Light control with covering materials, screen and/or lamps for plant growth and quality control

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19th of November 2009, Chiba University

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Introduction

- In intensive horticultural cultivation the natural light levels often limit crop production during several periods → too low / too high

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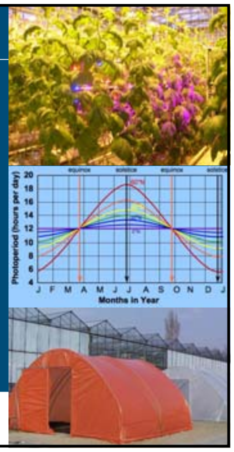
Introduction

- For an optimum plant production and product quality light intensity, light spectrum and photoperiod have to be adapted to the needs of the plants at every moment
- Covering, screen, lamp



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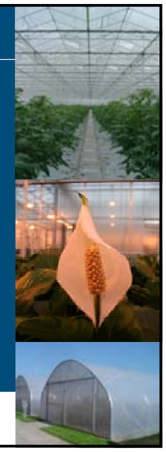
Outline

Light control by

1. Covering materials
   - More light
   - Diffuse light
   - Other spectrum
2. Screens
   - Screen less
   - Screen longer
   - NIR screening
3. Lamps
   - Traditional HPS
   - LED
4. Conclusions



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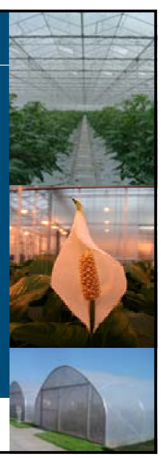
1. Covering materials



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More light

- Light intensity limiting factor in Northern latitudes, winter period
- 1% more light is 0.5-1% more production
- → depending on crop, season, other growth factors

Marcelis et al., 2006

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More light

More light by…

- Advanced covering material
  - White glass (+1-2%)
  - Modern coatings on glass (+5-8%)
  - New plastic films ETFE (+3%)
  - New surface structures (+5-8%)
- Lighter greenhoues construction (max +5%)
- Less installations (+1-3%)
- Roof angle (<1%)
- Greenhouse orientation
- Cleaning (up to 10%)

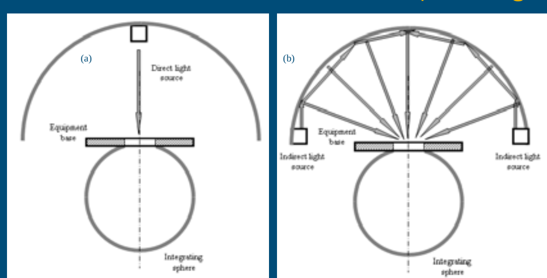
More light: covering materials

Clear sky → perpendicular; Clouded sky → hemispherical

Material	thickness	light transmission perpendicular	light transmission hemispherical
Floatglass	4 mm	89-90%	82%
White glass	4 mm	90-91%	83%
AR glass	4 mm	95-97%	89-90%
Diffuse glass	4 mm	90-91%	76-82%
PE / EVA films	200 µm	85-90%	78-82%
ETFE (F-Clean)	100 µm	93%	86%
PC sheet	12 mm	80%	61%
PMMA sheet	16 mm	89%	76%

More light: light measurement

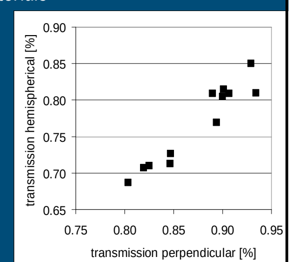
Measure hemispherical light



More light: plastic films

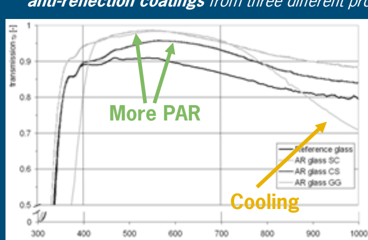
- PAR transmission different materials

Material	perpendicular	hemispherical
Producer 1-1 PE-EVA-film	89.0%	80.9%
Producer 1-2 PE-EVA film	89.4%	76.9%
Producer 1-3 PE-film +	82.0%	70.7%
Producer 2-1 PE-EVA-film	90.1%	81.5%
Producer 2-2 PE-EVA-film	84.7%	72.6%
Producer 2-3 PE-EVA-film	84.7%	71.3%
Producer 2-4 PE-EVA-film	80.3%	68.7%
Producer 2-5 PE-film	90.0%	80.5%
Producer 3-1 PE-EVA-film	82.5%	71.0%
Producer 3-2 PE-EVA-film	90.6%	80.9%
Producer 4-1 ETFE Film	92.9%	85.0%
Producer 4-2 ETFE Film	93.4%	81.0%



