UNIVERSITY OF THESSALY
School of Agricultural Sciences

N. R. Rigakis

"Theoretical and Experimental Investigation of Microclimate in Screenhouses"

PhD Dissertation

Volos-N. Ionia, July 15, 2015

Advisory committee

Constantinos Kittas, Supervisor University of Thessaly	Professor Agricultural Constructions
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ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
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Examination committee

Constantinos Kittas University of Thessaly	Professor Agricultural Constructions
Dimitrios Briassoulis Agricultural University of Athens	Professor Agricultural Constructions
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Dr. Thomas Bartzanas Centre for Research and Technology-Hellas	Senior Researcher Agricultural Engineer

Introduction

Introduction

- **Screenhouses**
  - Low cost but cost effective agricultural constructions
  - Protection against extreme climatic conditions

    (solar radiation, high wind, pests)

    Reduce irrigation water and pesticide inputs

- **Screened crops areas:**
  - Screenhouses Israel ≈ 2500 ha
  - Screened crops Greece (horizontal screens) ≈ 400 ha

- **Agricultural screens/nets**
  - Geometrical characteristics
  - Optical properties

  } Create the underneath environment

Screen & Screenhouse effect on microclimatic parameters

- **Reduce of solar radiation:**
  - Optical and geometrical characteristics of the screen/net
  - Type of supporting structure
  - Sun position (construction site)
  - Dust accumulation
- **Mixture of (i) natural light (freely passes through the holes) and (ii) modified light (passes through the thread material):**
  - Scattered light (porosity & color)
  - Optical modification of radiative environment (color or additives)
- **Reduce of air velocity and air exchange rate:**
  - Reduced as compared to the theoretical of an open field
  - Increased as compared to that of greenhouses

Screen & Screenhouse effect on microclimatic parameters

- **Air temperature and humidity** (barrier on the mommentum, heat and mass freely transfer)

- **Crop temperature and crop-to-air vapor pressure deficit**

Screen & Screenhouse effect on crop performance

- **Reduces ETc and crop water demands**
- **Reduces photoinhibition**
  - Photosynthetic performance is not decreased
  - No carbon waste for repairing photo-damages
- **Photosynthesis *vs* diffuse radiation**
  - Reduce canopy temperature and $VPD_{c\text{-}air}$, increasing stomatal conductance
  - Enhances photosynthesis
- **Light spectral quality on crops**
  - Photomorphogenesis
- **Increase productivity and quality of yield**
- **Increase of WUE and RUE**

Needed investigation

Lack of:

- **reports for suitability of different screen:**
  - **under various regional climatic conditions**
  - **for different crops**

- **a tool to predict air ventilation rate (and the internal microclimate) with respect to the ambient climatic conditions, the construction and the screen characteristics.**

- **a tool to predict crop productivity with respect to the screen properties and the regional climatic conditions**

Aim of the study

Investigate the influence of screens/nets properties (optical & geometrical) on screenhouse microclimate and its impact on the covered crops.

Detailed objectives of the present research:

- Characterization of screenhouse/crop microclimate.
- Measurements and modeling of ventilation performance of screenhouses
- Measurements and modeling of crop performance inside screenhouses

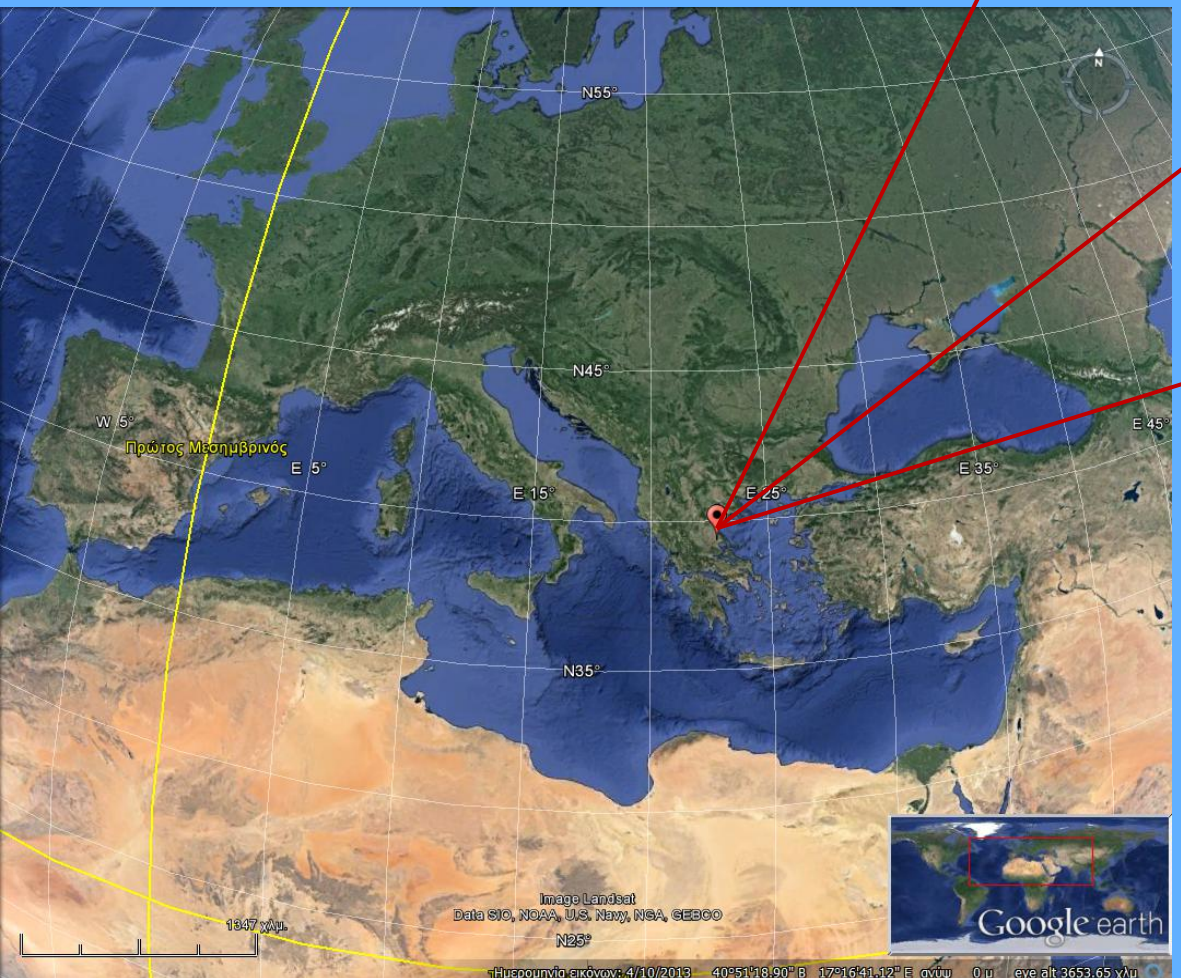
A practical aim of the present study is the

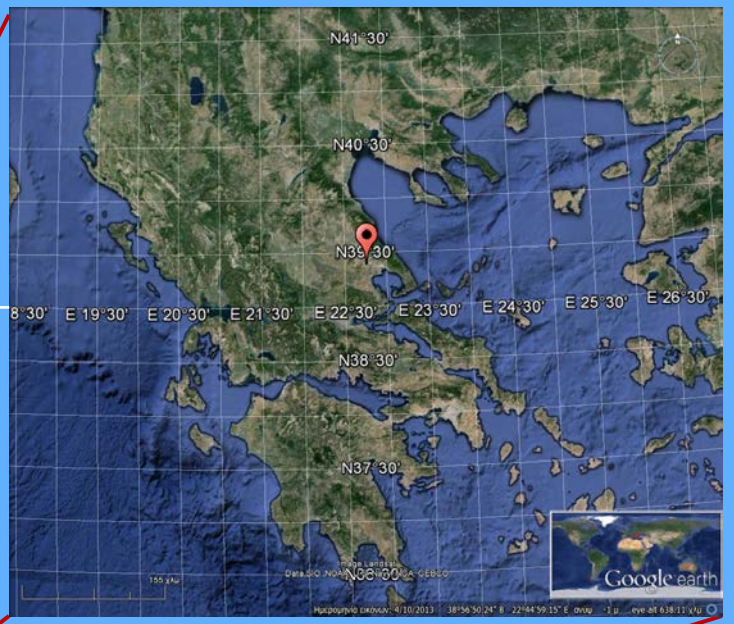
proposal of a tool for the best possible choice of a suitable covering screen

with respect to the local climatic conditions and crop.

Materials & Methods

Experimental Site





Velestino

Continental Eastern Greece

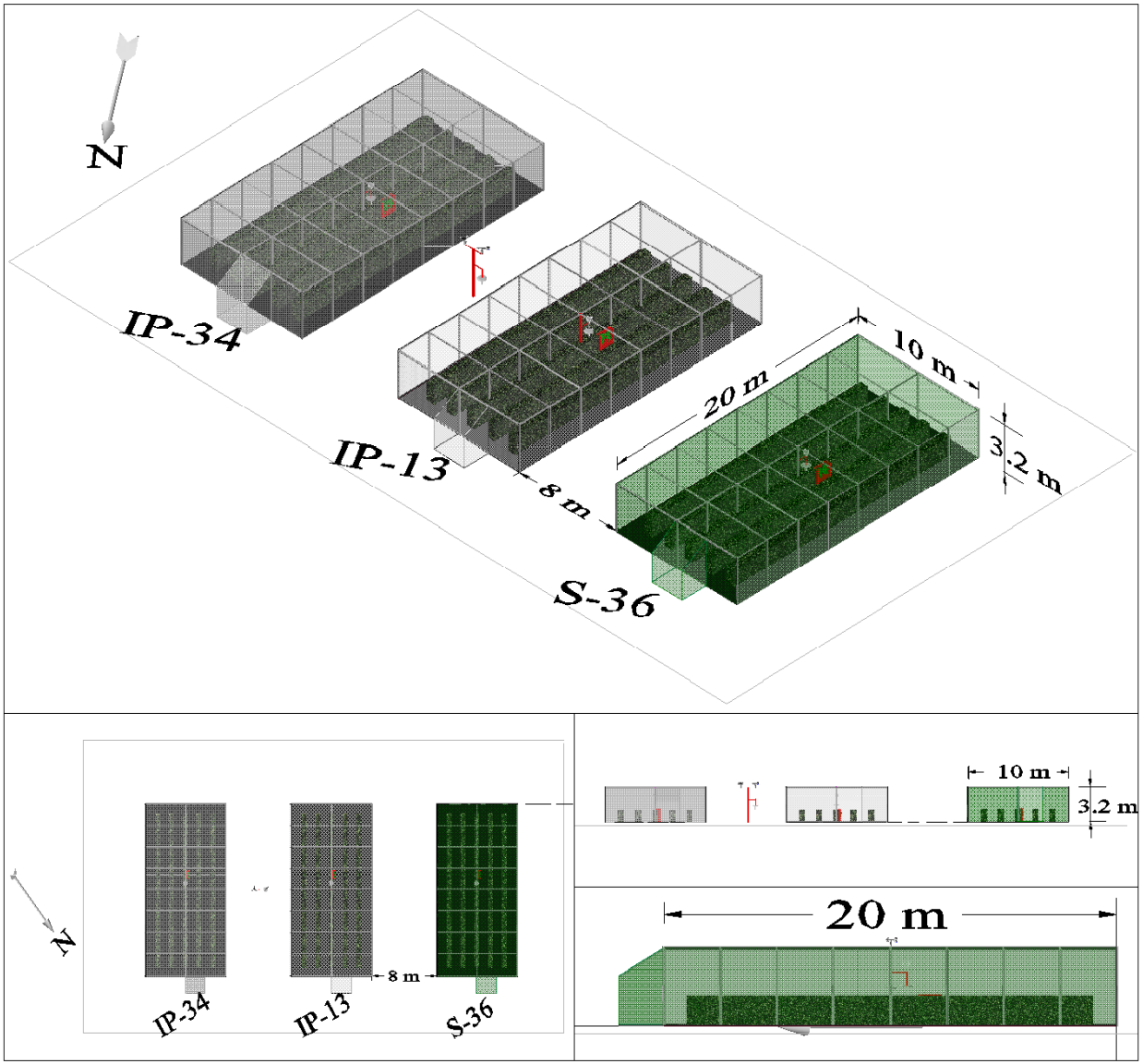
16 km from Volos (Coastal city)

- Latitude: 39.395º
- Longitude: 22.758º
- Altitude: 79 m

Experimental facilities

Experimental farm of the University of Thessaly

Experimental facilities



Screen geometrical characteristics

IPs (Meteor Ltd., Israel)

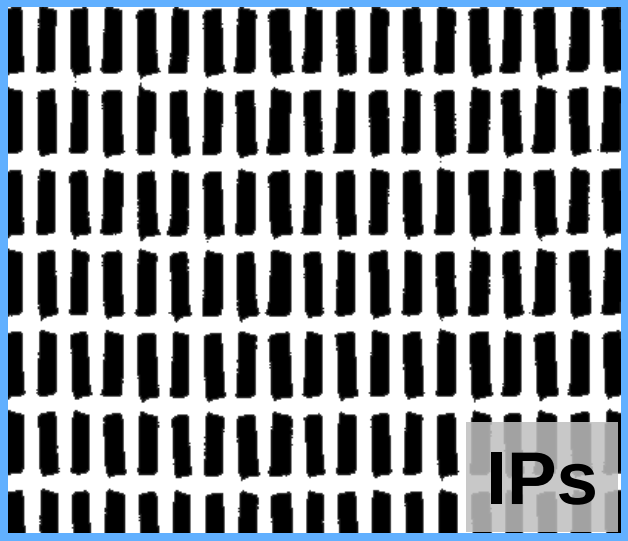
50-mesh

Porosity: 0.46

Hole size: 0.75 x 0.25 mm

Thread diameter: 0.24 mm

Thickness: 0.48 mm



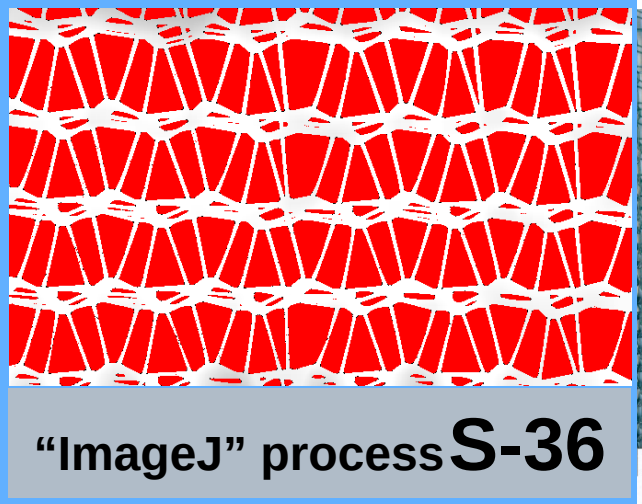
S-36 (Thrace Plastics Co S.A., Xanthi, Greece)

