Solutions for Horticulture Lighting
LEDs for efficient and reliable luminaire design - ensure sustainable growth of plants

OS S EEM DM | LED EVENEMENT | Thomas Brandes
Light is OSRAM
Motivation
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 control of the growing process.
  Target: understand the influencing factors and correlations - define the main process parameters and set-up a control loop.
Where it all began: High-Pressure Sodium HPS lamp

High-Pressure Sodium lamps: above 100 lm/W, @ wide wavelength range

Plants don’t have eyes: Efficacy in Lumen per Watt is misleading

Typical lifetime is ~8000h
Takes minutes to reach full power
Large lamps are most cost efficient
Established & well known

Improving the process and system life-time by dedicated control of spectrum and intensity with LEDs
LED opens new doors for horticulture lighting

LED Light is the efficient solution for Horticulture lighting - used to support, increase and enable the growth of plants by illuminating where and when needed:

- Top Lighting
- Inter Lighting
- Vertical Farming
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 influencing the growing, shape, development and flowering => photomorphogenesis of the plant. For the photosynthesis, the blue and red regions are most important. Get more details in a moment.

• **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.

For more info: see the sources: [0];[18]
Difference in absorption curves for photochemical reactions between the human eye and plants

Light is generating a photochemical reaction. In the eye, it reacts with our different photo receptors: version S, M, L. In plants, the light is reacting with Chlorophyll a and b.
Different regions of the wavelength in the illumination spectrum have different effects on the plants:

<table>
<thead>
<tr>
<th>Wavelength range [nm]</th>
<th>Photosynthesis</th>
<th>Further Effects</th>
<th>Further Effects</th>
<th>Further effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 – 280</td>
<td></td>
<td>Harmful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>280 – 315</td>
<td></td>
<td>Harmful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>315 – 380</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>380 – 400</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 – 520</td>
<td>Yes</td>
<td>Vegetative growth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>520 – 610</td>
<td>Some</td>
<td>Vegetative growth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>610 – 720</td>
<td>Yes</td>
<td>Vegetative growth</td>
<td>Flowering</td>
<td>Budding</td>
</tr>
<tr>
<td>720 – 1000</td>
<td>Germination</td>
<td>Leaf building and growth</td>
<td>Flowering</td>
<td></td>
</tr>
<tr>
<td>&gt; 1000</td>
<td></td>
<td>Converted to heat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [0]
Photosynthetic efficiency is mainly driven by Chlorophyll a and b

• Chlorophyll a and b
  Mainly responsible for 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]
Photomorphogenic effects are mainly influenced by Phytochromes Pr and Pfr

• Phytochrome Pr and Pfr

Phytochromes pr (red) and pfr (far red) mainly influence 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.
Today: Empiric focus in LED horticulture lighting on 450nm, 660nm and 730nm

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

![Wavelength spectrum diagram]

- Chlorophyll a
- Chlorophyll b
- Carotenoid
- Phytochrome Pr
- Phytochrome Pfr
- Deep Blue 450nm
- Hyper Red 660nm
- Far Red 730nm
Escaping the shadow - using far red 730nm

Plants react: One obvious influence of far red light on a plant is the active shade escape reaction.

**Illumination with 660nm:**
If the plant is illuminated mainly with 660nm it feels like illuminated in the direct sun and growth normally.

**Illumination with 730nm:**
If the plant is illuminated mainly with 730nm it feels like growing in the shadow of another plant that shades the sun light. Therefore the plant is reacting with an increased length growth to escape the shadow. This leads to taller plants – not necessarily impacting the cumulated bio mass.

Source: [0]
Special potential of LEDs in floriculture lighting
660nm and 730nm: Season Control

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.

Day & Night Cycle

Representing Daylight:
The cycle from Pr to Pfr is initiated by red light of 660nm

Representing Night:
Pfr is converted back to Pr.
This back conversion is actively influenced adding 730nm far red.

This enables a perfect control of the flowering timing independant of seasons.

