Diffuse Licht

Topfpflanzentag 14.01.2010, Straelen

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Background

- Vertical light distribution
  - Most light intercepted by upper leaves
  - Lower leaves contribute less to photosynthesis

Background

- Horizontal light distribution
  - Cast shadow from greenhouse construction elements
  - No uniform growth and development in greenhouse

Diffuse light = Scattered light

Objective

Research question:

- Do plant benefit if sunlight is scattered and re-distributed, so upper leaves intercept less, lower leaves more light?

Diffusing materials

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

50% 0%

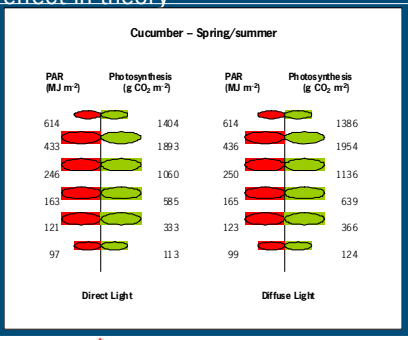
Haze

Natural Light Conditions

Month	Global radiation								
	Total [MJ m^{-2}]			Direct [MJ m^{-2}]			Diffuse [MJ m^{-2}]		
	De Bilt (NL)	Bari (I)	Tucson (USA)	De Bilt (NL)	Bari (I)	Tucson (USA)	De Bilt (NL)	Bari (I)	Tucson (USA)
Jan	162.6	202.4	342.3	12.8	86.7	247.4	49.7	115.6	94.9
Feb	104.7	211.2	383.5	20%	40%	70%	89.0	108.0	117.6
Mar	314.6	418.4	570.1				219.6	172.8	130.8
Apr	299.1	494.0	690.0	41.5	281.1	523.3	257.6	212.9	166.7
May	568.0	648.5	793.9	162.2	353.1	664.8	405.8	295.4	129.1
June	551.5	708.6	782.6	159.0	413.3	673.3	392.5	295.3	109.3
July	597.4	736.3	703.6	244.7	443.1	556.9	352.8	293.2	146.7
Aug	502.5	670.9	655.0	40%	60%	85%	354.4	245.5	165.5
Sep	342.3	446.5	581.7				218.3	186.1	128.4
Oct	163.7	332.8	501.4	37.9	173.4	384.8	125.8	159.4	116.6
Nov	89.9	237.0	367.8	26.0	108.8	269.7	63.9	128.2	98.1
Dec	54.0	222.2	315.4	14.4	81.9	230.3	39.7	140.3	85.1
Total	**3650**	**5329**	**6687**	**1081**	**2976**	**5198**	**2569**	**2353**	**1489**

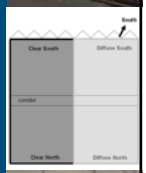
Breuer and Van de Braak (1989)
Heuvelink et al. (2003)
Rania and Giacomelli (2008)

Diffuse light effect in theory



Materials & Methods

- Clear/Diffuse, duplicated greenhouses
- Cucumber, 4 species potted plants
- Controlled and logged climate (temperature, humidity, radiation, light, CO_2, ventilation)



Materials & Methods

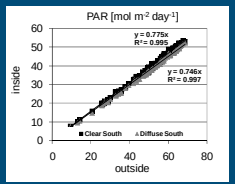
Light interception:
- In crop with sunscan system from Delta-T
- Different distances, crop heights
- Clouded and clear sky conditions

Crop observations:
- Destructives harvests (fresh and dry weight of stem, leaves, fruits in different crop layers, LAI)
- Photosynthesis in different crop layers
- Full light-response-curves
- SPAD, RuBisCo, Proteins
- Yield, growth rate

Results - Greenhouse climate

		Clear	Diffuse
Day	Air temperature [°C]	24.0	24.0
	Relative humidity [%]	72.1	73.2
	CO_2-concentration [ppm]	424.2	425.2
	Opening ventilation [%]	96.5	97.6

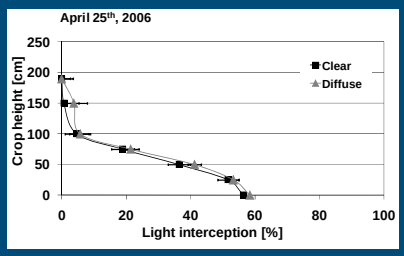
		North	South
Day	Air temperature [°C]	23.8	24.1
	Relative humidity [%]	69.3	76.0
	CO_2-concentration [ppm]	422.1	427.4
	Opening ventilation [%]	93.8	100.4