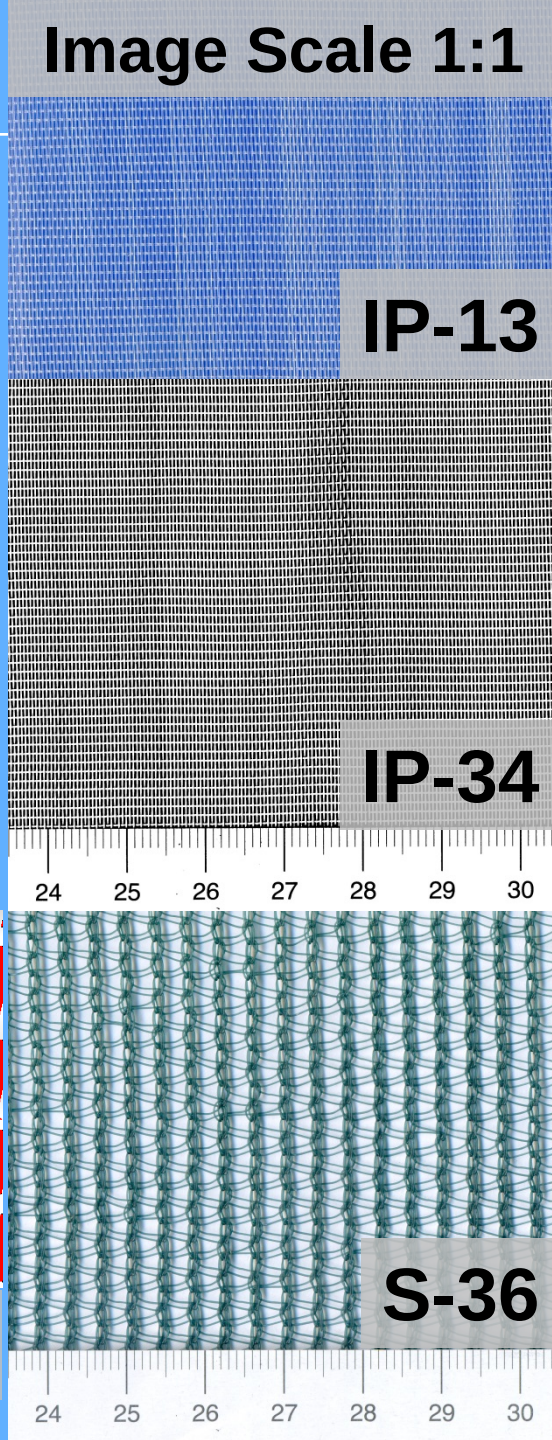
Complex texture (weave) → No mesh #

Porosity: 0.63

Thread diameter: 0.25 mm

Thickness: 0.80 mm



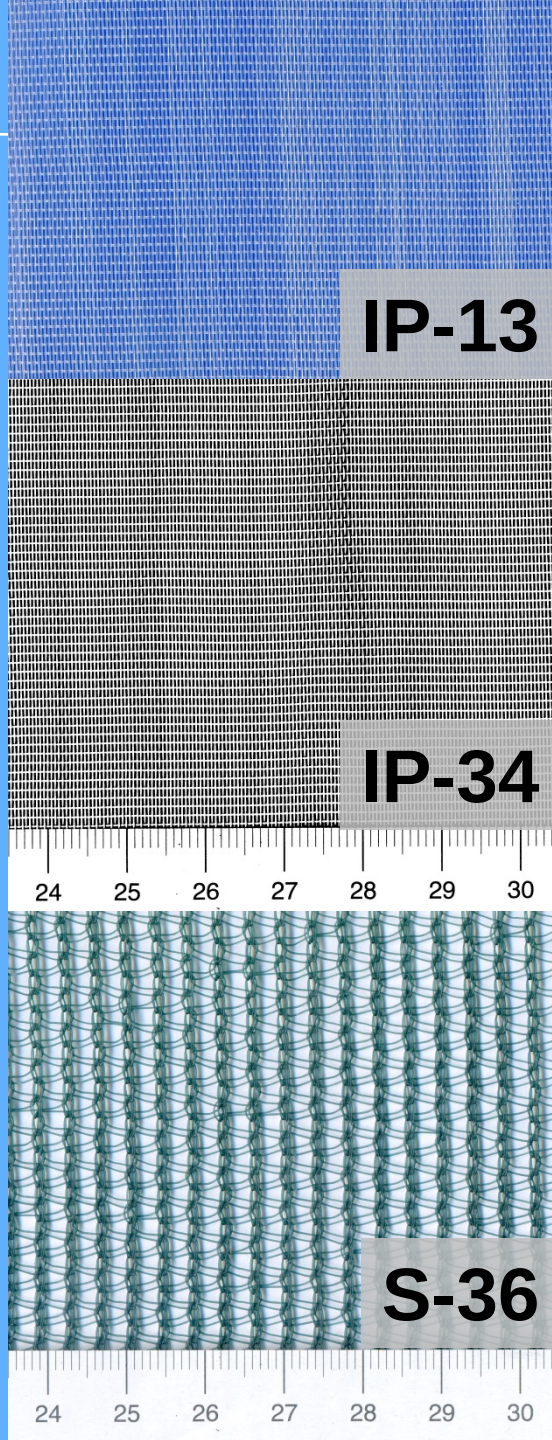


Screen optical properties

IP-13 (AntiVirus™)
Clear (transparent)
Mean light transmittance in lab (350-1100 nm) ≈ 87%
Nominal shading factor ≈ 13%

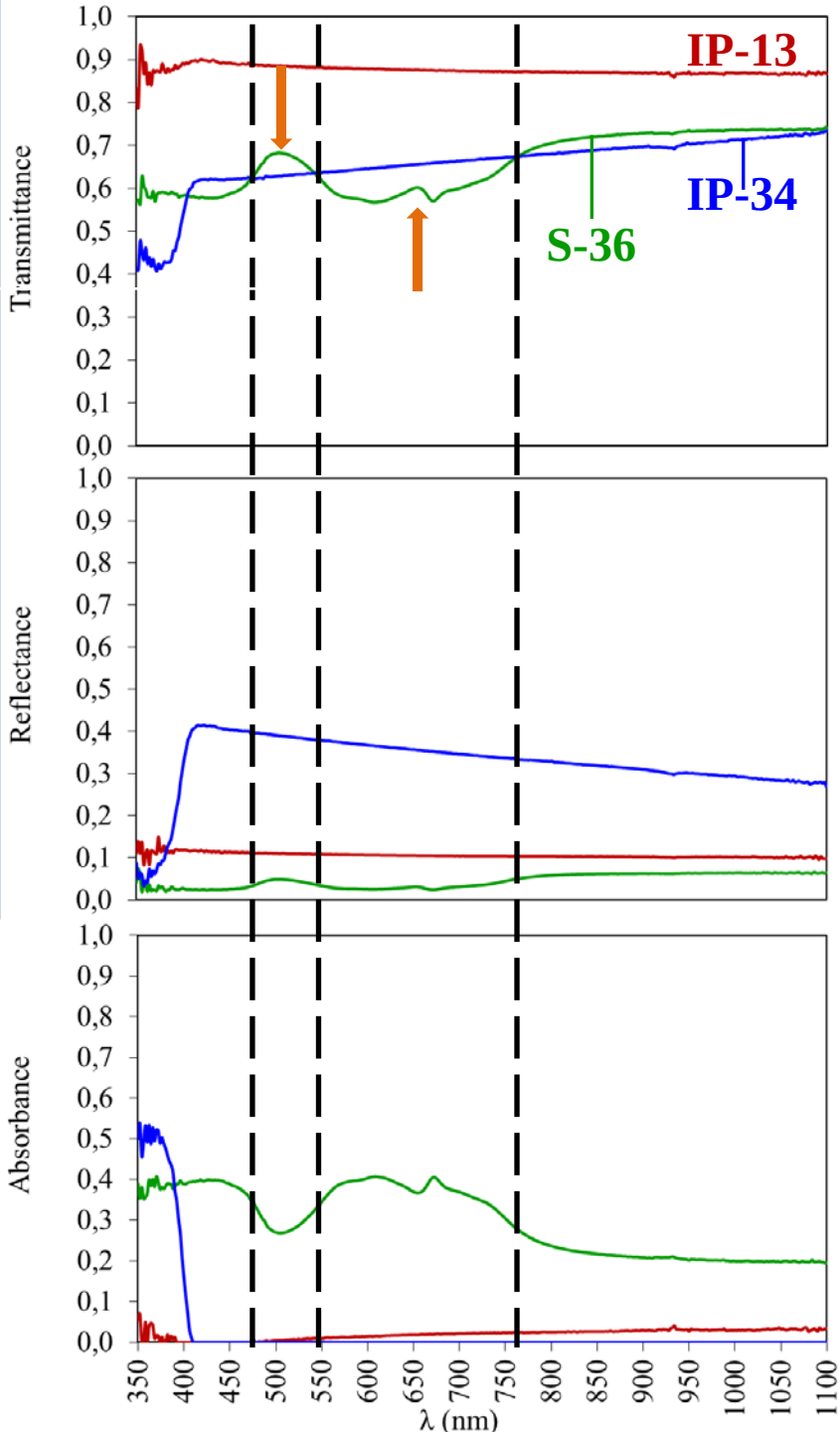
IP-34 (BioNet™)
White (opaque)
Mean light transmittance in lab (350-1100 nm) ≈ 66%
Nominal shading factor ≈ 34%

S-36
Green (semi-transparent)
Mean light transmittance in lab (350-1100 nm) ≈ 64%
Nominal shading factor ≈ 36%



Screen optical properties

Screen	τ	r	a	NSF
IP-13	0,87	0,11	0,02	0,13
IP-34	0,66	0,34	0,00	0,34
S-36	0,64	0,04	0,32	0,36

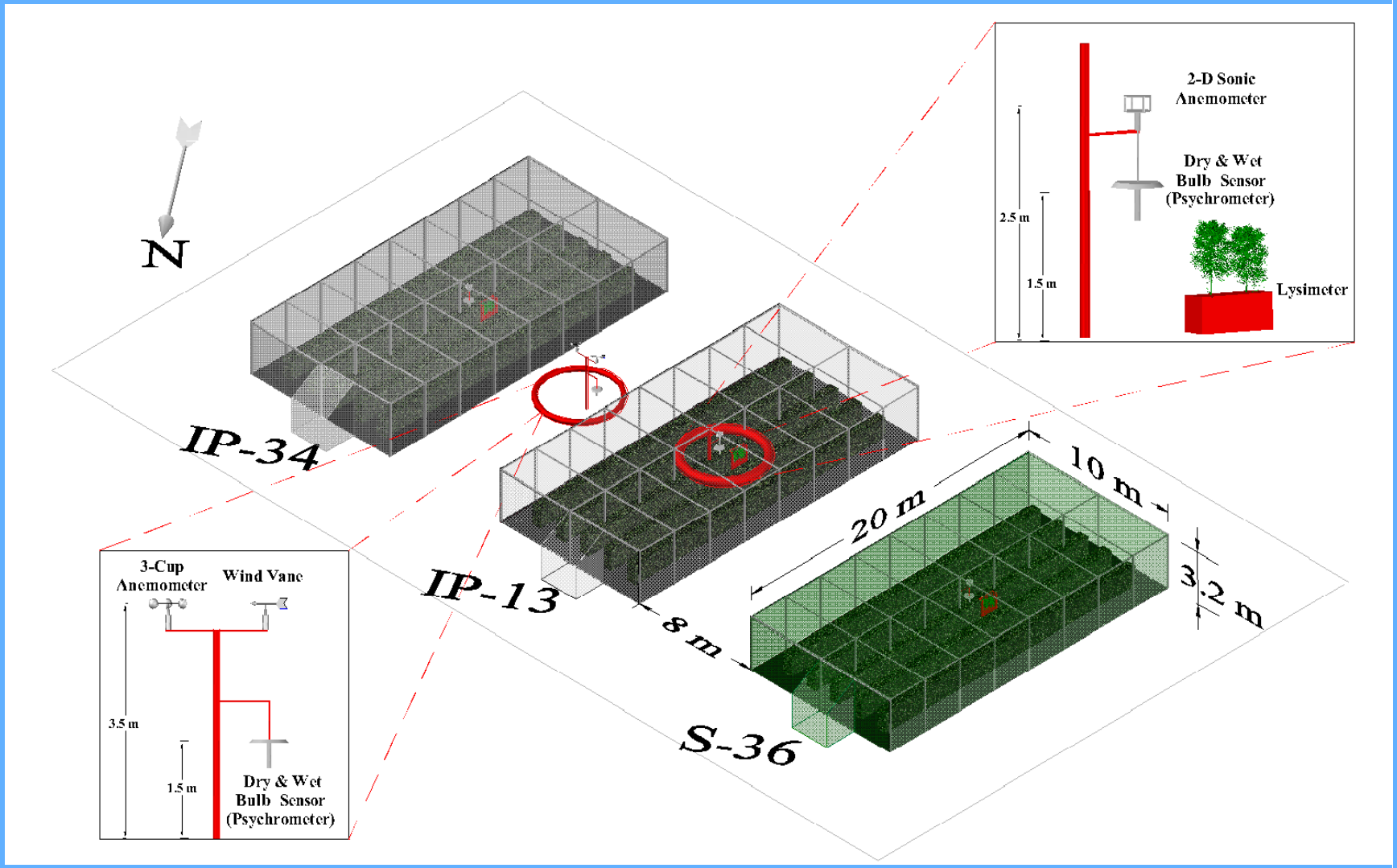


Cropping technique

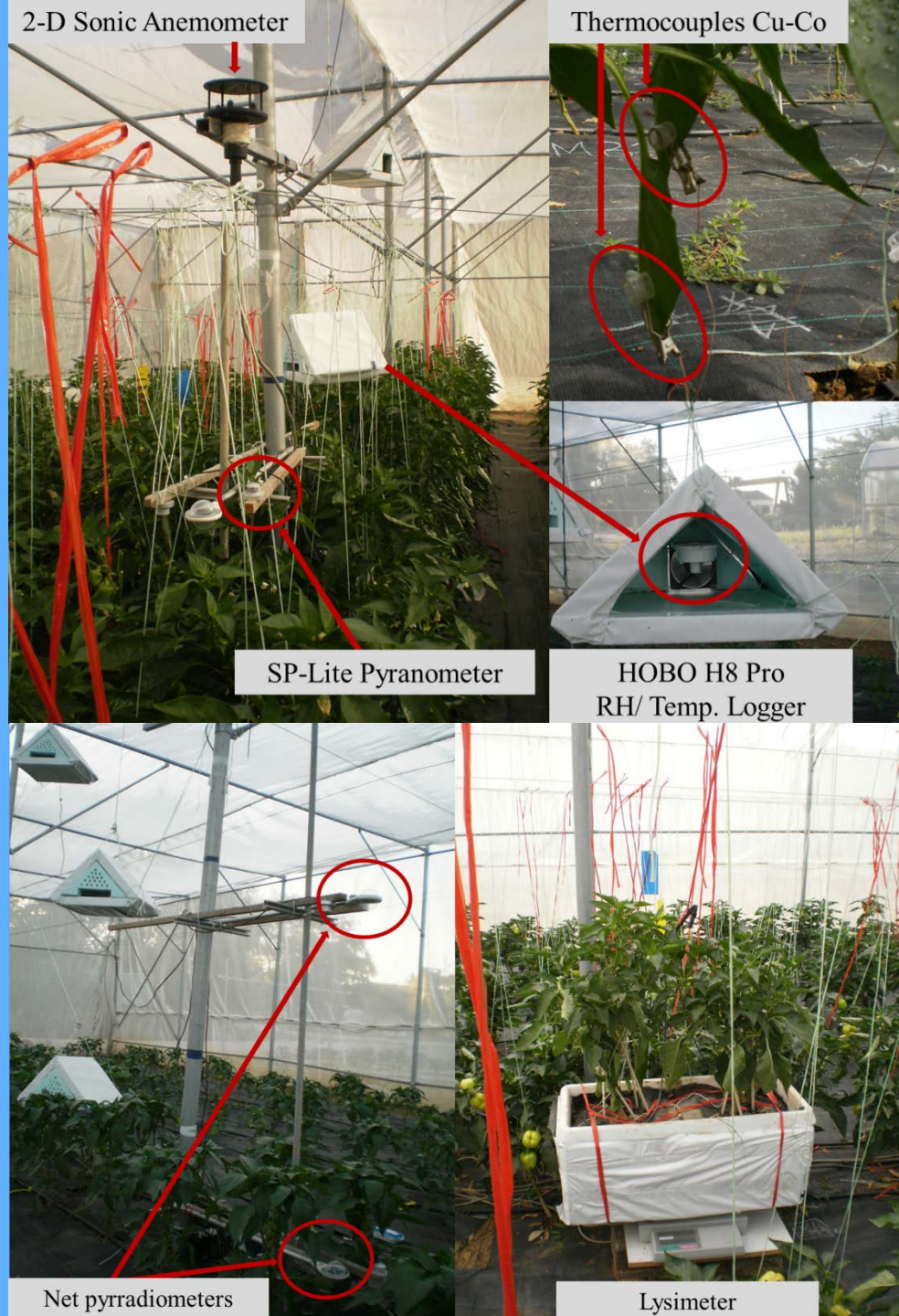
- **2 experimental periods**
  - 2011 & 2012
  - May ⟶ October
- **Transplanting** *(seedlings)*
  - *Capsicum annuum* var. Dolmi
    - May, 2011 and 2012
  - Plant density: 1.8 plants m^{-2}

