The effect of agricultural screen covers and screenhouses on crop microclimate, water consumption and insect penetration

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Summer School

Cover Materials for Greenhouses

24 – 30 September 2018

University of Thessaly

Outline of presentation

-- Review of common screens and structures
-- Microclimate
-- Crop water use
-- Water use efficiency
-- Insect penetration

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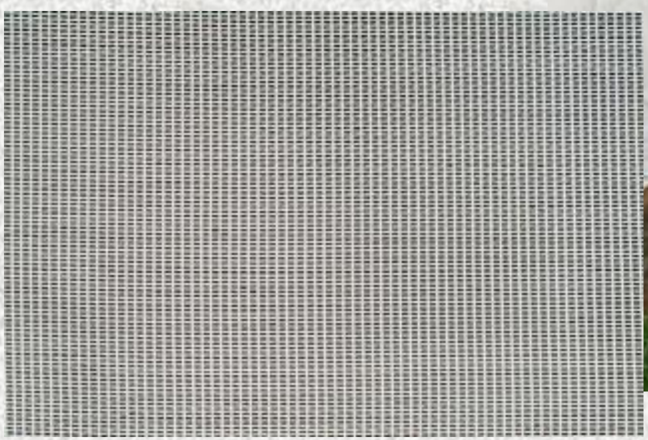
Current uses of screens in agriculture

1. Insect proof screens – exclude insects: 17-75 mesh
Reduce pesticide application – environmental friendly production.
Better access to world markets.



Polysack Inc., Israel

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Current uses of screens in agriculture

2. Shading screens (black) – reduce radiation load – save irrigation water – avoid sun damage.

Polysack Inc., Israel

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Current uses of screens in agriculture

3. Shading screens (transparent) – reduce radiation load – reduce crop water use – avoid sun damage – protect from hail - increase diffuse radiation.

Polysack Inc., Israel

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Types of Greenhouses and Screenhouses

A naturally ventilated greenhouse:
Screened sidewalls and roof vents

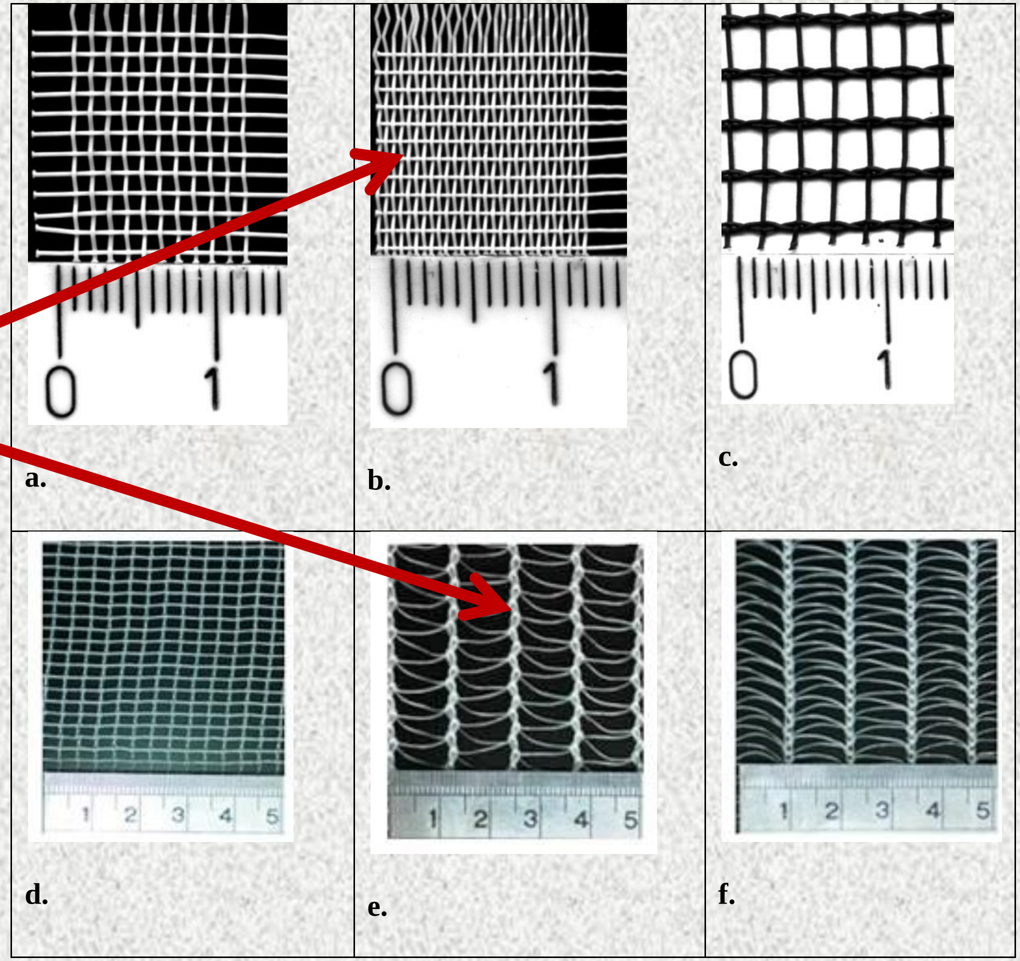
A shade screen cover

A screenhouse with sidewalls

Strong interaction between inside and outside -
No active climate control

Scanned images of screens (ruler in cm)

Notice the rectangular holes – the screen is not symmetrical



Analysis of the scanned image (eg. with NIH IMAGEJ software) gives the coverage (or solidity) of the screen (Möller et al., 2010).

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Effects of screens on crop microclimate

Examples from our studies:

- Temperature
- Humidity
- Radiation
- Wind

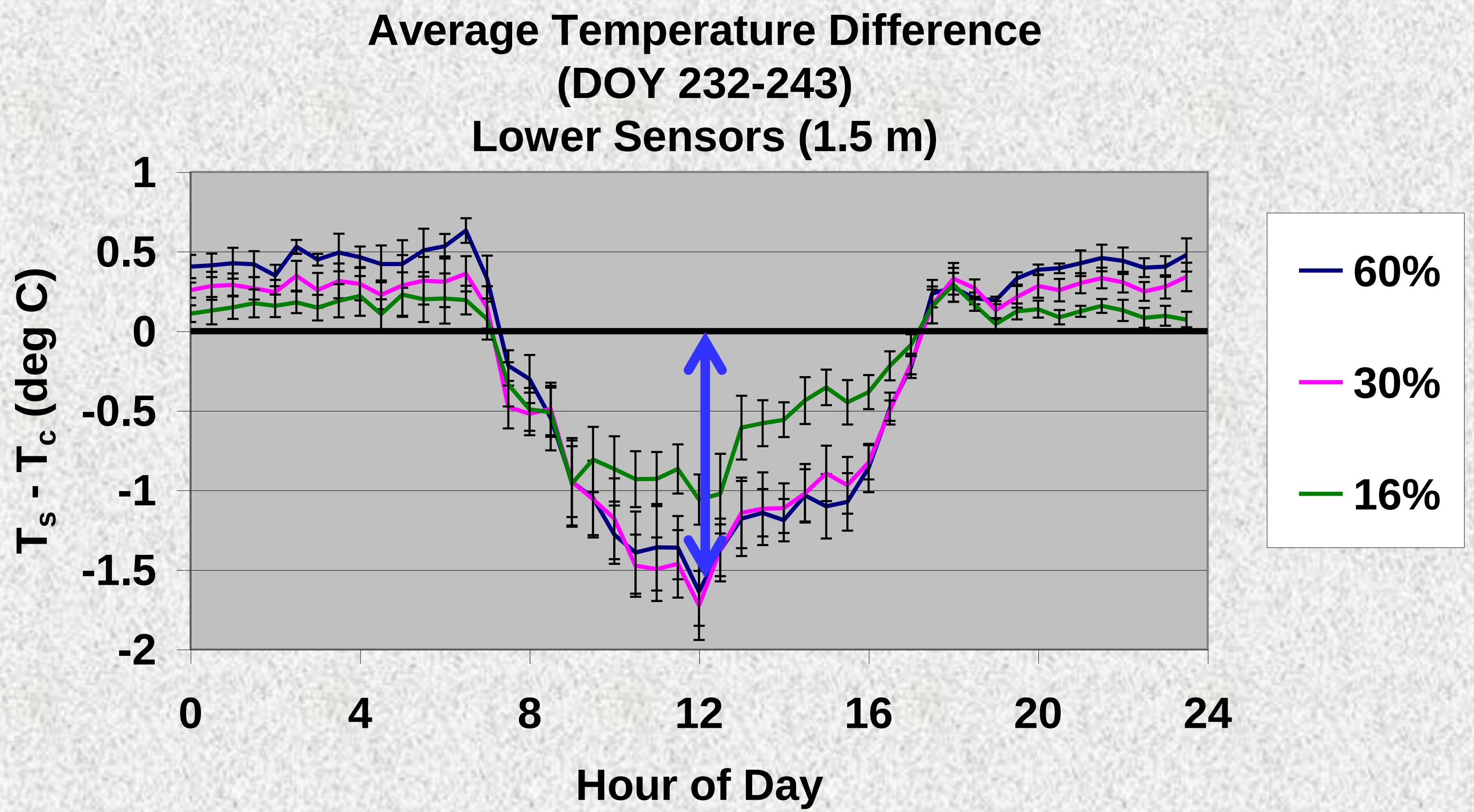
Effect of shading screens on apple orchards

south

	60%	16%	
	0%	60%	
	30%	30%	
	16%	16%	
	0%	30%	
east	16%	0%	west
	30%	60%	
	60%	60%	
	16%	0%	
	60%	16%	
	30%	30%	
	0%		