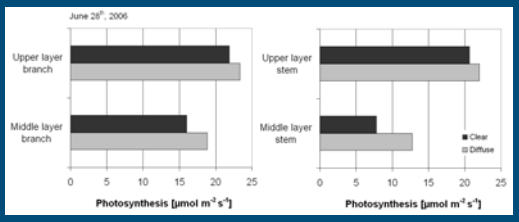
Equal climate between treatments, small differences North/South

3-5% less light under diffuse covering

Results: Light interception cucumber



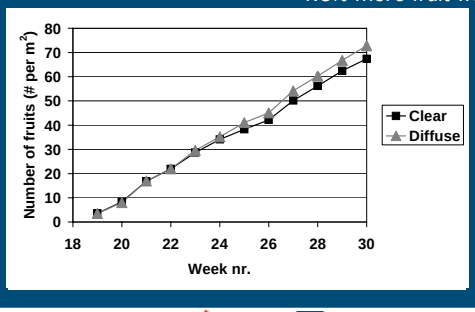
Results: Photosynthesis cucumber



Results: Yield cucumber

7.8% more fruits

4.3% more fruit weight

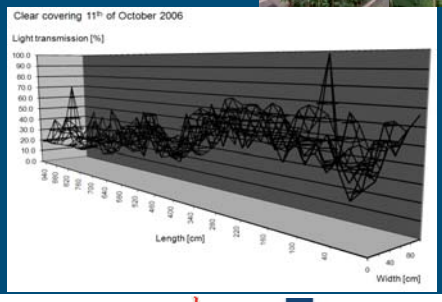


Conclusions

- Diffuse light is positive because…
  - Changed light penetration in crop
  - Diffuse light is absorbed more by middle leaf layers of cucumber
  - Higher photosynthesis in those leaf layers
  - Higher yield
- 1% light = 1% growth rule has to be re-defined
- Optimum diffusing properties have to be found

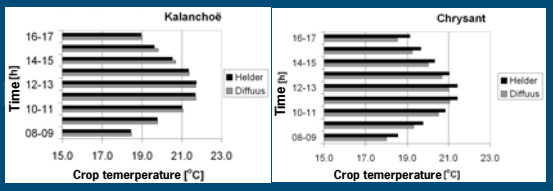
- Potplants

Results - Light distribution

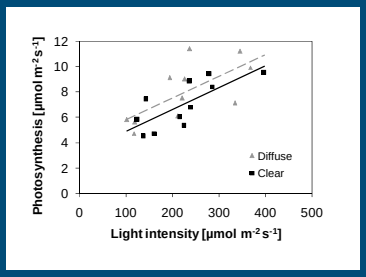


Results: Light distribution potplants

Results: Crop temperature



Results: Photosynthesis four potplants



Results: Growth chrysanthemum

	Week 41			Week 45		
	Clear	Diffuse		Clear	Diffuse	
Plant height [cm]	32.15	34.75	*	43.20	44.45	*
Number of branches [-]	4.50	5.50	*	4.90	4.85	ns
Number leaves [-]	71.0	93.2	*	78.2	88.7	*
Leaf area [cm^2]	900	1148	*	1175	1347	*
Leaf dry weight [g]	1.96	2.42	*	2.53	2.93	*
Stem dry weight [g]	1.39	1.78	*	4.31	5.00	*
SLA [m^2 g^{-1}]	-	-	-	0.047	0.046	ns
RGR [average g g^{-1} wk^{-1}]	0.56	0.70		0.94	1.06	
Number flowers [-]	-	-	-	27.4	30.7	*
Flower dry weight [g]	-	-	-	2.56	2.65	ns