Source: [0]
Control of the flower blossom: control the night length

It can make the flowers blossom in winter time or even prevent the blossoming in summer time. => Have the 730nm LED dimmable in the luminaire

Source: [0]
Background Knowledge Photon counting

Current method of weighing the spectrum is not adequate to actual plant absorption

<table>
<thead>
<tr>
<th>Situation today</th>
<th>More realistic approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>The whole spectrum is weighed equally by counting the photons in the photosynthetically active region (PAR)</td>
<td>Weighing the emission spectrum of the light source with plants' spectral sensitivity curve (“plm/W”)</td>
</tr>
<tr>
<td>Chlorophyll absorption spectrum</td>
<td>This curve is derived from the chlorophyll absorption spectrum taking into account internal energy transfer processes of the plant / leaves</td>
</tr>
</tbody>
</table>

Chlorophyll absorption spectrum

Plant sensitivity curve (DIN)*

* DIN 5031-10
One spectrum and 3 wavelength definitions: Peak - Centroid - Dominant

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

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

$\lambda_{\text{dom}}$ Dominant wavelength (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.
**Light level to apply - sorted by crop / plant / flower**

**Typical μmol/s.m² values for horticulture lighting**

<table>
<thead>
<tr>
<th>What light level for what type of crop?</th>
<th>What light level for what cut flower?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant</strong></td>
<td><strong>Plant</strong></td>
</tr>
<tr>
<td></td>
<td><strong>min μmol/s.m²</strong></td>
</tr>
<tr>
<td>Tomato</td>
<td>170</td>
</tr>
<tr>
<td>Pepper</td>
<td>70</td>
</tr>
<tr>
<td>Cucumber</td>
<td>100</td>
</tr>
<tr>
<td><strong>What light level for what potted plant?</strong></td>
<td><strong>What light level for what cut flower?</strong></td>
</tr>
<tr>
<td><strong>Plant</strong></td>
<td><strong>min μmol/s.m²</strong></td>
</tr>
<tr>
<td>Orchid/Phalaenopsis</td>
<td>80</td>
</tr>
<tr>
<td>Dendrobium</td>
<td>130</td>
</tr>
<tr>
<td>Bromelia</td>
<td>40</td>
</tr>
<tr>
<td>Anthurium</td>
<td>60</td>
</tr>
<tr>
<td>Kalanchoë</td>
<td>60</td>
</tr>
<tr>
<td>Potted chrysanthemum</td>
<td>40</td>
</tr>
<tr>
<td>Potted rose</td>
<td>40</td>
</tr>
<tr>
<td>Geranium</td>
<td>40</td>
</tr>
<tr>
<td>Orchid/Phalaenopsis</td>
<td>80</td>
</tr>
</tbody>
</table>

**Source**: [http://www.hortilux.nl/light-technology](http://www.hortilux.nl/light-technology)
# Effect of red light around 660nm on physiology of vegetables 1/3

<table>
<thead>
<tr>
<th>Plant</th>
<th>Radiation source</th>
<th>Effect on plant physiology</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indian mustard (Brassica juncea L.) Basil (Ocimum gratissimum L.)</td>
<td>Red (660 and 635 nm) LEDS with blue (460 nm) + 635 nm LED combination</td>
<td>Delay in plant transition to flowering as compared to 460 nm + 635 nm LED combination</td>
<td>[38]</td>
</tr>
<tr>
<td>Cabbage (Brassica olearacea var. capitata L.)</td>
<td>Red (660 nm) LEDS</td>
<td>Increased anthocyanin content</td>
<td>[33]</td>
</tr>
<tr>
<td>Baby leaf lettuce (Lactuca sativa L. cv. Red Cross)</td>
<td>Red (658 nm) LEDS</td>
<td>Phenolics concentration increased by 6%</td>
<td>[7]</td>
</tr>
<tr>
<td>Tomato (Lycopersicum esculentum L. cv. MomotaroNatsumi)</td>
<td>Red (660 nm) LEDS</td>
<td>Increased tomato yield</td>
<td>[39]</td>
</tr>
<tr>
<td>Kale plants (Brassica olearacea L. cv Winterbor)</td>
<td>Red (640 nm) LEDS (pretreatment with cool white light fluorescent lamp)</td>
<td>Lutein and chlorophyll a, b accumulation increased</td>
<td>[36]</td>
</tr>
<tr>
<td>White mustard (Sinapsis alba), Spinach (Spinacia oleracea), Green onions (Allium cepa)</td>
<td>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</td>
<td>Increased vitamin C content in mustard, spinach and green onions</td>
<td>[41]</td>
</tr>
<tr>
<td>Lettuce (Lactuca sativa ) Green onions (Allium cepa L.)</td>
<td>Red (638 nm) LEDS and natural illumination</td>
<td>Reduction of nitrate content</td>
<td>[40]</td>
</tr>
</tbody>
</table>

