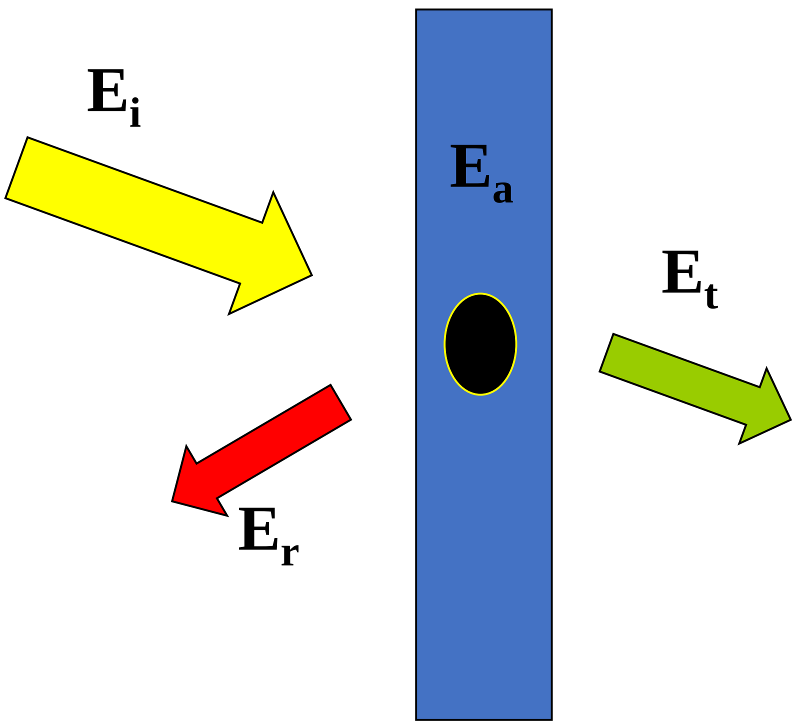
Photoselective cover materials & transmission

Evelia Schettini

Department of Agricultural and Environmental Science
University of Bari, Bari, Italy

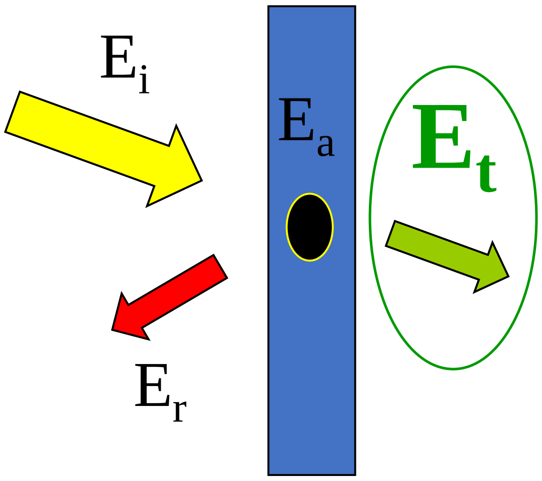
When radiant flux is incident upon a surface or medium, three processes occur: ***transmission, absorption, and reflection.***

The total incident radiation E_i on a body can be transmitted through the body (E_t), absorbed by the body (E_a), reflected from the body (E_r).

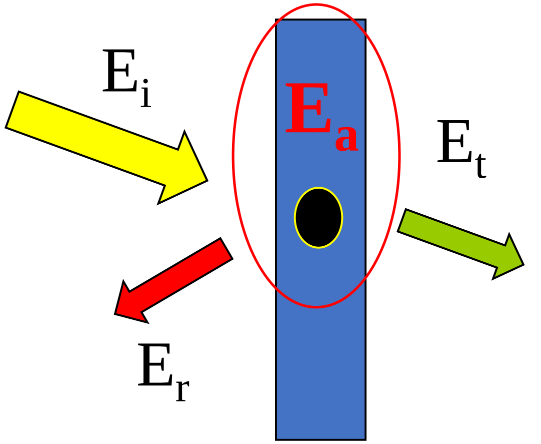


By energy conservation:

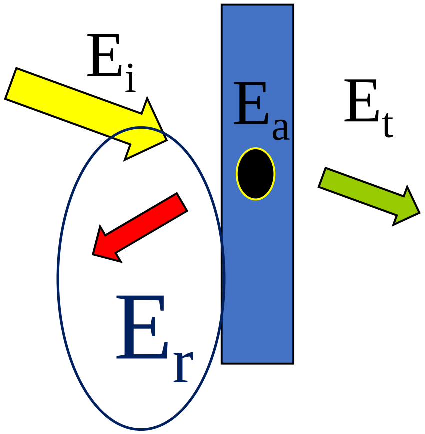
$$E_t + E_r + E_a = E_i$$



Transmission is the term used to describe the process by which incident radiant flux leaves a surface or medium from a side other than the incident side, usually the opposite side.



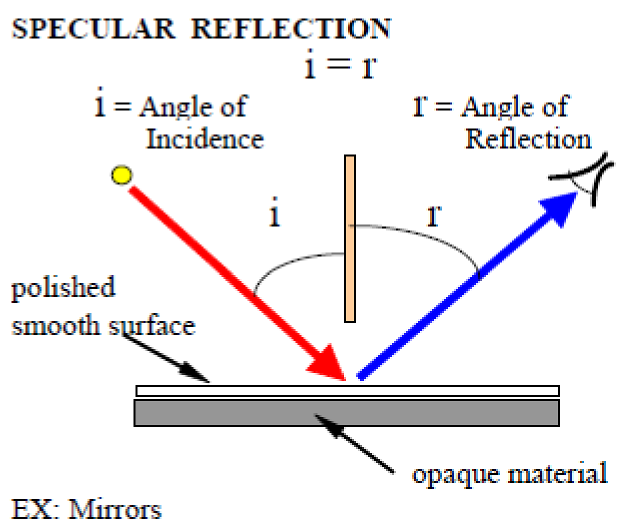
Absorption is the process by which incident radiant flux is absorbed, thus it is converted to another form of energy, usually heat.

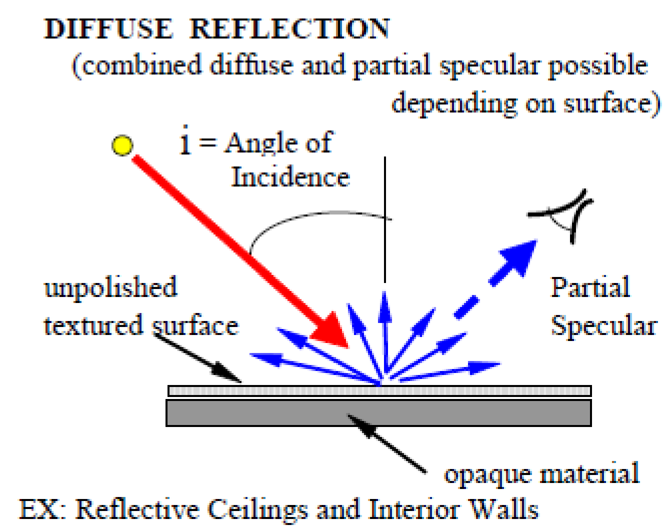


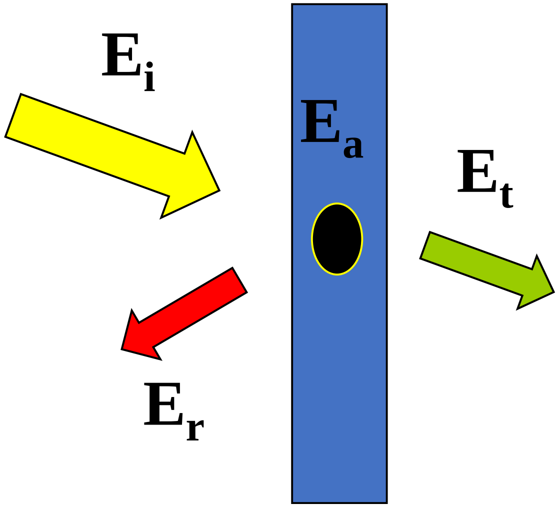
Reflection is the process where a fraction of the radiant flux incident on a surface is returned into the same hemisphere whose base is the surface and which contains the incident radiation.

The reflection can be specular (in the mirror direction) or diffuse (scattered into the entire hemisphere).

Diffusion reflection (also called scattering) is the process of deflecting a unidirectional beam into many directions.







$$E_t + E_r + E_a = E_i$$

$$\frac{E_t}{E_i} + \frac{E_r}{E_i} + \frac{E_a}{E_i} = \frac{E_i}{E_i}$$

τ = transmission coefficient= E_t / E_i

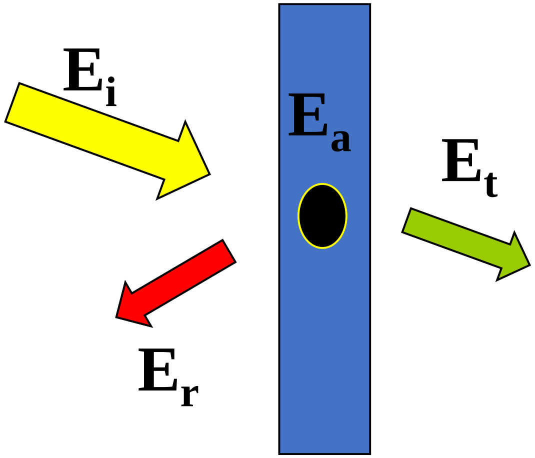
ρ = reflection coefficient = E_r / E_i

α = absorption coefficient = E_a / E_i

$$\boxed{\boldsymbol{\tau + \rho + \alpha = 1}}$$

(*Kirchoff's* Law)

Application of conservation of energy leads to the statement that the sum of the transmission, reflection, and absorption of the incident flux is equal to unity.



$$\boxed{\tau + \rho + \alpha = 1}$$

(Kirchoff's Law*)*

τ = transmission coefficient

ρ = reflection coefficient

α = absorption coefficient

τ, ρ and α depend on the wavelength, on the nature of the body, on its temperature, on the direction of incidence of the radiation and on the layer thickness.

Transparent body → $\tau = 1 \quad \rho = \alpha = 0$

Opaque body → $\tau = 0 \quad \rho + \alpha = 1$

White body → $\rho = 1 \quad \tau = \alpha = 0$

Blackbody → $\alpha = 1 \quad \rho = \tau = 0$

Grey Body → $\begin{cases} \alpha \neq 0 \\ \tau \neq 0 \\ \rho \neq 0 \end{cases}$

In general: $0 \leq \tau \leq 1; \quad 0 \leq \rho \leq 1; \quad 0 \leq \alpha \leq 1$

Emissivity (ε) *is defined as the ability of the surface of a body to radiate heat.*

Emissivity is a property that measures how much a surface behaves as a blackbody. A blackbody is a theoretically ideal radiator and absorber of energy at all electromagnetic wavelengths. The emissivity of a real surface varies as a function of the surface temperature, the wavelength, and the direction of the emitted radiation.

It is also defined as the ratio of the emissive power of any body to the emissive power of a blackbody, when both are maintained at the same temperature T.

$$\boxed{\varepsilon_{\lambda} = E_{\lambda} / E_{\lambda \mathrm{black}}}$$

ε is therefore dimensionless and can assume values between 0 and 1.

For a blackbody, ε= 1

For a white body, ε= 0.

In a closed system at thermal equilibrium, conservation of energy necessitates that emitted and absorbed fluxes are equal. Since the radiation field in such a system is isotropic (the same in all directions), the emittance and the absorptance must be equal:

$$\varepsilon = \alpha$$

This statement was first made by Kirchhoff (1860).

If the situation is such that one of the above Kirchhoff-type relations is applicable, then the emittance ε *may be substituted for the absorptance* α *in the equation* $\tau + \rho + \alpha = 1$

$$\boxed{\varepsilon = 1 - \tau - \rho}$$

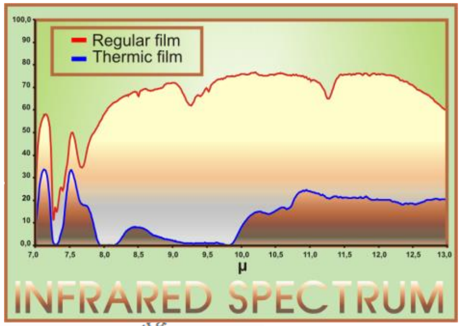
that is a relationship between transmittance, reflectance, and emittance.

A material with high emissivity is efficient in both absorbing radiation energy as well as emitting it. Therefore a good absorber is also a good emitter.

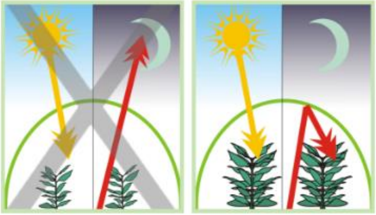
GREENHOUSE PLASTIC FEATURES:

- Clear 6 mil polyethylene film
- Anti dust protection - Reduces absorption of dust for long lasting transmittance
- **4 Year Rating & Warranty**
- Light transmittance > 90%
- Light Diffusion 20%

KRITIFIL® greenhouse films
Thermic effect



PLASTIKA KRITIS offers special thermic films, containing a combination of EVA and Infra-Red additives skilfully structured in the layers of the films, which absorb the Infra-Red radiation and reduce heat losses during the night.