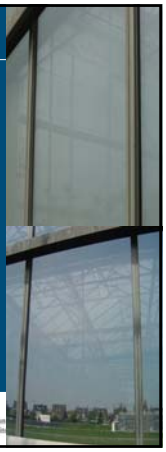
Results: Growth ficus

	Week 41			Week 49		
	Clear	Diffuse		Clear	Diffuse	
Plant height [cm]	39.2	41.1	*	64.1	63.0	ns
Number of branches [-]	9.25	9.95	**	12.8	13.0	ns
Number leaves [-]	31.5	34.0	ns	68.8	65.2	ns
Leaf area [cm^2]	496	532	**	1340	1247	**
Leaf dry weight [g]	2.02	2.11	ns	5.66	5.06	*
Stem dry weight [g]	0.93	0.92	ns	3.38	3.21	ns
RGR [average g g^{-1} wk^{-1}]	0.49	0.51		0.65	0.59	*
SLA [m^2 g^{-1}]	-	-	-	0.024	0.025	ns

Conclusions

- Diffuse light is positive because…
  - Changed light distribution in crop
  - Diffuse light is absorbed better than direct light
  - Higher photosynthesis under diffuse light
  - Lower crop temperature (chrysanthemum)
  - Higher growth rate
- Lower light transmission of covering material negative in winter
  → choose material without light loss

- Covering materials



Objectives

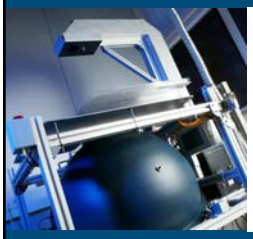
Research questions:

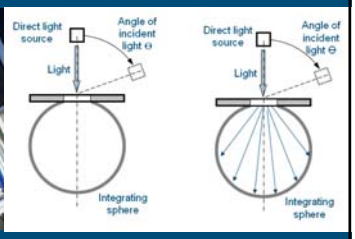
- Optical properties of available diffuse materials
- Simple method to characterise diffuse materials and impact on crop

Measurement method

- Optical properties measured:
  - Total transmission for photosynthetic active radiation (τ_{PAR}) in the range of 400-700nm
  - Light incidence on sample: perpendicular (τ_p) (NEN 2675)
  - Light incidence on sample: hemispherical (τ_h) (no norm!)
    → measured = calculated
  - Amount of scattered light by sample: haze (η_{PAR}) (ASTM D1003-07)

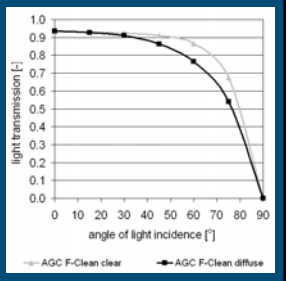
Measurement method





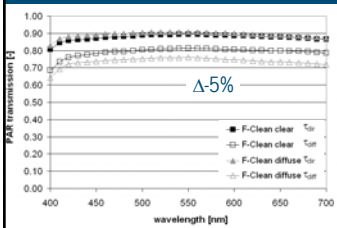
Measurement method

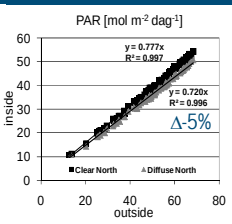
- Hemispherical light consists of light under all angles of incidence
- In average all angles occur on greenhouse, even in areas with a lot of direct light



Groglass 2008

Reesults: Greenhouse covering material





Perpendicular and hemipherical light transmission of diffuse and clear covering

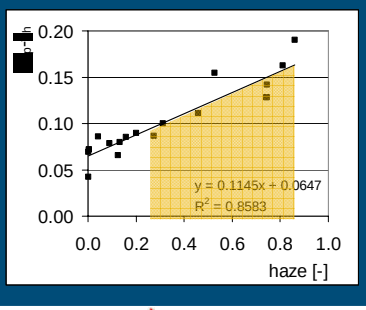
Measurements of daily PAR integral in- and outside experimental greenhouses with diffuse and clear covering Apr.-Sep. 2006 in NL

Measurement method

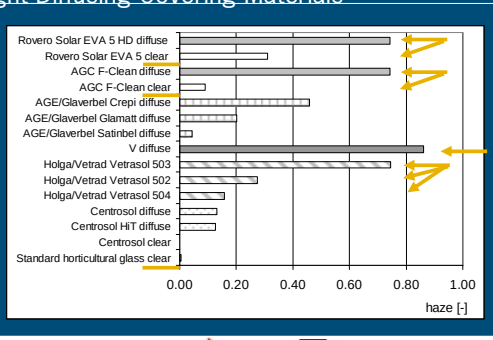
- Transmission for perpendicular light τ_p is no suitable measure for diffuse materials!
- Transmission for hemispherical light τ_h correlates in average well with light conditions in greenhouse