Source: [0]
## Effect of red light around 660nm on physiology of vegetables 2/3

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

Source: [0]
Effect of red light around 660nm on physiology of vegetables 3/3

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

Source: [0]
# Effect of blue light around 450nm on physiology of vegetables

<table>
<thead>
<tr>
<th>Plant</th>
<th>Radiation source</th>
<th>Effect on plant physiology</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cherry tomato seedling</td>
<td>Blue LEDs in combination with red and green LEDs, total PPF maintained at 300 μmol m⁻² S⁻¹</td>
<td>Net photosynthesis and stomatal number per mm² increased</td>
<td>[39]</td>
</tr>
<tr>
<td>Seedlings of cabbage</td>
<td>Blue (470 nm, 50 μmol m⁻² S⁻¹) LEDs alone</td>
<td>Higher chlorophyll content and promoted petiole elongation</td>
<td>[33]</td>
</tr>
<tr>
<td>(Brassica olearaceavar. capitata L.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinese cabbage</td>
<td>Blue (460 nm, 11% of total radiation) LEDs with red (660 nm) LEDs, total PPF maintained at 80 μmol m⁻² S⁻¹</td>
<td>Concentration of vitamin C and chlorophyll was increase due to blue LEDs applicatio</td>
<td>[32]</td>
</tr>
<tr>
<td>(Brassica campestis L.)</td>
<td>Blue (476 nm, 130 μmol m⁻² S⁻¹) LEDs</td>
<td>Anthocyanin (31%) and carotenoids (12%) increased</td>
<td>[7]</td>
</tr>
<tr>
<td>Baby leaf lettuce ‘Red Cross’</td>
<td>Blue (476 nm, 130 μmol m⁻² S⁻¹) LEDs</td>
<td>Anthocyanin (31%) and carotenoids (12%) increased</td>
<td></td>
</tr>
<tr>
<td>(Lactuca sativa L.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucumber ‘Bodega’ (Cucumis sativus) and tomato ‘Trust’ (Lycopersicon esculentum)</td>
<td>Blue (455 nm, 7-16 μmol m⁻² S⁻¹) LEDs with HPS lamp (400-520 μmol m⁻² S⁻¹)</td>
<td>Application of blue LED light with HPS increased total biomass but reduced fruit yield</td>
<td>[45]</td>
</tr>
<tr>
<td>Transplant of cucumber ‘Mandy F1’</td>
<td>Blue (455 and 470 nm, 15 μmol m⁻² S⁻¹) with HPS lamp (90 μmol m⁻² S⁻¹)</td>
<td>Application of 455 nm resulted in slower growth and development while 470 nm resulted in increased leaf area, fresh and dry biomass</td>
<td>[46]</td>
</tr>
</tbody>
</table>
### Effect of green light around 520nm on physiology of vegetables