north

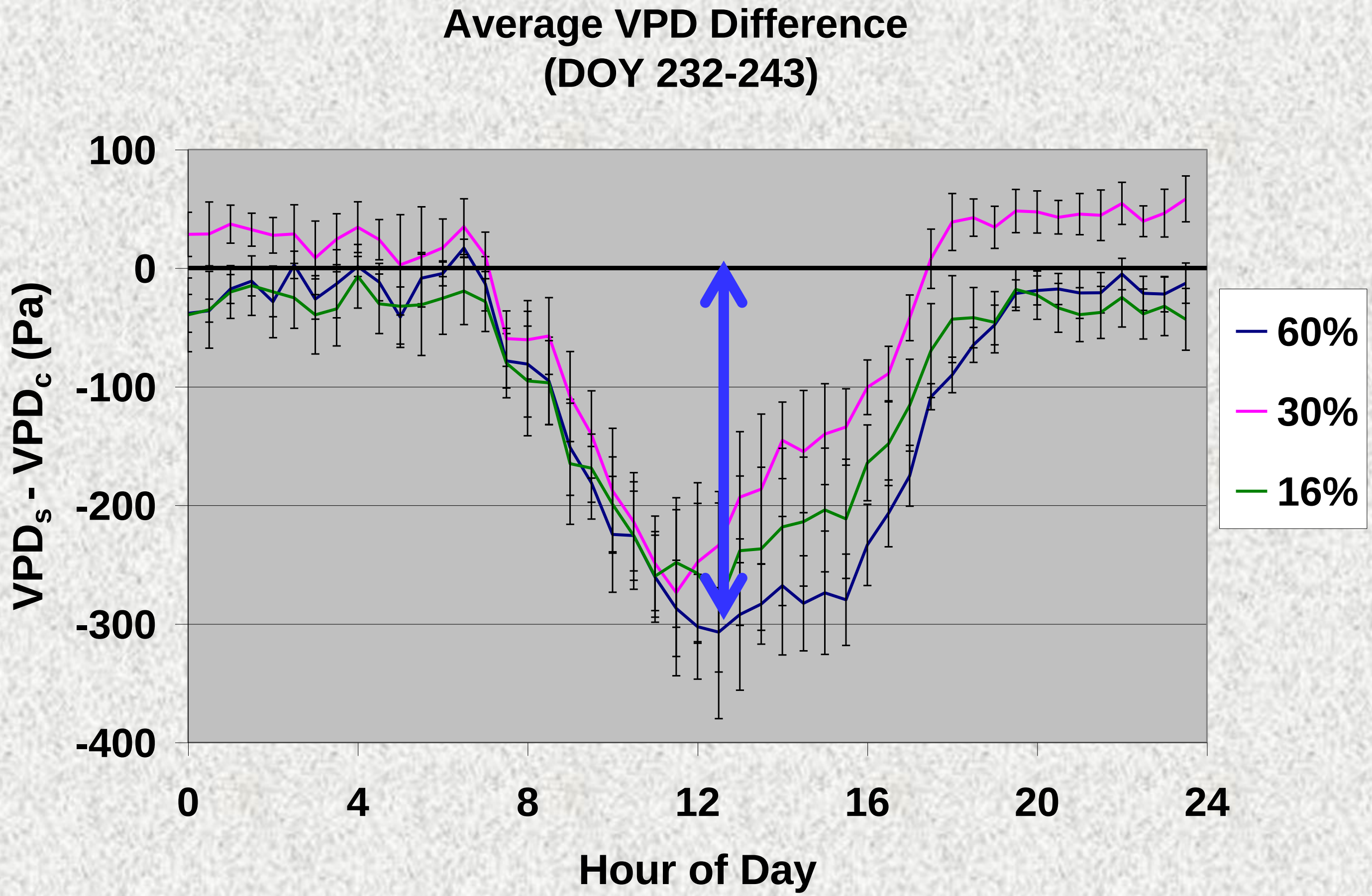
Effect of shading screens on air temperature



Temperature reduction ~ 1.5°C

Under the screens:
Cooler during the day.
Warmer during the night.

Effect of shading screens on VPD



Air is more humid

Under the screens:
Smaller VPD means the air is closer to saturation - a more “humid” air.

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Banana plantations grown inside shading screenhouses – a common practice in Israel

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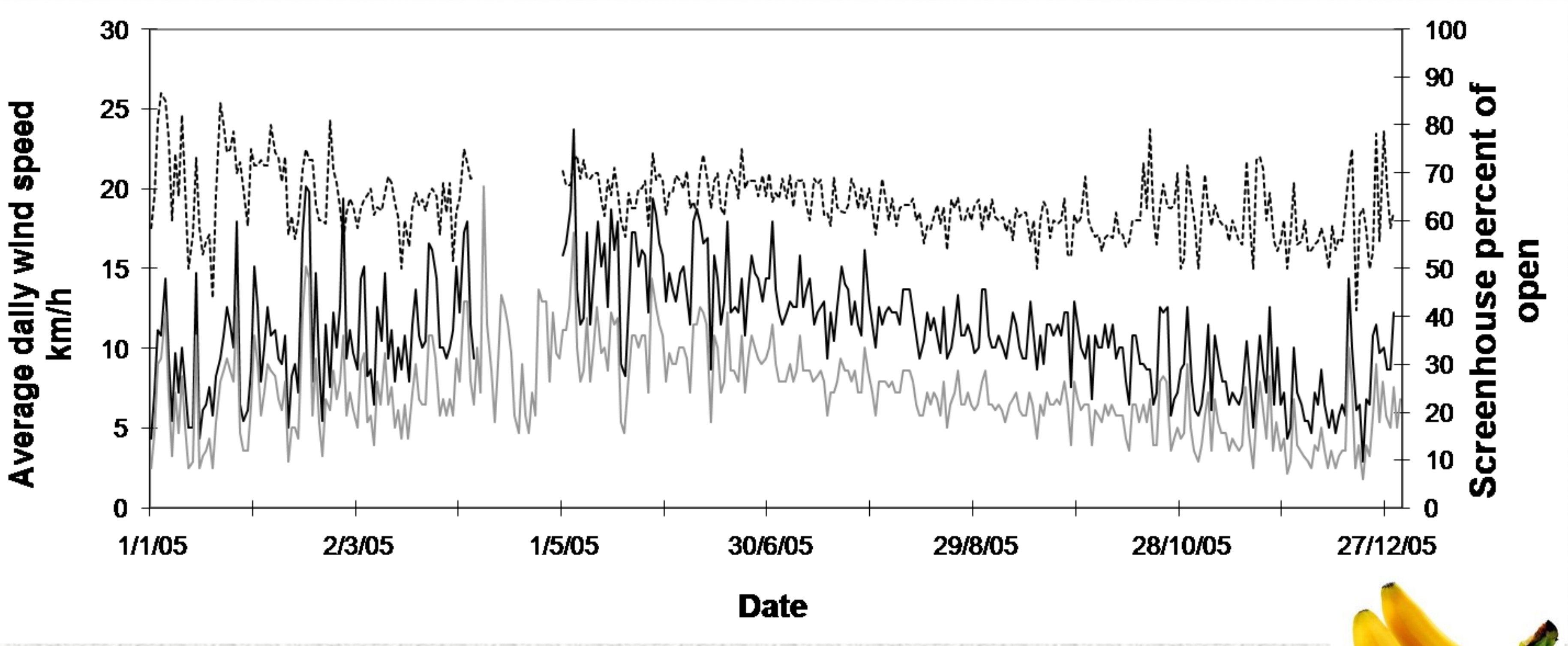
The effects of screens on wind speed

A 3-axis ultrasonic anemometer in a large banana screenhouse

Air speed at 5 m height in **covered** and **uncovered** banana plantations



Wind speed reduction ~ 35%

Open plantation
Screenhouse
Screenhouse percent

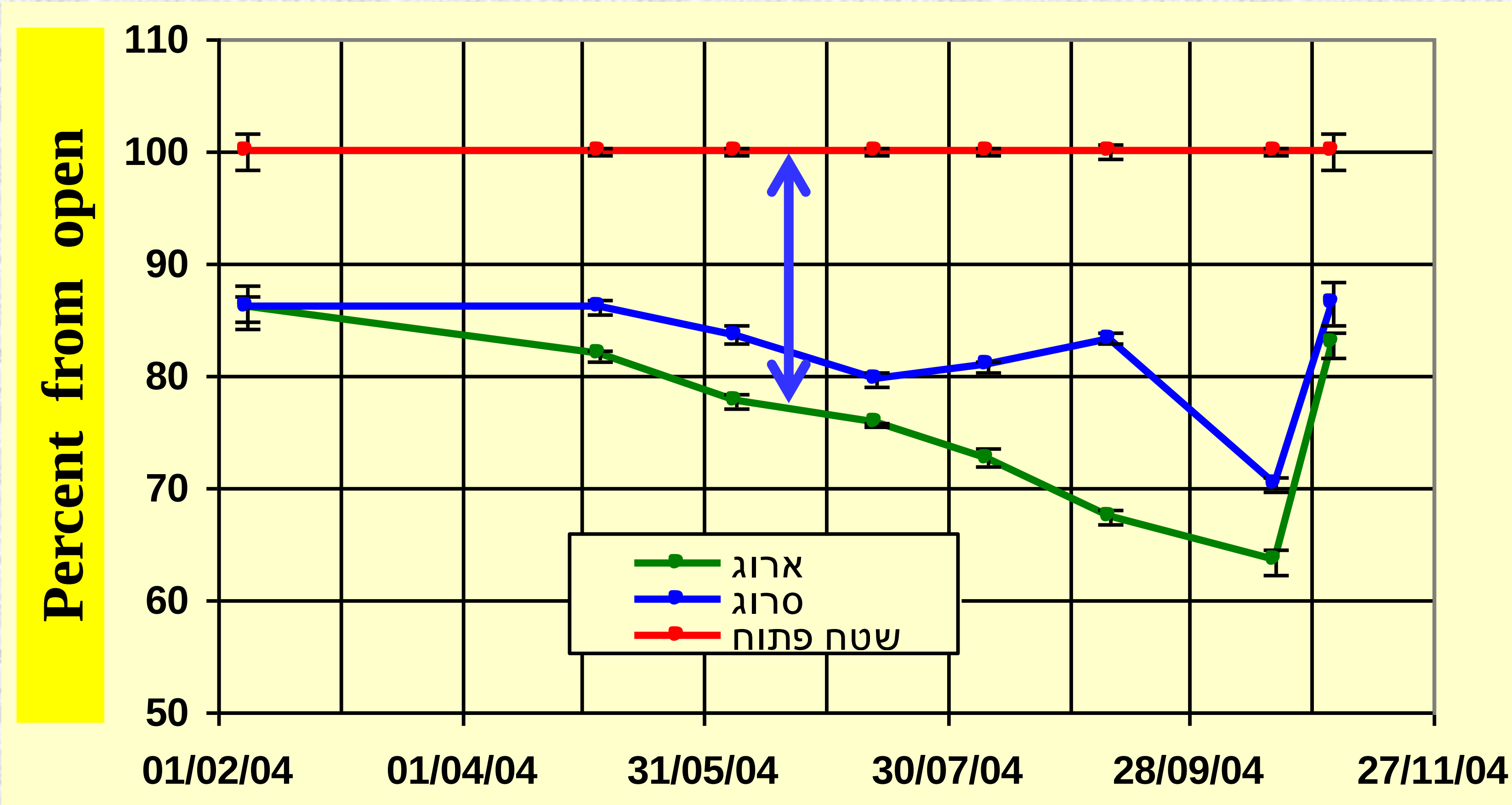
Y. Isaeli, Pers. Comm.

