Light regulation of plant form & function: towards full control of crop production

Prof dr Leo Marcelis

Head of chair group Horticulture & Product Physiology Physiology Wageningen University, The Netherlands.
Leo.Marcelis@wur.nl
Ever increasing control of production
Ever increasing control of production
Ever increasing control of production
Ever increasing control of production
An enormous yield increase

30 years:
- Yield doubled in many crops

Where is the limit?
Doubling possible!

- Cucumber +35%
- Tomato +113%
- Sweet pepper +90%
In 30 years yield doubled. Which part due to breeding? 0.9% per year (27% in 30 years)

Higashide & Heuvelink, 2009
Light use efficiency improved by:
- higher leaf photosynthesis
- deeper light penetration (less extinction)

Year of cultivar release

Higashide & Heuvelink, 2009
Greenhouses and Plant factories: precise control

- Precise control, but high energy demand for light
  - use light efficiently
  - choose light
  - balance light and other growth conditions
Light: many aspects

- Quanta → photosynthesis
- Energy → transpiration and heat
- Direction
- Spectrum
- Duration (day length)
- Timing

2014: Nobel prize for physics
Photosynthesis

$6 \text{CO}_2 + 6 \text{H}_2\text{O} \xrightarrow{\text{Light energy}} \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2$
More light $\rightarrow$ more growth

- Bigger plants
- Bigger inflorescence, with more flowers

$21^\circ C$

*Kalanchoe blossfeldiana*

$\mu$mol.m$^{-2}$.s$^{-1}$: 60 90 140 200
Light in greenhouses

- Use natural light (efficiently): it is for free!!
- High light transmission greenhouse
Direct and diffuse light
Direct or diffuse light

Direct light

Diffuse light
Tomato yield increases under diffuse light

Reference: clear glass
diffuse glass: 45, 62 or 71% haze
Coating: 50% haze (-5% transmission)
Contribution of different factors to increase in crop photosynthesis by diffuse light

Li et al. 2013
Potplants like more (diffuse) light

- Experiment on Anthurium
- In practice: 5 mol m\(^{-2}\) d\(^{-1}\) PAR
- When 7.5 mol m\(^{-2}\) d\(^{-1}\) plants ready in 16 instead of 22 weeks.
- Diffuse 10 mol \(\rightarrow\) additionally 20-30% larger plants

High light intensity: keep other growth factors in balance (RH, T, watering)
Lamps above and in between canopy

Hybrid lighting – HPS above, LED interlight

Dueck et al. 2010
Absorptance of leaves (rose cv Akito)

Young, reddish leaf
(2nd – 5th leaf)

Middle aged, green leaf
(5th -8th leaf)
Photosynthesis of leaves (rose cv Akito)

- Efficiency red leaves lower at 540-600 nm than green leaves
- Anthocyanins are probably screening the green light
Spectral effects on photosynthesis

Leaf photosynthesis: Spectral effects

Response crop ≠ single leaf

Assumption: crop consists of identical green leaves

Leaf: low absorptance green. Crop: more green absorptance
Red light: maximum photosynthesis → growing plants under red light?
Plants grown under different fractions of red and blue light (no other colours).

Measurement net photosynthesis in cucumber

Plants under solely red light → disturbed functioning of plants

LED: rapid gradual on/off switching
→ How does the plant respond?

Experiment: switching on all lamps simultaneously

Net Photosynthesis (µmol m⁻² s⁻¹)

1. RuBP regeneration
2. Rubisco activation
3. Stomatal opening

Time (hour:min)

Kaiser et al., 2014
Several photoreceptors in plants

![Image of photoreceptors and light spectrum]

- Perceived light: UV-B, UV-A, Blue, Green, Red, Far-red
- Photoreceptors: UVR8, Cryptochromes, Phototropins, ZTL, Phytochromes
Two states of phytochrome
Action spectrum photosynthesis and phytochrome

PSS = Phytochrome Stationary State = \frac{Pfr}{(Pfr + Pr)}
Chrysanthemum: short day plant
Can plants flower at long days?
By keeping PSS low?
15 hours light would enhance growth over 11 hours
Experiment

- *Chrysanthemum morifolium* cv. Zembla
- Four LED – light treatments, 100 $\mu$mol PAR $m^{-2}s^{-1}$, different wavelength distribution over the day