→ Transmission for hemispherical light τ_h and haze η to characterise diffuse materials

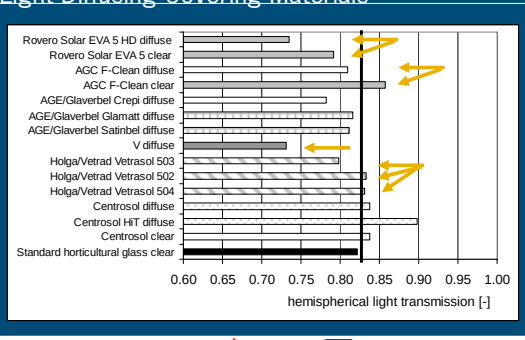
Light Diffusing Covering Materials



Light Diffusing Covering Materials



Light Diffusing Covering Materials



Light Diffusing Covering Materials

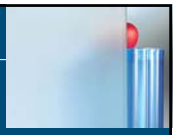
- Light loss and diffusing properties depend on surface structure or pigments added
  - Regular pattern (e.g. pyramides)
  - Irregular pattern
  - Macro-, micro-, nanostructures
  - Diffusing pigments
- Surface treatments often become clear if wet, materials with pigments remain diffuse

Light Diffusing Covering Materials

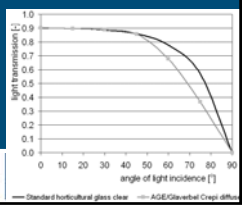
- Irregular wavy microstructure on surface
  - E.g. Centrosol diffuse, AGE/Glaverbel Glamatt, Hogla/Vetrad Vetrasol 504
- → small haze (up to 15%)
- → minor light loss (0-3%)

Foto up AGC Solatex, 2008
Foto down AGC Satinbel, 2008

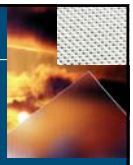
Light Diffusing Covering Materials



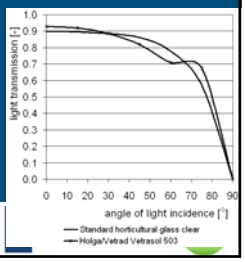
- Sandblasted or chemical treated glasses
  - E.g. V diffuse
- Very high light diffusion (>50%)
- Often high light losses (>5%)



Light Diffusing Covering Materials



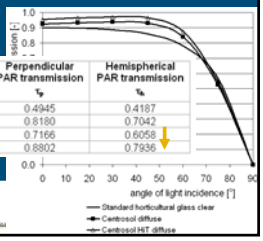
- Regular structure (e.g. micro-pyramides)
  - E.g. Vetrasol 503
- → good combination of high haze and low light loss



Future perspectives

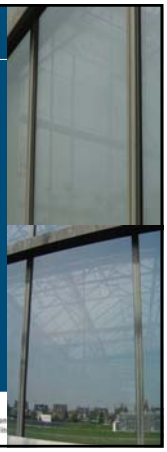
- Potentials for increase light transmission:
  - Basis glass: low-iron
  - Treatment of regular or irregular micro-structures with anti-reflection nano-structures
- Temporal coatings

Type	Product	Haze η	Perpendicular PAR transmission τ_p	Hemispherical PAR transmission τ_h
coating	Hermadix coating (1.3) dry	0.8716	0.4945	0.4187
coating	Hermadix coating (1.3) wet	0.5589	0.8180	0.7042
coating	Hermadix coating (1.7) dry	0.6849	0.7166	0.6058
coating	Hermadix coating (1.7) wet	0.1724	0.8802	0.7936

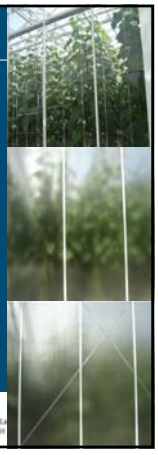


Conclusions

- Diffuse materials can be characterised by
  - haze η
  - hemispherical light transmission τ_h
- Materials with weavy structure or special regular patterns (like micro-pyramides) combine high light transmission and high haze
- → better materials can be developed with additional coatings
- → costs?
- → cleaning?



- Microclimate and crop morphology

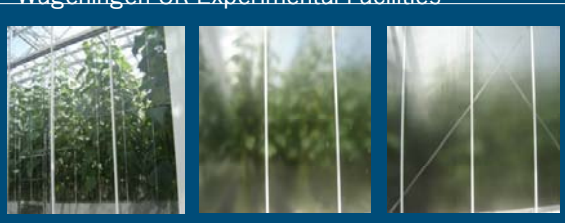


Objectives

Research questions:

- What is the relationship haze ~ light transmission?
- What is the effect of different haze factors on greenhouse climate and therfore on production?

Wageningen UR Experimental Facilities



	Control	Low haze	High haze
Haze	0%	30%	70%
Transmission	83%	83%	80%

Cucumber – first high wire crop

- Febr 15 to July 20
- Greenhouse climate
- Crop growth
- Crop physiology
- Production

Greenhouse climate: air temp, sunny days

	Temperature (°C)	Humidity (%)
Control	29.8	59.2
Low haze	29.4	59.7
High haze	29.1	60.8

Greenhouse climate: leaf temp, sunny days

	head	High in the crop	Low in the crop
Control	34.5	34.8	25.4
Low haze	32.8	34.4	24.7
High haze	32.4	33.7	24.6

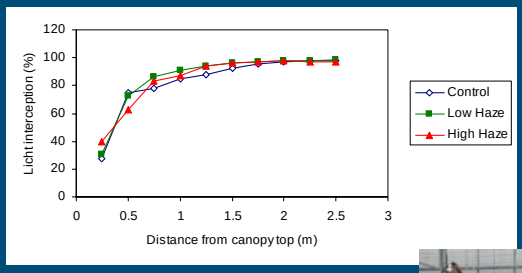
Crop growth - stem

	Stem length (cm/wk)	Stem diameter (mm)
Control	71	8.5
Low haze	67	8.8
High haze	68	8.7

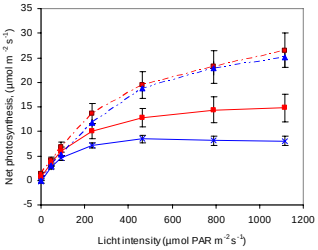
Crop growth - leaves

	Leaf develop-ment (#/wk)	LAI (m2/m2)	SLA (cm2/g)
Control	6.1	4.6	344
Low haze	5.7	4.2	338
High haze	5.9	4.1	322

Crop growth - Light interception



Crop growth – photosynthesis capacity

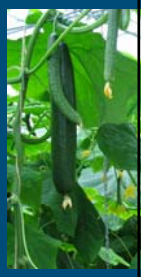


Production – time of flowering to fruit harvest

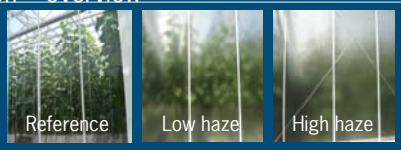
	Wk 19-21 (days)	Wk 24-26 (days)
Control	15.5	16.3
Low haze	15.2	15.9
High haze	14.6	15.9

Production – fruit weight and number

	Fruit weight (g)	Production (kg/m2)	Production (#/m2)
Control	401.3	54.4	135.9
Low haze	412.4	57.9 (6.5%)	140.6 (+3.5%)
High haze	417.0	59.4 (9.2%)	142.9 (+5.2%)



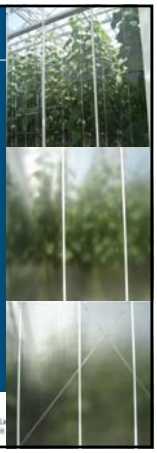
Production – overview



		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%

Conclusions

- Diffuse light resulted in:
  - Milder greenhouse climate on sunny days
  - Lower head temperature during high irradiation
  - Changes in crop morphology
- Roof materials with higher haze increase production
- → high light losses might be negative in winter



Covering vs. Screen

	Covering	Screen
Advantage in summer	++	++
Advantage in spring/autumn	++	+
Advantage in winter	-/o	+
Controllable	-/o	+
Light intensity on crop level	o/+	>-15%

e.g. Cucumber: no screens necessary with diffuse covering

e.g. Potplants: diffuse screens in combination with (high) shading

Wageningen UR Glastuinbouw
Innovations in Horticulture

Special thanks for my collegues
Tom Dueck, Jan Janse, Filip van Noort