Torn leaves in an open banana plantation

The lower wind speed inside the screenhouse avoids tearing the leaves


Woven screen
Knitted screen

Radiation under the screen as percent of an uncovered orchard

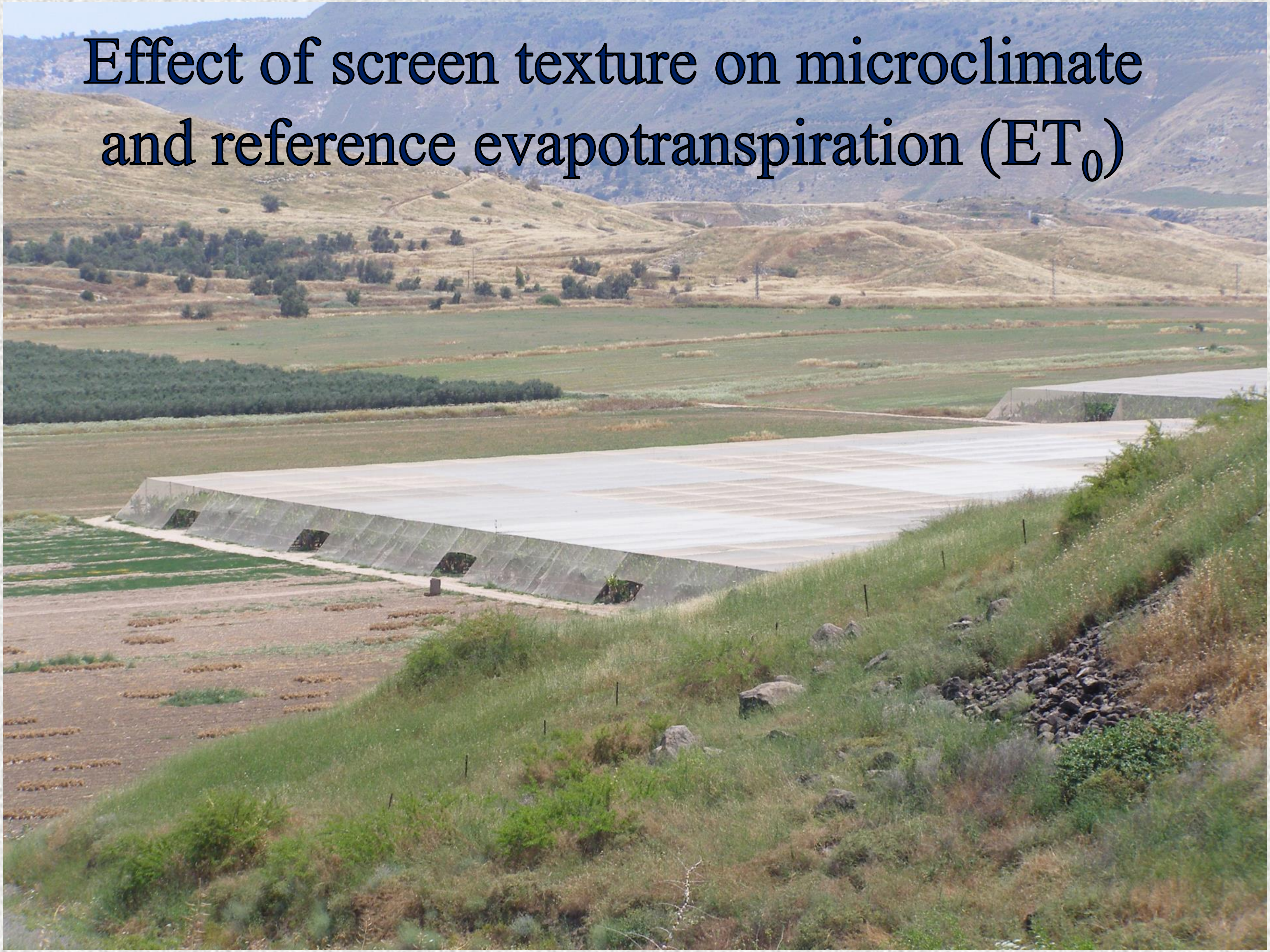


Radiation reduced by 15-35%

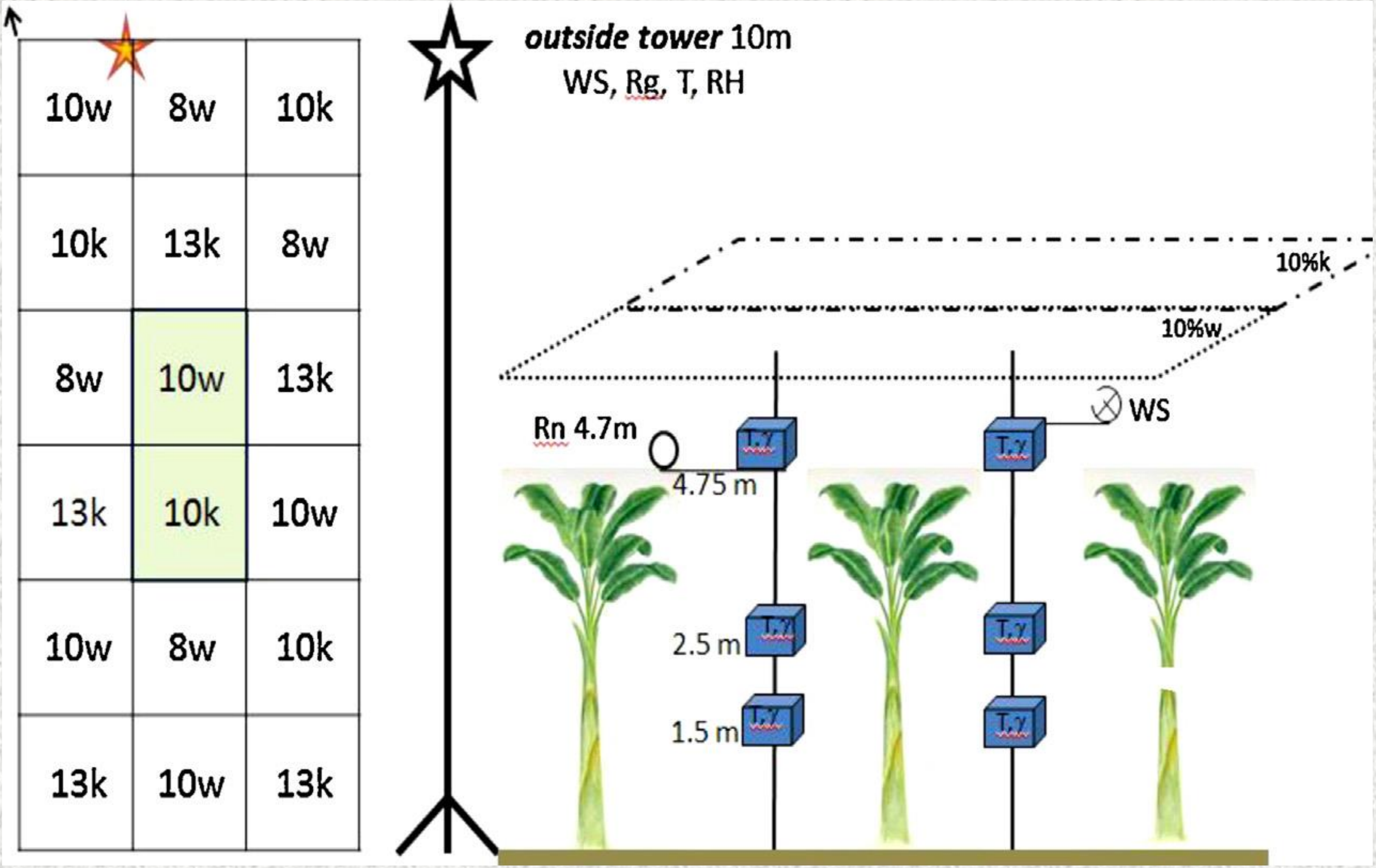
Open
Knitted
Woven

Y. Isaeli, Pers. Comm.

Effect of screen texture on microclimate and reference evapotranspiration (ET_0)

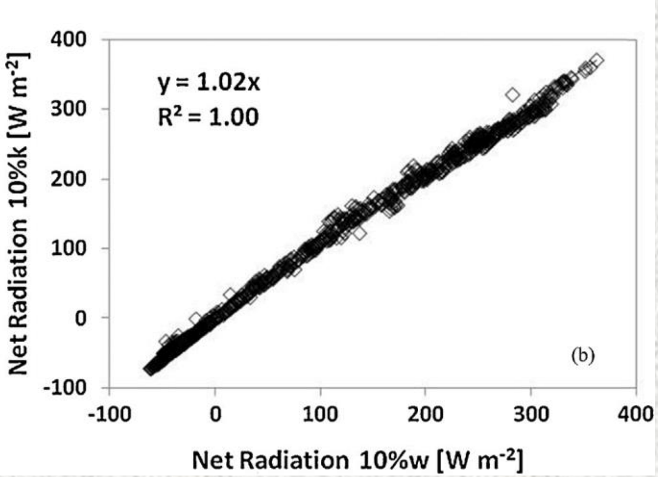


Effect of screen texture on microclimate and reference evapotranspiration

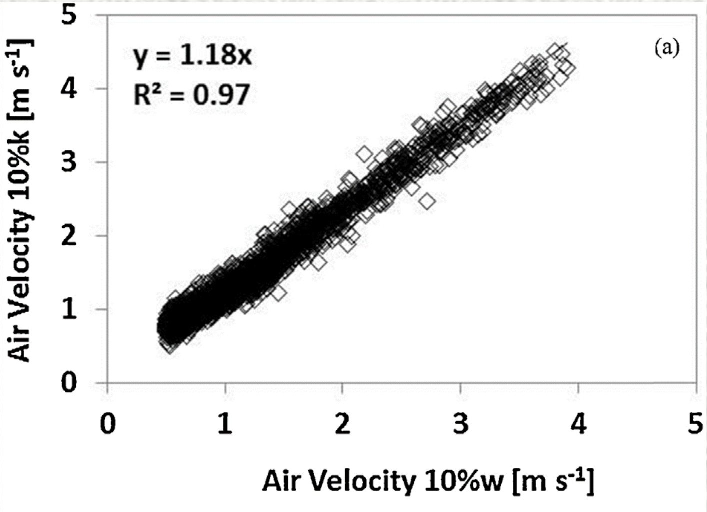


Pirkner et al., (2014)

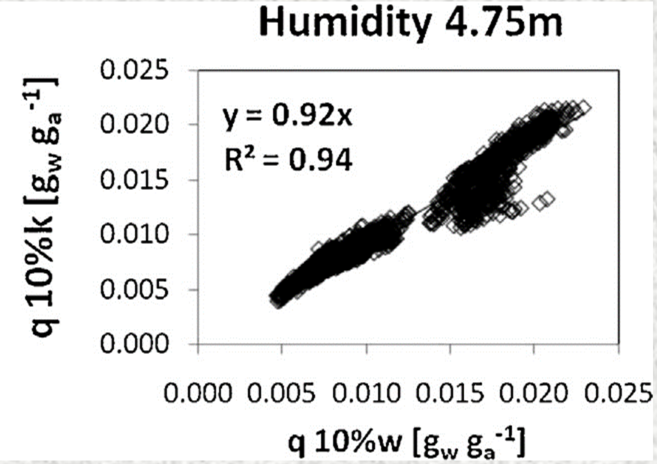
Effect of screen texture on microclimate