More light: modern coatings

- *Spectral transmission of glass with different* ***anti-reflection coatings*** *from three different producers (SA, CS, GG)*



- Increase of PAR by AR coating → Higher crop production
- Changed spectrum
- Possibilities for cooling
- Possibilities for energy saving with double materials

Hemming et al., Greensys 2009

More light: greenhouse design

- Increasing cover slope (South Europe)
- Minimized construction parts: e.g. no ventilation system: +1.5%
- Greenhouse orientation

Bakker et al., Greensys 2007

Diffuse light: background

Greenhouse covering materials are able to scatter light rays, transforming direct light into diffuse light

→ Better light penetration in high-grown crops

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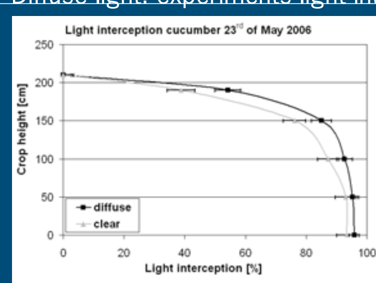
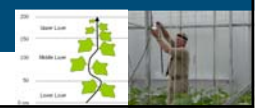
Diffuse light: experiments light interception



Hemming et al., 2007



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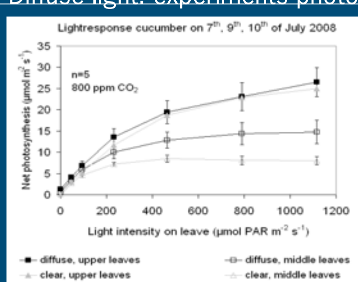
Diffuse light: experiments photosynthesis



Hemming et al., 2008

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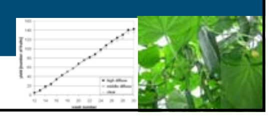
Diffuse light: experiment yield

		Low haze	High haze
Spring crop 2008	Kg/m²	+6.5%	+9.2%
	Nr/m²	+3.5%	+5.2%
Autumn crop 2008	Kg/m²	+8.8%	+9.7%
	Nr/m²	+5.3%	+6.1%

Dueck et al., Lightsym2009



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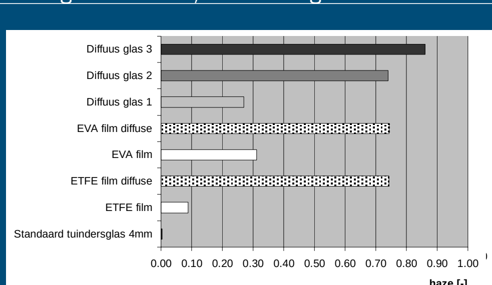
Diffuse light: materials, haze and light transmission



Be careful with light losses at high haze factors

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Hemming et al., 2008

Other spectrum: nets & screens

- Development of colored nets in order to reach desired physiological crop responses

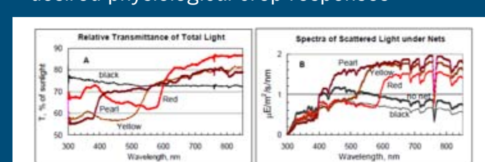

Fig. 1. Spectra of transmittance of total (direct+scattered) light (A), and spectra of scattered light intensity under the colored nets (B). The transmittance spectra were derived from spectra of total light under each net divided by the spectrum with no net. Total and scattered PAR intensity was 1894 and 295 (no-net), 1379 and 482 (Pearl), 1382 and 221 (black) µmol/m²/s/nm, respectively, measured at mid, clear day on 06/07.

