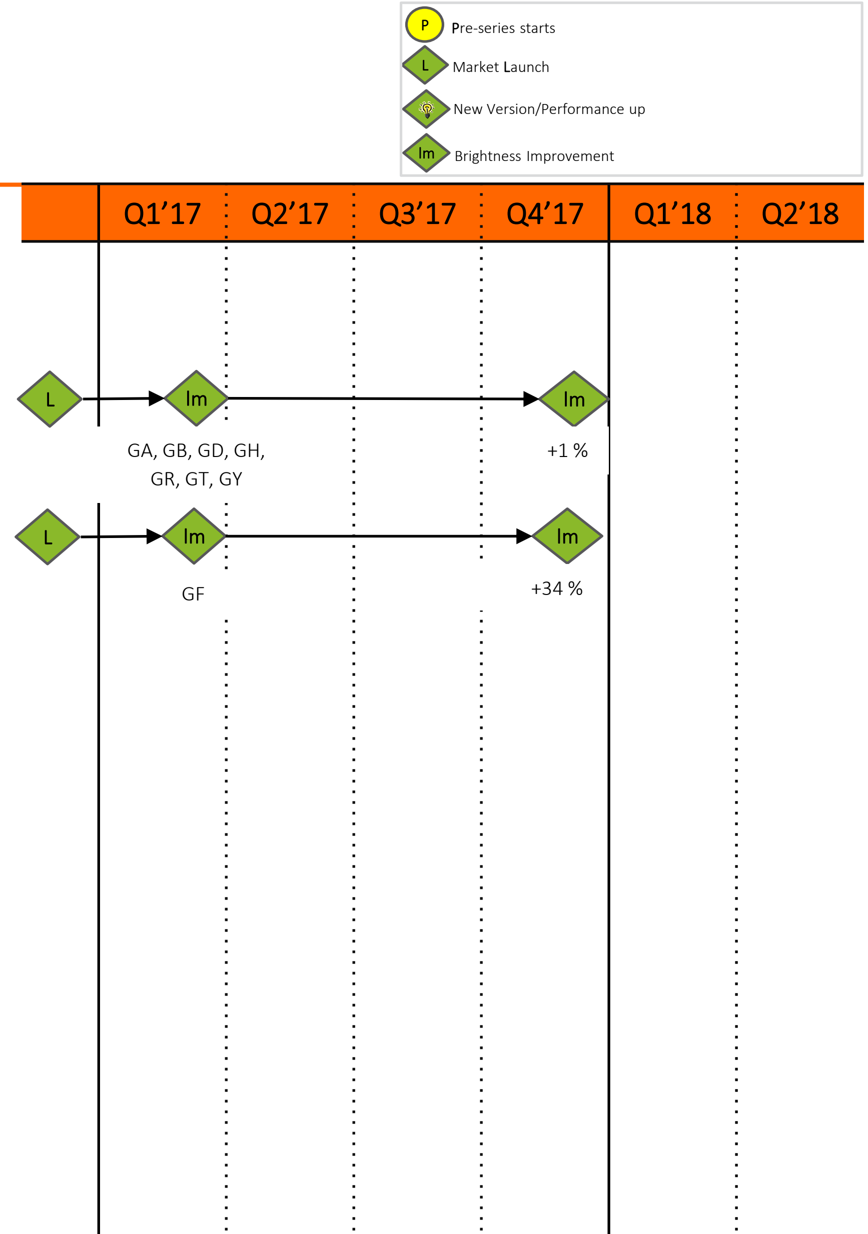
OSLON® SSL COLOR
New generation

color	type	$\lambda_{dom/peak}$	Typ Output (350 mA / 25 °C / 120°)	radiation angle
deep blue	GD CSxPM1.14	450 nm	685 mW	80° / 120°/ 150°
blue	GB CSxPM1.13	465 nm	30 lm	80° / 150°
true green	GT CSxPM1.13	528 nm	130 lm	80° /120°/ 150°
yellow	GY CSxPM1.23	590 nm	85 lm	80° /150°
amber-red	GA CSxPM1.23	617 nm	95 lm	80° / 120°/ 150°
red	GR CSxPM1.23	623 nm	70 lm	80° / 150°
hyper red	GH CSxPM1.24	660 nm	435 mW	80° / 120°/ 150°
far red	GF CSxPM1.24	730 nm	270 mW	80° / 120°/ 150°

OSLON® SSL

High Power-Color

[Gx family] New!			
Viewing angle 80 °, 120 °, 150 ° (8, S, H)			
Footprint 3.0x3.0mm	Max. current 1000mA	Peak Wavelength	Efficacy/ Efficiency
Deep Blue	GD CS(8,S,H)PM1.14	451nm	69%
Blue	GB CS(8,H)PM1.13	465nm	32 lm/W
True Green	GT CS(8,S,H)PM1.13	521nm	130 lm/W
Yellow	GY CS(8,H)PM1.23	593nm	105 lm/W
Amber	GA CS(8,S,H)PM1.23	625nm	130 lm/W
Red	GR CS(8,H)PM1.23	634nm	90lm/W
Hyper-red	GH CS(8,S,H)PM1.24	660nm	58%
Far-red	GF CS(8,S,H)PM2.24	730nm	39%



** Preliminary information is subject to change without notice*

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Appendix

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Definitions

Radiometry: deals with the detection and measurement of electromagnetic radiation across the total spectrum

Photometry: subfield of radiometry; radiometric power scaled by the spectral response of the human eye

Photon Flux: number of photons in a spectral range per unit time. When limited to the range 400-700 nm, it is termed Photosynthetic Photon Flux.

Mol/mol/µmol: In chemistry, a unit of measurement counting the number of atoms/molecules/electrons/etc. in a substance (for horticulture, photons) By definition, the number of photons in a mol is 6.022×10^{23} (Avogadro's number)

Photon: Discrete bundle (quantum) of electromagnetic radiation (light). Can be considered to be a particle (although it displays properties of waves as well). The energy of a photon depends upon its wavelength. Conversely, if the energy & wavelength are known, the number of photons can be calculated

Photosynthetically Active Radiation (PAR): Radiation between 400 nm and 700 nm. Spectral region most useful to plants for photosynthesis

Photosynthetic Photon Flux Density (PPFD): Radiation between 400 nm and 700 nm. Radiation hitting a surface

Definitions

Photosynthesis: A process used by plants and other organisms to convert light energy into chemical energy that can be later released to fuel the organisms' activities. This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesized from carbon dioxide and water.

Germination: Germination is the process by which a plant grows from a seed. It is also known as sprouting of a seedling from a seed.

Vegetative Growth: Vegetative Growth is the period between germination and flowering. It is also known as vegetative phase of the plant development. During this phase the plants are performing photosysthesis and accumulating resources which will be used for the flowering and reproduction in the later stage.

Photomorphogenesis: Because light is the energy source for plant growth, plants have evolved highly sensitive mechanisms for perceiving light and using that information for regulating development changes to help maximize light utilization for photosynthesis. The process by which plant development is controlled by light is called photomorphogenesis. Typically, photomorphogenic responses are most obvious in germinating seedlings but light affects plant development in many ways throughout all stages of development.

Flowering: The transition to flowering is one of the major phase changes a plant makes during its life cycle. The transition must take place at a time that is favorable for fertilization and the formation of seeds. The right photoperiod is essential for the flowering.

Etiolatio: Abnormal shape of plants due to significantly accelerated length growths caused by insuficient illumination which can be used for photosynthesis.

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Thank you.