Similar net radiation



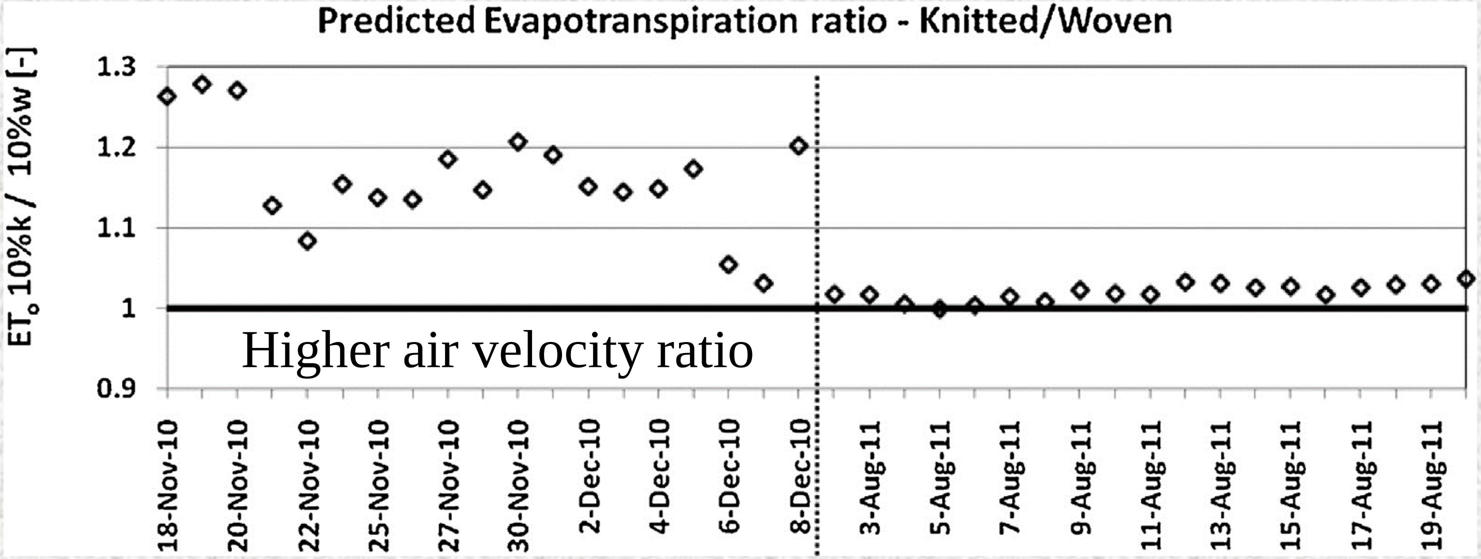
Higher velocity under knitted screen



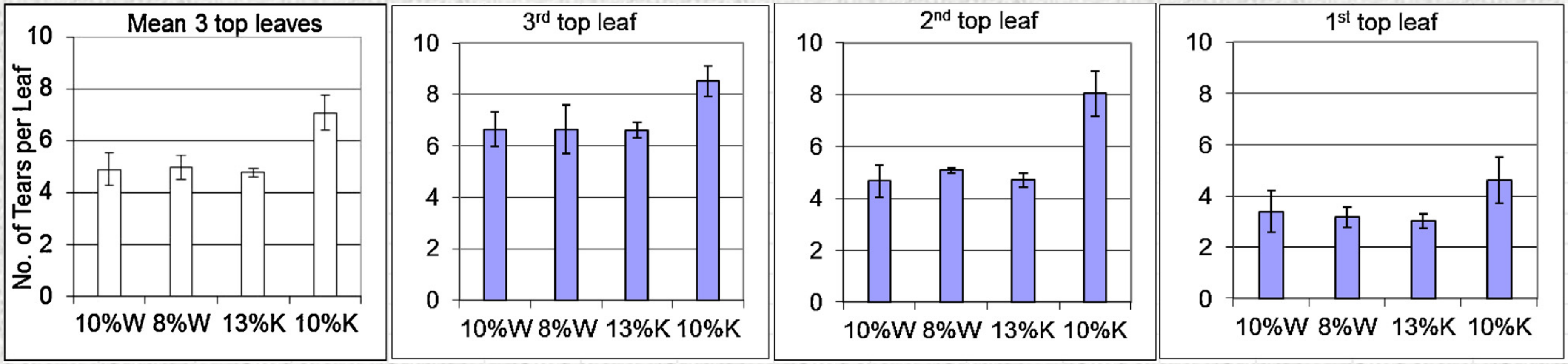
Lower abs. humidity under knitted screen

Pirkner et al., (2014)

Effect of screen texture on ET_0 and leaf tearing



Higher evapotranspiration under the knitted screen



Larger number of tears/leaf under the knitted screen

Pirkner et al., (2014)

The effect of a screenhouse on crop water use – evapotranspiration

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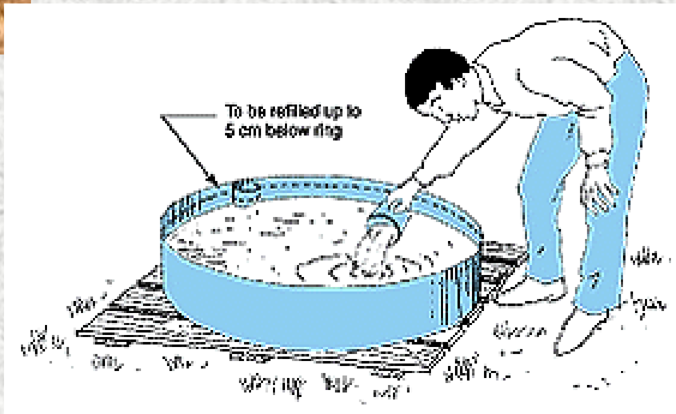
Class A Pan Evaporation – a standard climate variable



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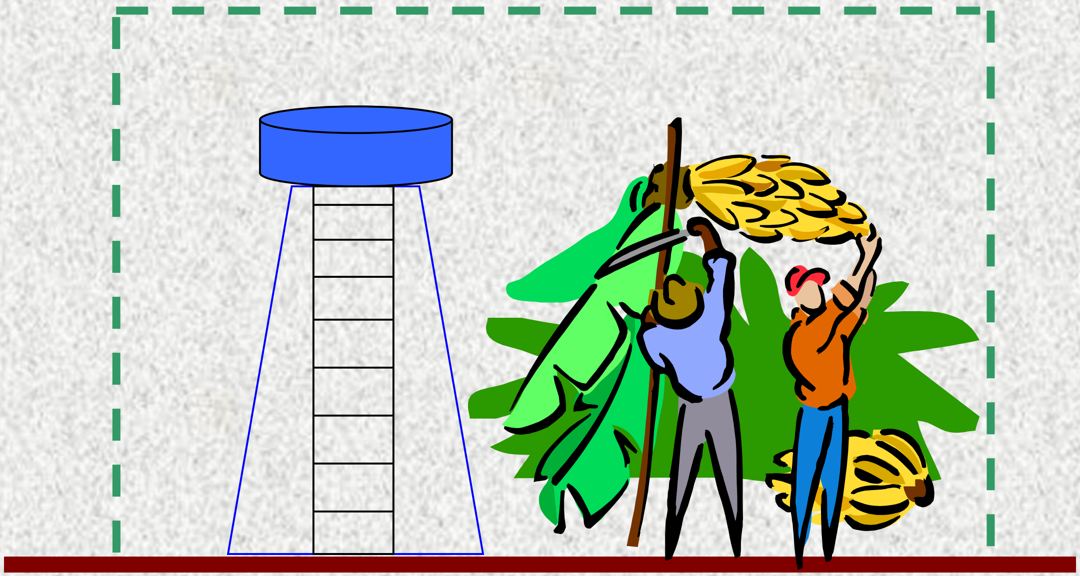
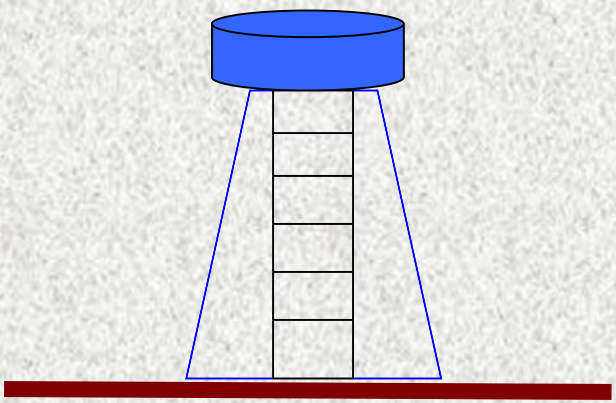
Pan evaporation in a banana screenhouse (Zemach 2004-2008)



Inside the screenhouse



Outside the screenhouse (open field)


03 26 2001

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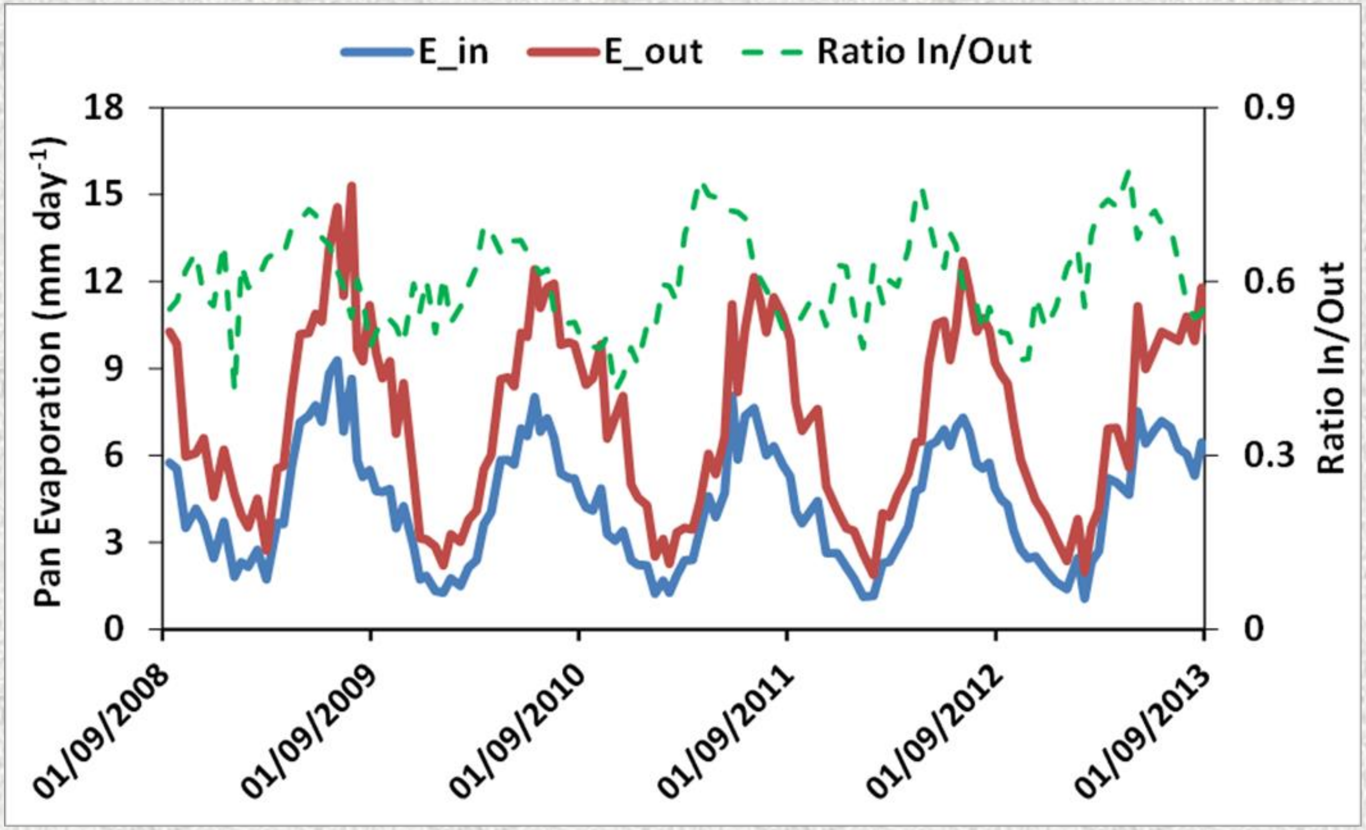
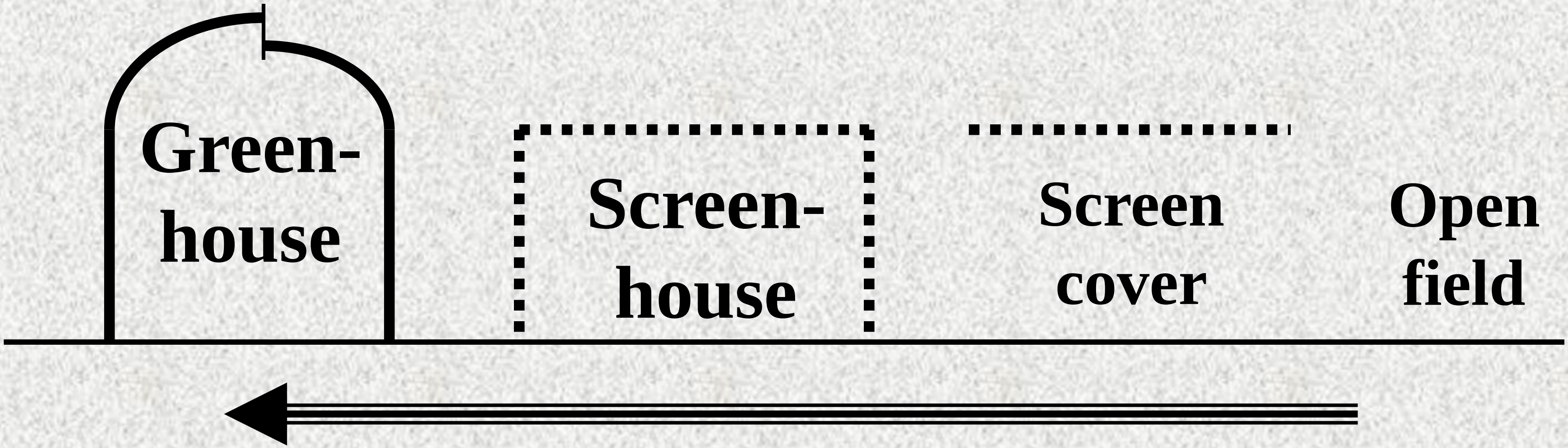
Pan evaporation inside and outside 2008-2013