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Shahak et al., 2008

Other spectrum: nets & screens

- Higher number of fruits results at comparable light intensity → changed light spectrum, more diffuse light

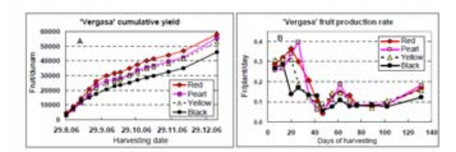
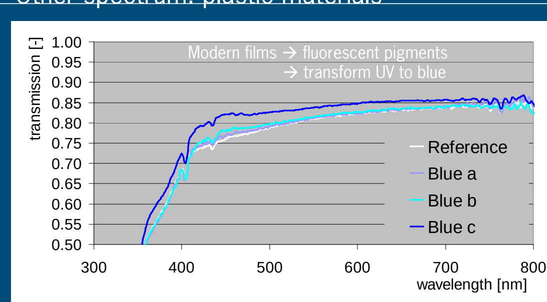


Fig. 2. Cumulative fruit yield (A, number of fruits harvested per 0.1 ha) and fruit production rate (B, # fruits/plant/day) in 'Vergasa' pepper under the colored vs. black net during the 2006 season at the Besor experimental station.

Shahak et al., 2008

Other spectrum: plastic materials



Spectrum changes are often combined with light reductions

EU-Spectrafoil

Hemming, 2006

Other spectrum: plastic materials

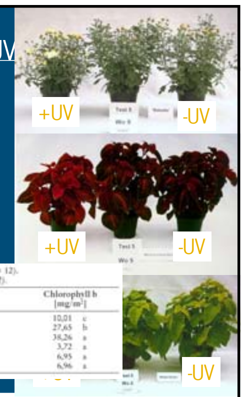
- Number of fruits - strawberry

EU-Spectrafoil

Hemming, 2006

Other spectrum: Non-visible UV

- UV also influences morphogenetic responses
- First experiments with different UV transmitting materials were carried out in 1996-1999:
  - Stem elongation
  - Coloring
  - Cholorophyll reduction



Tab. 3. Chlorophyllgehalte der Blätter von Coleus-Hybriden unter verschiedenen Folien (n = 12).
Chlorophyll contents of leaves of Coleus x hybrida cultivated under different plastic films (n = 12).

Sorte	Folie	UV-Transmission UVB	UVA	Chlorophyll a [mg/m²]		Chlorophyll b [mg/m²]	
'Wizard Velvet Red'	UV Plus	+	+	48,45	c	10,01	c
	Test 5	–	teils	96,27	b	27,65	b
	Test 6	–	–	125,75	a	38,26	a
'Golden Wizard'	UV Plus	+	+	27,51	b	3,72	a
	Test 5	–	teils	33,57	b	6,95	a
	Test 6	–	–	61,89	a	6,96	a

Hoffmann (Hemming), 1999

Other spectrum: Non-visible UV

- Higher production of strawberry under UV-blok films

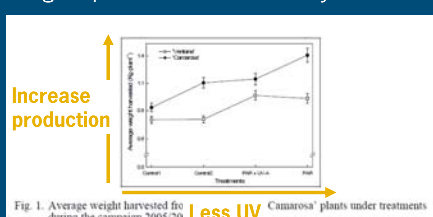


Fig. 1. Average weight harvested fr... during the campaign 2005/20... Camarosa' plants under treatments

Control 1 (common polyethylene film), Control 2 (film with high transmittance above 300 nm), PAR + UV-A (UV-B blocking film) and PAR (UV-B/A blocking film)

Casal et al., 2009

Other spectrum: Non-visible UV

- Better color of red lettuce under UV-transparant film → effect on anthocyanin, cyanidin 3-(6-malonyl) glucoside synthesis
- But lower fresh weight

Table 2. Mean color values: lightness, chroma, and hu... under 2 levels of light and 3 levels of ultraviolet ligh... +UV -UV

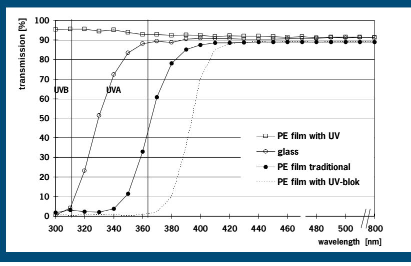
	Outside 100% light 100% UV	F-Clean + 50% shade... ...light ...UV	Lexan 100% light 0% UV
'Aruba' Oak Leaf	47.5, 31.9, 118.1	31.5, 8.01, 57.6	27.2, 5.2, 83.3
'Dark' Lollo Rossa	56.0, 41.7, 120.1	40.7, 16.8, 80.7	27.6, 10.9, 34.7
'Natividad' Red Lollo Rossa	58.7, 41.9, 119.0	34.3, 12.7, 71.8	27.0, 9.8, 21.2
'New Red Fire' Grand Rapids	54.5, 40.3, 117.4	33.4, 12.9, 82.0	27.8, 8.7, 30.6

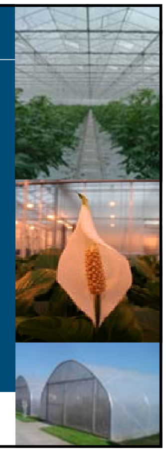
Mean values from 6 leaf measurements for each cultivar.