F-CLEAN plastics offer many benefits:

- Non-stick surface repels dirt
- Snow slides off naturally
- Anti-drip properties protect plants
- Clear grades let in the full spectrum of solar light
- Durable enough to last 25+ years

F-CLEAN ETFE film comes in various thicknesses from 60µm (2.4 mil) to 100µm (4 mil) and several gra… options that diffuse light, reduce ultraviolet light, and filter out 99% of visible light.

Grades

- F-CLEAN Clear (60µm, UV-Open) – admits the full spectrums of sunlight through the covering, providing the same light conditions as outside the greenhouse.
- F-CLEAN Diffused Series (60µm, UV-Open) – provides highly diffused sunlight evenly while maintaining high light transmission.
- F-CLEAN GR series – reduces the percentage of ultraviolet light admitted through the covering.
- F-CLEAN Grey (100µm) – significantly filters visible light – up to 99% – to provide a cool environment in hot weather.
- F-CLEAN Soft Shine (100µm)– enables light transmission of about 14%, while simultaneously blocking heat energy from solar light to prevent temperature build-up inside

Features

- Light transmittance up to 94%
- Translucent to ultraviolet light
- Anti-dripping and self-cleaning properties
- Very high reflection and refraction rates
- Extremely high tensile strength
- Low degradation from sunlight and heat (more than 30 years without any deterioration)

Applications

- Covering material for horticultural greenhouses
- Diffused versions restrict light intensity for sensitive crops
- Double layering of covered materials promotes heat retention, reducing the cost of heating
- Ultraviolet block series controls amount of ultraviolet light

Multisolar:
For crops that require a high greenhouse effect, a high amount of light and attenuated intensification, we produce an excellent diffused light thermal film: **Multisolar**.
Produced only with 5-layer technology, it achieves top performance in all its versions:

Multisolar 3, thickness 150 microns > Durability class: B (EN:13206).
Multisolar 33, thickness 200 microns > Durability class: D (EN:13206).
Multisolar 42, thickness 200 microns > Durability class: E (EN:13206).

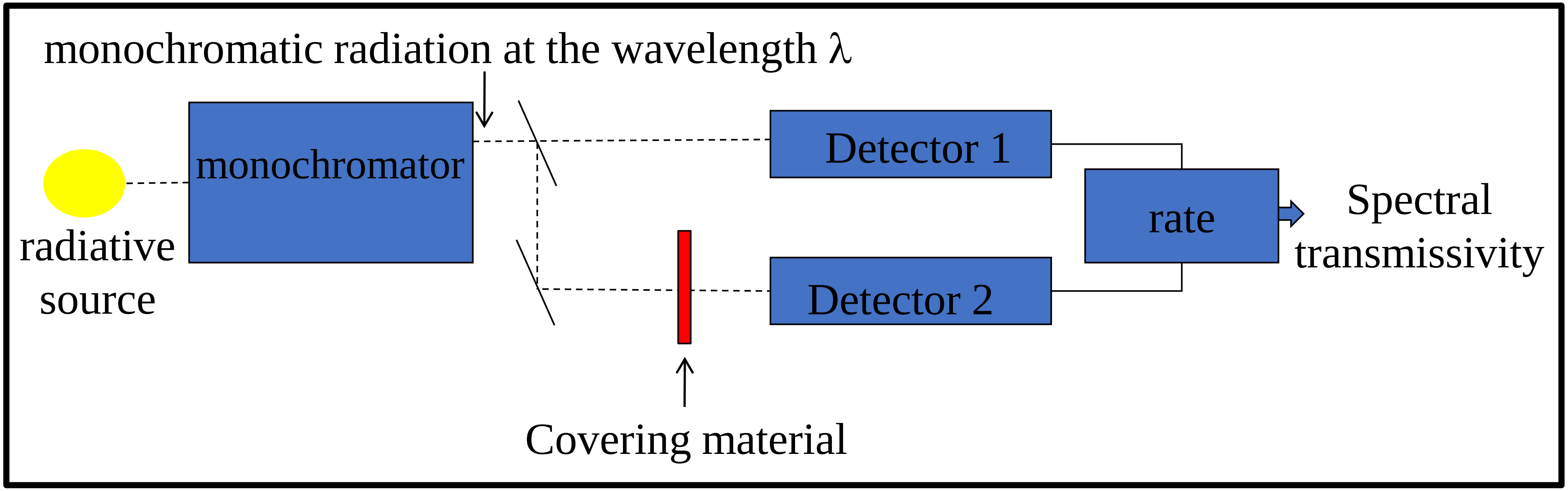
Anti-condensation (AD) and anti-fog (AF) package optional.

The radiometric characteristics of the covering materials vary according to:

- *kind of material*
- *thickness*
- *color*
- *aging*
- *wavelength of the radiation*
- *angle of incidence between solar radius and material surface.*

Radiometric characterization of the covering materials

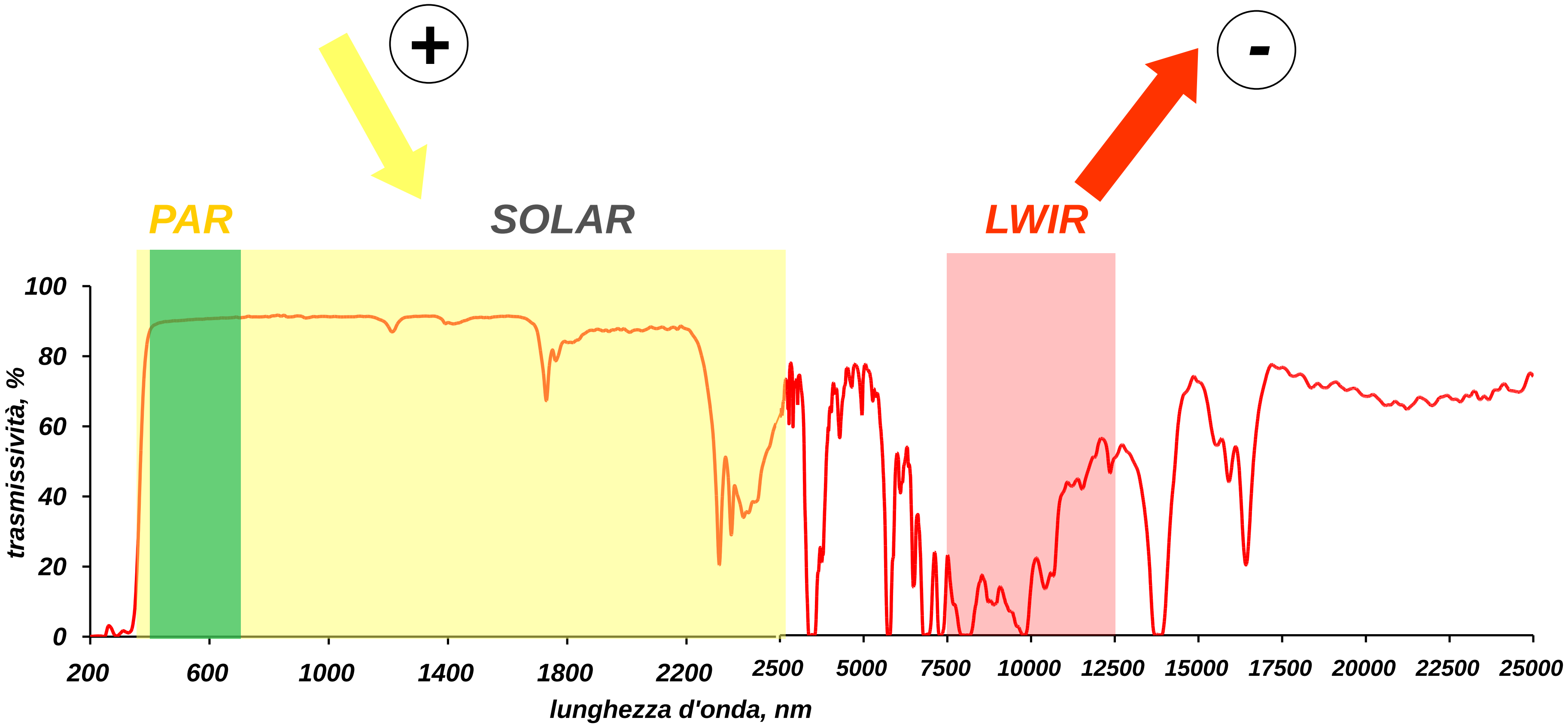
Spectral transmissivity measured by means of ***spectrophotometers***



The spectral transmissivity of a material at a given wavelength λ indicates the fraction of incident radiant energy that passes through the material in the wavelength range centered on the wavelength λ


A double beam UV-VIS-NIR spectrophotometer (Lambda 950, Perkin-Elmer) equipped with an integrating sphere (diameter 60 mm).
A FT-IR spectrophotometer (1760X, Perkin-Elmer).

Transmissivity curves in the wavelength range from 200 to 25000 nm



solar = 200-2500 nm

Photosynthetically Active Radiation (PAR) = 400-700 nm

Long wave infrared (LWIR) = 7500-12500 nm

- *in addition to spectral transmissivity curves, reflectivity curves are measured using special spectrophotometer accessories*
- *the emissivity (or absorbance) curves are calculated as a complement of the reflectivity and transmissivity curves by means of the relation:* $\tau + \rho + \varepsilon = 100$, *where we assume* $\varepsilon = \alpha$
- *the reflectivity coefficients and the emissivity coefficients are calculated using the same formulas used for the transmission coefficients*

Radiometric coefficients

- *The transmissivity coefficients in the solar range (300-2500 nm) are calculated as the weighted average value of the spectral transmissivity using the spectral distribution of the solar radiation at the ground level as weighting function.*
- *The LWIR transmissivity coefficient was calculated as the average value over the wavelength interval between 7500 nm and 12500 nm.*

Film	Thickness (μm)	τ_{solar}^{total} (%)	$\tau_{solar}^{diffuse}$ (%)	τ_{PAR}^{total} (%)	$\tau_{PAR}^{diffuse}$ (%)	τ_{LWIR} (%)	ρ_{solar} (%)	ρ_{PAR} (%)	ε_{LWIR} (%)
LDPE	60	91.12	9.68	91.38	13.67	81.88	8.09	8.11	12.60
LDPE	40	90.35	21.52	89.95	27.05	39.73	9.16	9.70	55.35

The covering material must perform the following functions:

- *transmission of the incident solar radiation and modification of the internal microclimatic parameters by means of the greenhouse effect, according to the radiometric properties of the material (which define its behavior to radiation);*
- *reduction of energy losses by convection, due to the physical presence of the material;*
- *crop protection against adverse weather conditions such as wind, rain, hail and snow.*

Criteria for the selection of covering materials

- *high transmittance to solar radiation, to UVA (320-400 nm), to PAR (400 -700 nm), to short and medium IR (700-3000 nm)*
- *low transmittance to LWIR (7500-12500 nm)*
- *good mechanical properties*
- *lightness and ease of assembly*
- *stability of the mechanical and radiometric characteristics during the expected useful life*
- *low cost*

Spectral effects on plant growth

The process of photosynthesis is affected by main factors, such as:

- Temperature
- Carbon Dioxide Concentration
- Solar radiation
- Solar radiation intensity
- Solar radiation quality
- Solar radiation duration
- Oxygen
- Water
- Mineral Elements
- Air Pollutants
- Chemical Compounds
- Chlorophyll Contents
- Protoplasmic Factor
- Accumulation of Carbohydrates

The global solar radiation which enters the interior space of a greenhouse can be divided into:

- *Ultra Violet (UV)*
- *Photosynthetically Active Radiation (PAR)*
- *Near InfraRed (NIR)*

UV radiation is divided into three bands:

- *UV-A (320-400 nm)*
- *UV-B (280-320 nm)*
- *UV-C (100-280 nm)*

PAR refers to wavelengths from 400 to 700 nm.

Infrared radiation covers the following ranges:

- *Near InfraRed (NIR, 780-3000 nm)*
- *Mid InfraRed (MIR, 3000-50000 nm)*
- *Far InfraRed (FIR, >50000 nm)*

*Only **the PAR part of the incoming radiation is absorbed by the plants and is important for their growth and photosynthesis**.*

***NIR leads to increase greenhouse air temperature**. NIR is absorbed by greenhouse construction elements. NIR is less absorbed by the plants.*

Greenhouse heating caused by global radiation is desirable during cold months, but not during hot months because results in high air temperatures in greenhouse interior space and thus reduction of crop production.

Specific manipulations of the radiation which enters the greenhouse interior space can offer advantages.

Most plants are observed to have maximum photosynthetic sensitivity in the ***blue*** *(400-500 nm) and* ***red*** *(600-700 nm) regions, but also use 50% of the* ***green*** *radiation (500-600 nm).*

During plant development, these regions have particular importance at different stages of plant growth.