<table>
<thead>
<tr>
<th>Plant</th>
<th>Radiation source</th>
<th>Effect on plant physiology</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red leaf lettuce <em>(Lactuca sativa L. cv Banchu Red Fire)</em></td>
<td>Green 510, 520 and 530 nm LEDs were used, and total PPF was 100, 200 and 300 ( \mu \text{mol m}^{-2} \text{ S}^{-1} ) respectively</td>
<td>Green LEDs with high PPF (300 ( \mu \text{mol m}^{-2} \text{ S}^{-1} )) was the most effective to enhance lettuce growth</td>
<td>[37]</td>
</tr>
<tr>
<td>Transplant of cucumber ‘Mandy F1’</td>
<td>Green (505 and 530 nm, 15 ( \mu \text{mol m}^{-2} \text{ S}^{-1} )) LEDs with HPS lamp (90 ( \mu \text{mol m}^{-2} \text{ S}^{-1} ))</td>
<td>505 and 530 nm both resulted in increased leaf area, fresh and dry weight</td>
<td>[46]</td>
</tr>
<tr>
<td>Red leaf lettuce <em>(Lactuca sativa L. cv Banchu Red Fire)</em></td>
<td>Green 510, 520 and 530 nm LEDs were used, and total PPF was 100, 200 and 300 ( \mu \text{mol m}^{-2} \text{ S}^{-1} ) respectively</td>
<td>Green LEDs with high PPF (300 ( \mu \text{mol m}^{-2} \text{ S}^{-1} )) was the most effective to enhance lettuce growth</td>
<td>[37]</td>
</tr>
<tr>
<td>Tomato ‘Magnus F1’ Sweet pepper ‘Reda’ Cucumber</td>
<td>Green (505 and 530 nm, 15 ( \mu \text{mol m}^{-2} \text{ S}^{-1} )) LEDs with HPS lamp (90 ( \mu \text{mol m}^{-2} \text{ S}^{-1} ))</td>
<td>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</td>
<td>[47]</td>
</tr>
<tr>
<td>Transplant of cucumber ‘Mandy F1’</td>
<td>Green (505 and 530 nm, 15 ( \mu \text{mol m}^{-2} \text{ S}^{-1} )) LEDs with HPS lamp (90 ( \mu \text{mol m}^{-2} \text{ S}^{-1} ))</td>
<td>505 and 530 nm both resulted in increased leaf area, fresh and dry weight</td>
<td>[46]</td>
</tr>
</tbody>
</table>

**Source:** [0]
Horticulture Lighting
Example LED light ratios for different purposes

<table>
<thead>
<tr>
<th>General purpose – high efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>LD Cxxx</td>
</tr>
<tr>
<td>LH Cxxx</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Vegetative Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>LD Cxxx</td>
</tr>
<tr>
<td>LH Cxxx</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Wavelength</th>
<th>mW Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD Cxxx</td>
<td>450nm</td>
<td>75%</td>
</tr>
<tr>
<td>LH Cxxx</td>
<td>660nm</td>
<td>25%</td>
</tr>
</tbody>
</table>

A high blue content in the spectrum is recommended for growth of the seedlings.

Source: http://www.illumitex.com/illumitex-leds/surexi-horticulture-leds/
A few System considerations…

- **Optics** – Homogeneous light is needed for even crop growth and efficient energy use.

- **Thermal** – Lighting should not cause plants to exceed optimal grow temperature.

- **Mechanical** – Slim and semitransparent fixtures use less space and allow natural sunlight to reach plants.

- **Quality** – Components with humidity robustness and fixtures with proper ingress protection are recommended.
## Horticulture Lighting - OSLON® Family – current versions

### Features

- 3 Different radiation angles: 80°, 120°, 150°
- EQ White to add green content
- High reliable ceramic package with superior lifetime and corrosion stability

### Applications

- Top Lighting, inter lighting and multilayer cultivation
- Urban Farming
- Algea Growth and agriculture lighting