Shioshita et al., 2007

Other spectrum: covering materials

- UV transmission of different materials

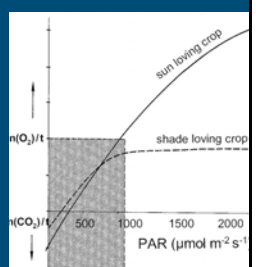




2. Screens

Screen less in summer

- During periods / In regions with high irradiation plants have to be protected against too much light
- However….
- More light (less screening) increases plant production even with potplants
- More light is possible if other climate factors are adapted:
  - High humidity level during daytime (80%)
  - Allow higher temperatures
  - Allow higher CO_2

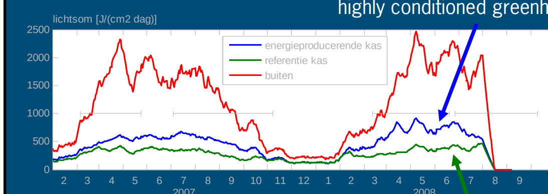


Gijzen, 1995

Screen less in summer

Lightsum (J/(cm² day))

more light
highly conditioned greenhouse



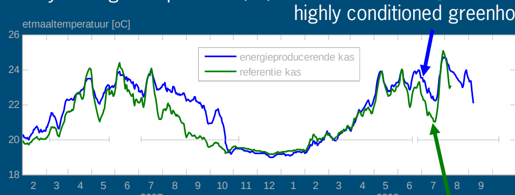
Reference

Van Noort, 2008

Screen less in summer

Daily average temperature (°C)

more light
highly conditioned greenhouse



Reference

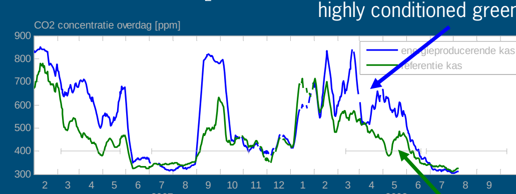
More light, higher temperature

Van Noort, 2008

Screen less in summer

Daytime average CO_2 level (ppm)

more light
highly conditioned greenhouse



Reference

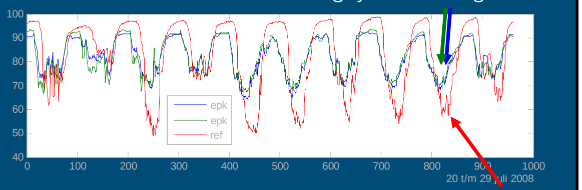
Highly conditioned greenhouse – less ventilation – more CO_2

Van Noort, 2008

Screen less in summer

Relative humidity in summer (%)

more light
highly conditioned greenhouse



Reference

Highly conditioned greenhouse – less variation in rh – more light possible without leave damage

Van Noort, 2008

Screen less in summer

Anthurium 'Saxo'

Areca

Left: highly conditioned greenhouse;
Right: reference

Screen more in winter

- Keep screen longer closed
  → energy saving (1.6 m^3/m^2/year)
  → small effect on production (-0.3kg/m^2/year)
  → higher humidity levels

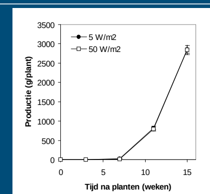
Table 1. Effects of screen opening criterion on the number of screening hours, RH, energy consumption, production and financial evaluation of energy costs (0.18 € m^{-3} gas) and production loss (0.90 € kg^{-1}; reference is opening at 1 W m^{-2}).