- **Irrigation**
  - Drip-laterals *(1 dripper per plant (2 l h^{-1}))*
  - Applied water
    - Soil mechanical properties
    - Fixed integral of outside solar radiation (Katsoulas et al., 2006)
    - Fixed Crop coefficient (Kc) (Allen et al., 1998; FAO)
      - Initial stage (Kc,ini = 0,6)
      - Mid-season stage (Kc,mid =1,05 – 1,1)
      - End of the late season stage (Kc,end =0,9)

Microclimate monitoring system configuration



- **Solar radiation**
  - Pyranometers
- **Net radiation**
  - Above + Below canopy
  - Net pyrradiometers
- **Air velocity and direction**
  - Internal (2.5 m above ground):
    - 2-D sonic anemometers
  - External (3.5 m above ground):
    - Cup anemometer + wind vane
- **Air temperature and humidity**
  - Aspirated psychrometers
  - Temperature and Rel. humidity sensors
- **Transpiration rate**
  - Lysimeter (Scale + Plant Container)
- **Canopy temperature**
  - Thermocouples (10 leaves)



➢ Diffuse solar radiation

- Pyranometer + Shadow ring
- Pyranometer *(Diffuse ratio)*

➢ Screenhouse spectral properties

- LI-1800 portable spectroradiometer
- Range: 350-1100 nm
- Intervals:1nm
- Clear sky conditions
- Alternately in the open field & in the middle of each screenhouse construction

Crop determinations

- **Destructive measurements**
  - 4 plants per treatment
    (1 plant per block)
  - 3-week intervals

- **Fresh & dry weight** (aerial part)
  - Stems
  - Leaves
  - Fruits

  Oven dried for 48 h at 85°C

  DMP was calculated:

DM plant^{-1}= DW_{stems}+DWleaves+DWfruits

- **Leaf area**
  - All leaves scanned (LA leaf^{-1})

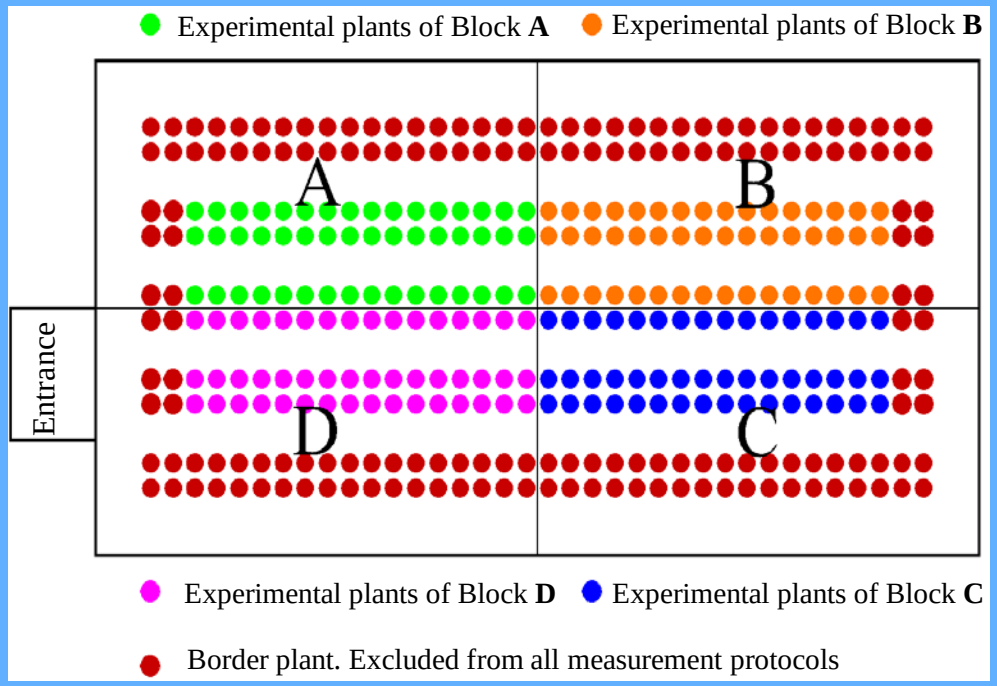
Image analysis software (DT-scan; DeltaT-Devices, USA)

LA was calculated:

- LA plant^{-1}= $\sum$ LA leaf^{-1}
- LAI = 1,8* LA plant^{-1}

- 4 treatments:
  - **"Cont":** Open field – Contol
  - **"IP-13"**
  - **"IP-34"**
  - **"S-36"**

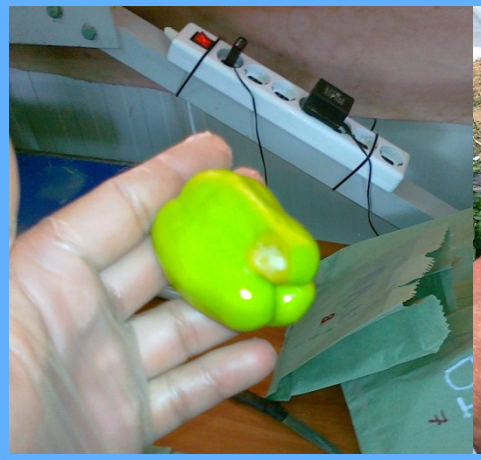
Configuration of the experimental plots



Crop determinations

- **Crop yield**
  - Harvest once a week
  - Ripened fruits
  - 8 plants per treatment
    (2 plants per block)
    - **Fresh fruit weight**
    - **Number of fruits**

- **Fruit quality**
  - Defects
    - Sunscald
    - Blossom End Rot (BER)
    - Insect attacks
  - Marketable yield calculation
  - Fruit size



Statistical analysis

- **Agronomical data :**

Univariate Analysis (General Linear Model Analysis)

Level of significance at $P < 0.05$

Duncan's Multirange **Post Hoc** Tests.

- **Simulations (model *calibration and validation)***

Non-linear regression analysis using Marquardt's algorithm (Marquardt, 1963).

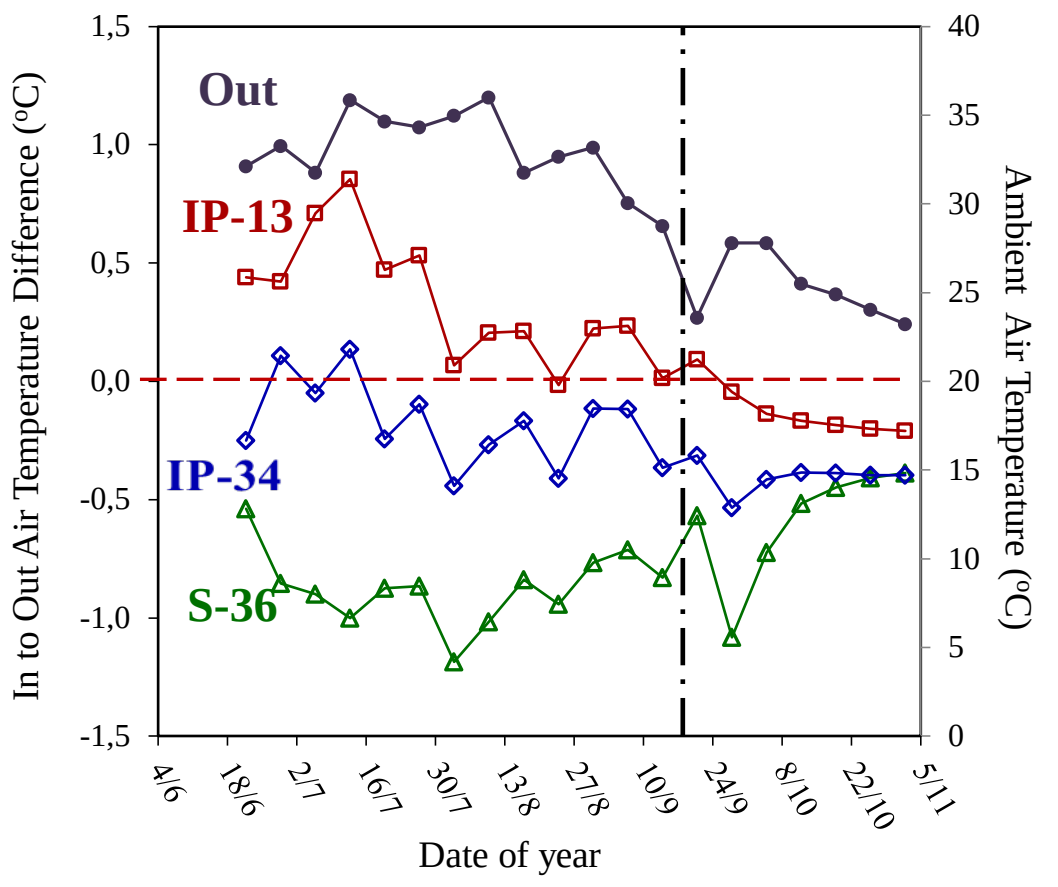
Results

Microclimate investigation

Results

Air temperature (Seasonal evolution)

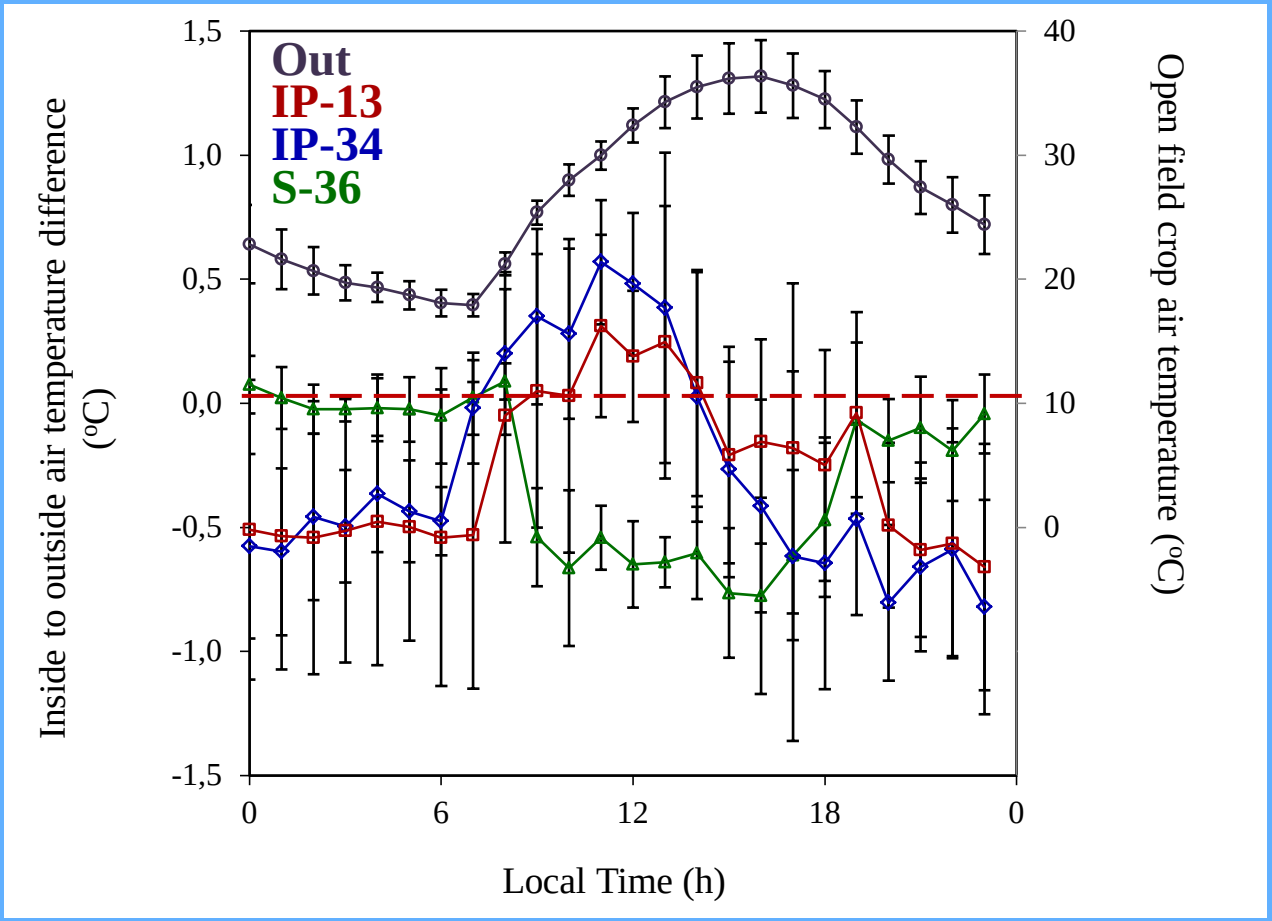
Inside-to-outside air temperature differences (ºC)



Weekly averages of mean daytime (11:00 – 17:00 h; local hour) values

Air temperature (Daily evolution)