Open field
Inside the screenhouse

Ratio inside/outside
Average for May-November ~ 60%

A challenge: measuring and predicting crop water use in modified climates



Can we use the same models?

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Pepper grown in a 50-mesh insect-proof screenhouse

An eddy covariance system – evapotranspiration

Sap flow sensor in the stem

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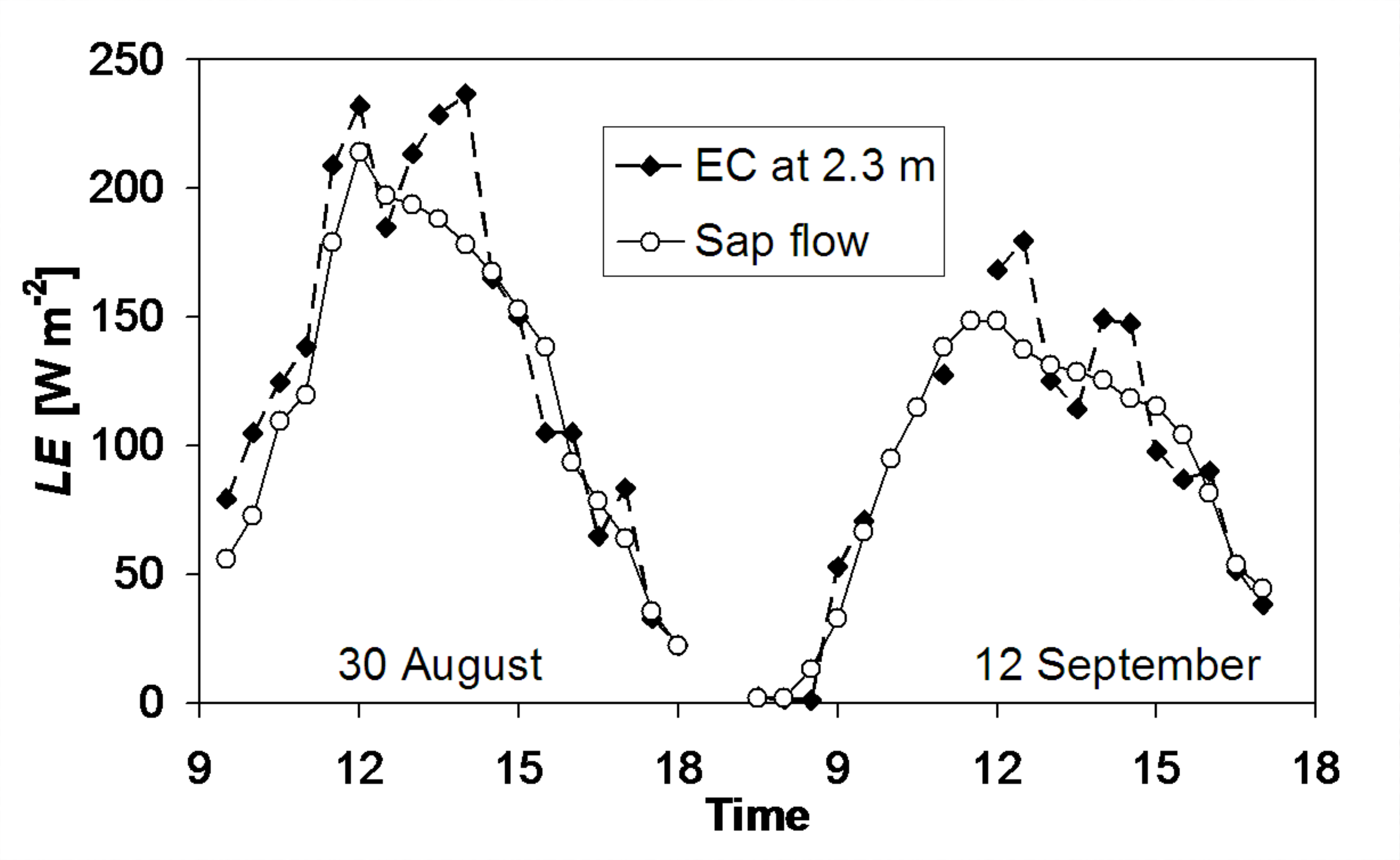
Comparison between diurnal courses of sap flow and evapotranspiration in a pepper screenhouse



LE is latent heat flux in Wm^{-2}

A Modified Penman-Monteith Equation for Screenhouses

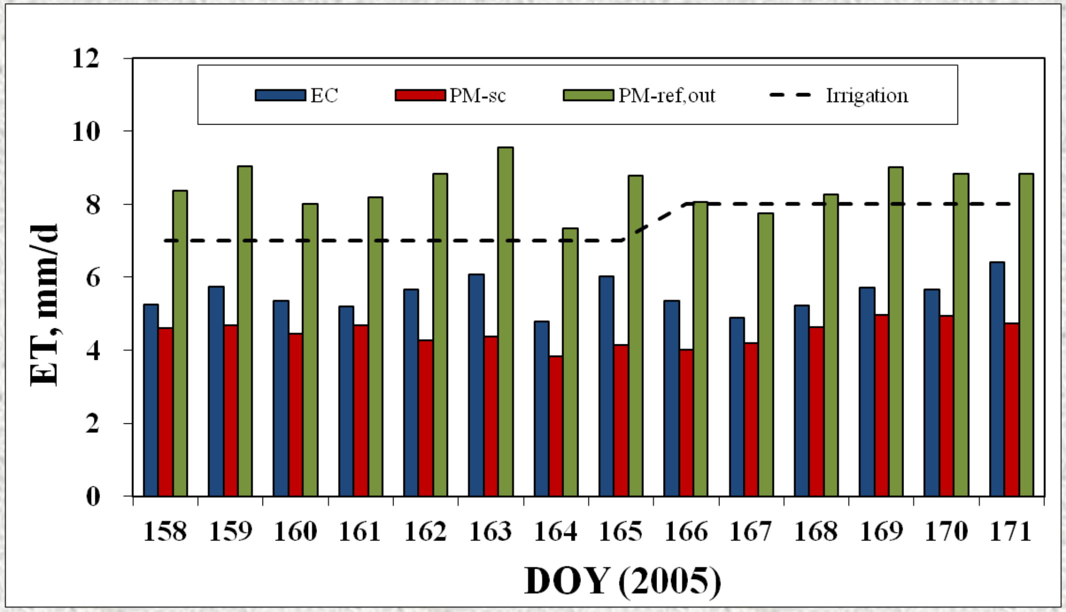
$$\lambda E = \frac{\Delta}{\gamma^* + \Delta^*}\left(R_n - G\right) + \frac{\rho c_p}{r_a(\gamma^* + \Delta^*)}\left[e_s(T_a) - e_a\right]$$

$$\Delta^* = \Delta\left(1 + \frac{r_b}{r_a}\right) \qquad \gamma^* = \gamma\left(1 + \frac{r_c + r_b}{r_a}\right)$$

R_n – Net radiation (Wm^{-2})
G – Soil heat flux (Wm^{-2})
e – Vapor pressure (Pa)
T – Air temperature (K)
r_a – Aerodynamic resistance ($s\ m^{-1}$)
r_b – Boundary-layer resistance ($s\ m^{-1}$)