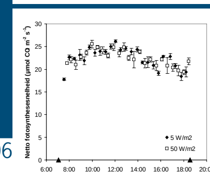
Screen open criterion (W m^{-2})	Screens closed (hours)	RH > set point (hours)	Gas consumption (m^3 m^{-2} $year^{-1}$)	Production (kg m^{-2} $year^{-1}$)	Energy costs-production loss (€ ha^{-1})
1	1673	156	39.6	61.86	-
2	1680	170	39.6	61.86	-
5	1718	168	39.4	61.86	360
10	1759	176	39.2	61.85	630
25	1853	175	38.8	61.80	900
50	1924	190	38.4	61.75	1170
100	2014	203	38.1	61.64	720
150	2049	214	38.0	61.57	270

Dieleman and Kempkes, 2006

Screen more in winter

- They also carried out an experiment:
- "Durinta" (ented)
- Planted 12 January 2004
- 2 treatments:
  - Screen open at irradiation of 5 W/m^2
  - Screen open at irradiation of 50 W/m^2
- Screen: SLS 10 Ultra plus
- End of experiment: 1 May 2004





Dieleman and Kempkes, 2006

Screens: Non-visible NIR

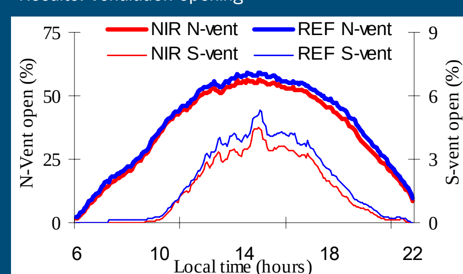
Experiment NIR-reflecting inside screen (800-1100 nm)
- Screen: 40% reflection of NIR energy
- Crop: 45% reflection of NIR radiation
- Installation parallel to roof

Greenhouse climate control:
- Temperature
- Artificial lighting (100 micro mol m^{-2} s^{-1})
- CO_2 injection (1000ppm)

Kempkes et al., 2008

Screens: Non-visible NIR

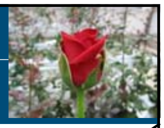
Results: ventilation opening

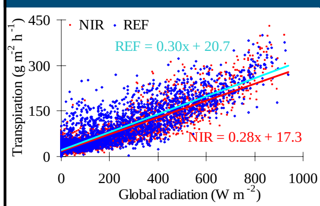


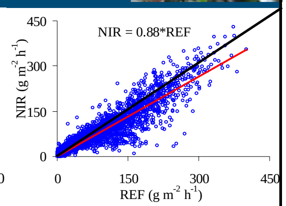
Kempkes et al., 2008

Screens: Non-visible NIR

Results: crop ranspiration







Transpiration VS global radiation outside

NIR VS REF transpiration

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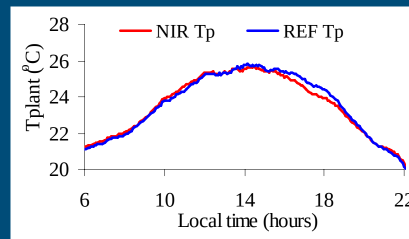
Kempkes et al., 2008

Screens: Non-visible NIR

Results: crop development



Slower crop development in NIR due to lower temperature in NIR

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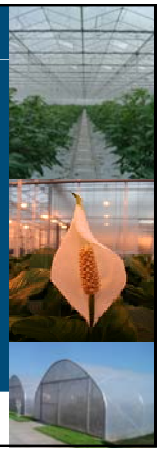
3. Lamps



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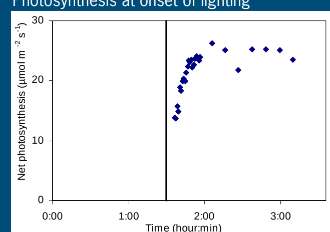
Traditional HPS: light intensity vs. duration

Photosynthesis at onset of lighting



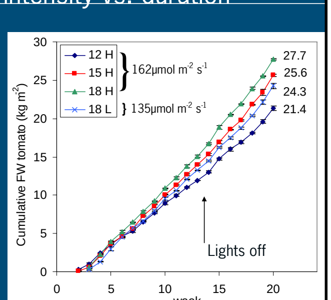
Start with half of artificial lighting
→ saves energy (k€25 d^{1} or M€3.75 $season^{1}$ Dutch greenhouse sector)

WAGENINGEN UR Productschap Tuinbouw

Dueck, 2006

Traditional HPS: light intensity vs. duration

- Highest production in 18 h lighting with high intensity
- Difference in production continues to end of light period + 6 weeks; thereafter similar
- Given the same light sum, a higher light intensity results in more production



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Dueck, 2006

Traditional HPS: light intensity vs. duration

Intensity > duration
(same light sum - to wk 20)