### LED Portfolio

<table>
<thead>
<tr>
<th>LED Type</th>
<th>OSLON SSL</th>
<th>OSLON SSL</th>
<th>OSLON SSL</th>
<th>OSLON SSL</th>
<th>OSLON SQUARE</th>
<th>OSLON SSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Deep Blue</td>
<td>Hyper Red</td>
<td>Far Red</td>
<td>EQW</td>
<td>CRI 90 5,700 K</td>
<td>CRI 70 5,000 K</td>
</tr>
<tr>
<td>Wavelength</td>
<td>450 nm</td>
<td>660 nm</td>
<td>730 nm</td>
<td>-</td>
<td>5,700K</td>
<td>5,000K</td>
</tr>
<tr>
<td>Radiation Angle 80°</td>
<td>GD CS8PM1.14</td>
<td>GH CS8PM1.24</td>
<td>GF CS8PM1.24</td>
<td>LUW CR7P</td>
<td>GW CS8PM1.PM</td>
<td></td>
</tr>
<tr>
<td>Radiation Angle 120°</td>
<td>GD CSSPM1.14</td>
<td>GH CSSPM1.24</td>
<td>GF CSSPM1.24</td>
<td>LUW CQAR</td>
<td>GW CSSRM1.CC</td>
<td></td>
</tr>
<tr>
<td>Radiation Angle 150°</td>
<td>GD CSHPM1.14</td>
<td>GH CSHPM1.24</td>
<td>GF CSHPM1.24</td>
<td>LUW CRDP</td>
<td>-</td>
<td>GW CSHPM1.PM</td>
</tr>
</tbody>
</table>
Horticulture Lighting
OSLON® Family – improved & NEW versions

Key Features

- Efficacy upgrade with latest technology
  - 450nm: +5% lm/W
  - 660nm: +15% lm/W
  - 730 nm: +8% lm/W
- High reliable and high performance LED with superior corrosion robustness

Customer Benefit

- In preparation: 660nm 2mm²
- Footprint compatible OSLON family
- Info: Polarity 660nm and 730nm has changed compared to LH CP

<table>
<thead>
<tr>
<th>Values @ 25 °C</th>
<th>Binning current</th>
<th>Max. current</th>
<th>Viewing Angle</th>
<th>Typ. Radiant Flux</th>
<th>Typ. Radiant Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>GD CSxPM1.14</td>
<td>350 mA</td>
<td>1000 mA</td>
<td>80° &amp; 150°</td>
<td>690mW</td>
<td>2,48 µmol/J</td>
</tr>
<tr>
<td>GH CSxPM1.24</td>
<td>350 mA</td>
<td>1000 mA</td>
<td>80° &amp; 150°</td>
<td>425mW</td>
<td>3,08 µmol/J</td>
</tr>
<tr>
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OSLON® SSL Quality & Reliability 2/3
LH CPDP 800mA
OUTLOOK: What is next - Set the feedback loop!
Near IR spectroscopy may open new doors

Near-infrared spectroscopy (NIRS)
Detects molecular fingerprint of substances

Technology
- A broadband IRED with 700nm to 1050nm spectrum is used to illuminate a sample.
- The reflected light is received by a sensor.
- Based on the spectrum of the reflected light the molecular structure of the sample is analyzed

Why
- Measure the plant or blossom status
- Set the control to optimize the growing process

This opens new opportunities and new potential using a closed control loop in horticultural lighting

Effective definition of growth patterns condensed in dedicated algorithms for optimised plant growing.
Broadband IR emitter is a vital part of the control system

- Broadband IR emitter for IR spectroscopy
- Blue chip converted into broadband IR 700nm – 1050 nm
- Blue peak desired as indicator/target point
- OSLON black flat with ±60°
- New parts to follow: SFH 4736: with +/-45°

Samples available
OUTLOOK: Set the feedback loop:

- Analyse the growing process status of the plant
- Control the plant growing process by setting time / wavelength / intensity / additional process parameters
- Define optimized growing pattern to get optimized growing result
Invitation: Please have a look to the stand!

Thank you for your attention!
Appendix
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 $6.022 \times 10^{23}$ (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 photosynthesis 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 insufficient illumination which can be used for photosynthesis.
References


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References


References


Thank you.