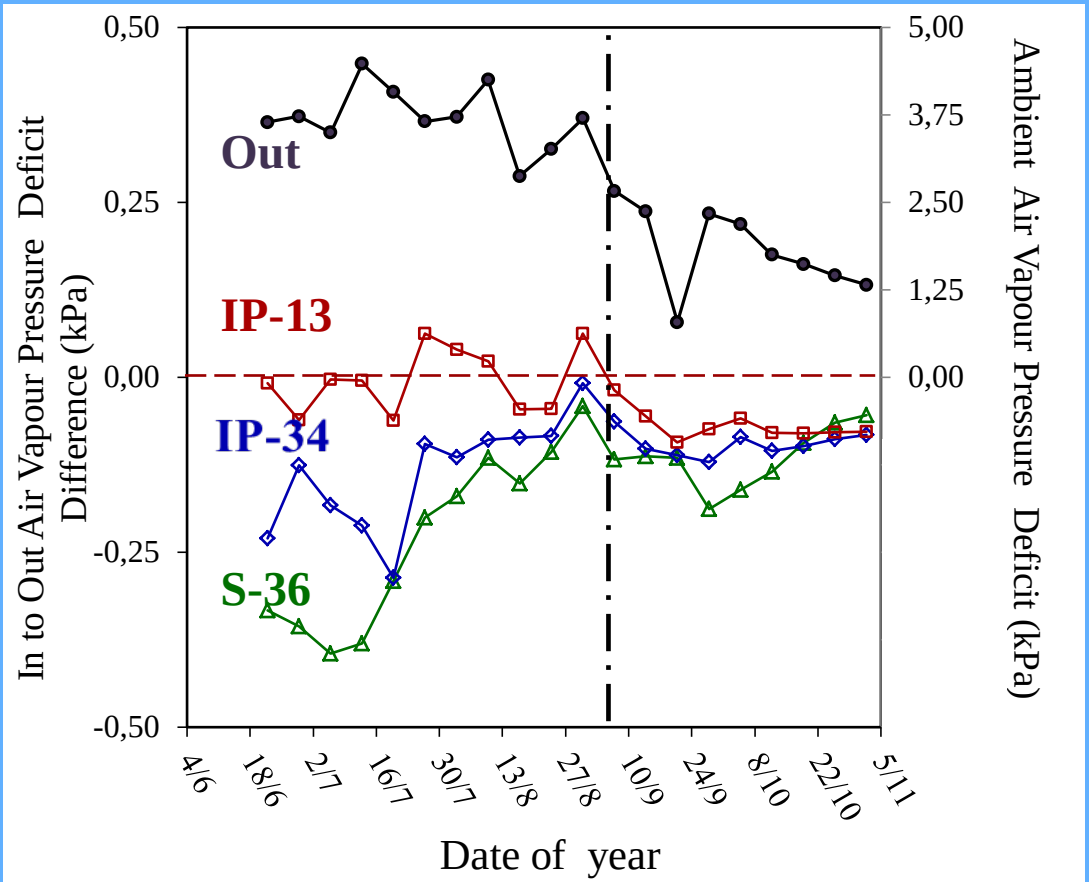
Inside to outside air temperature difference (ºC)



Average values of 6 days (August 20-25)

Air vapour pressure deficit (Seasonal evolution)

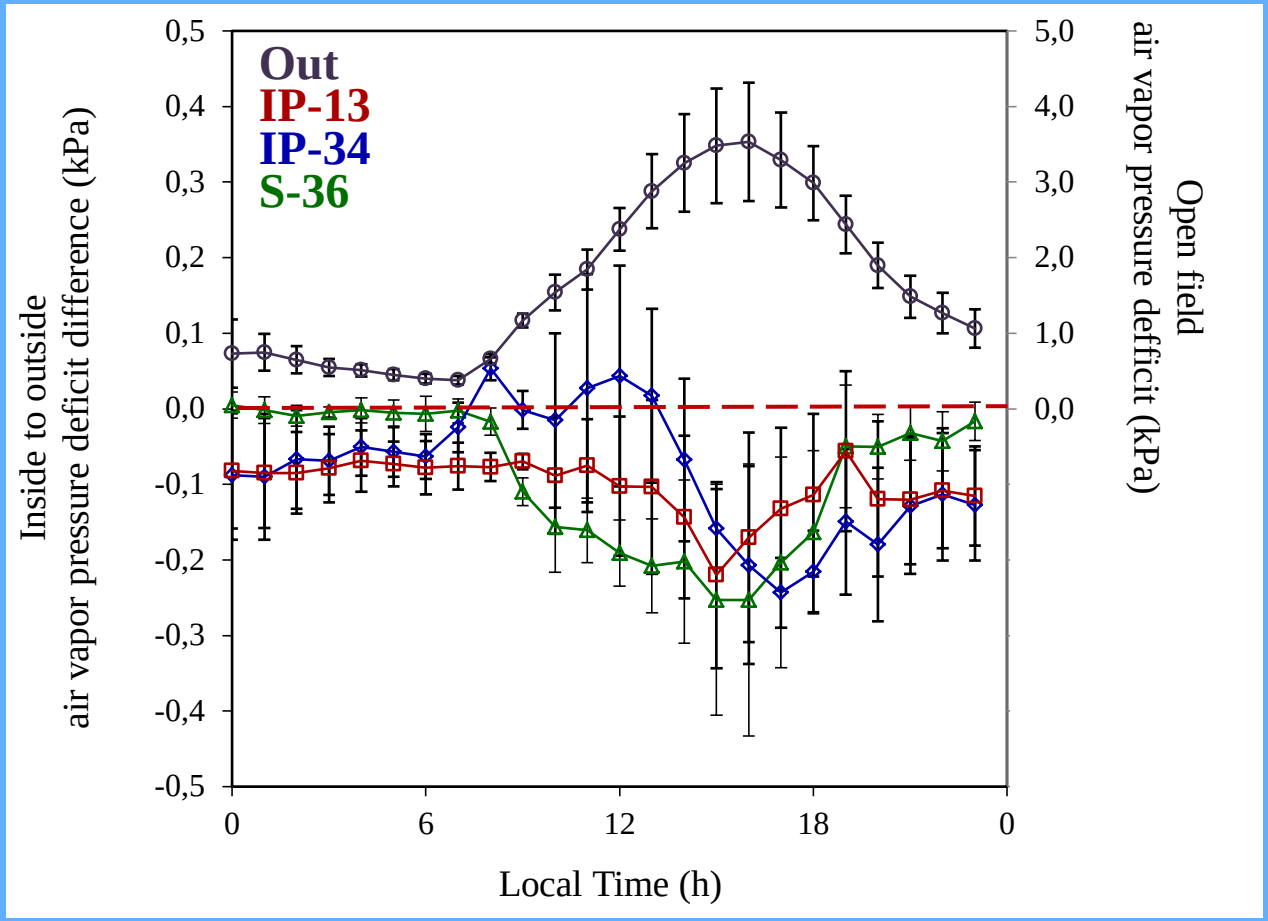
Inside-to-outside air vapour pressure deficit differences (kPa)



Weekly averages of mean daytime (11:00 – 17:00 h; local hour) values

Air vapour pressure deficit (Daily evolution)

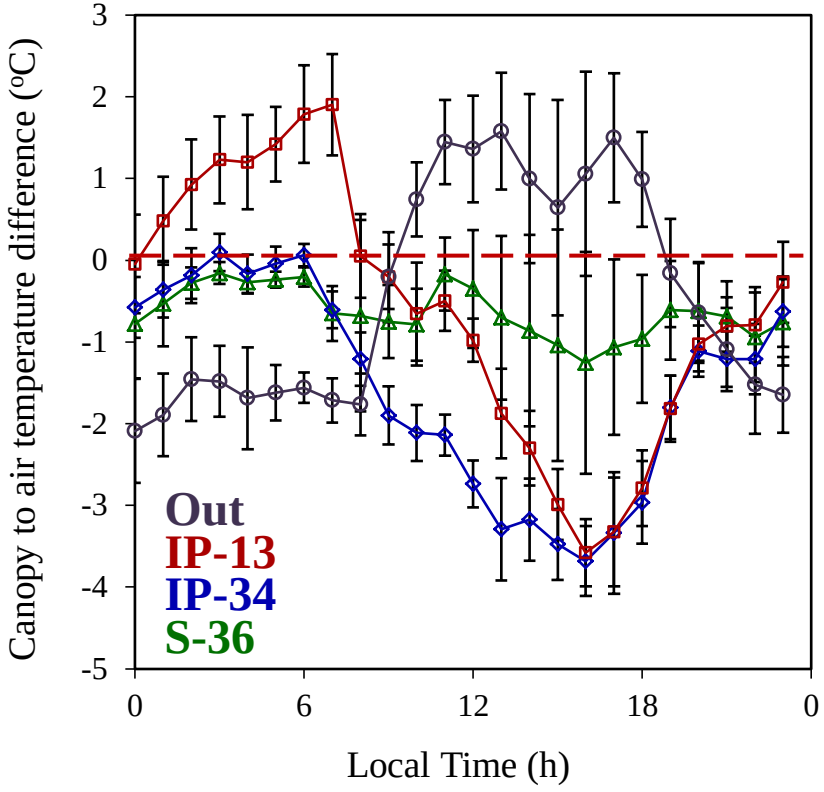
Inside to outside vapour pressure deficit difference (kPa)



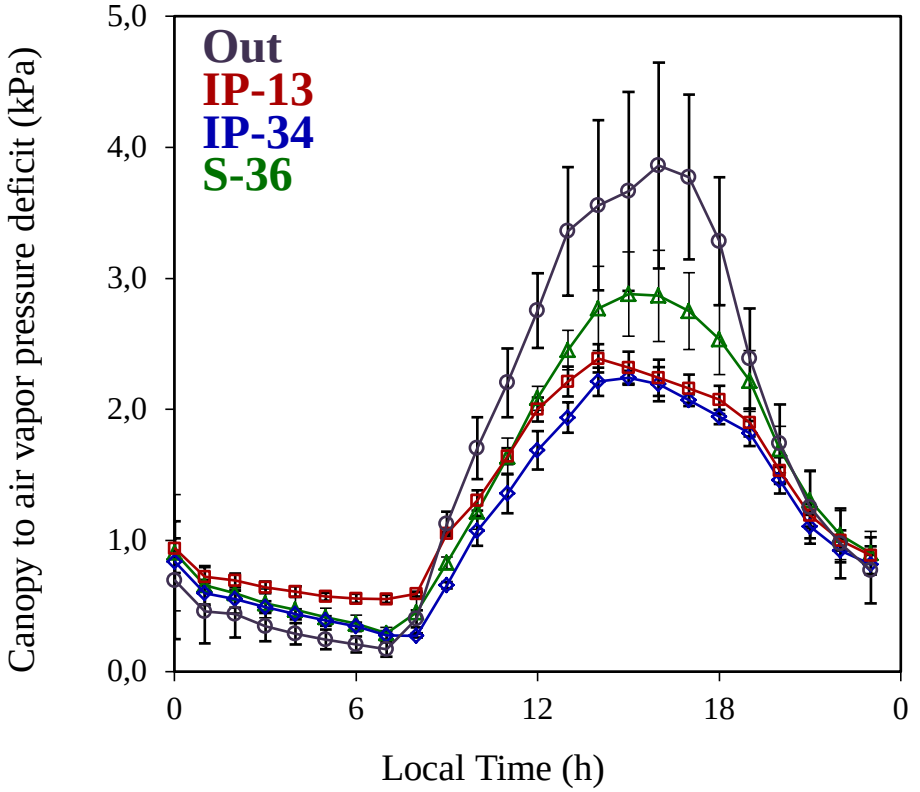
Average values of 6 days (August 20-25)

Canopy-to-air temperature difference & Canopy-to-air vapour pressure deficit (Daily evolution)

$\delta T_{c\text{-}air}$ (ºC)



$D_{c\text{-}air}$ (kPa)



Average values of 6 days (August 20-25)

Comfortable conditions for improved crop performance below screens

Radiative environment characteristics

Results

Global solar radiation

Monthly averages of daily integral values

Month	Cont R_G (MJ m^{-2} d^{-1})	IP-13 R_G (MJ m^{-2} d^{-1})	IP-34 R_G (MJ m^{-2} d^{-1})	S-36 R_G (MJ m^{-2} d^{-1})
May	19,48^{a}	14,53^{b}	11,68^{c}	12,28^{bc}
June	28,26^{a}	21,15^{b}	16,92^{c}	17,84^{c}
July	25,62^{a}	18,75^{b}	15,41^{c}	15,98^{c}
August	22,08^{a}	16,30^{b}	13,52^{c}	13,64^{c}
September	17,07^{a}	12,87^{b}	10,62^{c}	10,31^{c}
October	11,32^{a}	8,89^{b}	7,24^{c}	6,90^{c}

Seasonal screenhouse transmittance

$$\tau_G = \frac{R_{G,i}}{R_{G,o}}$$

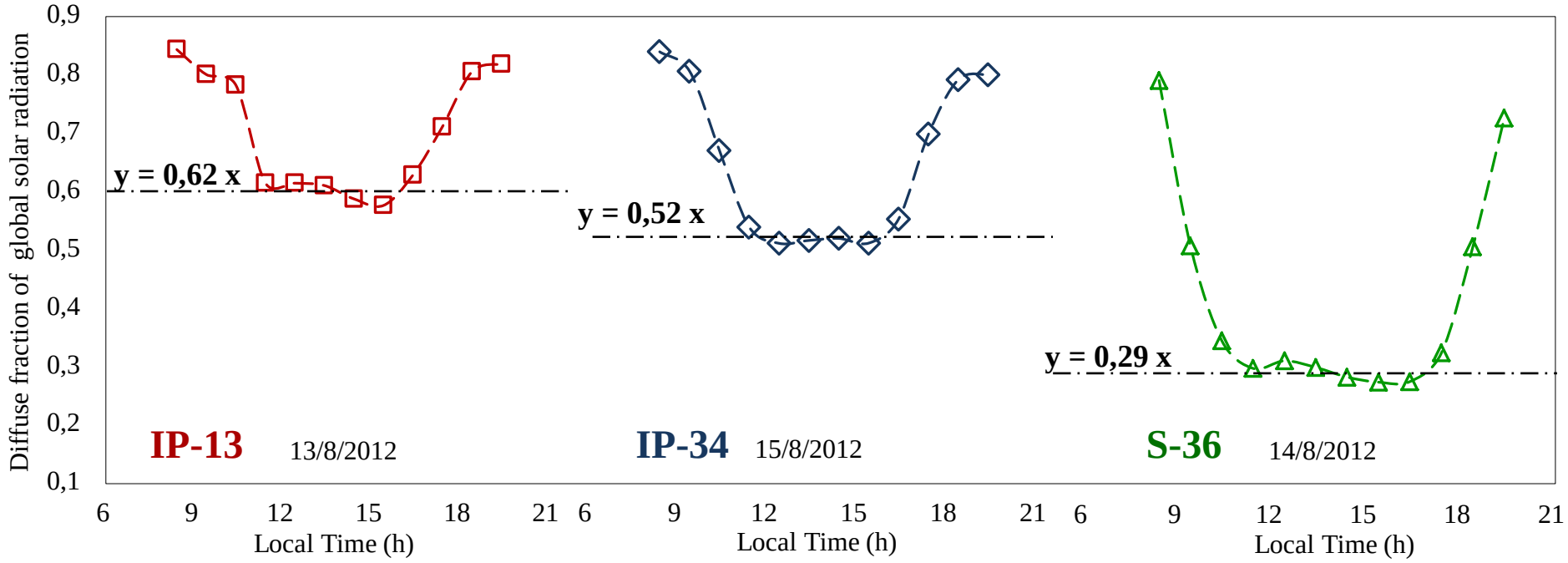
IP-13 $\tau_G = 0.75$

IP-34 $\tau_G = 0.61$

S-36 $\tau_G = 0.62$

Diffuse fraction of solar radiation (Daily evolution)