- Intensity: 18 L vs 18 H (135 vs 162 µmol m^{-2} s^{-1})
  - 8.4% more light
  - 14.0% more production
- 1% more light -> 1.7% more production
- Duration: 15 H vs 18 H (3 hours more)
  - 7.9% more light
  - 8.2% more production
- 1% more light -> 1.0% more production

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Dueck, 2006

Interlighting

- Interlighting
- Hypothesis: better utilization of the energy used for the lighting by giving part of the radiation to the middle/lower parts of the canopy
- (→ compare diffuse light)
- Comparison of interlighting with toplighting

WAGENINGEN UR — Gunnlaugsson and Adalsteinsson, 2006

Interlighting: HPS

- Interlighting with HPS
- Results in higher PPF in middle / lower in crop with increasing amount of interlight used

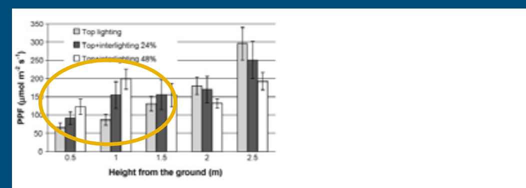


Fig. 3. Artificial photosynthetic photon flux (PPF) in each lighting regime at different heights near the plant row when all the lamps are on. Values represent sums of vertical and horizontal PPF ± standard deviation (n = 24).

WAGENINGEN UR — Hovi-Pekkanen and Tahvonen, 2008

Interlighting: HPS

- Results in higher yield and better quality, especially in spring, but not significantly in summer crop
- Here production in weight and numbers yearround

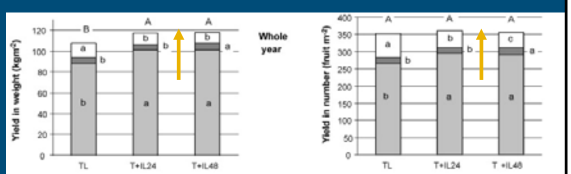


Fig. 4. Effect of lighting regime on yield grading at different times of the year. Different letters indicate significant differences (P < 0.05) lighting, T + IL24 = top + interlighting 24%, T + IL48 = top + interlighting 48%.

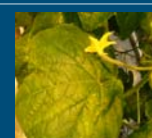
WAGENINGEN UR — Hovi-Pekkanen and Tahvonen, 2008

Trouwborst et al., Lightsym2009

Interlighting: LED

Absorbed light	Control (mol/m²/s)	%	Inter-lighting (mol/m²/s)	%
natural light	286	17.9	275	17.3
HPS light	1314	82.1	798	50.1
LED light			520	32.6
sum	1600	100.0	1593	100.0

Based on light absorption an equal light sum → advantage of increase in light absorption has disappeared due to leaf curling



WAGENINGEN UR — PHILIPS sense and simplicity — stw — Kas als Energiebron

LED: different systems

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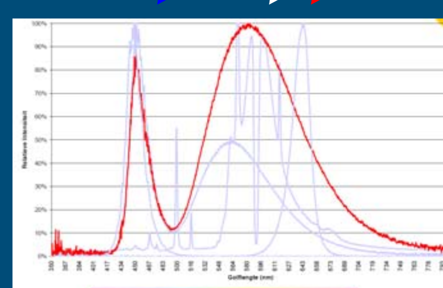
LED: spectrum

LED-blue — LED-warm white — LED-red



Reference: Hortilux Schréder, Sjaak Vergeer

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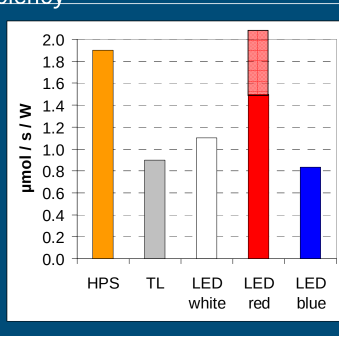
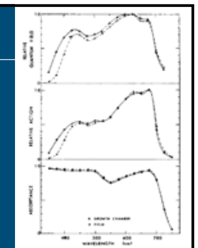
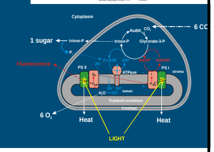
LED: efficiency



LED: photosynthetic efficiency

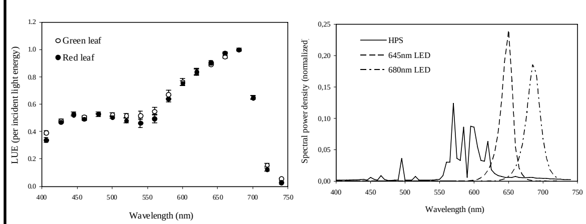
- Optimisation of LED on crops
- Technical: improve knowledge on action spectrum photosynthesis
- Crops: major Dutch greenhouse crops
- Energy: improvement of lighting efficiency (gram product per Watt) by > 10-15%





Snel, Hogewoning, van Ieperen et al.