Measuring crop water use and aerodynamic properties of the screenhouse

Measured and modeled evapotranspiration in a banana screenhouse



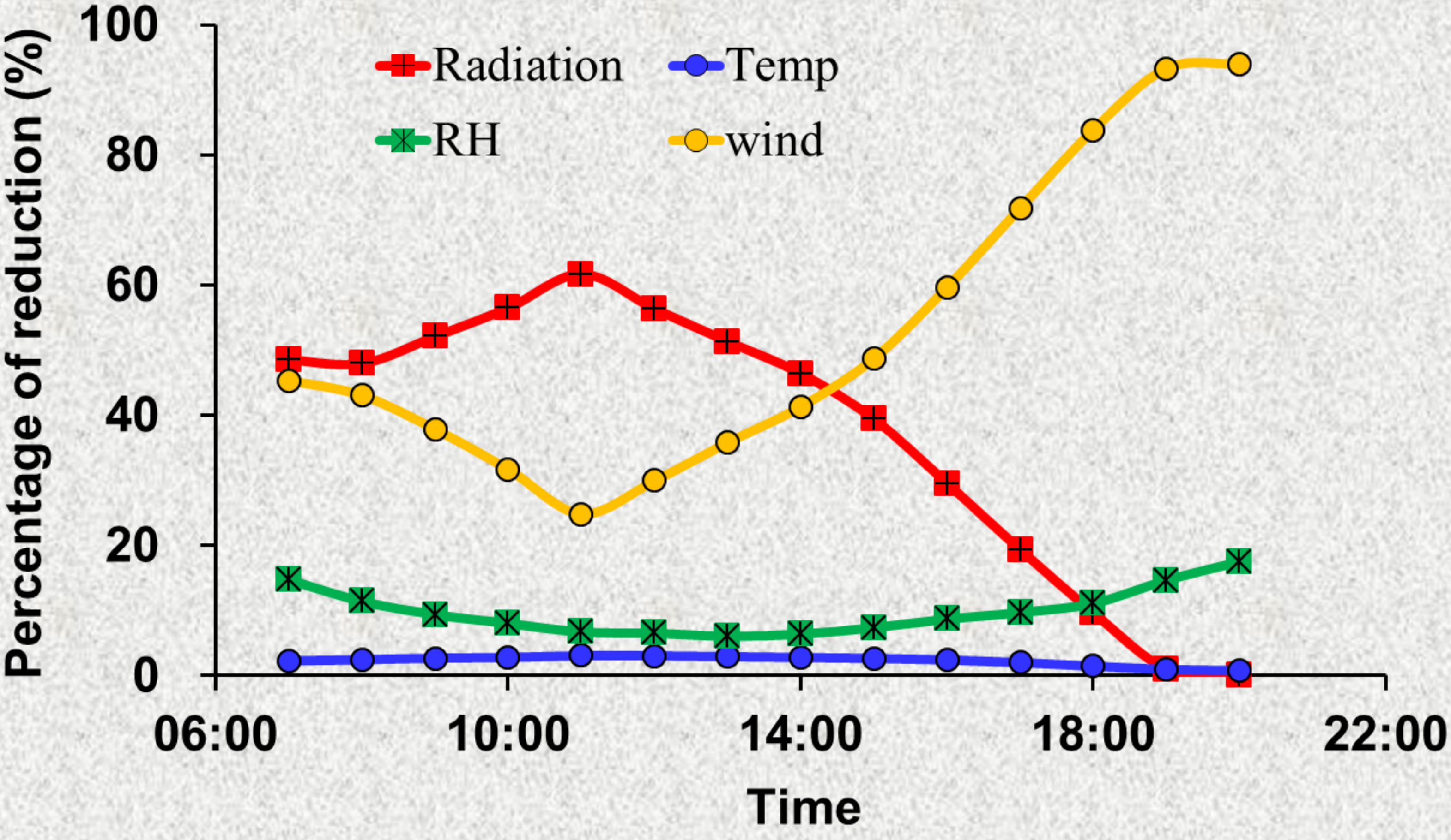
Blue- measured inside

Red – modeled inside

Green – modeled outside

$$\frac{\textbf{Measured } \ ET \textbf{ inside}}{\textbf{Modeled } \ ET \textbf{ outside}} = 0.65 \pm 0.014$$

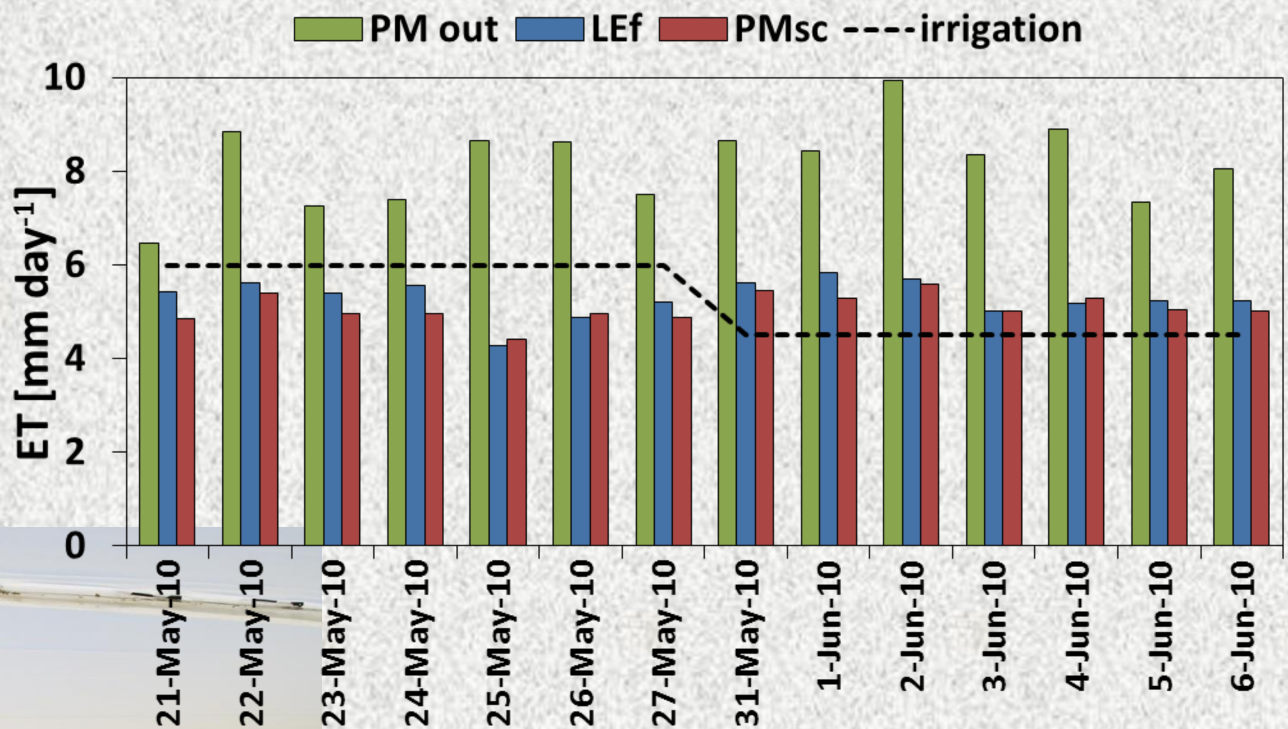
ET reduction by screen compared to open field



Haijun et al., AFM, 2015

Measured and modeled evapotranspiration in a covered vineyard

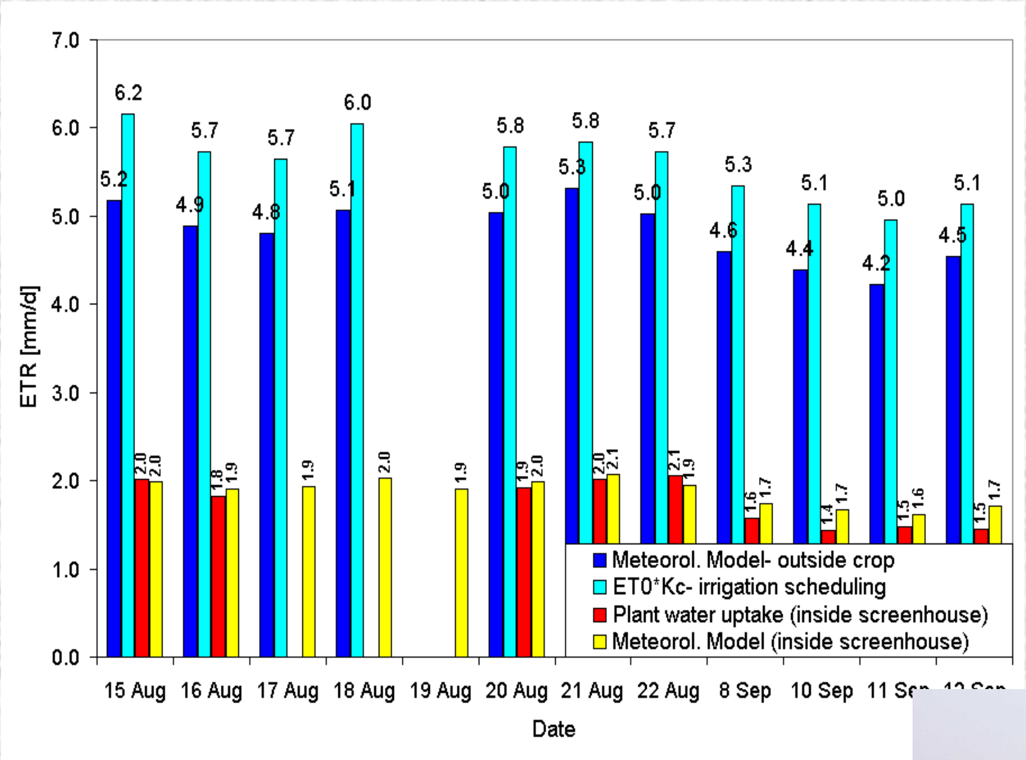
Blue- measured inside
Red – modeled inside
Green – modeled outside



$$\frac{\textbf{Measured } ET \textbf{ inside}}{\textbf{Modeled } ET \textbf{ outside}} = 0.66 \pm 0.09$$

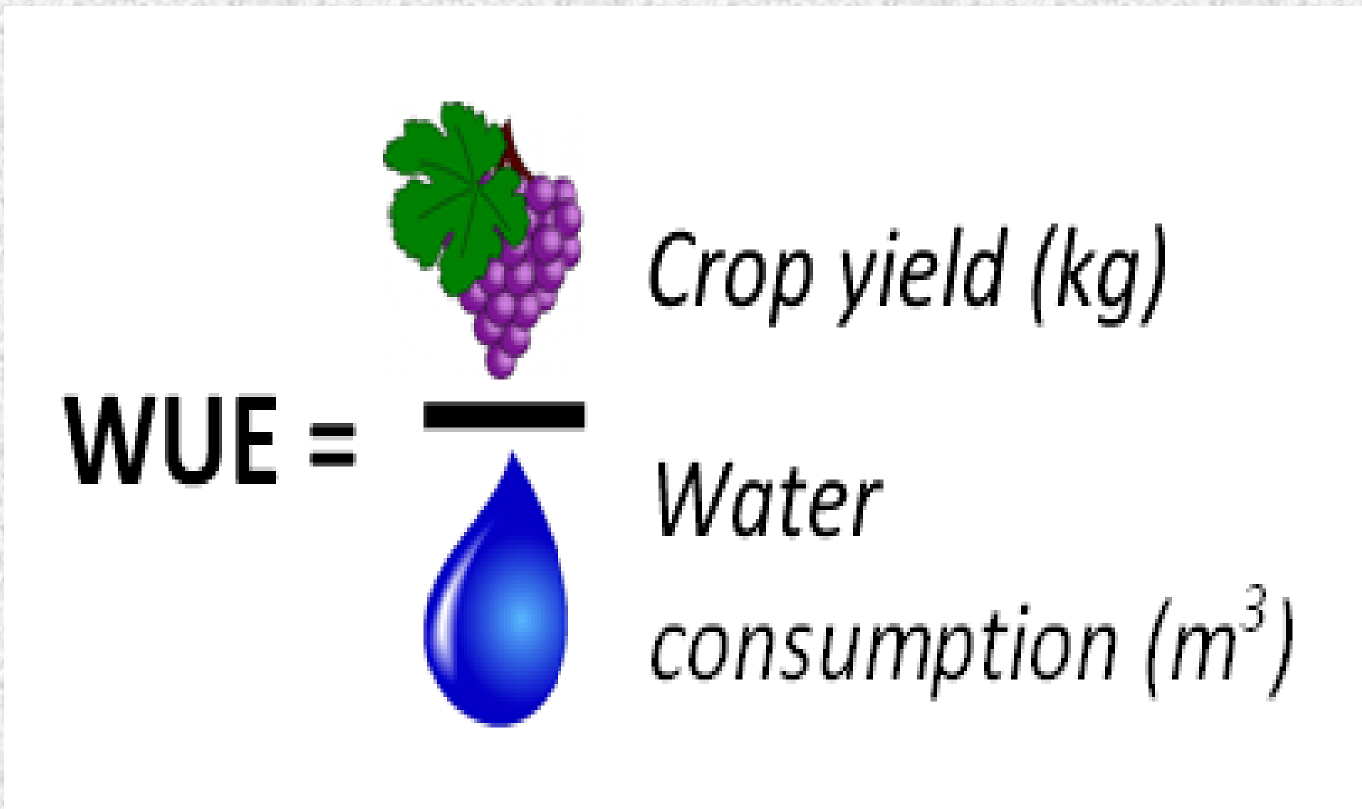
Pirkner et al., IJB, 2015

Evapotranspiration of a pepper plantation: inside the screenhouse and outside



$$\frac{\text{Measured } ET \text{ inside}}{\text{Modeled } ET \text{ outside}} \approx 0.4$$