$$f - R_{G;dif,i} = \frac{R_{G;dif,i}}{R_{G,i}}$$



$f - R_{G;dif,i} = 0.66$

$f - R_{G;dif,i} = 0.62$

$f - R_{G;dif,i} = 0.40$

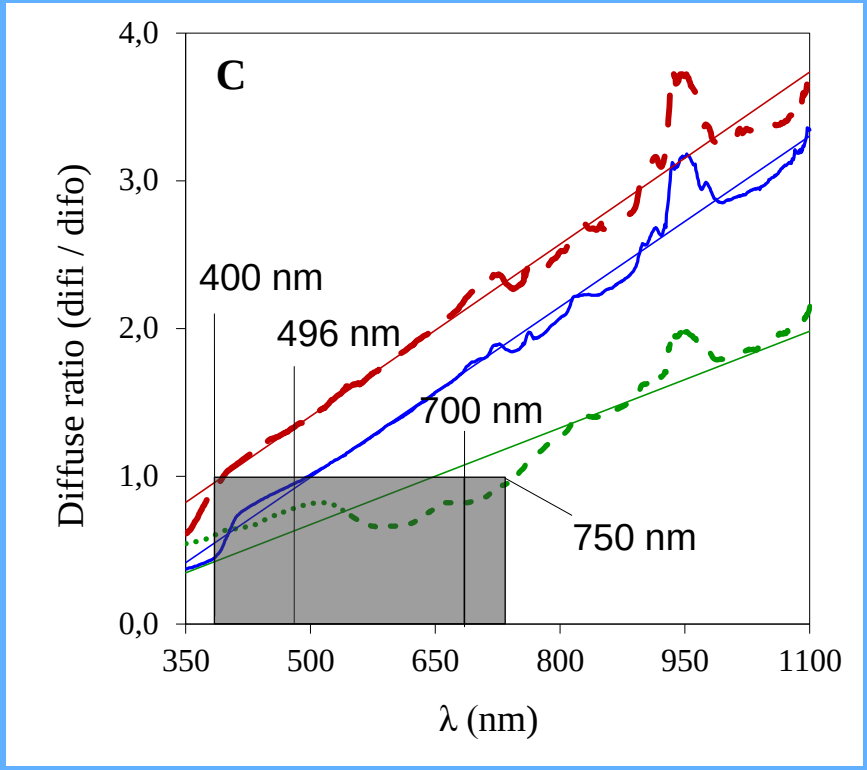
Seasonal daily Screenhouse fraction of diffuse-to-global solar radiation

Spectral distribution of diffuse ratio

(350-1100 nm; W m^{-2} nm^{-1})

Diffuse ratio
(enrichment ratio)

$$\tau_{dif} = \frac{\mathrm{dif_i}}{\mathrm{dif_o}}$$



Crop transpiration rate investigation

Crop Transpiration Model

Crop Transpiration rate

Monteith, 1973 Baille et al., 2006

Radiative

$$A = \frac{\delta}{\delta + \gamma(1 + g_a/g_c)} \qquad \boldsymbol{A = \alpha f_1(LAI) = \alpha\left[1 - e^{-kLAI}\right]}$$

$$\boldsymbol{Tr_i = \lambda E = A R_s + B D}$$

$$B = \frac{\rho C_p g_a}{\delta + \gamma(1 + g_a/g_c)} \qquad \boldsymbol{B = \beta f_2(LAI) = \beta LAI}$$

Advective

$$\boldsymbol{Tr_i = (\alpha\left[1 - e^{-kLAI}\right])R_s + (\beta LAI)D}$$

Non-linear regression using Marquardt's algorithm (Marquardt, 1963)

Crop Transpiration Model

Aerodynamic, total and stomatal conductance

Calculations

$$H_c = R_{n,int} - \lambda E_c$$

$$g_a = \frac{H_c}{\rho C_p \Delta T}$$

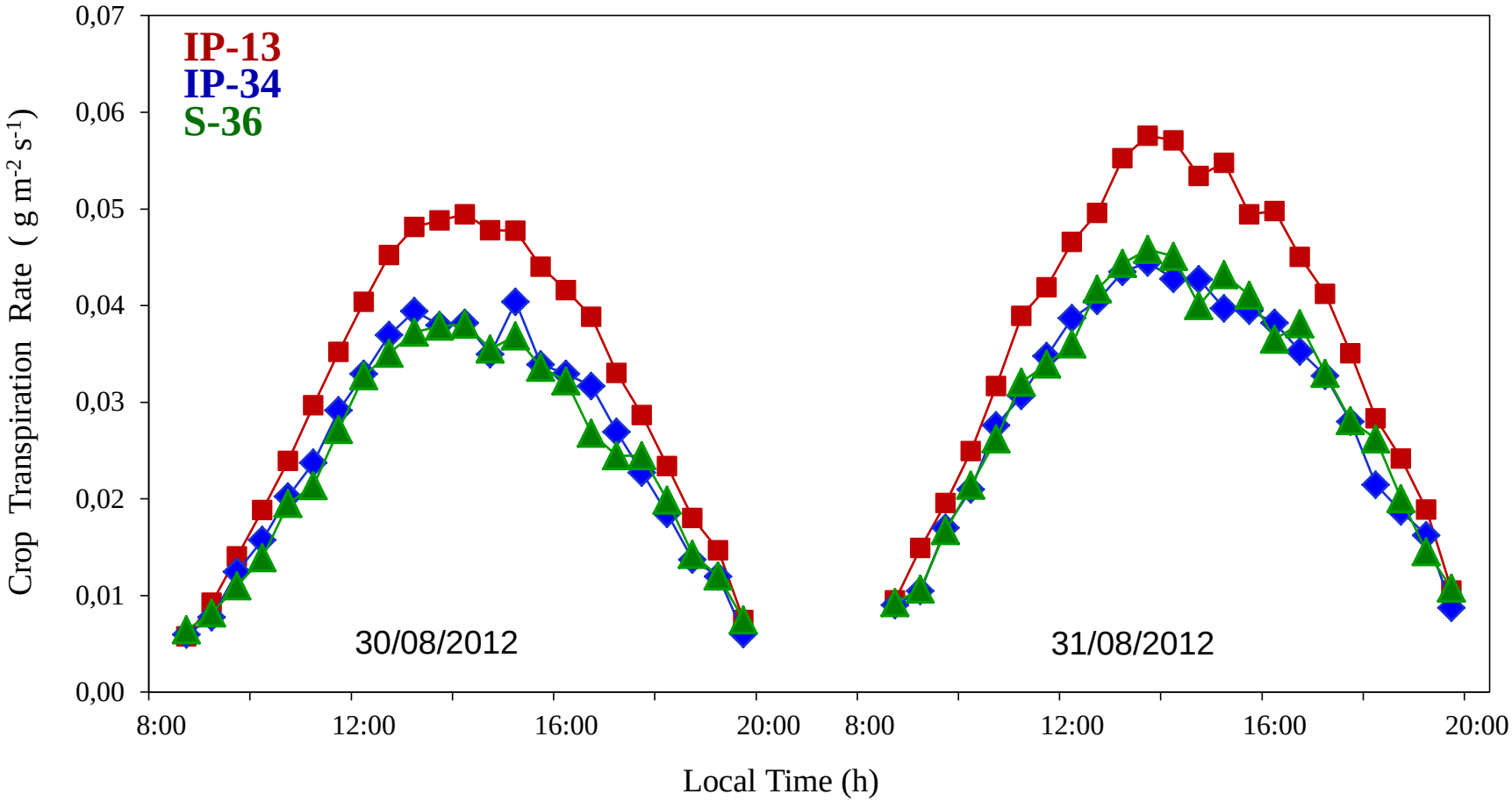
$$g_t = \frac{\lambda E_c \gamma}{\rho C_p D_{c-air}}$$

$$g_c = \frac{g_a g_t}{g_a - g_t}$$

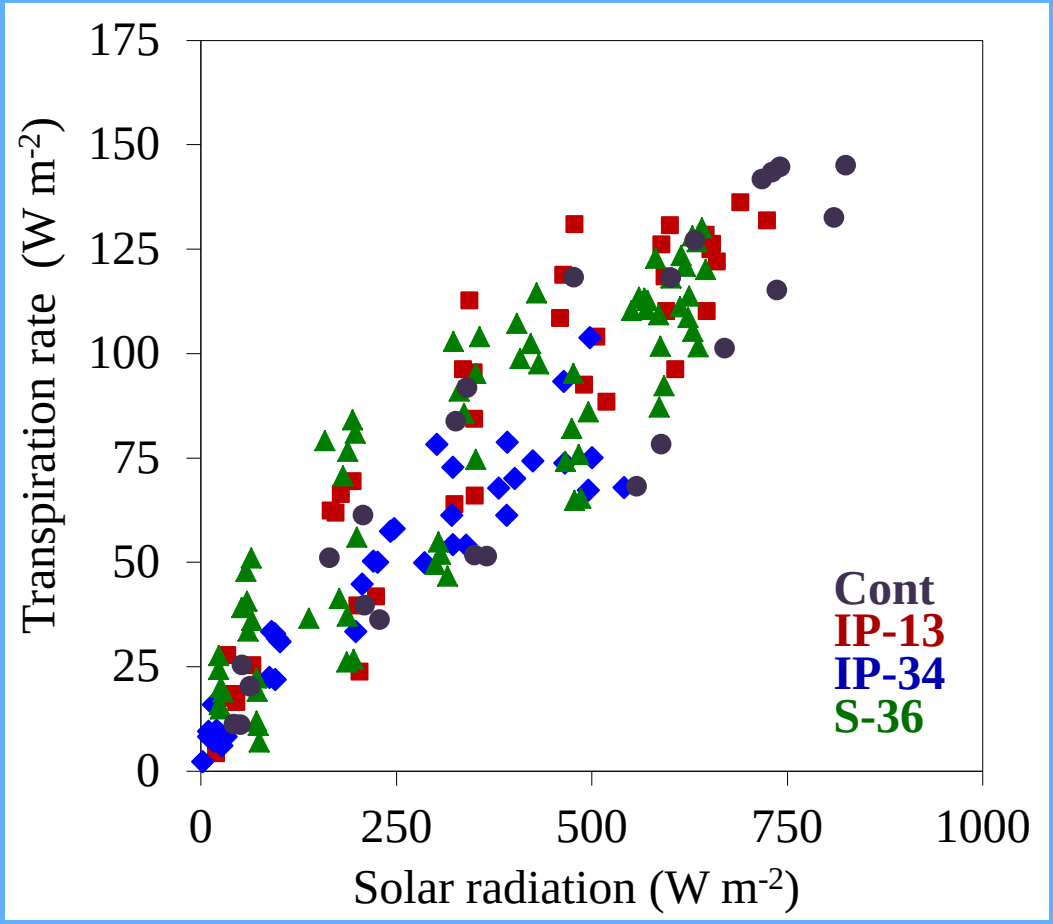
Crop transpiration rate

Results

Crop transpiration rate (Daily evolution)



Transpiration rate *vs* solar radiation



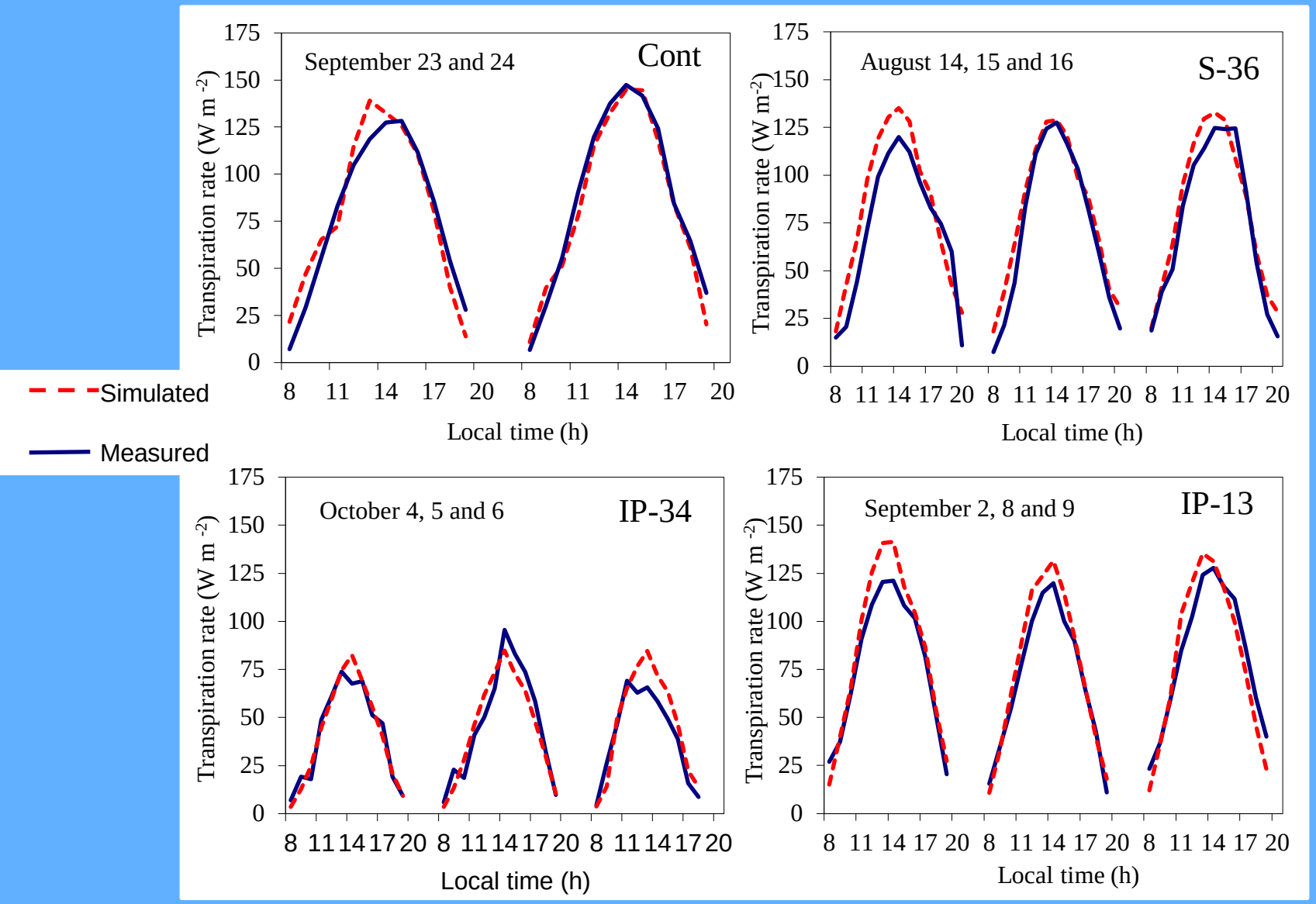
Crop Transpiration Model (Calibration)

$$Tr_i = \lambda E = (\boldsymbol{\alpha}[1 - e^{-kLAI}])R_s + (\boldsymbol{\beta} LAI)D$$