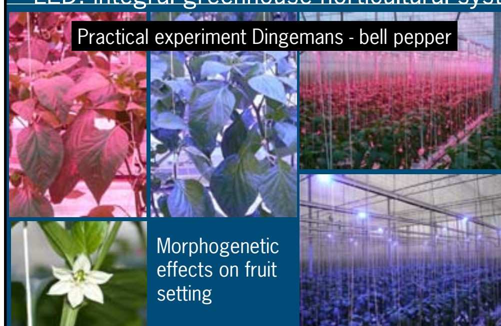
Rose (cv Akito): light energy use efficiency



	HPS		LED 645nm		LED 680nm	
Leaf Stage:	Green	Red	Green	Red	Green	Red
Light Use Efficiency:	100%	96%	136%	136%	128%	126%

Paradiso et al. Greensys 2009
Marcelis et al., this conference

LED: integral greenhouse horticultural systems

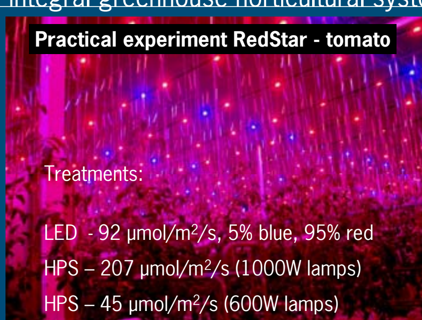


Red LEDs

Blue LEDs

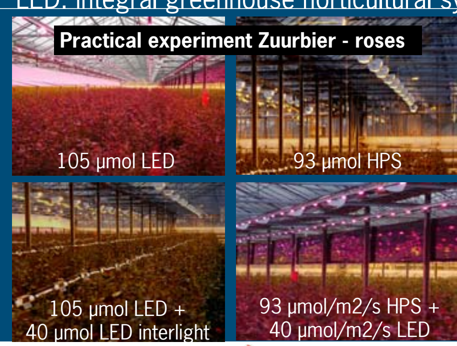
Nederhoff et al., 2009

LED: integral greenhouse horticultural systems



Nederhoff et al., 2009

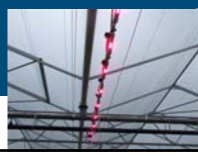
LED: integral greenhouse horticultural systems

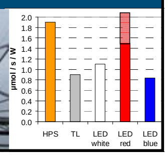


Dueck et al., Lightsym2009

LED: Conclusions

- Production (tomato, bell pepper, rose) under LEDs in practice is comparable or higher than under HPS
- Physiological / morphogenetical process control via spectra
- LEDs are different from HPS (colour, lower crop temperature)
- → "Learning to grow with LEDs" → new experiments
- Improvements of LEDs can be expected (energy-efficiency, colour, costs)
- Optimize LED within horticultural system





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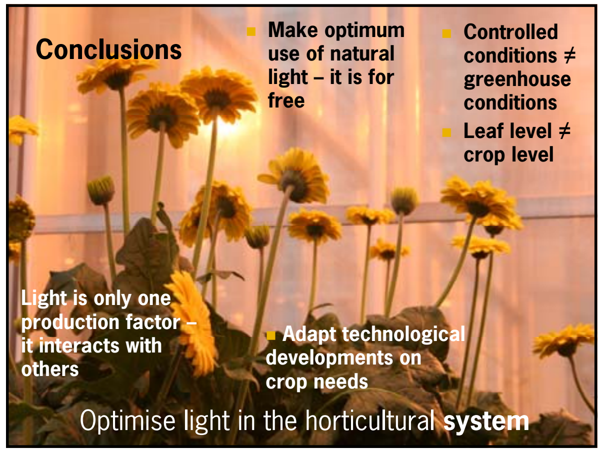

Wageningen UR Greenhouse Horticulture Innovations for and together with the horticultural sector

Thank you:
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