Blue radiation *is particularly important for the initial stage of plant growth and during the blooming process.* ***Red radiation*** *is, for the majority of plants, necessary for successful development throughout the period of general growth.* ***Green radiation*** *plays an important role in photosynthesis.*

Increasing the efficiency of photosynthesis therefore requires enhancement of the ***red radiation*** *region (while controlling the proportion of* ***far red radiation****) and, for special applications, the* ***blue radiation*** *range.*

An excessive proportion of ***far red radiation*** *may lead to unwanted stem elongation.*

The ***red*** *to* ***infrared regions*** *are responsible for the thermic effects which influence flowering and ripening of crops.*

Excessive ***UV radiation*** *may cause burning and necrosis in plant tissue and blackening of outer petals in some flowers, while at low levels the same radiation initiates photosynthetic reactions and seed germination while activating certain plant pigments.*

A high overall level of visible radiation inhibit the development of shade preferring varieties.

Since the optimum solar radiation intensity and radiation spectrum are essential for optimum plant growth and development, much effort is focussed on the development of transparent greenhouse covering material with improved optical properties.

Greenhouse films are becoming more than just a protective cover. They are active structures, functionalized with different attributes to enhance growth.

20% of the global market for agricultural plastics can be won by solar radiation manipulating materials:

- ***Photoselective materials***
- ***Photoluminescent materials***
- ***Shading nets***
- ***NIR blocking film***
- ***UV blocking film***

Photoselective greenhouse covering films

The horticulture industry prefers uniform compact plants *because it increases consumer acceptance, makes it easier to pack and ship mature plants, and speeds plant establishment in the field. Traditionally, chemicals have been used to produce compact plants, but because of increasing environmental concerns, researchers are investigating alternative methods to produce compact plants.*

The photoselective covering materials are cladding materials with incorporated pigments in order to modify the solar radiation spectrum which enters the greenhouse.

Photosynthesis, photomorphogenesis and the growth of the plants can be affected. Photomorphogenesis is the process that determines the form, colour and flowering of plants.

Several plastic and pigment manufacturers are working together to develop innovative photoselective material designed to absorb ***Red radiation*** *(600- 700 nm) wavelengths and decrease* ***R:FR*** *ratios of the radiation spectrum, thereby producing taller plants.*

Photoselective greenhouse plastic films can remove ***Far Red radiation*** *to use as a growth regulator substitute.*

FR radiation *absorbing dyes should be stable in plastic films. Optimum dye concentrations should be incorporated into films without excessively reducing the transmission of photosynthetic photon flux.*

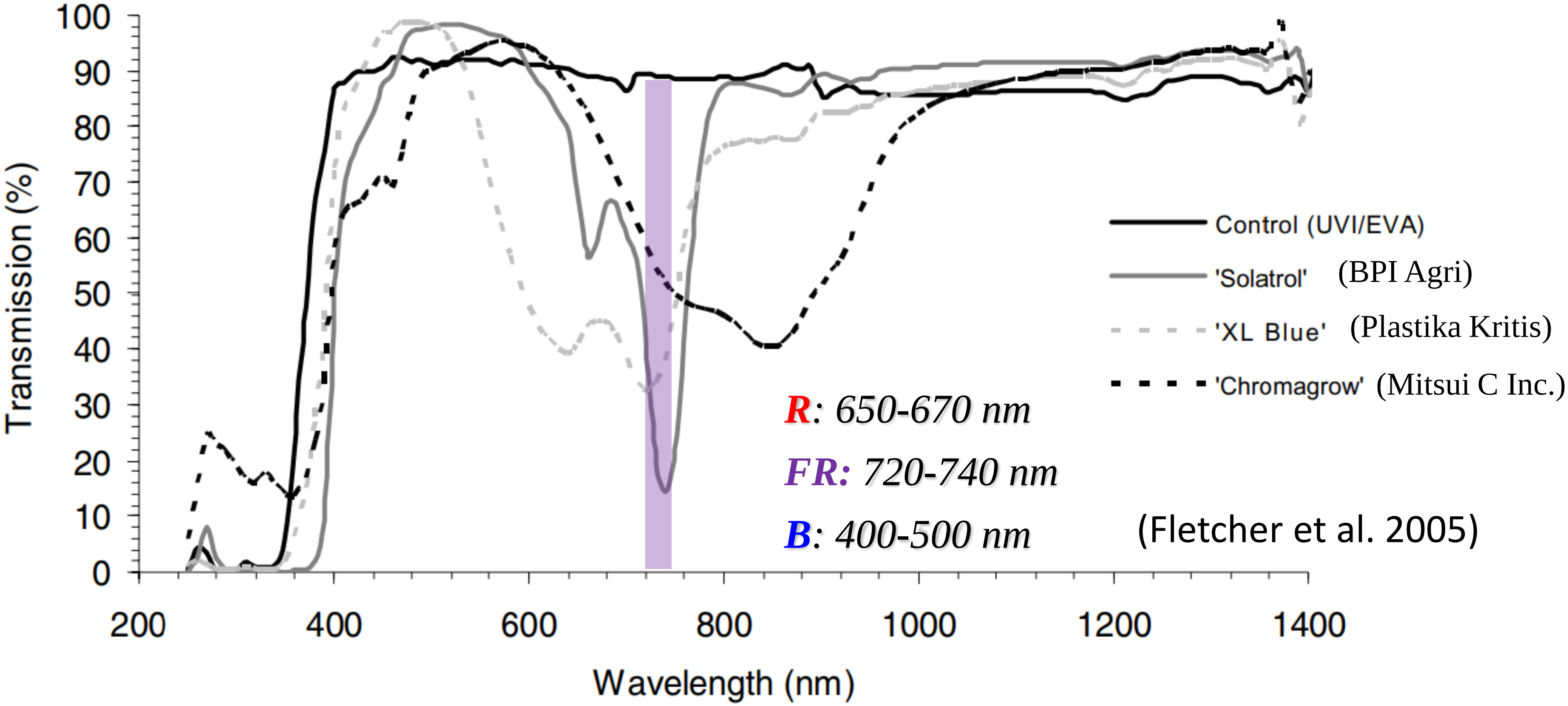
Short film lifetime is a limitation with the photoselective films.

Red radiation *is known to enhance seed germination, reduce stem elongation of seedlings, and promote lateral shoot growth of many plant species.*

The effects of ***FR radiation*** *are mostly the opposite of* ***R radiation****.*

*Environments high in R radiation relative to FR radiation (****high R:FR ratio****) are favorable* ***for production of short and compact plants.***

The magnitude of the response depends on the species and cultivar.



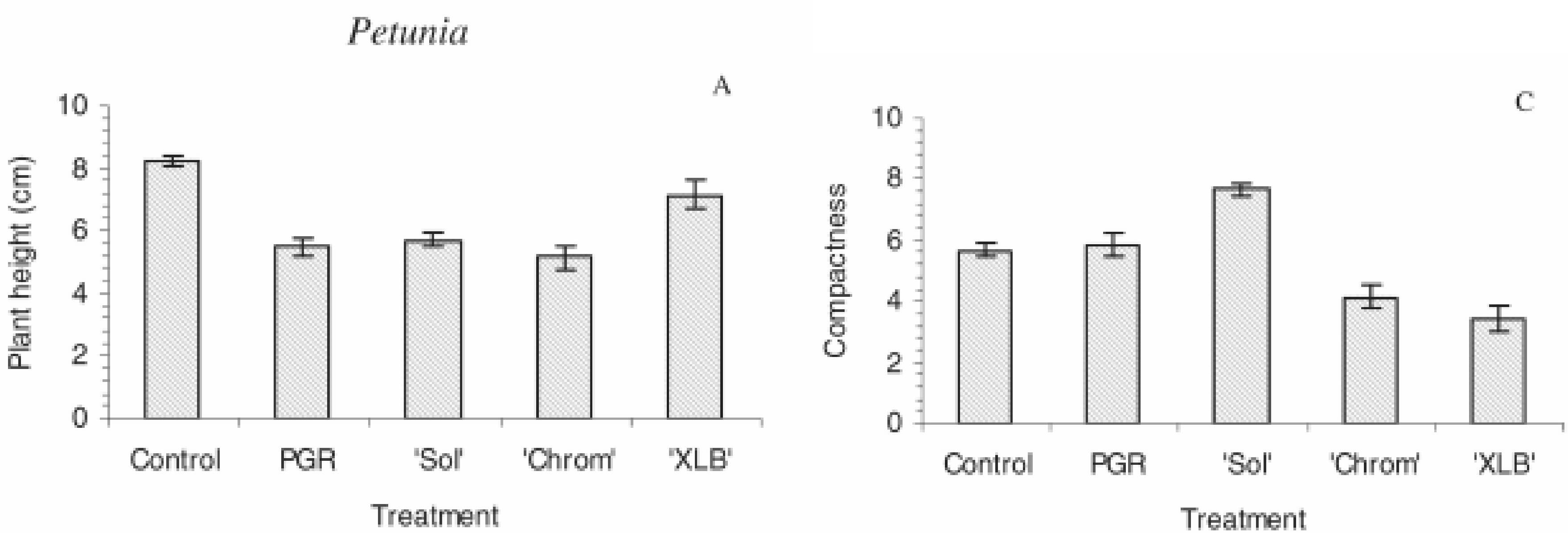
'Solatrol' exhibited a much higher absorption of ***FR radiation*** *than the other two films and had the highest* ***R****:**FR*** *ratio.*

'Chromagrow' showed a broader, but less intense ***FR*** *absorption than 'Solatrol' and produced a lower* ***R****:**FR*** *ratio.*

'XL Blue' showed only a small change in both the ***red*** *and* ***FR*** *areas of the spectrum producing a similar* ***R****:**FR*** *ratio to the control film. 'XL Blue' significantly reduced the transmission of PAR.*

Treatment	PAR (400–700 nm) (% transmission)	R:FR ratio
Control (UVI/EVA)	87	1.0
Control (UVI/EVA; PGR-treated)	87	1.0
'Solatrol'	84	3.8
'Chromagrow'	82	1.8
'XL Blue'	69	1.1

PGR: Daminozide plant growth retardant



(Fletcher et al. 2005)

CLARIX BLUE *(P.A.T.I, Italy) is a photoselective clear film enhances the quality of solar radiation by blocking the* ***Red Spectrum*** *with the P.A.R.*

The specific blue photoselective filter is effective in equilibrating the plant growth, developing more compact plants.

The ***blue radiation*** *affects the colour of the leaves and flowers will be very vivid in colour and favoring the fruits ripening process instead of the vegetative production.*

References

De Salvador F. R., Scarascia Mugnozza G., Vox G., Schettini E., Mastrorilli M., Bou Jaoudé M. (2008) “Innovative Photoselective and Photoluminescent Plastic Films for Protected Cultivation” Acta Horticulturae (ISHS), vol. 801, 115-122.

Fletcher J. M. , A. Tatsiopoulou, M. Mpezamihigo, J. G. Carew, R. G. C. Henbest & P. Hadley (2005) Far-red light filtering by plastic film, greenhouse-cladding materials: effects on growth and flowering in Petunia and Impatiens, The Journal of Horticultural Science and Biotechnology, 80:3, 303-306.

Rajapakse, N. C., Young, R. E., McMahon, M. J. and Oi, R. (1999). Plant height control by photoselective filters: current status and future prospects. HortTechnology, 9, 618-624.

Schettini E., F. R. De Salvador, G. Scarascia Mugnozza, G. Vox. (2011) “Radiometric properties of photoselective and photoluminescent greenhouse plastic films and their effects on peach and cherry tree growth” Journal of Horticultural Science & Biotechnology, 86 (1): 79–83

Wilson, S. B. and Rajapakse, N. C. (2001). Use of photoselective plastic films to control growth of three perennial salvias. Journal of Applied Horticulture, 3, 71-74.

Photoluminiscent greenhouse covering films

Luminescence is a form of cold body radiation, i.e. radiation that is not a result from heat. Photoluminescence is a luminescence in which the excitation source is solar radiation.

Photoluminescent covering materials shift radiation wavelengths to provide the optimal conditions for crops.

Rose plants grown under photoluminescent film were more productive and the flowers were of a higher quality.

*Photoluminescent plastic films shift **green radiation** into **red radiation** since it was assumed that **green radiation** is less effective for photosynthesis and a higher amount of **red radiation** was assumed to increase photosynthesis.*

However, total PAR transmission of those films was reduced.

*Films should be developed with the aim to absorb parts of the **ultraviolet**, **blue** and **green** region of the spectrum and shift it to **red radiation** in order to change **red**:**far-red** ratio. Also these films reduce total PAR radiation.*

*Another option is the development of fluorescent plastic films, which only absorb **ultraviolet radiation** and shift that into PAR with the aim that the total amount of PAR is enlarged and radiation quality is optimised for several plant processes.*

Experimental field

Valenzano (Bari, Italy) - latitude 41° 05’ N

6 steel arched roof greenhouses

6.00 m x 6.00 m

ridge height: 3.80 m *East-West oriented*

gutter height: 2.40 m *ventilation: four ample vents*

Two photoselective films, GREEN4% and GREEN2%, were made by adding green transparent Vibatan polyethylene and UV stabilisers.