Saving water means: Increasing the Water Use Efficiency (WUE)



Irrigation experiment
in a banana screenhouse

Four irrigation levels:

100% of outside (~2200mm/year)

85%

70%

55%

Yield (Ton/ha) vs. Irrigation (m^3/ha)
Plantation WUE

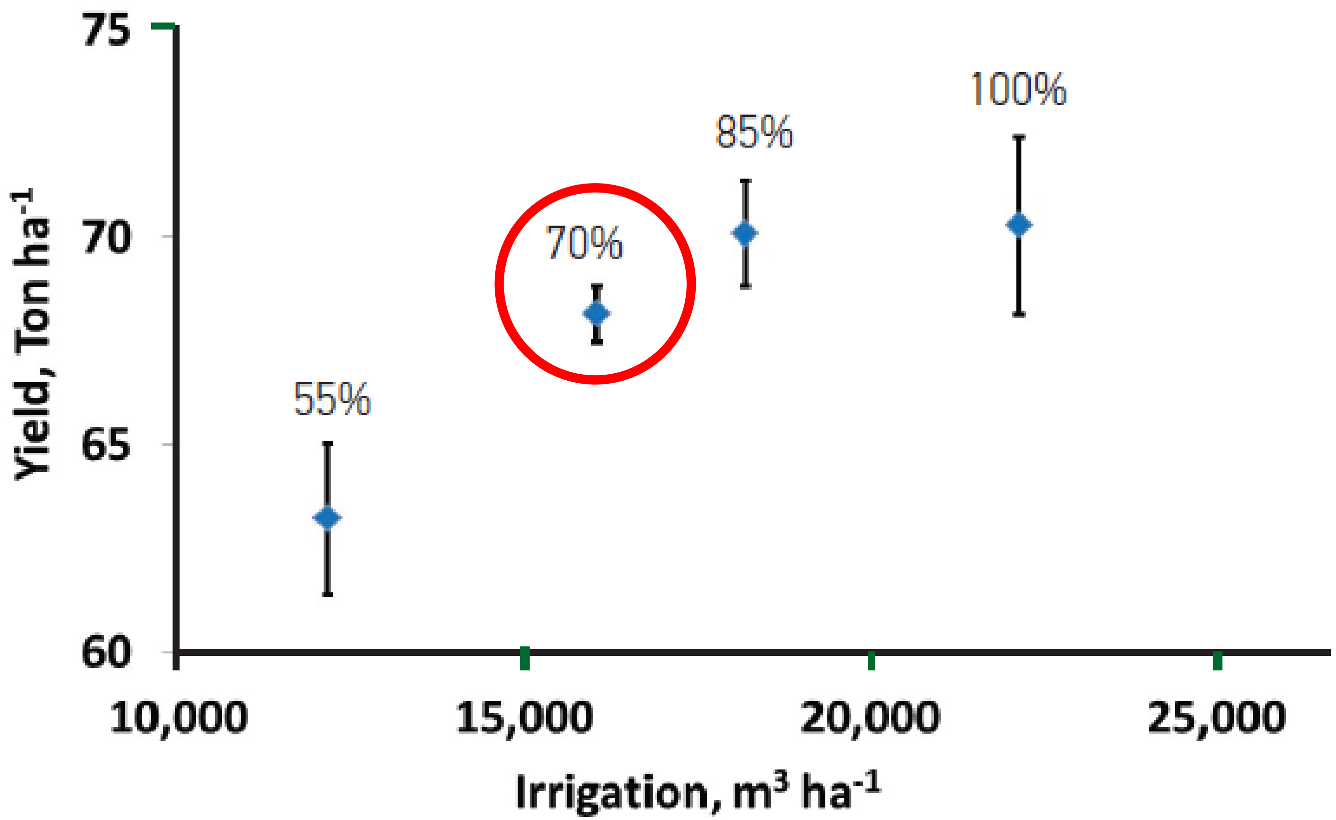


Fig. 4: Mean annual banana yield as a function of the mean annual irrigation, for the years 2004-2007. Percentage indicates the irrigation amount relative to open banana plantations in this region.

Tanny et al., Israel Agriculture, 2015

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Heat pulse technique - installation

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Comparisons between measurements and models (2015-2016)

	mm/day					
	Greenhouse			Screenhouse		
	mm/day		STDEV	mm/day		STDEV
Actually measured	2.54	±	0.78	2.43	±	0.90
ET $_{FAO56}$ out Daily	2.12	±	0.46	2.12	±	0.46
ET $_{FAO56}$ out Hourly	2.41	±	0.66	2.41	±	0.66
ET $_{FAO56}$ in Hourly	2.34	±	0.73	1.70	±	0.49
ET scr	2.74	±	0.90	2.13	±	0.72
PM in (for Pepper)	2.28	±	0.76	2.24	±	0.68
ET gr	2.59	±	0.87	N/A		N/A
ET pt	2.59	±	1.00	1.66	±	0.59
ET rb	2.38	±	0.78	2.28	±	0.66
Ratio: Model/HP	**Ratio**		**NSC**	**Ratio**		**NSC**
ET $_{FAO56}$ Daily out	0.90		0.34	1.07		0.59
ET $_{FAO56}$ Hourly out	0.98		0.88	1.14		0.83
ET$_{FAO56}$ Hourly in	0.93		0.79	0.74		-0.03
ET scr	1.06		0.94	0.96		0.62
PM in (for Pepper)	0.89		0.81	0.98		0.63
ET gr	1.01		0.89	N/A		N/A
ET pt	1.00		0.62	0.71		-0.11
ET rb	0.93		0.88	0.99		0.79

Ratio: Periodic

NSC: Daily

Protected cultivation of pepper

Actual irrigation by internal microclimate

Treatment	Irrigation (m^3/dunam) 15/8/16-15/5/17 Greenhouse	Screenhouse*
Penman (external hour)	778	762
Penman (internal) (PMrb)	596	692
Penman (external recommended)	830	841
60% of recommended	635	643

Greenhouse – reduction of 28%
Screenhouse – reduction of 18%

*Add 100 mm rain to the screenhouse

Yield

Greenhouse	Export (Kg/m^2)	Total (Kg/m^2)
Penman (external hour)	a 9.4	a 10.4
Penman (internal) (PMrb)	a 9.4	a 10.3
Penman (external recommended)	a 9.3	a 10.4
60% of recommended	b 7.8	b 8.8

No significant difference between 2 and 3

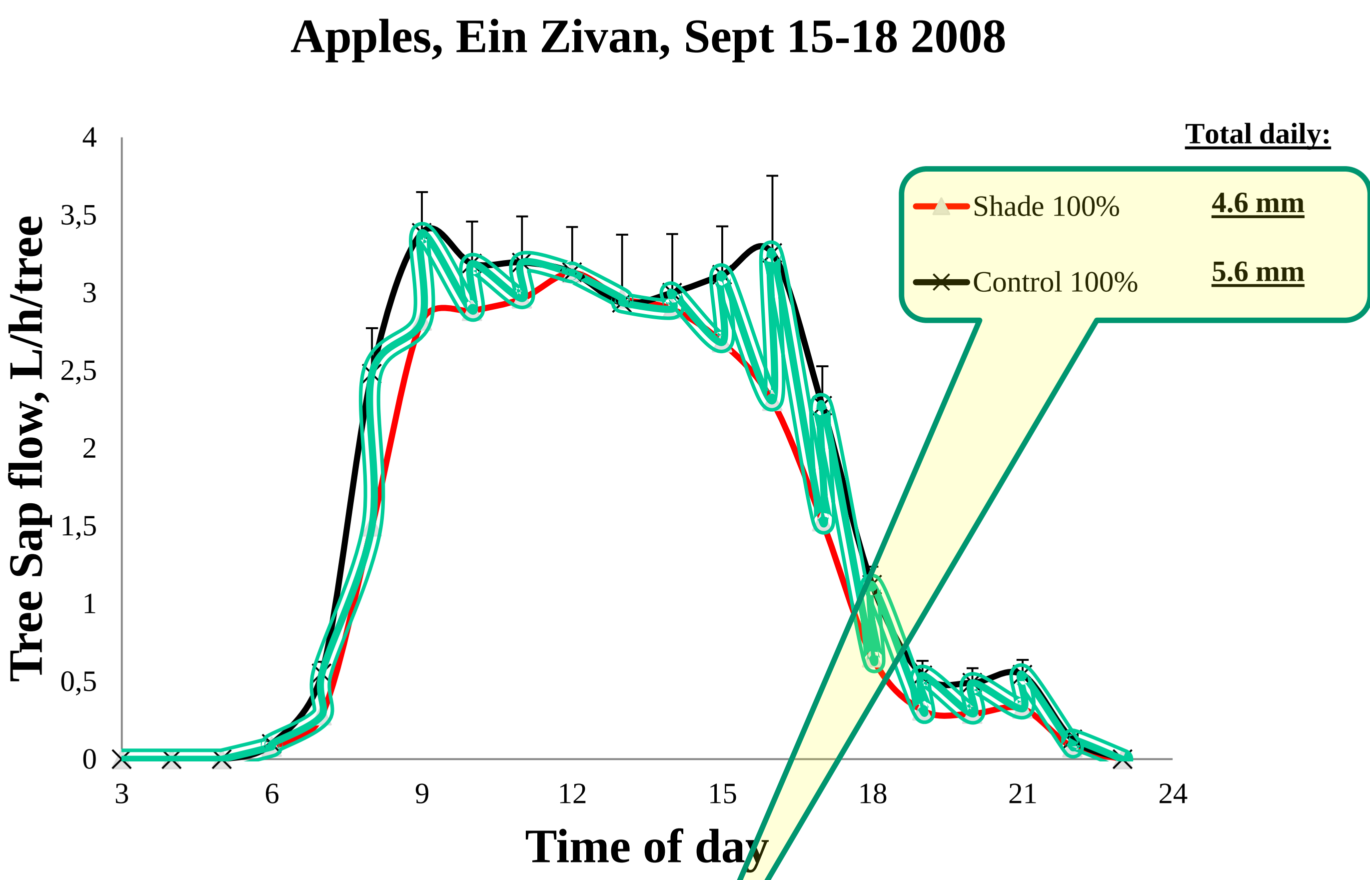
Screenhouse	Export (Kg/m^2)	Total (Kg/m^2)
Penman (external hour)	a 9.78	a 11.7
Penman (internal) (PMrb)	ab 8.87	a 11.1
Penman (external recommended)	b 8.1	b 10.1
60% of recommended	b 8.16	b 10.1

Treatment 4 (60%) – fertilization problem

Cover increased water use efficiency ~ 20 - 35%

Screen covered apple orchard

Tree sap flow sensors. 36 trees were measured continuously



Screens increased water use efficiency ~ 20%

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The effect of insect-proof screens and airflow direction on insect penetration

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Insect penetration is associated with airflow

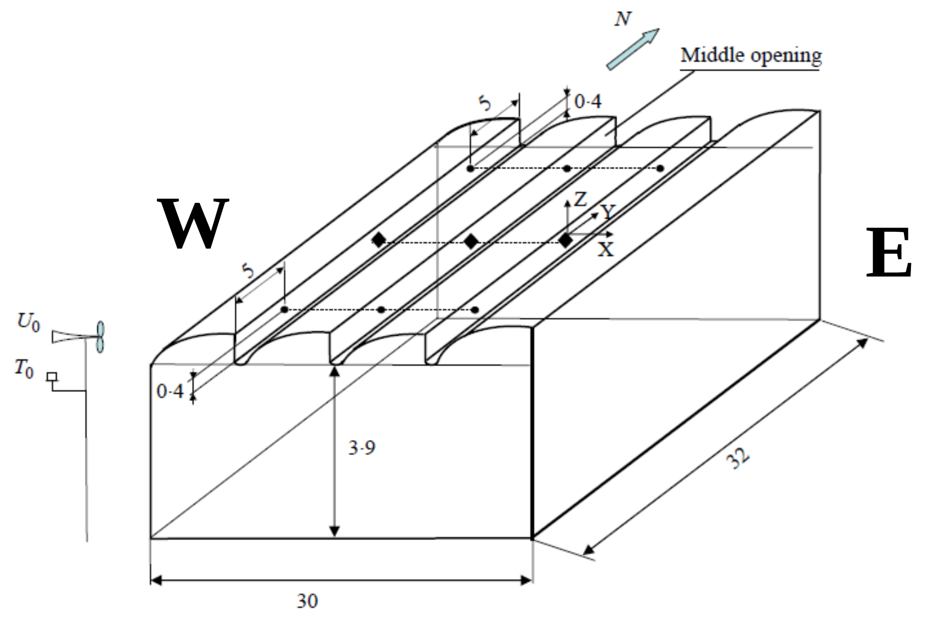

Fig. 1. Schematic view of the greenhouse and location of the anemometers: ●, 1D sonic anemometer; ◆, 3D sonic anemometer; all dimensions are in m; U_0, ambient wind; T_0, ambient temperature; X, Y and Z are axes along which air velocity components were measured; dimensions in m

- Greenhouse with small (0.5 m) pepper plants
- Roof windows opened without insect-proof screens
- Air velocity and direction measured by ultrasonic anemometers placed near the openings.

Teitel et al. (2005), Biosystems Engineering, 92(3), pp. 341-353

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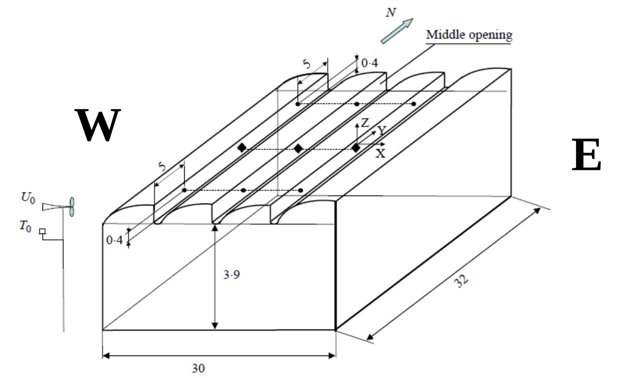
Probability of inflow through a certain opening edge

Table 3
Probability of inflow through a certain opening edge: ES, eastern opening southern edge; EN, eastern opening northern edge; WS, western opening southern edge; WN, western opening northern edge

Wind azimuth range, deg	*Date*	*Probability of inflow*			
		Opening and edge			
		ES	*EN*	*WS*	*WN*
0–89	9–21 Sept.	0·08	0·07	0	
	3–7 Oct.	0·14	0·13	0	0
90–179	9–21 Sept.	0·18	0·18	0·02	
	3–7 Oct.	0·13	0·15	0·01	0·08
180–269	9–21 Sept.	0·27	0·19	0·09	
	3–7 Oct.	0·15	0·34	0·04	0·24
270–360	9–21 Sept.	0·15	0·01	0·04	
	3–7 Oct.	0·09	0	0	0
All directions	9–21 Sept.	0·68	0·45	0·15	
0–360	3–7 Oct.	0·51	0·62	0·05	0·32



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Insect penetration is associated with airflow

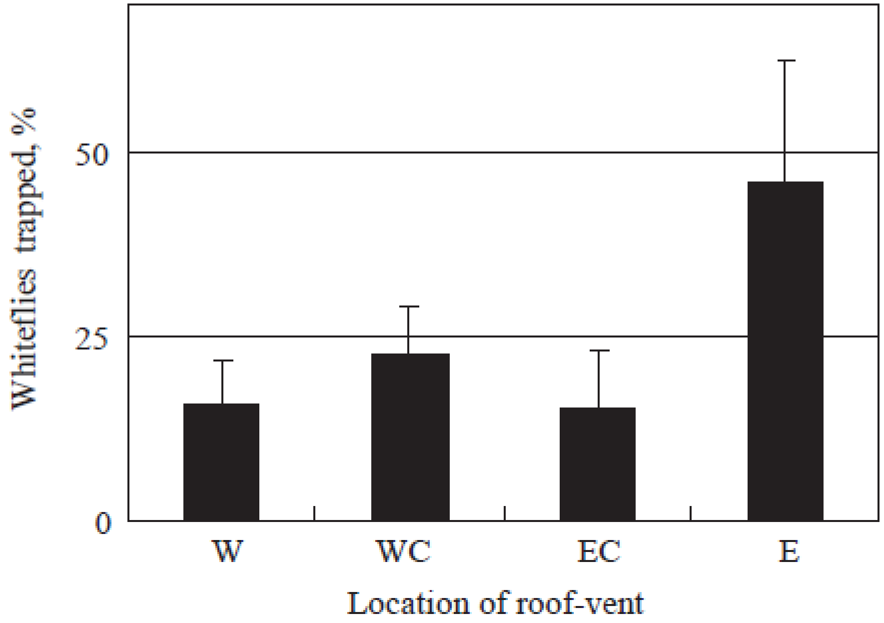
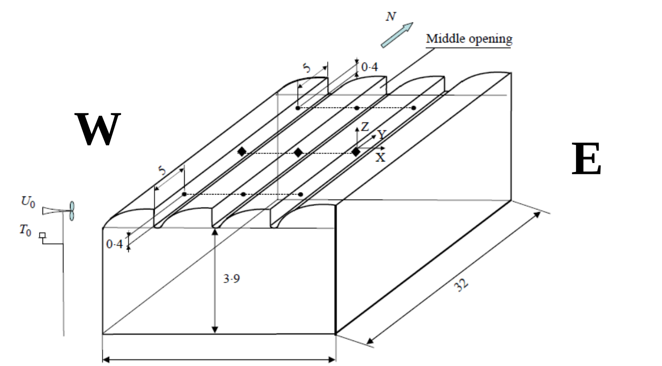


Fig. 12. The distribution of whiteflies trapped under the various roof openings, autumn 2003 (7 trapping days; side-openings closed; a mean of 125 whiteflies day^{-1}): W, western opening; WC, western–central opening; EC, eastern–central opening; E, eastern opening



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Invasion of whiteflies into naturally-ventilated greenhouses with screened roof openings

The experimental setup

- Two naturally-ventilated greenhouses with roof windows, 0.7 m high.
- Young pepper plants
- **A** – low mesh, 22% shading (knitted)
- **B** – dense, 50-mesh, insect proof (woven)
- Both greenhouses – side openings with 50-mesh screens.
- Yellow traps at 2.5 and 0.4 m height, in and out.

Measurements periods

- I – roof windows screened and opened, 3 weeks
- II – roof windows shut with plastic sheets, 4 weeks
- III - roof windows screened and opened, 4 weeks

Teitel et al. (1999) Acta Horticulturae 507, pp. 25-34

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Results

A naturally-ventilated greenhouse with screened roof openings

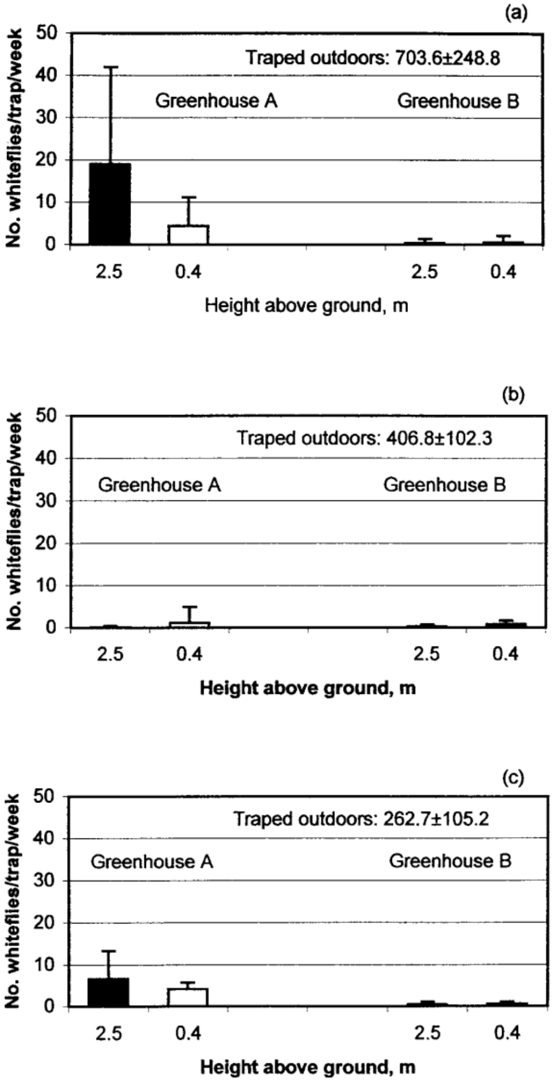

Fig. 3. Traped whiteflies per week per trap indoors and outdoors in three successive periods(a,b&c). (a) period I; (b) period II; (c) period III.

Screened, open

Plastic, closed

Screened, open

Measurements periods

- I – roof windows screened and opened, 3 weeks
- II – roof windows shut with plastic sheets, 4 weeks
- III - roof windows screened and opened, 4 weeks

Teitel et al. (1999) Acta Horticulturae 507, pp. 25-34

Major conclusions

- ✓ Screens reduce air velocity and radiation.

- ✓ Reductions of between 35-60% in evapotranspiration were realized under the screens, depending on screen and crop type.

- ✓ Increase in water use efficiency:
  - banana - 20-30%.
  - apple 10-20%.
  - Pepper 20-35%.

- ✓ Insects penetrate with airflow; insect screens efficiently block invasion.

- ✓ Future research –
  - - optimization of the use of screens.
  - - improve the water use efficiency.
  - - Study other crops.

Thank you!
Questions?

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