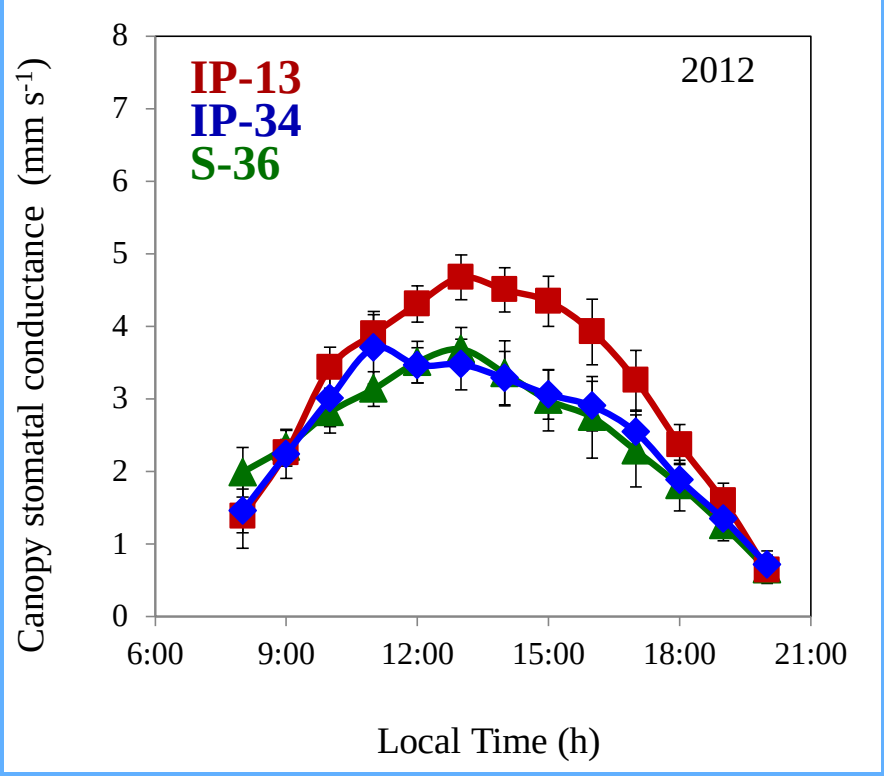
Treatment	α (W m^{-2}) Estimate	β (kPa^{-1}) Estimate	[1]R^2
Cont	0.248	12.8	0.99
IP-13	0.223	3.1	0.98
IP-34	0.199	4.9	0.97
S-36	0.243	7.7	0.97

[1]R^2, coefficient of determination.

Crop Transpiration Model (Validation)



Canopy stomatal conductance



August 20-31, 2012

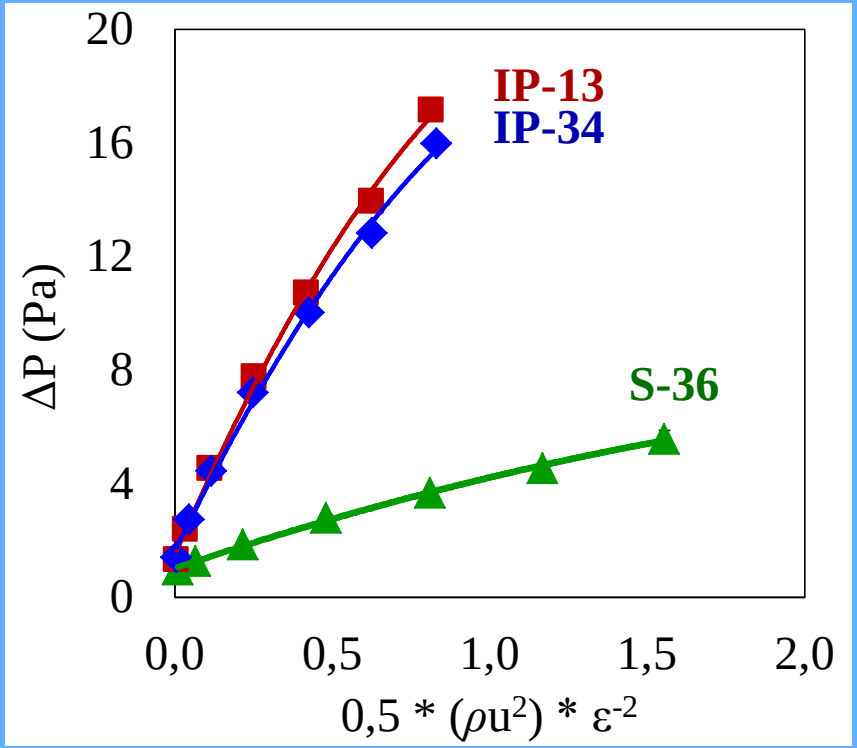
Ventilation rate determination

Air flow characteristics of porous screens

Discharge coefficient
(Bernoulli's equation)

$$\Delta P = 0.5\frac{\rho u^2}{\varepsilon^2 C_{ds}^2} = 0.5\frac{\rho u^2}{C_{ds^*}^2}$$

Non-linear regression
(Marquardt, 1963)



Screen	Estimate	[1]R²	[2]df
IP screens (pooled data)	**1.013**	0.91	55
S-36	**1.262**	0.76	27

[1]R²: Models coefficient of determination, [2]df: Degrees of freedom

Air flow characteristics of porous screens

Inertial factor & permeability *(Forchheimer's equation)*

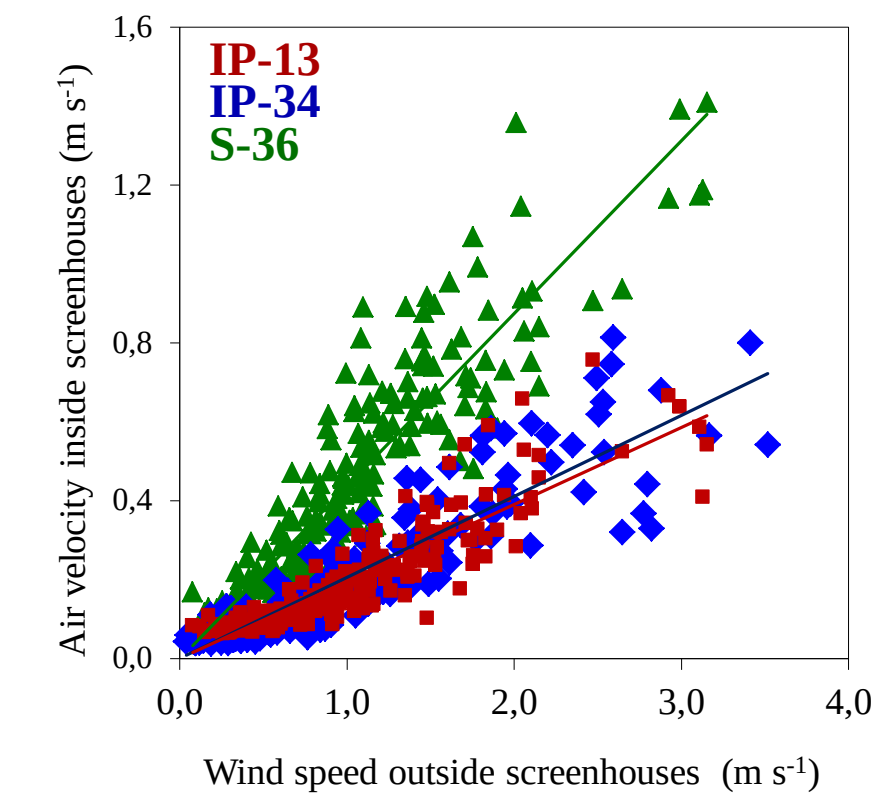
Non-linear regression (Marquardt, 1963)

$$(\mu/\boldsymbol{K})\boldsymbol{u} + \rho\left(\boldsymbol{\Upsilon}/\boldsymbol{K}^{1/2}\right)|\boldsymbol{u}|\boldsymbol{u} = \boldsymbol{\partial P}/\boldsymbol{\partial x}$$

Screen	[1]n	[2]R^2	[3]**K×10^{-9}**	[4]**Y**	[5]ε	[6]Δx×10^{-4}
IPs	56	0.99	**2.93**	**0.210**	0.46	4.80
S-36	28	1.00	**19.8**	**0.065**	0.63	8.00

[1]n: number of measurements;[3]R^2: coefficient of determination; [4]K: permeability (m^2); [5]Y: inertial factor; [6]ε: porosity; [7]Δx: thickness of the screen / net (m)

Air velocity inside screenhouses *vs* external wind speed



IPs data were pooled after t-test (Dagnelie, 1986).

$$u_{in_{IP}} = \mathbf{0.201}\ (\pm 0.005)\ u_o - (7.00 * 10^{-4})(\pm 0.005), \text{with } R^2 = 0.81$$

$$u_{in_{S-36}} = \mathbf{0.437}\ (\pm 0.013)\ u_o + (1.04 * 10^{-4})(\pm 0.015), \text{with } R^2 = 0.84,$$

Calculations for ventilation rate determination

Calculations for ventilation rate determination

Ventilation rate estimates

Water vapour balance technique

*(*water vapour as tracer gas; Boulard and Draui, 1995)

$$\rho\, V_{sc} \frac{dx_i}{dt} = -\rho\, Q(t)[x_i(t) - x_O(t)] + Tr_i(t)$$

- V_{sc}: screenhouse volume (m^3)
- Q : ventilation rate ($m^3\ s^{-1}$)
- $x_i(t)\ and\ x_O(t)$: inside and outside concentrations of water vapour (air absolute humidity).

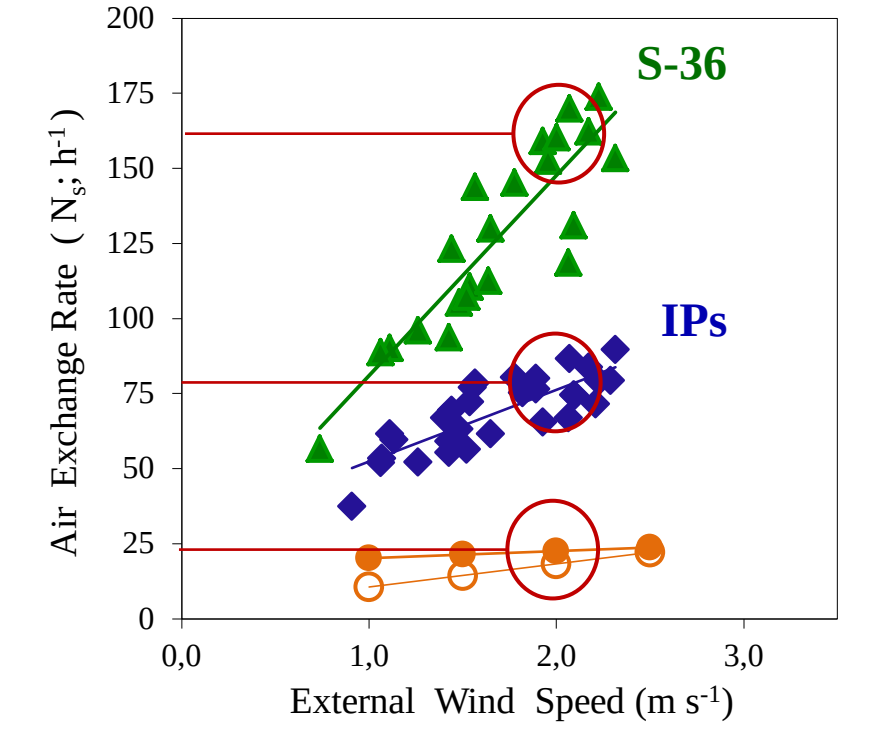
Air flow rate (ventilation rate) (G_{sc}; $m^3\ s^{-1}$)

$$G_{sc} = A_g \frac{Tr_i(t) - h\frac{d\bar{x}_i}{dt}}{(\bar{x}_i - x_o)}$$

Screenhouse air exchange rate (N, in h^{-1})

$$N = 3600 \frac{G_{sc}}{V_{sc}}$$

Screenhouse air exchange rate *vs* external wind speed



Commercial Pepper & Banana screenhouses

$$N_{IP} = \mathbf{23.8}\ (\pm 3.2)\ u_o + 28.5\ (\pm 5.5), \quad \text{with } R^2 = 0.66,$$

$$N_{S-36} = \mathbf{66.6}\ (\pm 7.7)\ u_o + 14.4\ (\pm 13.4), \quad \text{with } R^2 = 0.79$$

Screenhouse ventilation modelling

Air flow rate (ventilation rate) (G_{sc}; $m^3\ s^{-1}$)

$$G_{sc} = \frac{A_T}{2} C_d \sqrt{C_w}\, u + G_{sc,o}$$

- A_T: ventilation area (m^2)
- C_d: the discharge coefficient of the screenhouse
- C_w: wind related coefficient
- $G_{sc,o}$: vent. rate observed at zero wind velocities ($m^3\ s^{-1}$)

Screenhouse ventilation modelling
(Dual & Wind effect coefficients)

	$C_d\sqrt{C_w}$		$G_{sc,o}$			
Screenhouse	Estimate	[1] Sig.	Estimate	**Sig.**	[2]R^2	[3]df
IP (Pooled Data IP-13 & IP-34)	**0.133**	0.00	5.064	0.00	0.66	30
S-36	**0.371**	0.00	***2.532***	***0.30***	0.79	21

	C_w		
Screenhouse	Estimate	[1] Sig.	[2]R^2
IP (Pooled Data IP-13 & IP-34)	**0.003**	0.00	0.66
S-36	**0.008**	0.00	0.79

Generalization of the results

1. Estimation of the $C_d\sqrt{C_w}$ for commercial pepper and banana screenhouses (Tanny et al., (2006, 2003)).

2. Estimation of the C_d values of the constructions knowing the characteristics (*K, Y, ε, Δx*) of their screens:
   - Bionet: C_{ds^*}= 0.465
   - Crystal Shade Net: C_{ds^*}= 0.616

3. Estimation of the C_w of the constructions
   - Pepper screenhouse of 0.68 ha: C_w = 0.0001
   - Banana screenhouse of 8 ha: C_w = 0.0002