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Duration</th>
<th>Wavelength Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Day</td>
<td>11h</td>
<td>80% red / 20% blue</td>
</tr>
<tr>
<td>Long Day</td>
<td>15h</td>
<td>80% red / 20% blue</td>
</tr>
<tr>
<td>Long Day special</td>
<td>15h</td>
<td>SD(11h) + additionally 4h blue</td>
</tr>
<tr>
<td>Short Day Blue</td>
<td>11h</td>
<td>11h blue</td>
</tr>
</tbody>
</table>

4 Climate rooms (22°C, 65% RH, ambient [CO$_2$])

Van Ieperen et al.
# Duration to flower initiation (from start of treatment)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Day</td>
<td>(11h RB)</td>
</tr>
<tr>
<td>Long Day</td>
<td>(15h RB)</td>
</tr>
<tr>
<td>Long Day&lt;sub&gt;special&lt;/sub&gt;</td>
<td>(15h SD+4h B)</td>
</tr>
<tr>
<td>Short Day&lt;sub&gt;Blue&lt;/sub&gt;</td>
<td>(11h B)</td>
</tr>
</tbody>
</table>

- **Short Day** (11h RB) duration: 28-29 d
- **Long Day** (15h RB) duration: 60 d
- **Long Day<sub>special</sub>** (15h SD+4h B) duration: **28-30 d**
- **Short Day<sub>Blue</sub>** (11h B) duration: 28-29 d
Optimal day length.

Tomato: assumed to be day length neutral

Production related to total light sum, but at 14 hour more growth than at 18 hours day length
Too long day length: may disturb growth
Species and cultivar dependent.
A single gene (CAB-13) confers tolerance in tomato

Velez Ramirez et al. 2014
Nature communications
Spectral effects on morphology → determine effect on biomass
cucumber, 3 lamp types, climate room, 100 µmol m\(^{-2}\)s\(^{-1}\)

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Net Assimilation</th>
<th>Total Plant Dry Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS</td>
<td>4.9(^a)</td>
<td>611(^b)</td>
</tr>
<tr>
<td>FT</td>
<td>4.9(^a)</td>
<td>440(^c)</td>
</tr>
<tr>
<td>AS</td>
<td>4.5(^b)</td>
<td>1001(^a)</td>
</tr>
</tbody>
</table>

Hogewoning, Van Ieperen et al. 2010
Light spectrum strongly influences elongation (Petunia, growth chamber)

RB-LED 80/20     HPS     Solar (Plasma) light

Van Ieperen et al. 2010
The whole spectrum is relevant.
E.g. Effect of blue at background of solar light

Sole blue light $\rightarrow$ elongated plants
(suggests interaction between photoreceptors)

Kalaitzoglou et al., 2014, unpublished
Influence of light on leaf morphology

HPS | LED
Intumescence
when not correct spectrum
In particular far red and UV may help
Plant temperature

Cucumber

Day

Night

Tomato

$T_{tissue} - T_{air}$ (°C)

$T_{tissue} - T_{air}$ (°C)
Temperature apical bud deviates from air.

Exp: constant climate (PAR = 450 μmol m⁻² s⁻¹, T_air = 20°C, wind speed = 0.6 m s⁻¹), variable air humidity

Savvides et al 2013. Plant Cell Environm
Leaf temperature

Air temperature was 18°C

<table>
<thead>
<tr>
<th></th>
<th>Light Intensity (μmol m(^{-2}) s(^{-1}))</th>
<th>Leaf temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS</td>
<td>300</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>18.0</td>
</tr>
<tr>
<td>LED</td>
<td>300</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>17.2</td>
</tr>
</tbody>
</table>
Light affects diseases

- Red light at night (4 hours)

![Graph showing the effect of red light on mildew]

Hofland et al. 2012
Light on tomato fruit → more vitamin C

Two hypotheses

- Sugar availability
- Direct light effect
  - Electron transport
  - Light signalling: biosynthesis pathway

![Graph showing vitamin C levels in two tomato cultivars under control and LED conditions.](image)

Acta Hortic. 2012
Conclusions

- Control level is increasing → Crop production increasing
- Light has many aspects
  - Intensity
  - Direction
  - Spectrum
  - Heat (energy)
- All plant processes in control
  - Photosynthesis, growth, development
  - Quality
  - Disease
  - Health related compounds
- Light should be in balance with other growth conditions
Thank you for your attention