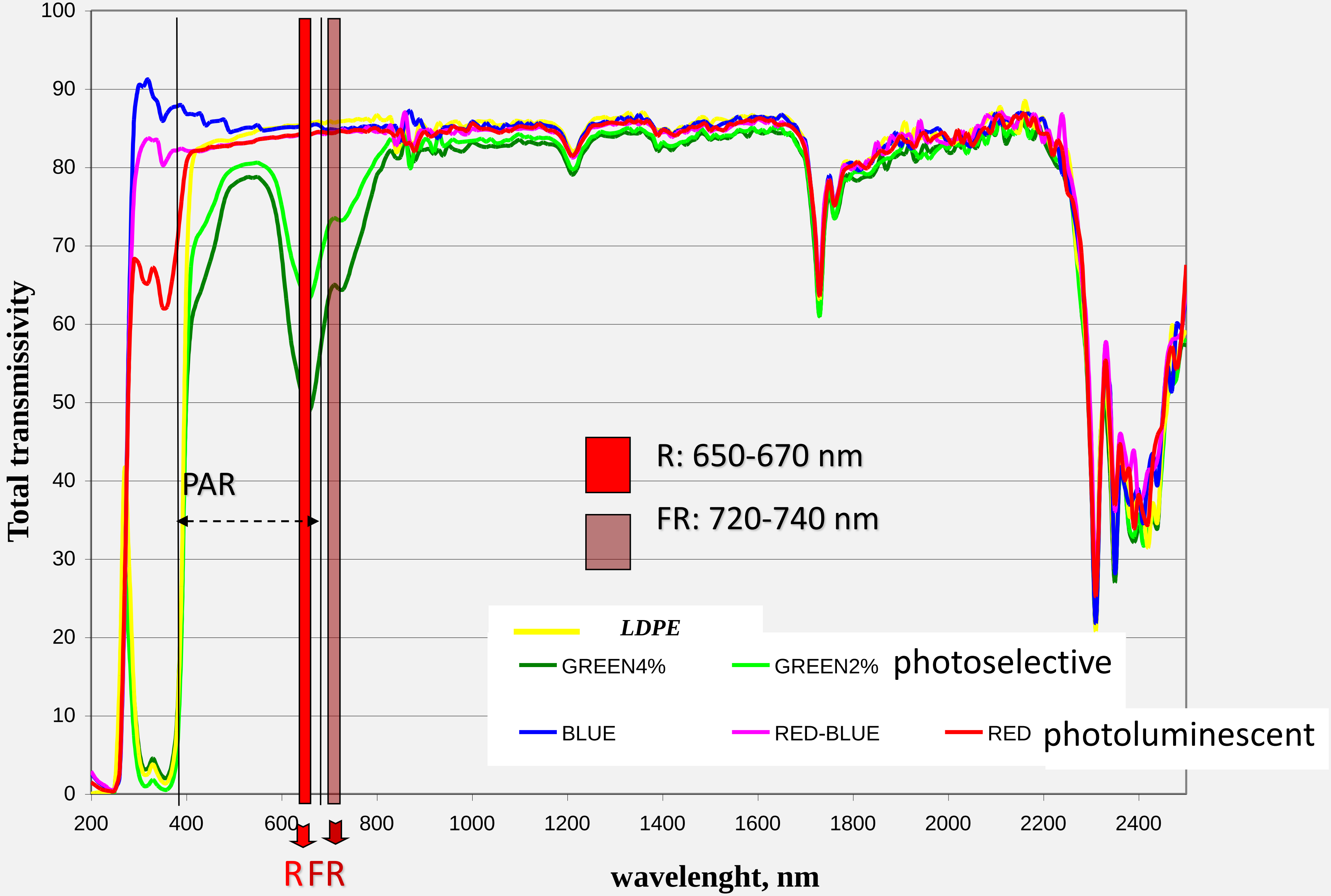
*Three photoluminescent transparent films, RED, BLUE and RED-BLUE, were made by adding masterbatches with the capacity to absorb UV radiation in order to retransmit it in the wavelength of **red**, **blue** and **red-blue** radiation; no anti-UV stabilisers.*

A transparent LDPE film with anti-UV stabilisers.

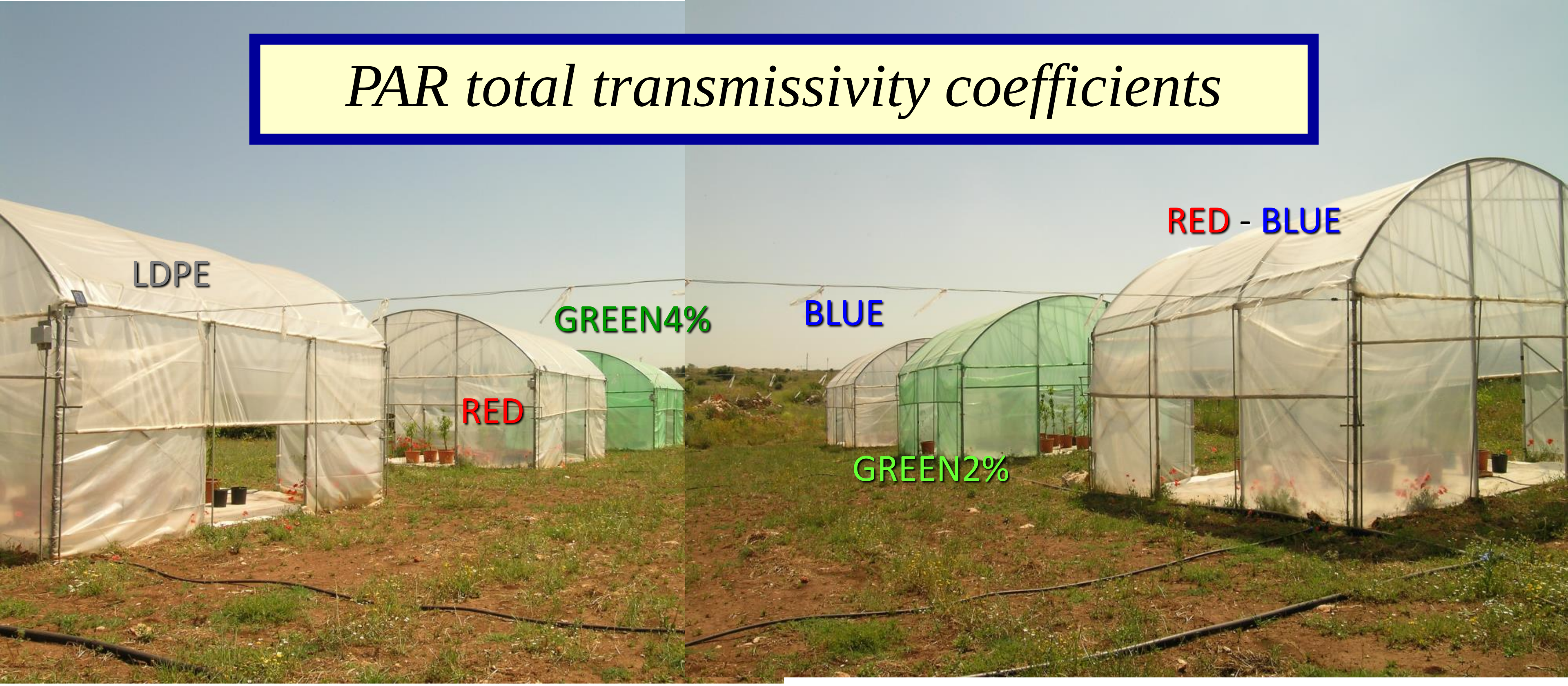
from April
to September 2007

Cherry trees (cultivar Lapins on Gisela 6 rootstock)
Peach trees (cultivar Messapia on Missour rootstock)

Total spectral transmissivity in the solar range

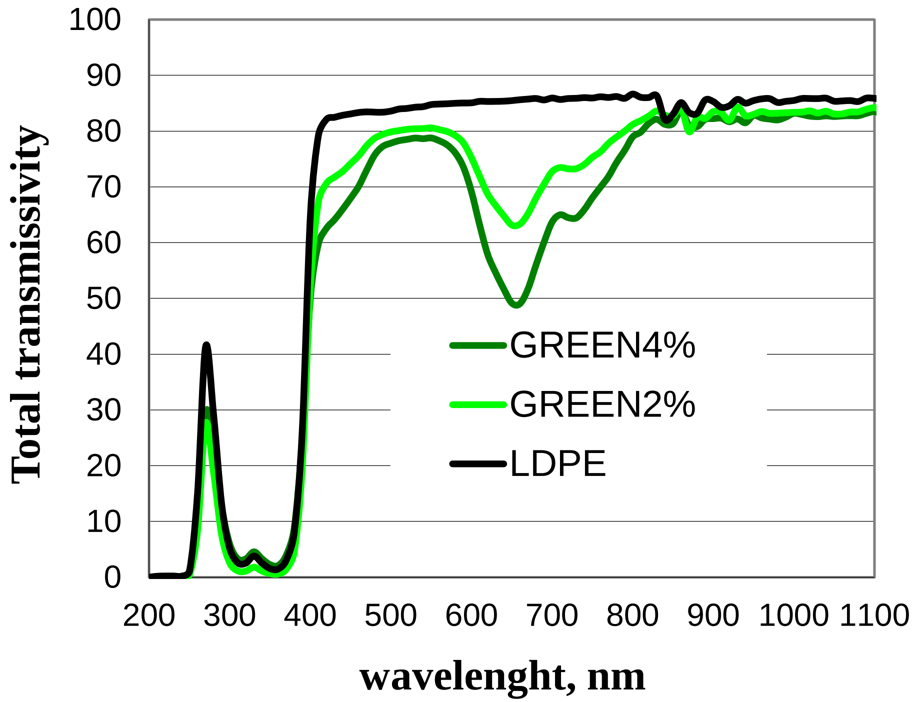


PAR total transmissivity coefficients



LDPE	RED	BLUE	RED-BLUE	GREEN2%	GREEN4%
84.1 %	83.4 %	83.8 %	83.4 %	73.8 %	67.4%

Total transmissivity of the photoselective films



Photoluminescent effect of the RED, BLUE and RED-BLUE films

	absorbed radiation	emitted radiation
RED	290-350 nm	600-650 nm
BLUE	280-380 nm	420-490 nm
RED-BLUE	290-400 nm	420-490 nm and 610-620 nm

R: 650-670 nm

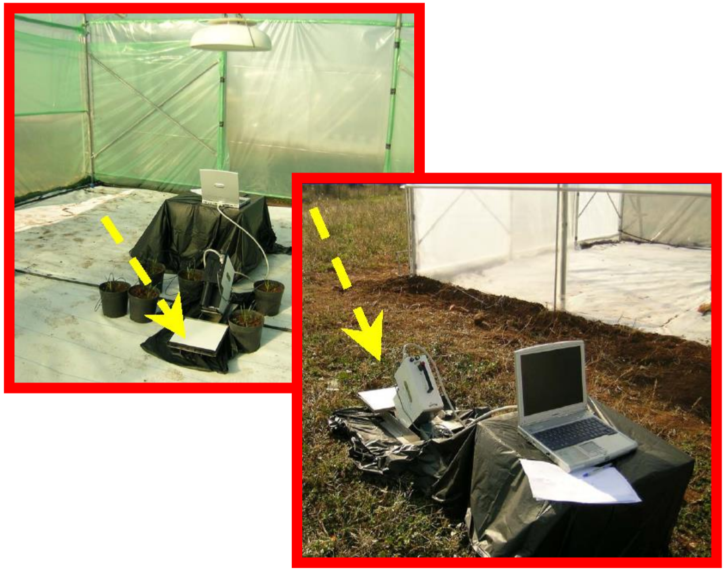
FR: 720-740 nm

B: 400-500 nm

UV-A: 320-400 nm

UV-B: 280-320 nm

Radiation quality parameters



Film	R/FR	B/FR
LDPE	1.13	3.40
RED	1.13	3.48
BLUE	1.13	3.49
RED-BLUE	1.13	3.47
GREEN2%	1.01	3.58
GREEN4%	0.93	3.72

in open field

R/FR = 1.14

B/FR = 3.75

20 June 2007, at noon, clear sky conditions

Seasonal increase in peach and cherry shoot length (cm)

	Open-field	LPDE	RED	BLUE	RED-BLUE	GREEN2%	GREEN4%
Peach	13.5 a	18.3 b	27.2 c	22.4 b	20.8 b	31.0 c	46.1 d
Cherry	39.3 a	49.8 b	55.8 c	48.9 b	45.1 b	47.6 b	68.7 c