4. Generalization of the results and estimate the C_w values for different constructions

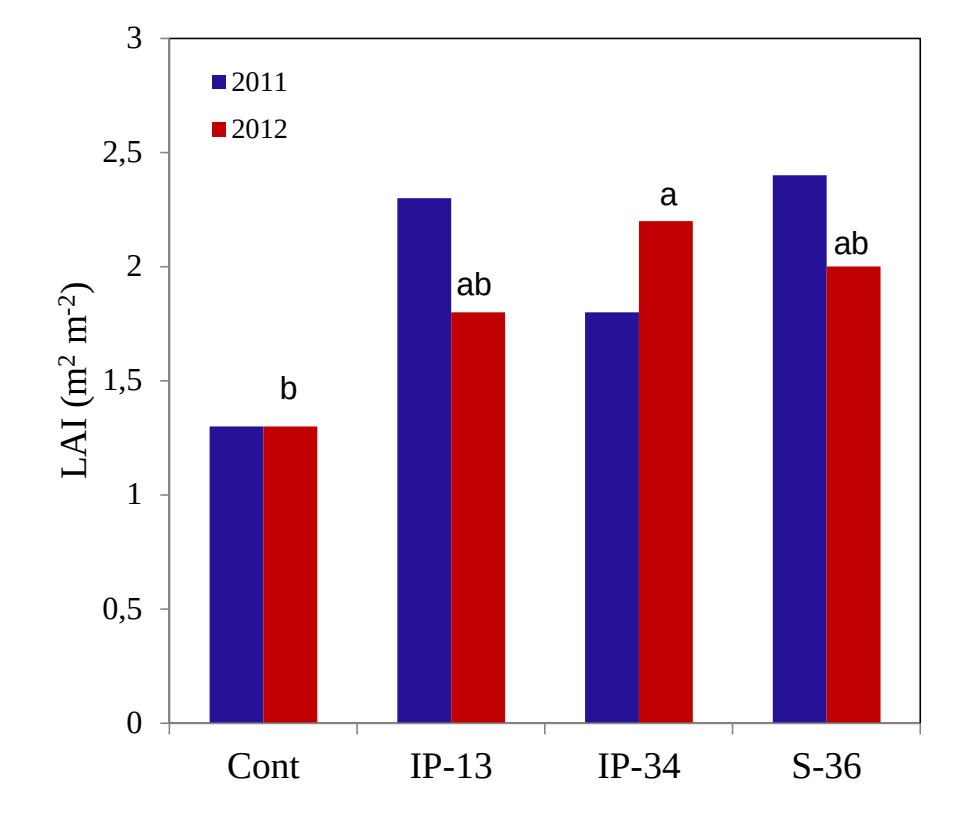
Relationship between C_w and the screenhouse volume (V_{sc}):

$$C_w = 0.166\ V_{sc}^{-0.59}, \text{ with } R^2 = 0{,}78$$

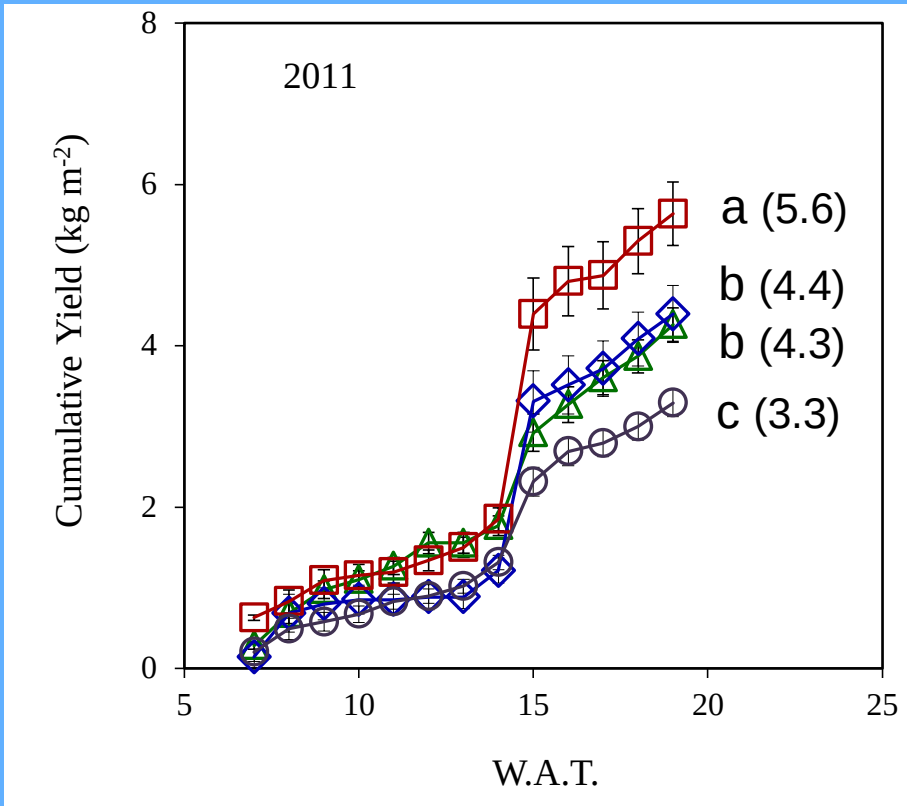
Crop performance

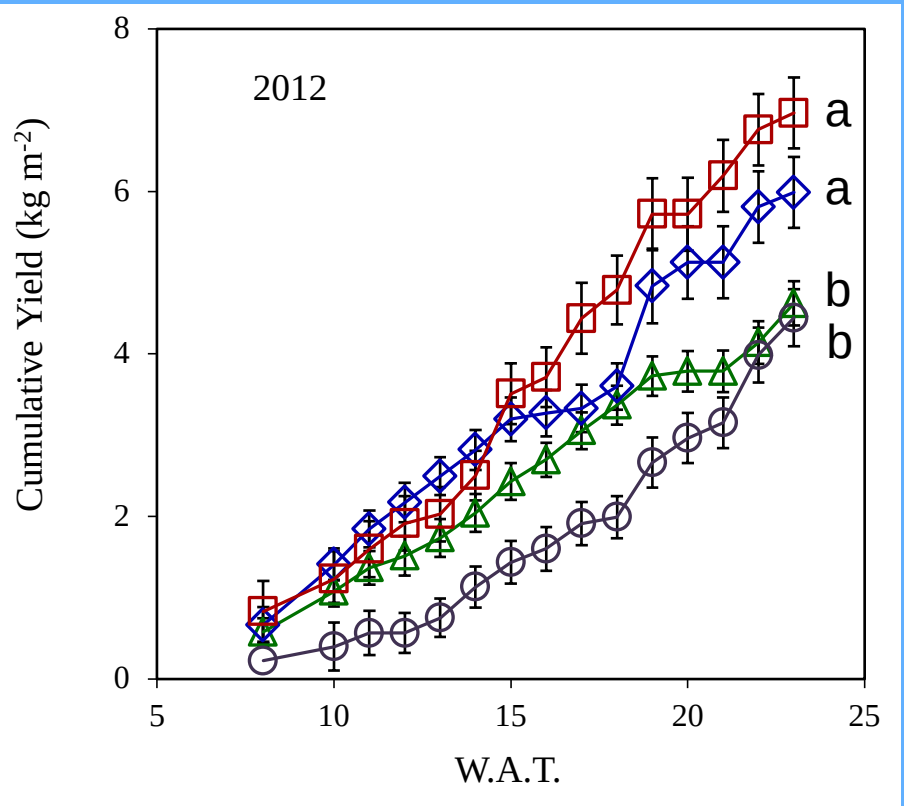
Results

Leaf Area Index



Crop yield


2011
Cumulative Yield (kg m-2)
W.A.T.
a (5.6)
b (4.4)
b (4.3)
c (3.3)
0
2
4
6
8
5
10
15
20
25


2012
Cumulative Yield (kg m-2)
W.A.T.
a
a
b
b
0
2
4
6
8
5
10
15
20
25

Quality of yield

Treatment	Marketable production as % fraction of		Fruit size	Defects as % fraction of Total Fruit number (# m^{-2})			
	[1] T.F.F.W.	[2] T.Fr.#	[3] g $fruit^{-1}$	Sunburn	BER	Thrip	Helicoverpa
Cont	59,8 ^{c}	55,7 ^{b}	82,1 ^{b}	14,06 ^{a}	13,54 ^{a}	14,06 ^{a}	2,60 ^{a}
IP-13	86,9 ^{b}	86,0 ^{a}	102,0 ^{a}	0,80 ^{b}	8,00 ^{ab}	5,20 ^{b}	0,00 ^{b}
IP-34	90,6 ^{a}	89,5 ^{a}	104,4 ^{a}	1,42 ^{b}	6,67 ^{b}	2,38 ^{b}	0,00 ^{b}
S-36	89,5 ^{ab}	87,4 ^{a}	107,9 ^{a}	0,00 ^{b}	7,69 ^{b}	4,95 ^{b}	0,00 ^{b}

$^{a, b, c}$: Means with different superscript letters within the same column are statistically significantly different (a=0.05).

[1] : T.F.F.W. is the Total Fresh Fruit Weight (kg m^{-2}).

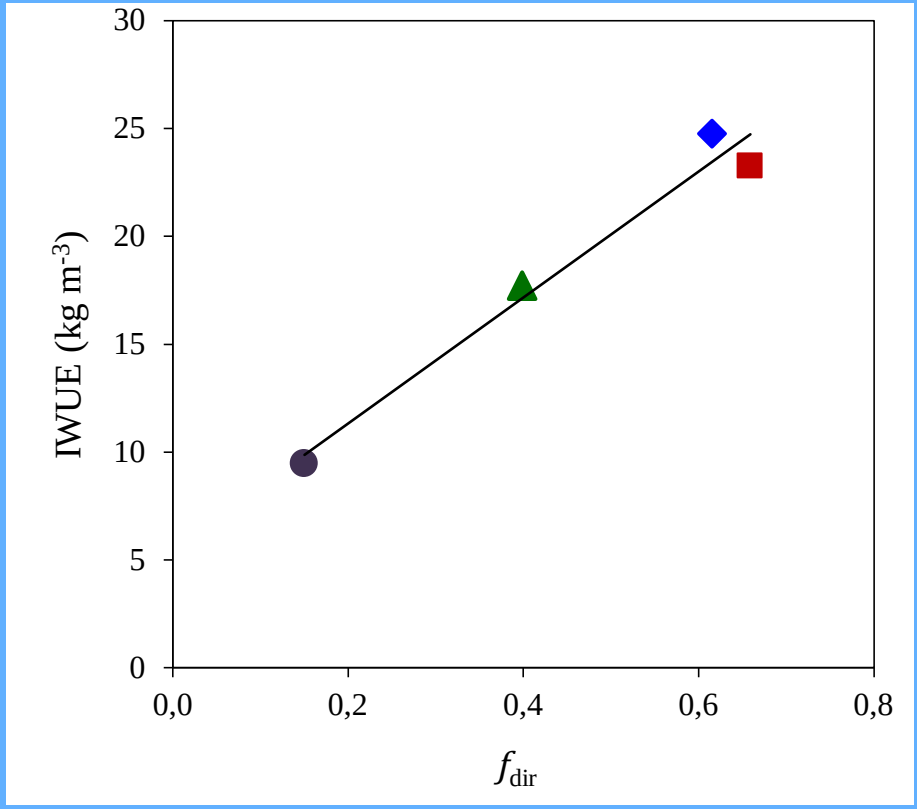
[2] : T.Fr.# is the Total Fruit number (# m^{-2}).

[3] : Fruit size as determined from the ratio of (total yield)/(fruit number).

Irrigation Water Use Efficiency (IWUE)

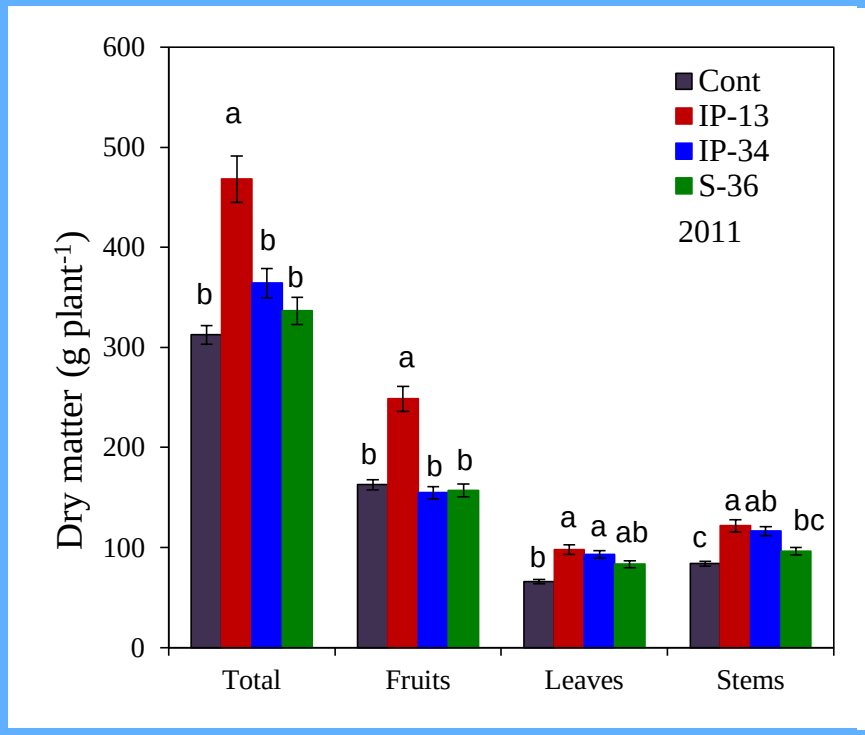
	IWUE (kg m^{-3})	
Treatment	2011	2012
Cont	6,6	7,4
IP-13	15,2	16,7
IP-34	15,5	17,5
S-36	13,9	13,2

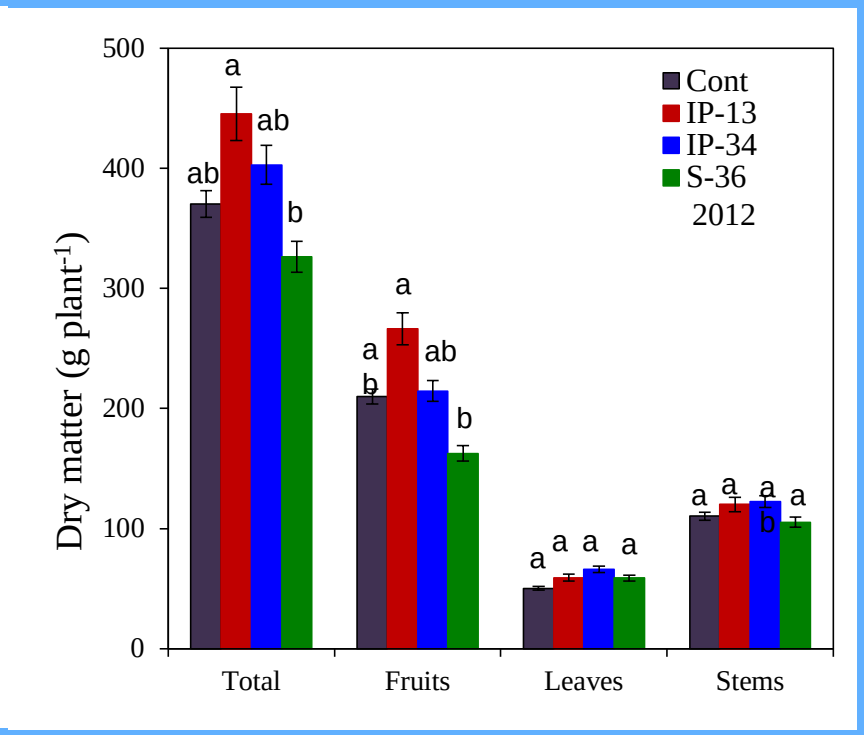
IWUE vs Diffuse fraction of solar radiation