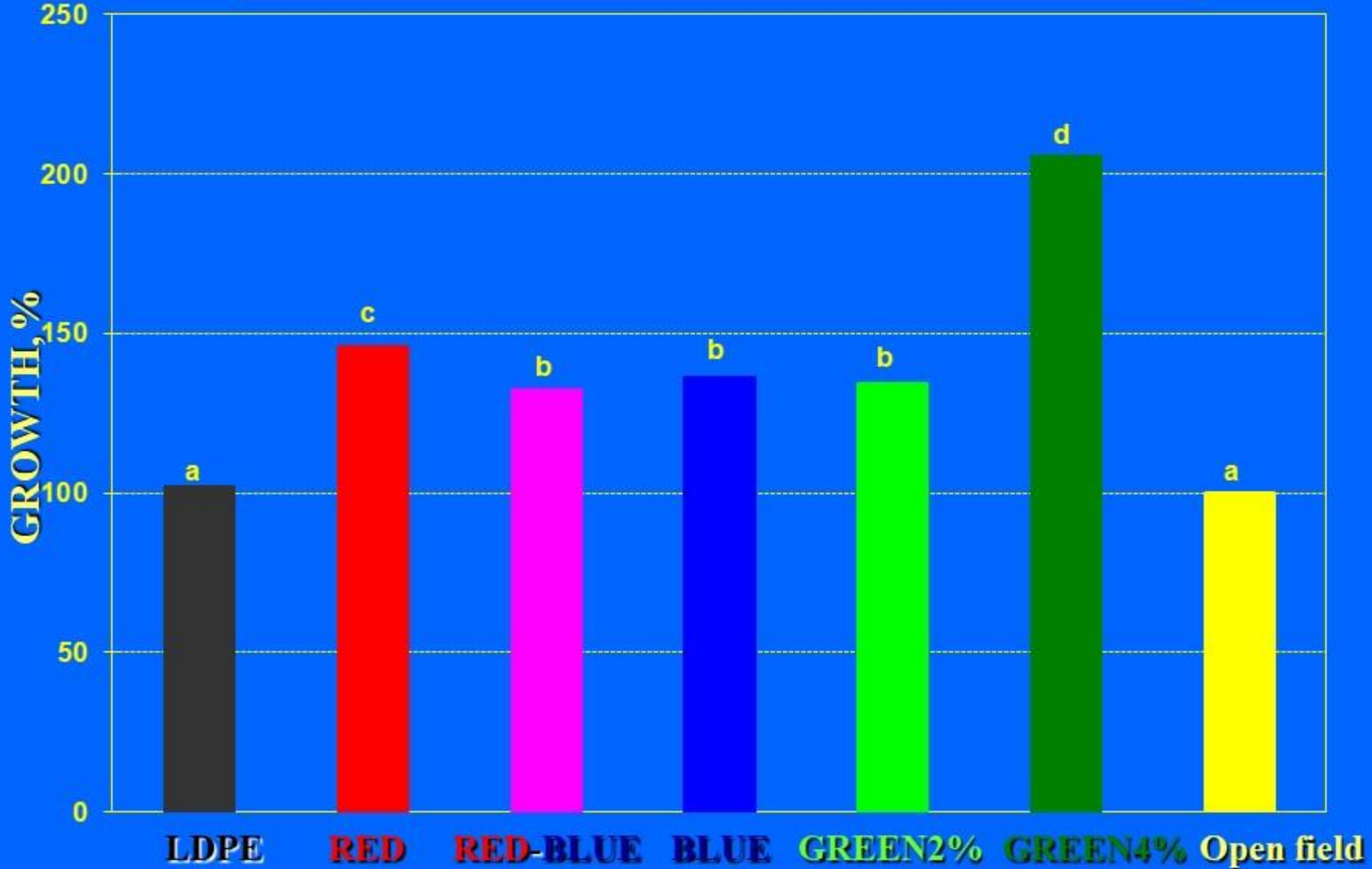
★

The photoselective GREEN4% films that reduced the R/FR ratio from 1.14 (open-field) to 0.93 enhanced the shoot growth of peach (46.1 cm) and cherry trees (68.7 cm) compared to trees grown in the open-field.

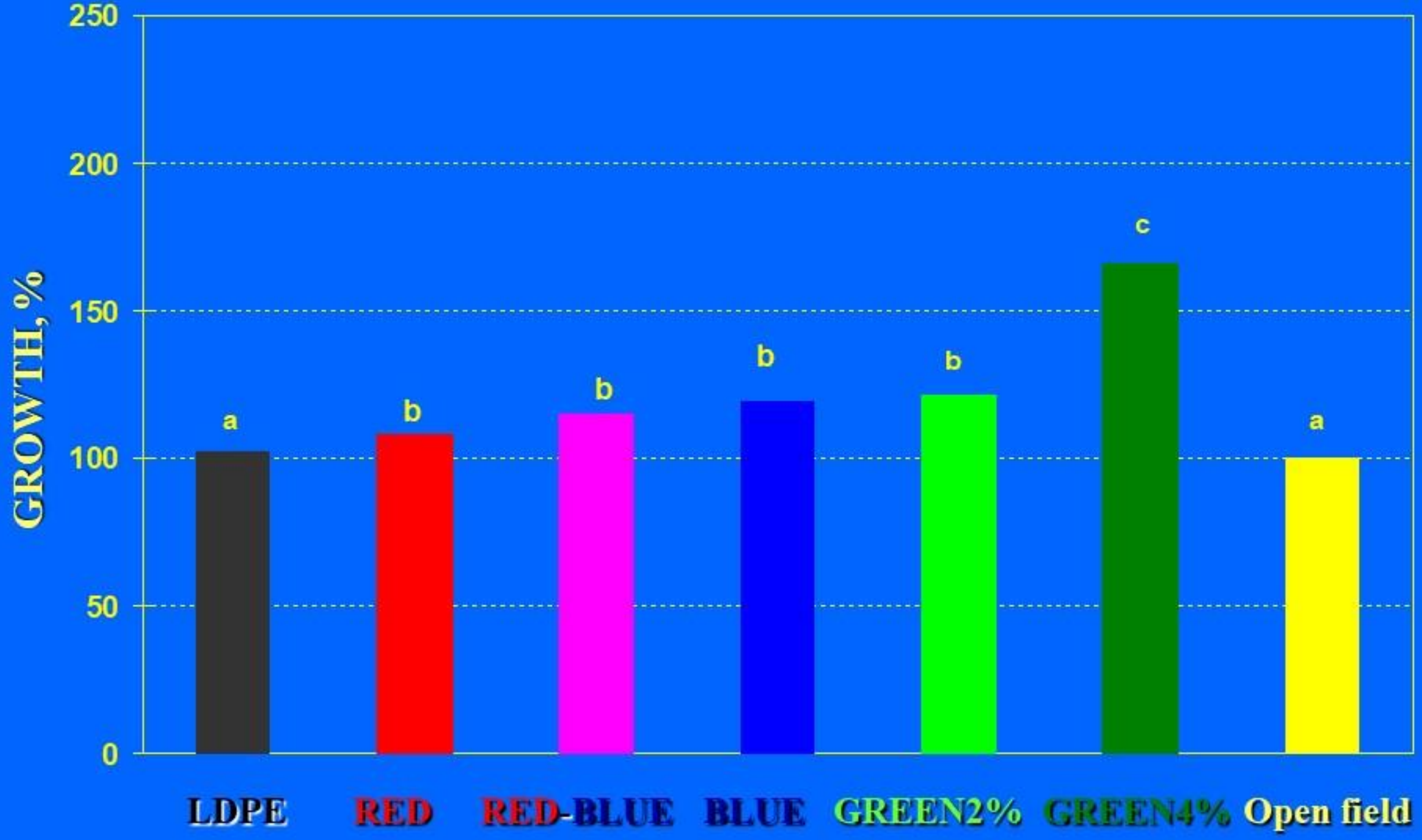
LDPE

GREEN4%

Annual Growth of Peach Trees



Annual Growth of Cherry Trees



The obtained results showed that the changing in spectral distribution of solar radiation interacted with the vegetative activity: different quantities of solar radiation in different parts of the spectrum (R/FR and B/FR) influenced the shooting growth of the peach and the cherry trees.

References

González, A., R. Rodgígbuez, S. Bañon, J.A. Franco, J.A. Fernández, A. Salmerón and E. Espí 2003: Strawberry and Cu- cumber Cultivation under Fluorescent Photoselective Plastic Films Cover. Acta Hort. 614, 407–413

Hemming S. , E.A. van Os, J. Hemming and J.A. Dieleman. The Effect of New Developed Fluorescent Greenhouse Films on the Growth of Fragaria x ananassa ‘Elsanta’. Europ.J.Hort.Sci., 71 (4). S. 145–154, 2006.

Kittas, C. and A. Baille 1998: Determination of the spectral properties of several greenhouse cover materials and evaluation of specific parameters related to plant response. J. Agr. Eng. Res. 71, 193–202

Pearson, S., A.E. Wheldon and P. Hadley 1995: Radiation transmission and fluorescence of nine greenhouse cladding materials. J. Agr. Eng. Res. 62, 61–70.

Shading nets

Shading nets are used to reduce the entering of solar radiation and consequently the air temperature inside the screen-house or greenhouse during the warmest periods; another important use is to protect plants from adverse weather conditions, such as wind, hail and frost, and also from birds and aphids.

The shading factor, ranging from 10% to 90%, represents the capacity of the net to reduce the incoming solar radiation.

The shading factor is related to the average value of the transmissivity of the net in the solar radiation wavelength band from 380 nm to 760 nm, but it does not give information on the spectral distribution of the radiation passing through the net in such interval.

High summer temperatures greatly limit greenhouse productivity.

The common damage-reduction approach is to limit the amount of solar radiation that enters the greenhouse, either by whitewash or shadow screens, which have a high reflectivity across the whole solar spectrum.

Nets are extensively used in fruit-tree farming.

One of the principal problem with protected tree cultivation is the control of plant height, which can be achieved with the use of growth regulators but is preferably accomplished with agronomic techniques including dwarfing rootstocks, regulated irrigation deficit, and modified radiation environment.

Colored shade nets are being intensively tested primarily because of their ability to manipulate the spectra of radiation reaching the crops below.

They can be used to change ***red*** *to* ***far-red*** *radiation ratios that are detected by phytochromes, the amounts of radiation available to activate the* ***blue****/****ultraviolet-A*** *photoreceptors,* ***blue*** *radiation involved in phototropic responses mediated by phototropins, and radiation at other wavelengths that can influence plant growth and development.*

THE AMALFI COAST

Experimental field

Valenzano (Bari, Italy) - latitude 41° 05’ N

6 steel arched roof greenhouses East-West oriented
6.00 m x 6.00 m
ridge height: 3.80 m
gutter height: 2.40 m
peach trees (‘Messapia’) on Missour rootstock

Red net, 40%

Blue net, 40%

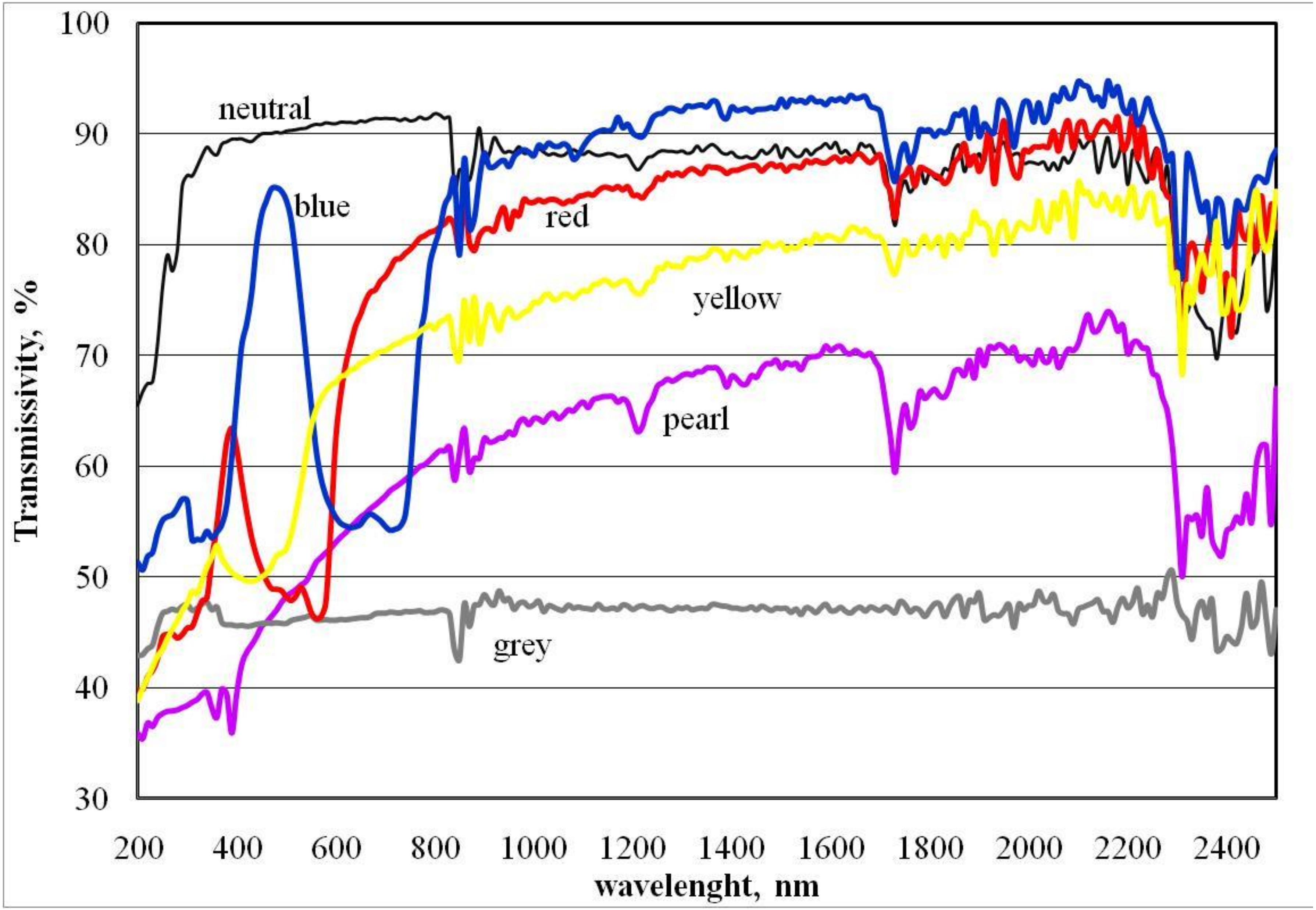
Neutral net, 12%

Pearl net, 40%

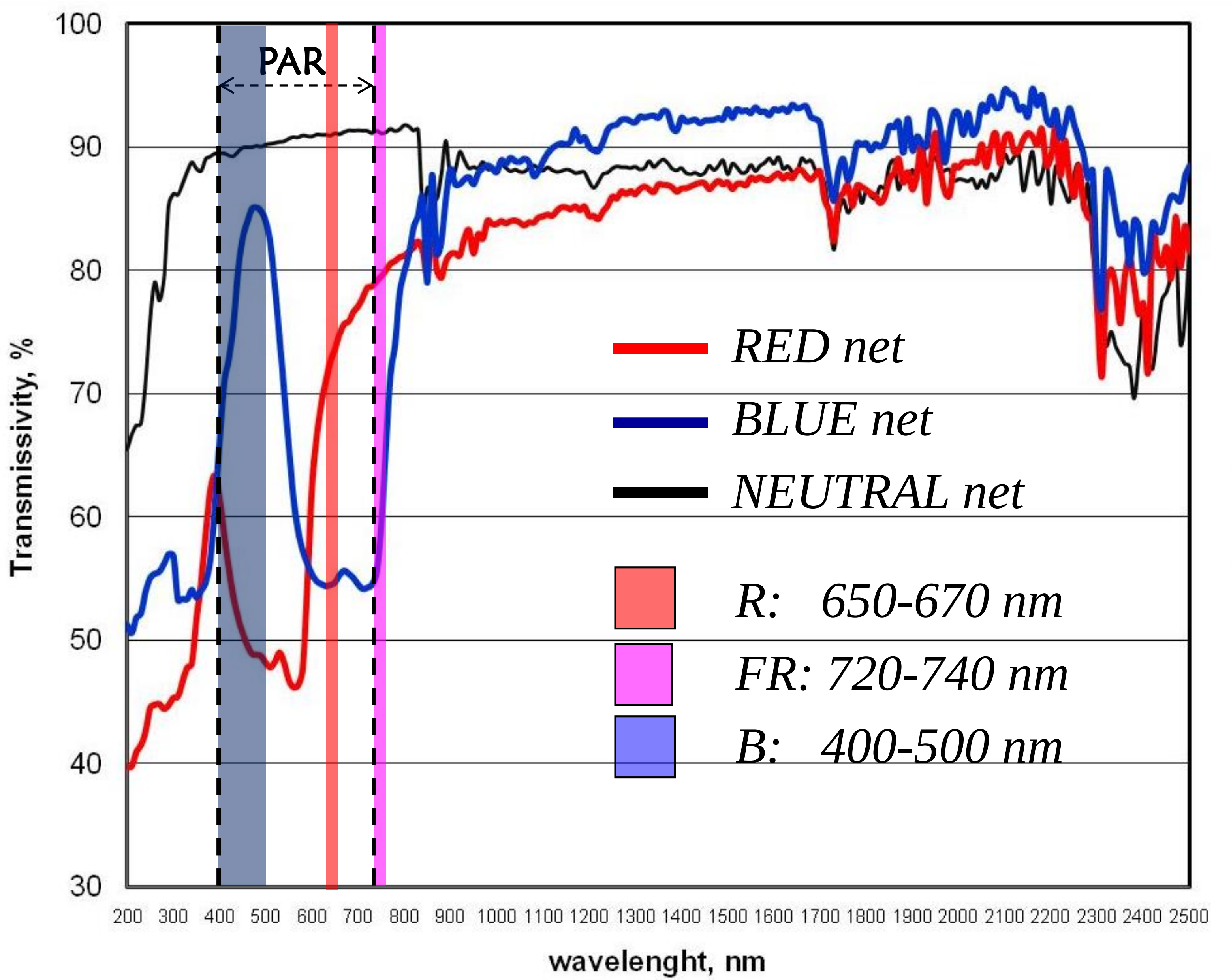
Yellow net, 40%

Grey net, 40%

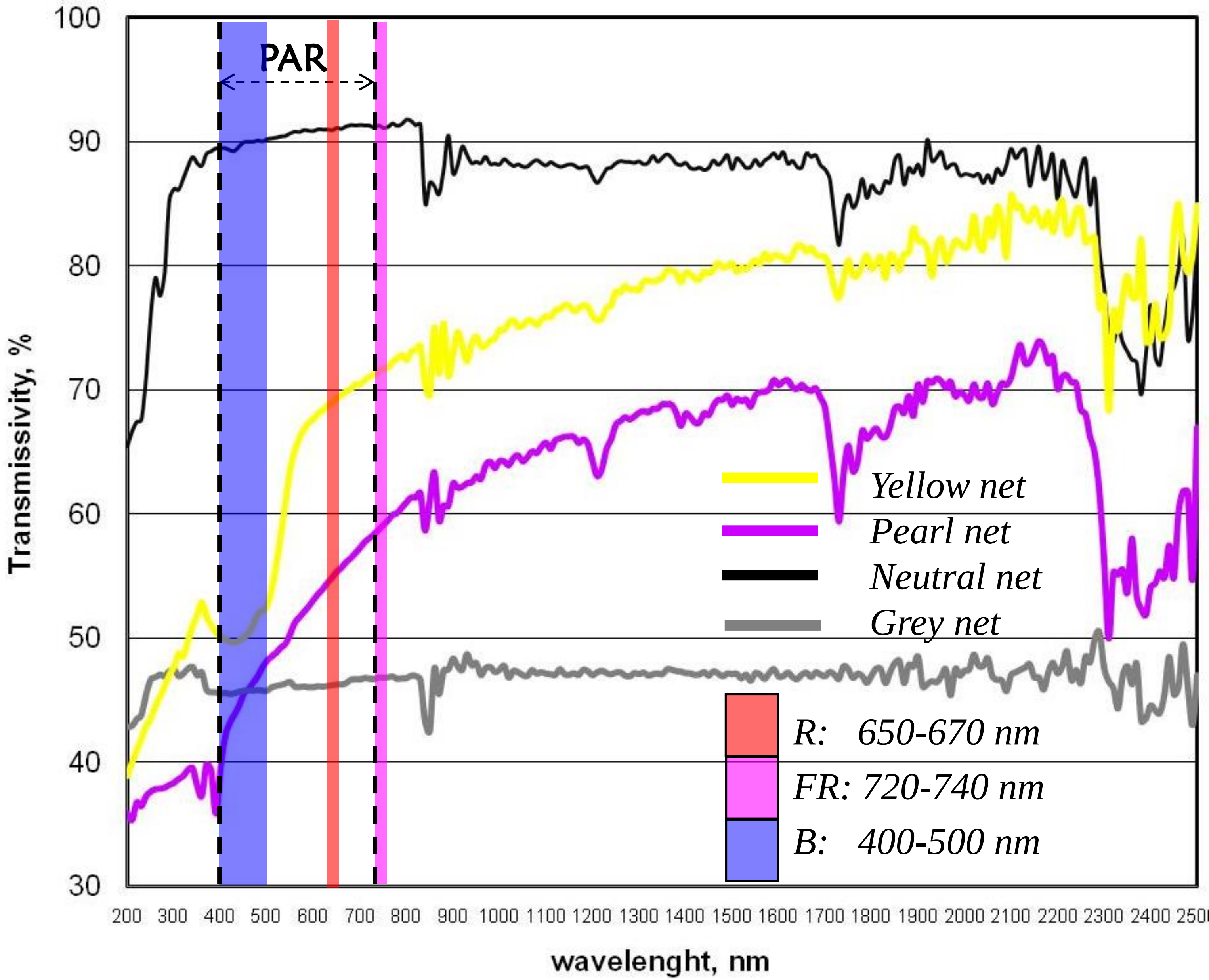
Total spectral transmissivity



Total spectral transmissivity



Total spectral transmissivity



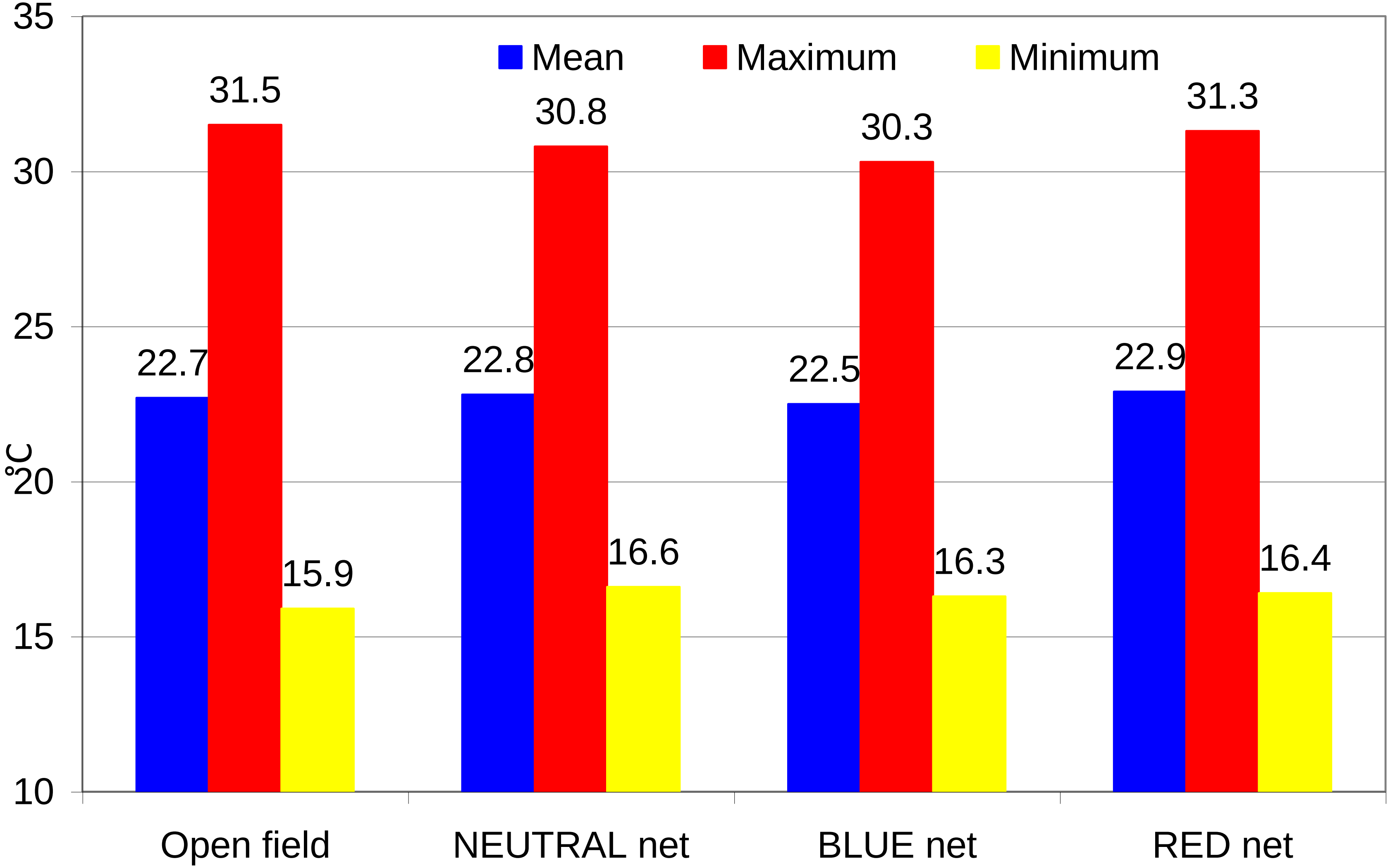
Transmissivity coefficients and ratios

	RED	BLUE	GREY	PEARL	YELLOW	NEUTRAL
Solar total (%)	**71.20**	**75.00**	**46.60**	**57.10**	**68.20**	**89.70**
PAR total (%)	**58.20**	**66.70**	**46.10**	**50.80**	**61.30**	**90.60**
PAR diffuse (%)	**14.30**	**18.70**	**5.40**	**15.90**	**27.50**	**23.60**
UV total (%)	**55.30**	**54.60**	**46.60**	**39.00**	**51.30**	**88.60**
LWIR (%)	**62.30**	**64.20**	**45.60**	**58.90**	**58.90**	**66.70**
τ_R / τ_{FR}	**0.95**	**1.01**	**0.99**	**0.95**	**0.98**	**1.00**
τ_B / τ_{FR}	**0.66**	**1.45**	**0.98**	**0.77**	**0.71**	**0.98**

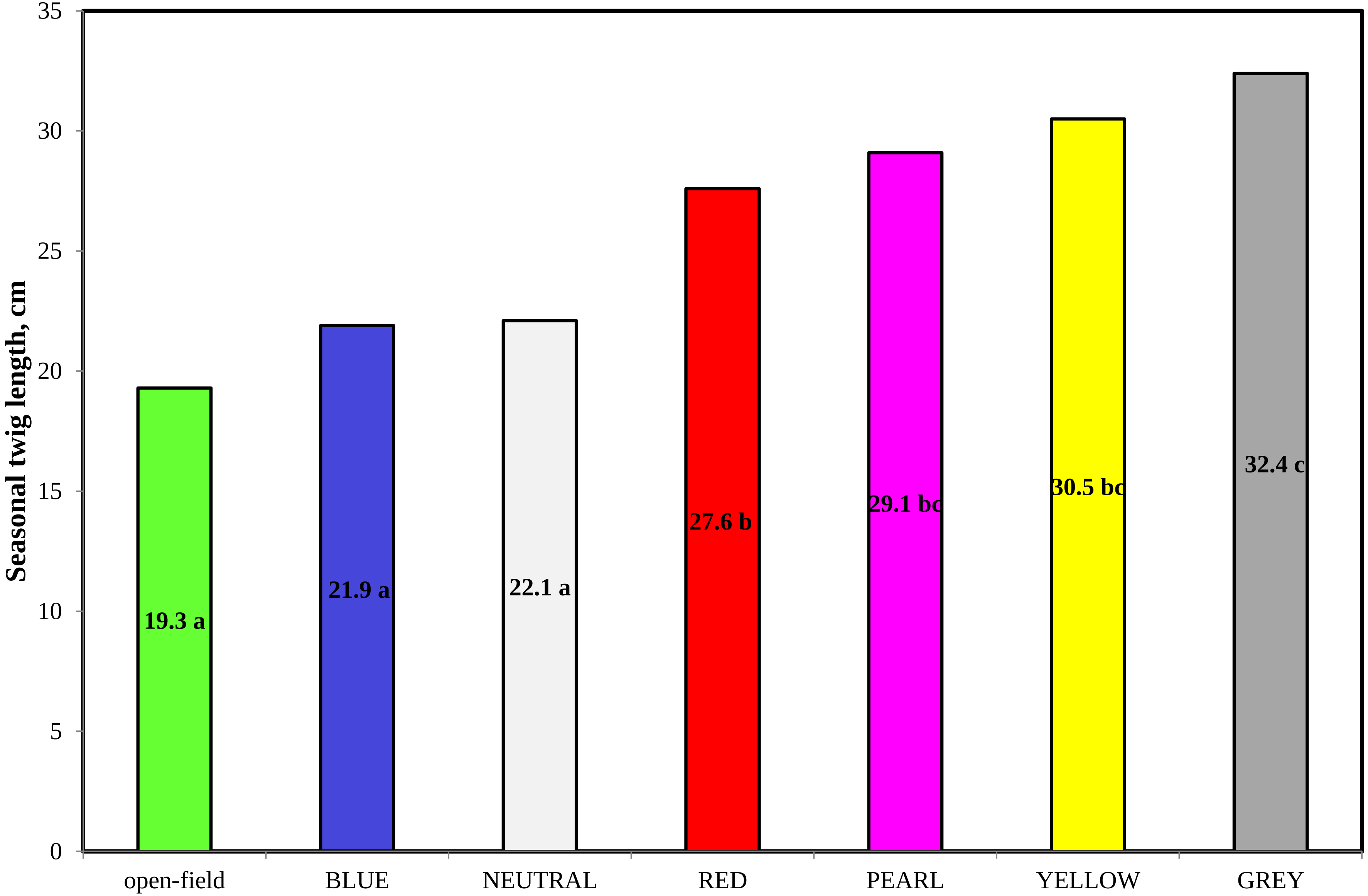
solar = 300-2500 nm
PAR (Photosynthetically Active Radiation) = 400-700 nm
LWIR (long wave infrared radiation) = 7500-12500 nm

Average air temperature

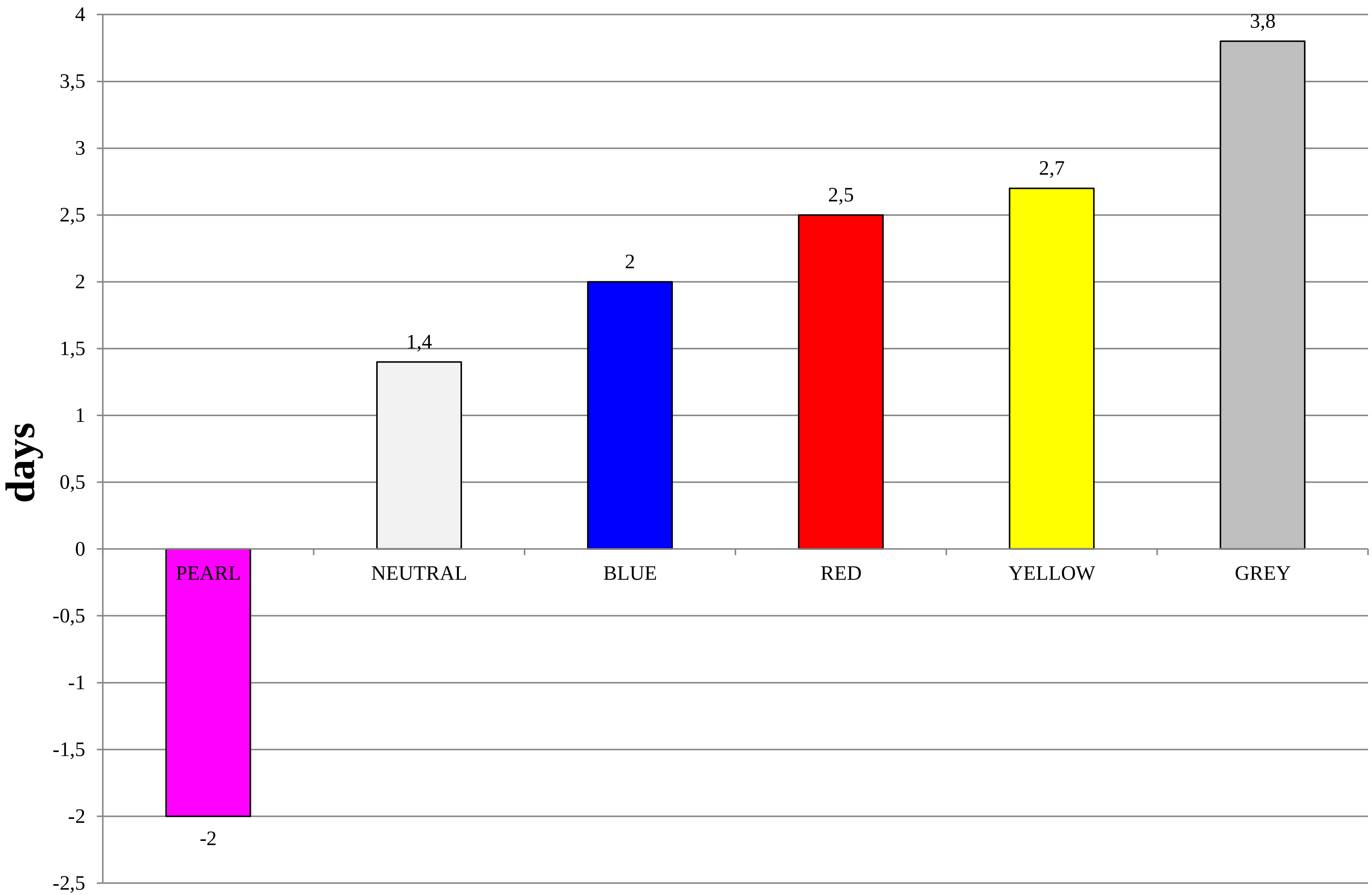
(calculated over the cultivation period)



Seasonal twig length



Harvest
delay or anticipation versus OPEN FIELD



*The RED net and the PEARL net influenced the vegetative growth probably due to the reduction of their R/**FR** ratios in comparison to the outdoor natural radiation ratio, so that affected plant photomorphogenesis and phytochrome.*

For the YELLOW net and the GREY net the vegetative growth was mainly connected to their radiometric characteristics, thus reducing summer stress conditions.

*The vegetative growth was less manifest inside the greenhouses covered with the **NEUTRAL net** and the BLUE net; this was probably due to the presence of **blue radiation** (B, 400-500 nm) in the growing environment, **which has a depressive effect on tree growth**.*

References

Oren-Shamir, M., Gussakovsky, E. E., Shpiegel, E., Nissim-Levi, A., Ratner, K., Ovadia, R., Giller, Y. E. and Sharak, Y. 2001. Coloured shade nets can improve the yield and quality of green decorative branches of Pittosporum variegatum. J Hortic Sci Biotech, 76 (3): 353-361.

Ovadia, R., Dori, I., Nissim-Levi, A., Shahak, Y. and Oren-Shamir, M. (2009). Coloured shade nets influence stem length, time to flower, flower number and influorescence diameter in four ornamental cut-flower crops. Journal of Horticultural Science & Biotechnology, 84, 161-166.

Schettini, E., De Salvador, F.R., Scarascia Mugnozza, G. and Vox, G. (2011). Evaluation of coloured nets in peach protected cultivation. Acta Horticulturae, 893: 235-242

SchettiniE. , F. R. De Salvador, G. Scarascia-Mugnozza, G. Vox (2012) Coloured covering materials for peach protected cultivation. Acta Horticulturae, 952: 201-208

Shahak., Y., Gussakovsky, E.E., Cohen, Y,. Lurie, S. 2004. Colornets: a new approach for light manipulation in fruit trees. Acta Hort. 636: 609-616.

Ultraviolet (UV) absorbing films

*Nowadays **it is requested safer food and environment protection**. Regulations on maximum residue limit in foods are more and more strict. Thus it is demanded minor pesticide use within cultivation procedure.*

*Research suggests **alternative methods for pest and diseases control.***

***The use of Ultraviolet (UV) absorbing films as greenhouse covering materials can be an alternative technique to chemical use for pest and diseases control**.*

***UV-absorbing film for greenhouse covering creates a radiation environment unfavourable to harmful insects**. UV-absorbing films do not only block insect pests but also reduce spread of insect-borne viruses. UV-absorbing films can reduce crop diseases caused by a range of fungi that use UV as an environmental cue for sporulation.*

The researches on UV-exclusion indicate that plants vary widely in their response to ambient UV-B.

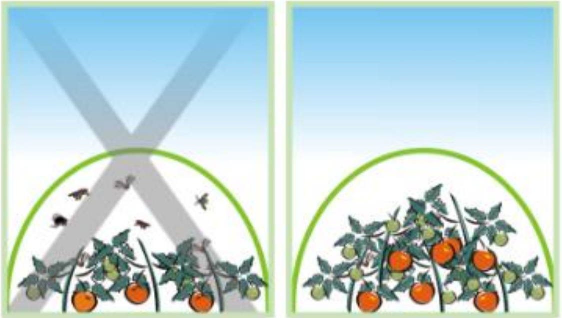
It is well documented that UV-absorbing films suppress several foliar diseases, but their impact on crop yield and quality still needs investigation.

In Israel, no significant differences were found on growth, yield, maturation time and fresh and dry weight values of tomatoes (Solanum lycopersicum L.) grown under UV-absorbing films.

In Greece, the effect of UV-absorbing films on eggplant (Solanum melongena L.) crop behaviour and production were analysed: growing soilless eggplant under UV-absorbing material can be achieved with the same or better results as under standard covering material.

In Spain, an increase in tomato yield was reported when UV-absorbing films were used.

PLASTIKA KRITIS has developed a range of special disease control films, which contribute efficiently in "Integrated Pest Management" and help to reduce the usage of pesticides.



An important type of disease and insects control films is "UV-blocking" films, which absorb UV-radiation up to 380 nm, thus achieving:

- Reduction of the population of whiteflies, thrips, miners, aphids and other insects in greenhouses, thereby also reducing the viruses which are vectored by these insects.
- Control of the spread of certain diseases (such as botrytis), by reducing the sporulation of the relevant pathogenic fungi.
- Reduction of "blackening" of red rose petals, thereby increasing their commercial value.

References

González A, García-Alonso Y, Espí E, Fontecha A, Salmerón A, 2004. Viral diseases control with UV-absorbing films in greenhouses of southern Spain. Acta Hortic 659: 331-338

Kittas C, Tchamitchian M, Katsoulas N, Karaiskou P, Papaioannou Ch, 2006. Effect of two new UV-absorbing greenhouse-covering films on growth and yield of an eggplant soilless crop. Sci Hortic 110: 30-37

Monci F, García-Andrés S, Sánchez F, Moriones E, Espí E, Salmerón A, 2004. Tomato yellow leaf curl disease control with UV-absorbing plastic covers in commercial plastic houses of southern Spain. Acta Hortic 633: 537-542

Papaioannou Ch. , N. Katsoulas , P. Maletsika , A. Siomos and C. Kittas, Effects of a UV-absorbing greenhouse covering film on tomato yield and quality . Spanish Journal of Agricultural Research 2012 10(4), 959-966

Raviv M, Antignus Y, 2004. UV radiation effects on pathogens and insects pests of greenhouse-grown crops. Photoch Photobiol 79: 219-226

NIR-reflecting materials

The quality and quantity of radiation entering the greenhouse can be altered by blocking NIR from entering greenhouse interior space.

The NIR-reflecting materials became somewhat available in the forms of:

- ***transparent sheets (glass or plastic films),***
- ***movable screens or nets***
- ***water-soluble powders (fluid-roof covers).***

The benefits of using such materials for covering greenhouses permanently or seasonally depend on the external climate conditions.

Using NIR-reflecting materials for covering greenhouses permanently in northern countries may have negative effect on crop growth and productivity in winter months.

Fluid-Roof Covers

Considering a glasshouse, a ***water film flowing on the greenhouse roof*** *was studied. The water film was 0.5 mm thick, and a drop of 4-5°C in the inside air temperature could be achieved.*

A water film up to 10 mm thickness *did not reduce the PAR transmission significantly; however, it* ***blocks (via absorption and reflection) only about 5% of the NIR****.*

Therefore, the cooling effect of a water film flowing on the greenhouse roof is unable to provide enough drop in the greenhouse air temperature in regions where summer air temperatures reach 50°C.

(Morris et al., 1958)

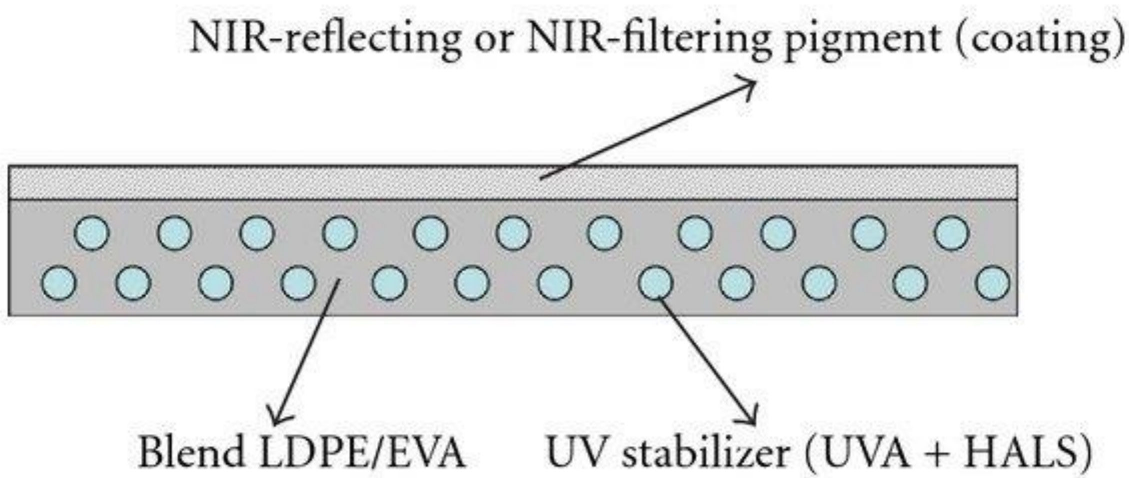
Instead of pure water, ***a solution of $CuSO_4$ (copper sulfate) in water*** *can be used to selectively* ***transmit most of the PAR and absorb most of the NIR.*** *The fluid-roof covers can remove, via absorption, more than 50% of solar energy incident on the greenhouse cover; thus the radiation heat load in the greenhouse can be reduced. At solar noon, the fluid roof cover could maintain the inside air temperature about 5°C below the outside temperature.*

Although the fluid-roof cover prevents a considerable amount of heat from entering the greenhouse, its transmission of PAR is relatively low because of the complex structure.

For a double layers made of polycarbonate sheets (1.5 mm thick) and filled with liquid radiation filter (1.5% $CuSO_4$-water solution), the transmittance of PAR did no exceed 63%.

NIR-reflecting covering films

The transmittance of fluoropolymers and polyethylene based films with NIR-reflection additives to PAR is in the range from 62% to 72% compared to 63% for the fluid-roof cover. And reflectance of these products to NIR was in the range from 37% to 54% compared to 66% for the fluid-roof cover.



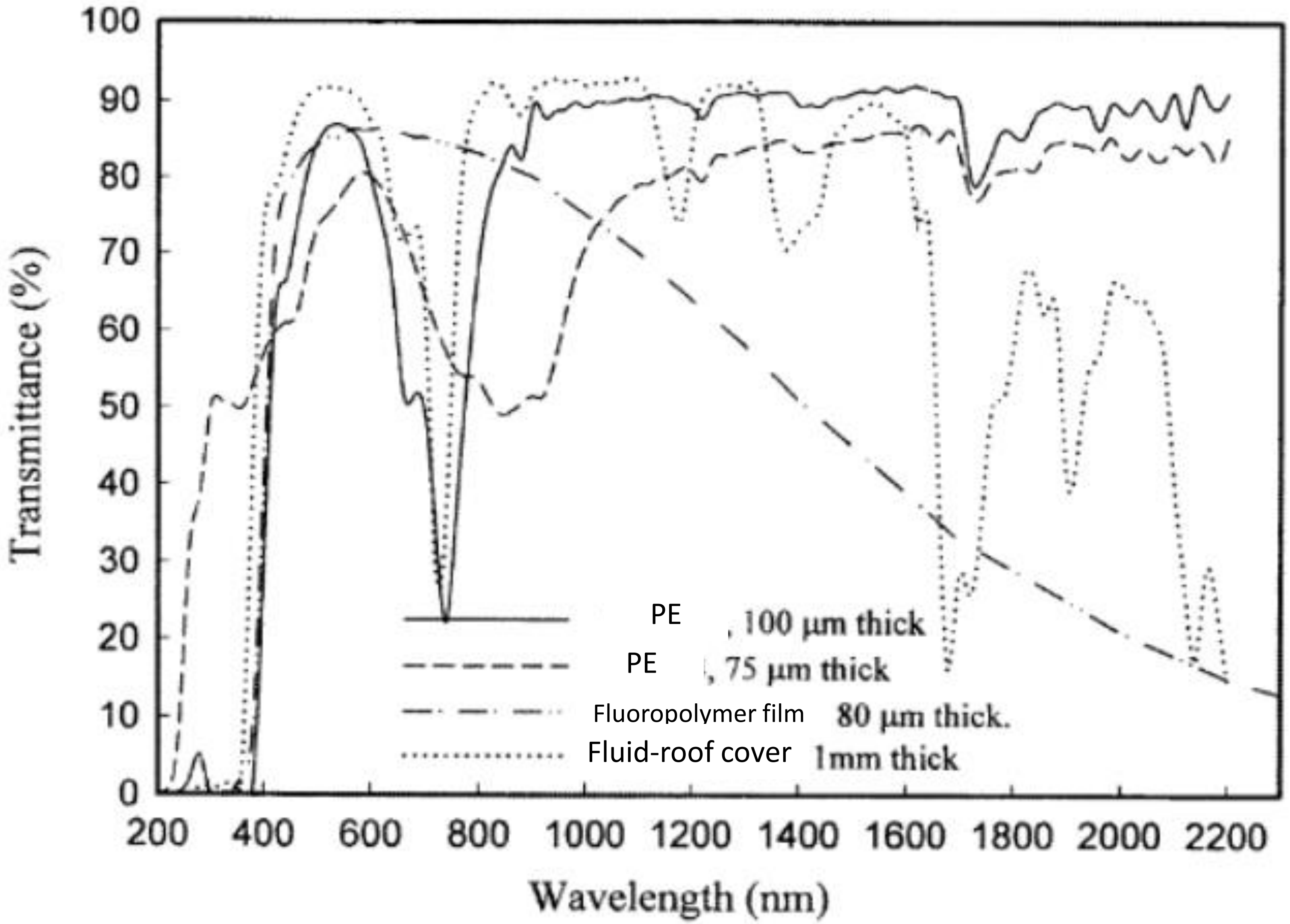


Fig. 1 Spectral transmittance at a normal incidence of the greenhouse cover materials used in Abdel-Ghan et al., 2001

The polycarbonate fluid-roof cover showed a higher ability to reject incident solar energy than the other covers.

To avoid the complexity and the high cost of the fluid-roof covers, the newly developed films designated as Fluoropolymer film and the two PE films could be used as simple alternative greenhouse covers in hot regions.

Fluoropolymer film and the PE film characterized by 75 μm thickness showed a higher PAR transmittance than the fluid-roof covers and a lower transmittance in the UV and IR range than the PE film characterized by 100 μm.

Abdel-Ghan et al., 2001

List of UV additives used in this study.

Sample no.	Functionality	Description
UVA1	UV stabilizer masterbatch	It is a concentrate of light stabilizers and thermal stabilizers in pellet form. It contains UV stabilizers and IR thermal stabilizers in polyethylene carrier.
UVA2	Antioxidant masterbatch	It is a concentrate of antioxidant agents in pellet form. It contains a combination of antioxidants in polyethylene carrier.
UVA3	UV stabilizer masterbatch	It is a UV stabilizer specifically developed for polyolefins. It is suitable for all applications using LDPE, LLDPE, and PP.

List of the samples prepared and used this study.

Sample no.	Composition
S1	LLDPE 6821 (80%) + EVA 218 (20%)
S2	S1 (99.5%) + NIR1 (0.5%)
S3	S1 (99.5%) + NIR2 (0.5%)
S4	S1 (99.5%) + NIR3 (0.5%)
S5	S1 (99.5%) + NIR4 (0.5%)
S6	S1 (99.5%) + NIR5 (0.5%)
S7	S1 (98%) + UVA1 (2%)
S8	S3 (99.5%) + UVA2 (0.25%) + UVA3 (0.25%)
S9	S5 (99.5%) + UVA2 (0.25%) + UVA3 (0.25%)

LLDPE: Linear-low-density-polyethylene
EVA: Ethylene-vinyl acetate

Composition and important properties of NIR-reflective additive used in this study.

Sample no.	Pigment code	Composition	TSR*
NIR1	Blue 424	CoAl	42%
NIR2	Yellow 10P110	NiSbTi	69%
NIR3	Orange 10P225	CrSbTi	63%
NIR4	Green 223	CoNiZnTi	25%
NIR5	Brown 10P850	MnSbTi	35%

TSR: Total solar reflectance is the percentage of the total solar energy reflected by the pigment.

(Syed et al., 2013)

Average values in percentage for transmittance and reflectance in UV, PAR, and NIR regions for control and various blend samples.

Sample	*T* (%) UV	*T* (%) PAR	*T* (%) NIR	*R* (%) NIR
S1	41.2	70.8	81.0	7.6
S2	43.1	62.4	67.3	8.3
S3	46.5	65.3	69.7	10.1
S4	46.7	58.8	66.5	13.9
S5	52.6	70.1	77.2	8.5
S6	42.2	42.5	53.3	12.2
S7	29.9	65.7	74.6	9.7
S8	12.4	60.1	75.9	11.6
S9	16.0	35.8	40.3	31.5

(Syed et al., 2013)

References

Abdel-Ghany A., Kozai T., Chum C. Evaluation of selected greenhouse covers for use in regions with a hot climate. 2001. J. Trop. Agr. 45(4) : 242 - 250

Abdel-Ghany, A & Al-Helal, I & M Alzahrani, Saeed & Alsadon, Abdullah & M Ali, Ilias & Elleithy, Rabeh. (2012). Covering Materials Incorporating Radiation-Preventing Techniques to Meet Greenhouse Cooling Challenges in Arid Regions: A Review. The Scientific World Journal. 2012. 906360. 10.1100/2012/906360.

Morris G. , E. S. Trickett, F. H. Vanstone, and D. A. Wells, "The limitation of maximum temperature in a greenhouse by the use of a water film on the roof," Journal of Agricultural Engineering Research, vol. 3, pp. 121–130, 1958.

Syed K. H. Gulrez, Ahmed M. Abdel-Ghany, Ibrahim M. Al-Helal, Saeed M. Al-Zaharani, and Abdullah A. Alsadon, "Evaluation of PE Films Having NIR-Reflective Additives for Greenhouse Applications in Arid Regions," Advances in Materials Science and Engineering, vol. 2013, Article ID 575081, 8 pages, 2013. https://doi.org/10.1155/2013/575081.

Prof. Evelia Schettini, PhD
Engineer
Department of Agricultural and Environmental Science
University of Bari
via Amendola 165/A - 70126 Bari - Italy
Tel: ++39 080 5443060 / Fax: ++39 080 5442977
Email: evelia.schettini@uniba.it
Skype: evelia.schettini