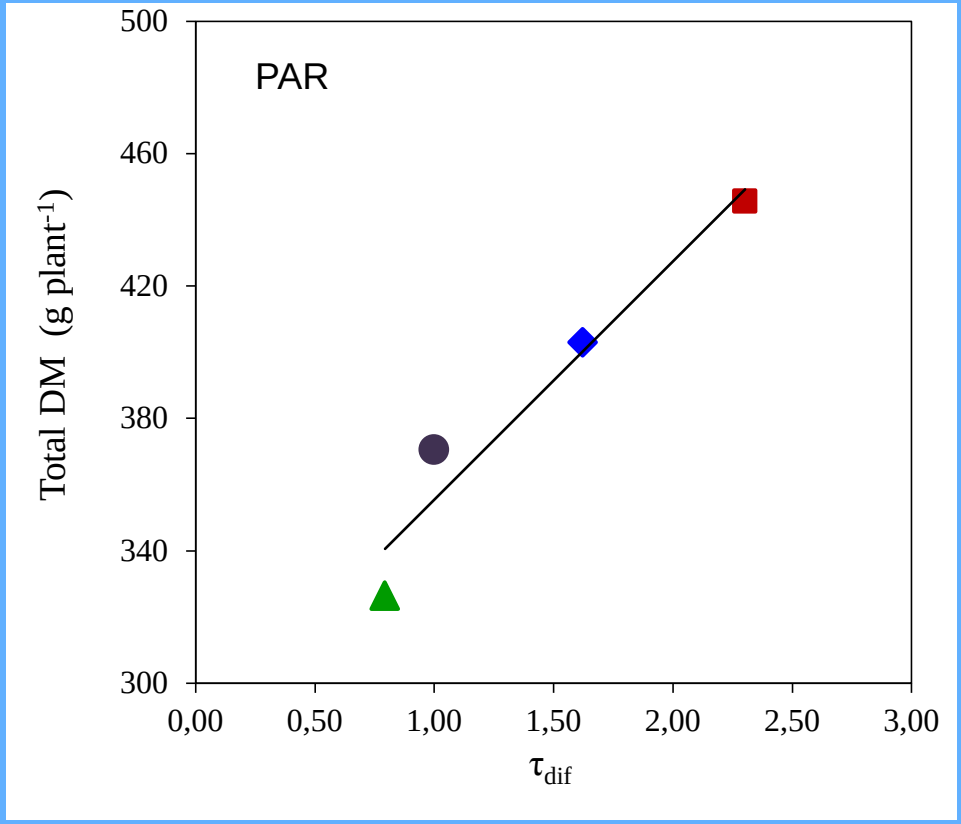
$f\mathrm{R}_{\mathrm{G;dif}}$: $\mathrm{IWUE} = 29.18 * f\mathrm{R}_{\mathrm{G;dif}} + 5.49, \quad with\ R^2 = 0.97$

Dry Matter Production





Total dry matter per plant vs diffuse ratio (enrichment)



Simulating Dry Matter Production

Interception model (Marcelis et al., 1998)

$$f_{i-I} = \mathrm{I_{abs,L}}/\mathrm{I_o} = (1-\rho)\left(1-\mathrm{e}^{-\mathrm{k}*\mathrm{L}}\right)$$

- **ρ**: canopy reflection (0.07 after Marcelis et al., 1998)
- **k**: extinction coefficient (0.7after Marcelis et al., 1998)
- **L**: LAI ($m^2\ m^{-2}$)

Daily PAR interception (PARi)

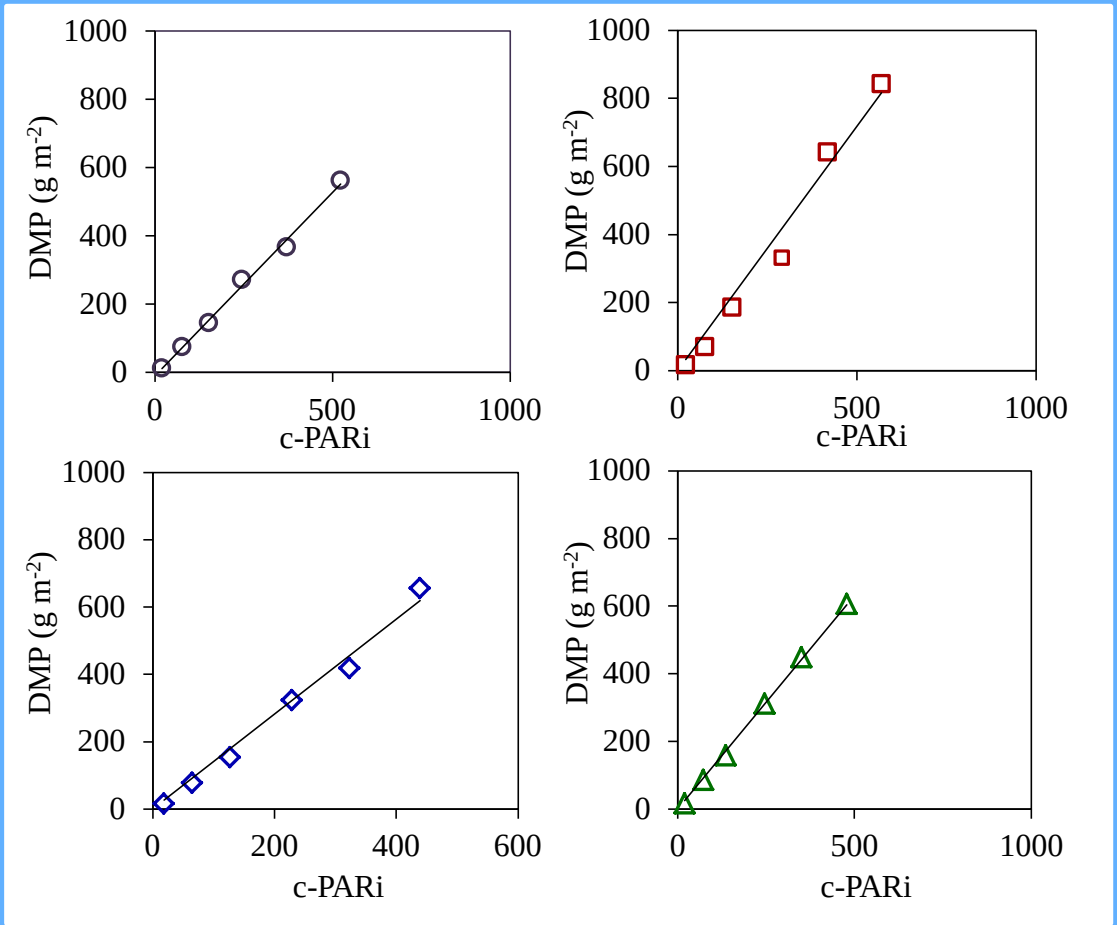
$$\mathrm{PAR}_i = f_{i-PAR} * ((\mathrm{PAR/TOTAL})_{LICOR1800} * \Sigma R_{s,x}) = f_{i-PAR} * 0.57 * R_{s,x}$$

DMP model

$$\mathrm{DDMP}_i = \mathrm{c} - \mathrm{PAR}_i * \mathrm{RUE}$$

- DDMP_i: Daily increment DMP ($g\ m^{-2}$)
- RUE: Radiation Use Efficiency ($g\ MJ^{-1}$)

DMP Model Calibration (Data of 2011 period)



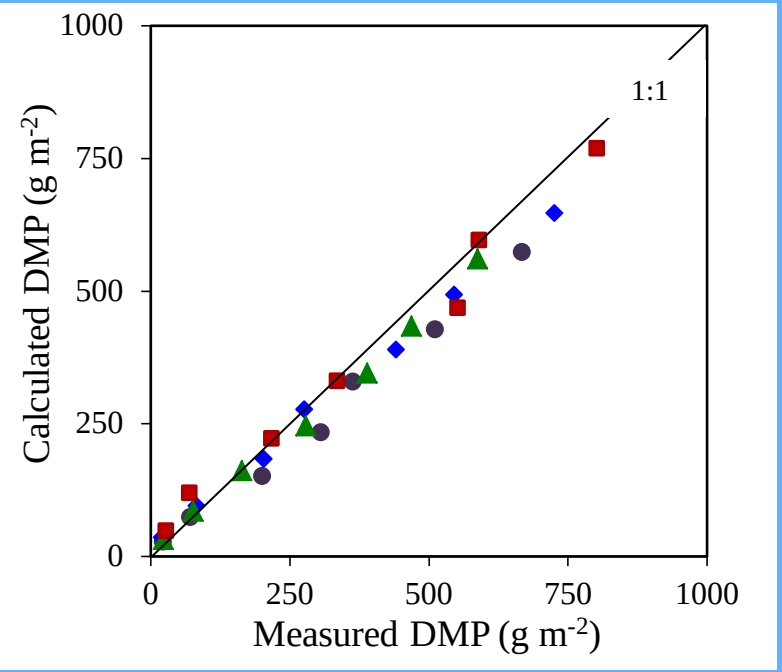
Cont $\mathrm{DMP} = \mathbf{1.05}\ (\pm 0.0220\ \mathrm{St.\ Error}) \times (\mathrm{c-PARi}), \quad (R^2 = 0.99)$

IP-13 $\mathrm{DMP} = \mathbf{1.44}\ (\pm 0.0631\ \mathrm{St.\ Error}) \times (\mathrm{c-PARi}), \quad (R^2 = 0.98)$

IP-34 $\mathrm{DMP} = \mathbf{1.41}\ (\pm 0.0449\ \mathrm{St.\ Error}) \times (\mathrm{c-PARi}), \quad (R^2 = 0.99)$

S-36 $\mathrm{DMP} = \mathbf{1.26}\ (\pm 0.0128\ \mathrm{St.\ Error}) \times (\mathrm{c-PARi}), \quad (R^2 = 1.00)$

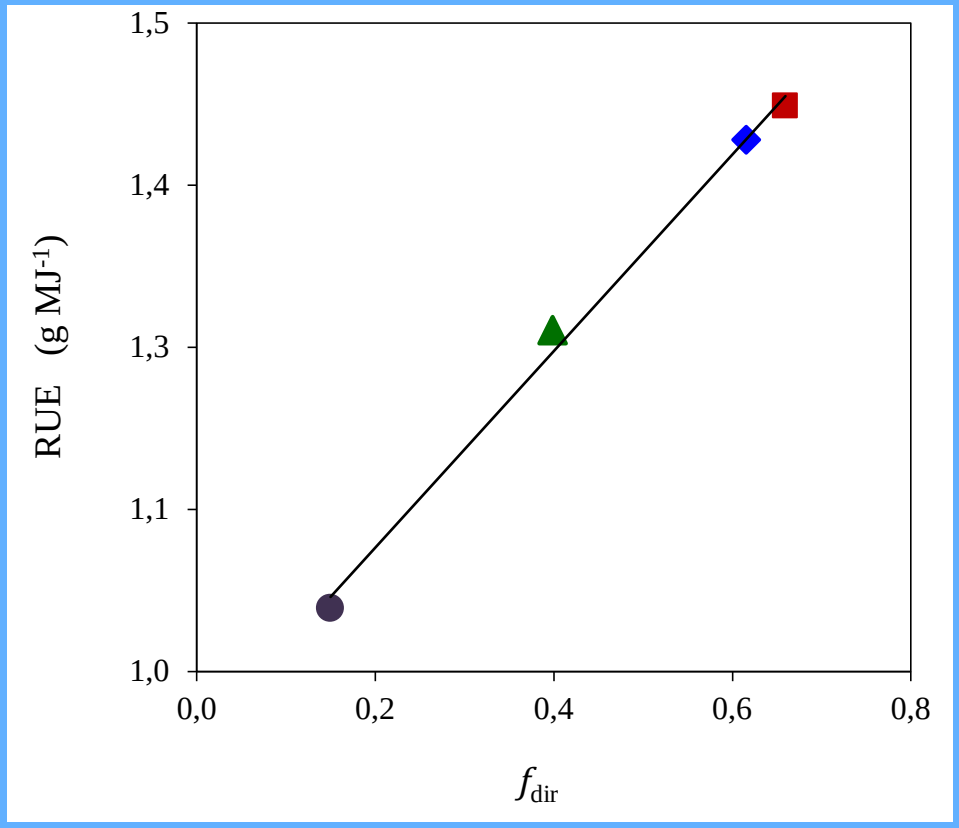
DMP Model Validation (Data of 2012 period)



Performance of statistical indices (Stöckle et al., 2004)

Validation set	[2]n	[3]RMSE	[4]RE	[5]d	[6]m	[7]R^2	[8]Performance
Cont	7	59,481	0,19	0,98	**0.84**	0,99	**poor**
IP-13	7	39,885	0,11	0,99	0.95	0,98	G
IP-13 (Pld-IPs model)	*(7)*	*(41,406)*	*(0,11)*	*(0,99)*	*(0.95)*	*(0,98)*	***(G)***
IP-34	7	42,117	0,13	0,99	0.91	0,99	G
IP-34 (Pld-IPs model)	*(7)*	*(38,340)*	*(0,12)*	*(0,99)*	*(0.92)*	*(0,99)*	***(G)***
S-36	7	27,356	0,10	0,99	0.93	1,00	**VG**

RUE vs Diffuse fraction of solar radiation



$$fR_{G;dif}: \ RUE = 0.76\, fR_{G;dif} + 0.94\ , \qquad \text{with} \quad R^2 = 1.00$$

Conclusions

Conclusions

1. Reduction of solar radiation respectively to the optical properties of the screens/net. (Differences Lab. *vs. in situ*)

2. Screens increased the diffuse R_G (color & porosity), increasing the RUE under screenhouse conditions.

3. Ventilation rate of experimental small scale screenhouses was much higher than that of commercial, large scale screenhouses.

4. The C_d, C_w and $C_d\sqrt{C_w}$ coefficient of the constructions were estimated and a method for estimating the ventilation performance for screenhouses with respect to their structure and screen characteristics was proposed (different C_d, C_w coefficients).

Conclusions

5. Screenhouse microclimate created under Mediterranean summer conditions was favourable for pepper crop production, resulting in increased total and marketable yield and yield quality as compared to that of the open field crops.

6. Crop transpiration rate and water consumption reduced inside screenhouses by 25% to 45%, increasing IWUE.

7. The crop growth was successfully simulated by means of a model that predicts the DMP using as input only the c-PARi by the crops.

Practical suggestions

- ✓ The most favourable shade intensity was the moderate shade (≈20-25%; IP-13) as compared to the heavy shade (≈34-38%; IP-34), assuming color similarity (neutral color; clear vs white color)
  - IP-13 produced 21% more than the IP-34.

- ✓ The most favourable screen color was the neutral (white) as opposed to the green, at equal shade intensities.
  - IP-34 produced 17% more than the S-36.

- ✓ Cover the crops with green nets only if the is no other color option.

Future work

- ✓ Further improvement of the developed ventilation model by taking account more types of screens and structures.
- ✓ Development of a model that predicts the internal microclimate with respect to the external microclimatic conditions.
- ✓ The numerical simulation of the microclimatic performance of screenhouses by means of CFD tools is very challenging.
- ✓ Investigation of different screen/net types on the performance of different crops and varieties (cucumber, tomatoes, cherry or purple tomatoes).
- ✓ Integration of a screenhouse construction by a hydroponic crop aiming to the enhanced productivity under harsh soil and microclimate conditions.

Acknowledgements

- Members of the advisory committee.

- Members of the examination committee.

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Thank you very much for your attention !

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Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης