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Effect of shading and insect proof nets on screenhouse light environment

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Abstract

Screenhouses covered by shading or insect proof screens are becoming popular among growers in arid and semiarid regions like the Mediterranean area, due to the environmental, economic and agronomic benefits they offer. The positive impact of a net-covering on plant behaviour can be mostly explained by the more favourable microclimate under a screenhouse than outdoors. However, manipulation of light environment by shading using screens requires the knowledge of the characteristics and parameters of the modified light regime, on both the quantitative and qualitative aspects of light environment under the screens. Thus, the effects of cover optical properties on screenhouse radiative environment were investigated, under Mediterranean conditions during summer in Central Greece, under three net-screen materials (i) a pearl insect-proof screen (IP-78), (ii) a white insect proof screen (IP-59) and (iii) a green shade-screen (GS-62) with values of the transmittance to photosynthetically active radiation (τPAR) of 78%, 59% and 62%, respectively. All screens induced impoverishment in the blue wavelength band (B, 400-500 nm) and enrichment in near-infrared broadband (NIR, 700-1100 nm) with respect to PAR (400-700 nm), and modified photomorphogenetic parameters such as the ratios B:FR (Blue vs Far-Red), R:FR (Red vs Far-Red) and the phytochrome ratio, ζ.

Keywords: screenhouse, transmittance, light quality, microclimate

1 Introduction

Screenhouses, also called net-houses, are becoming popular among growers in arid and semiarid regions like the Mediterranean area, due to the environmental, economic and agronomic benefits they offer (Castellano et al., 2008). Insect proof screenhouses are environmental friendly as they reduce the amount of chemical inputs in pesticides and their associated costs, health risks for workers and potential environmental pollution (Möller et al., 2004). Economically, screenhouses have lower cost compared to conventional greenhouses (Möller & Assouline, 2007). The reduction of solar radiation due to net-covering allows alleviating conditions of stress-induced limitations of the physiological fluxes (Stanhill & Cohen, 2001) which are a major constraint in the productivity and quality of greenhouse-grown crops. The positive impact of a net-covering on plant behaviour can be mostly explained by the more favourable microclimate under a screenhouse than outdoors. Screens modify in a positive way several microclimatic variables that drive plant physiological and morphological processes, i.e. incident light, air and soil temperature, air humidity and air speed, among the most relevant. Net-covering increased the relative fraction of diffuse radiation that positively affected the amount of radiation absorbed by crops (Goudriaan, 1977), the photosynthetic rate (Spitters, 1986; Monteith & Unsworth, 1990), crop radiation use efficiency (Cockshull et al., 1992), crop yield (Healey et al., 1998) and the spatial distribution inside the greenhouse of both solar radiation (Dayan et al., 1986) and yield (Adams et al., 2000). Several studies in semiarid areas have demonstrated that crops grown under net experience a notable increase in production (Leonardi et al., 2000; Kittas et al., 2012; Kitta et al., 2012) and/or in quality (Rylski, 1986; Whaley-Emmons & Scott, 1997) with respect to open-field crops.

Net-covering has a positive effect on plant physiology by preventing a down-regulation of photosynthesis during periods of high radiation (Medina et al., 2002; Kato et al., 2003). As counterpart, nets reduce the amount of light during periods of low radiation, therefore limiting the potential for plant light capture and biomass production. There is therefore a compromise to find between the requirements of protecting the plants from excessive radiation load and high temperature, and the objective of maximising light capture and standing biomass of the plant canopy. This compromise is not straightforward to find. Manipulation of light environment by artificial shading requires the knowledge of the characteristics and parameters of the modified light regime, on both the quantitative and qualitative aspects. Some previous studies have dealt with the quality of screenhouse light environment (Shahak, 2008; Schettini et al., 2012; Schettini & Vox, 2012), but most of studies on the agronomic impact of nets consider only the quantitative aspects, that is, the amount of light reduction due to the nets. The parameter that is currently used by manufacturers to characterise the impact on light is the shading factor (SF, %), which corresponds to the relative amount of radiation that is absorbed and reflected in the visible range (380-760 nm) of solar radiation (Castellano et al., 2008), or in the photosynthetically active radiation (PAR: 400-700 nm). As such, SF represents a quantitative estimate of the light loss due to the net, but does not inform on the qualitative (spectral) changes. Accordingly, this work aims to provide more insight into the qualitative modification of the light environment under screenhouses.

2 Materials and methods

2.1 Screenhouses and plant material

The experiments were performed in three experimental flat roof screenhouses, N–S oriented (36º declination clockwise from North), located at the University of Thessaly near Volos (Velestino: Latitude 39º 22’, longitude 22º 44’, altitude 85 m), on the continental area of Eastern Greece. The geometrical characteristics of the screenhouses were as follows: length of 20 m, width of 10 m and height of 3.2 m.

Three different screens were tested. Two were insect-proof (IP) screens manufactured by Meteor Ltd., Israel: (1) a pearl 50 mesh (20/10) AntiVirus™ screen with a mean PAR (400-700 nm) transmittance of 78%, that is, a PAR-shading factor of 22% (hereafter, IP-78); and (2) a white 50 mesh BioNet™ (BN) with a mean PAR transmission of 59% (hereafter IP-59). The third one was a green shade screen (Thrace Plastics C S.A. Xanthi, Greece) with a mean PAR transmission of 62% (hereafter GS-62). The IP has a regular mesh netting of 0.27 mm x 0.27 mm, while the green shading net, due to its different knitting, present meshes that are irregular in size and arrangement (dimensions varying in the range 0.5 mm to 3.0 mm).

Sweet pepper plants (*Capsicum annuum L*., cv. Dolmi) were transplanted on May. Plants were laid out 0.5 m apart in the row, in five double rows with a distance between the double rows of 1.2 m, resulting in a plant density of 1.8 plants per m^2. Cropping techniques (fertigation, pruning, chemical treatments) were identical in all treatments.

2.2 Measurements

Air temperature and relative humidity inside and outside the screenhouses were measured by means of temperature and humidity sensors (HOBO Pro RH/Temperature Data Logger, Onset Computer Corp, MA, U.S.A.) placed 1.5 m aboveground inside a protective shield against solar radiation. The solar radiation inside and outside the screenhouses was measured by means of solarimeters (SP Lite Silicon Pyranometer, Campbell Scientific, Inc.,

U.S.A) placed 2.4 m aboveground. Measurements took place every 30 s and 10-minute average values were recorded in a data logger (model DL3000, Delta-T Dev., Cambr., U.K.).
Measurements of the spectral transmittance of the three screens were made in situ by means of a LI-COR portable spectroradiometer (model LI-1800, LI-COR, Lincoln, NE, USA) in the range 400 nm to 1100 nm at 1 nm interval. The spectroradiometer was located at 0.8 m aboveground in the middle of each screenhouse. All measurements were made under clear sky conditions between 12:00 to 14:00 h (local time) at an interval of 3 min, alternately in the open field and in the middle of the screenhouse compartments. The measurements were repeated 6 times during the experimental period. For each screenhouse, five sets (inside and outside) of measurements were taken per measuring date. The average spectral distribution was calculated from the individual curves obtained between 12:00 and 14:00 h. All spectral data were expressed as spectral irradiance in W m^{-2} nm^{-1}.
Using the solar radiation spectra measured in the open-field (subscript 'o') and inside the screenhouses (subscript 'i'), the following broadband integrals of solar radiation (W m-2) in the blue wavelength band (B, 400-500 nm), the photosynthetically active radiation (PAR, 400-700 nm) and the near infrared wavelength band (NIR, 700 nm to 1100 nm) were calculated. The respective screen transmittances in the B (τB), PAR (τPAR) and NIR (τNIR) wavelength bands were then obtained by calculating the ratios:

$$\tau_B = \frac{B_i}{B_o}, \quad \tau_{PAR} = \frac{PAR_i}{PAR_o} \text{ and } \tau_{NIR} = \frac{NIR_i}{NIR_O}$$

The screen transmittance to global solar radiation (τ_G) was calculated from the pyranometer data sets. The literature on plant photomorphogenesis indicates that two main photoreceptors are involved in the perception of light quality, the phytochrome and the cryptochrome (Chen et al., 2004; Spalding & Folta, 2005). The most frequent way for characterising the phytochrome response is through the ratio of red to far red light, which is generally quoted as ζ. According to Kittas et al. (1999), ζ was calculated as the narrow wavelength band ratio of red (R, 655-665 nm) to far-red (FR, 725-735 nm) light. A surrogate to ζ is the broad wavelength band ratio R:FR, where R and FR are in the wavelength bands of 600-700 nm and 700-800 nm, respectively.
The cryptochrome response is generally analysed through the morphogenetically active radiation (MAR), defined as the amount of radiation in the broad wavelength band 400-500 nm (Rajapakse & Kelly, 1995; Maas & Bakx, 1995). In this study, we used the ratios B:R and B:FR, where B corresponded to the wavelength band 400 - 500 nm.
The statistical package SPSS (SPSS-14.0 for Windows standard version, 2005, SPSS BI Greece S.A.) was used for statistical analysis of the data. Data were analyzed using ANOVA, with the level of significance set at $P < 0.05$, and Duncan's multirange post hoc tests.

3 Results

3.1 Screenhouse transmittance

The season-averaged spectral transmittance determined in situ under the three screenhouses is presented in Fig. 1. The transmittance of the two insect-proof (IP) screens increased rapidly from 350 to 450 nm and reached a plateau in IP-78 after 500 nm, while it increases moderately from 450 to1100 nm in IP-59. The green shading net (GS-62) presents low transmittance values between 550 nm and 700 nm, a characteristic of green materials, and a higher UV (350-400 nm) transmittance.
The mean values of screenhouse transmittance in the B (τB), PAR (τPAR) and NIR (τNIR) broad wavelength bands were statistically different (Table 1).

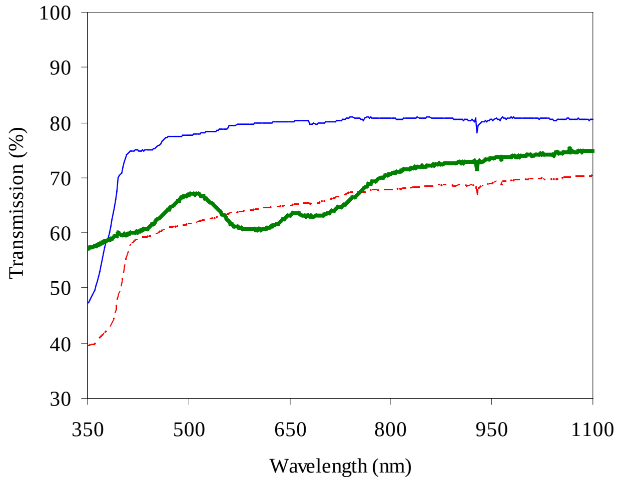

Fig. 1. Mean spectral transmittance determined in situ during the 2011 growing season for the three screenhouses. Thin line = IP-78, dashed thin line = IP-59, thick line = GS-62.

Table 1. Mean values of light quality parameters under the three screenhouses (IP-78, IP-59 and GS-62) and in open-field (OF). The standard deviation of the values is given in parenthesis. Means in the same line followed by different letters are statistically different (P < 0.05).

	IP-78	*IP-59*	*GS-62*
τ_B *(400-500 nm)*	*0.70 (±0.02)a*	*0.51 (±0.02)c*	*0.60 (±0.01)b*
τ_{PAR} *(400-700nm)*	*0.78 (±0.02)a*	*0.59 (±0.02)c*	*0.62 (±0.01)b*
τ_{NIR} *(700-1100nm)*	*0.82 (± 0.02)a*	*0.66 (±0.02)c*	*0.71 (±0.01)b*
τ_G *(300-3000nm)*	*0.81 (± 0.03)a*	*0.66 (±0.05)c*	*0.70 (±0.05)b*

All screens induced a relative enrichment in NIR and depletion in B light with respect to PAR, with τ_{NIR} approximately 20-30% higher than τ_B. The relationships linking the broad wavelength bands transmittance to the global solar radiation transmittance, τ_G, were quasi linear (Fig. 2), the slope of the relationships being indicative of the sensitivity of each broadband transmittance to changes in global transmittance for solar radiation induced by the screen material. The slope of the τ_{NIR} vs τ_G was close to 1 ($\tau_{NIR} = 0.99\tau_G$ -1.56), whereas the slope of τ_{PAR} vs τ_G and τ_B vs τ_G were 1.20 and 1.39, respectively, indicating that τB was the transmittance most affected by the presence of the screen material. The transmittance to global solar radiation (τ_G) was found slightly higher than τ_{PAR} for all screens, but not significantly different (Table 1).
All broadband ratios show a slight downward seasonal trend throughout the two periods of observation, which could be ascribed to seasonal changes in beam incidence angle, dust accumulation and ageing. The latter might explain the lower average values of τ_{PAR} in 2012 with respect to 2011, by respectively 4%, 2% and 6% in IP-78, IP-59 and SG-62.

3.2 Light quality parameters

All screens presented slight but significant changes in light quality parameters with respect to those measured in the open-field (Table 2). The phytochrome-related ratios (ζ and R:FR) and the cryptochrome-related ratio B:FR showed significantly lower values under screens than in the open-field.
The ratio R:FR was conservative in the open-field, but decreased with time in the three screenhouses during the second half of the observation period (Fig. 3), suggesting that dust accumulation and seasonal change in beam incidence might lead to a relative enrichment in FR-light with respect to R-light. A tight correlation (Fig. 4) was found between τ_{PAR} and the ratio R:FR (R^2 = 0.92): R:FR = 0.025 τ_{PAR} +1.009

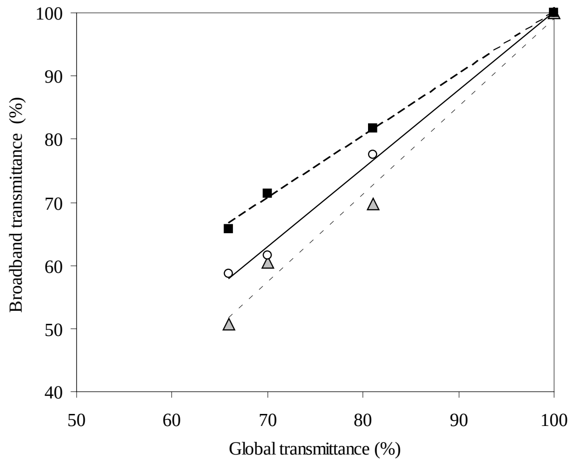

Fig. 2. Screenhouse broad wavelength band transmittances vs global solar transmittance. Lines are linear regression of the data. Triangles: B; squares: NIR; circles: PAR. Equations are: for B, τ_B = 1.39 τ_G -40.04; for PAR: τ_{PAR} = 1.20 τ_G -23.99; for NIR: τ_{NIR} = 0.99 τ_G -1.56.

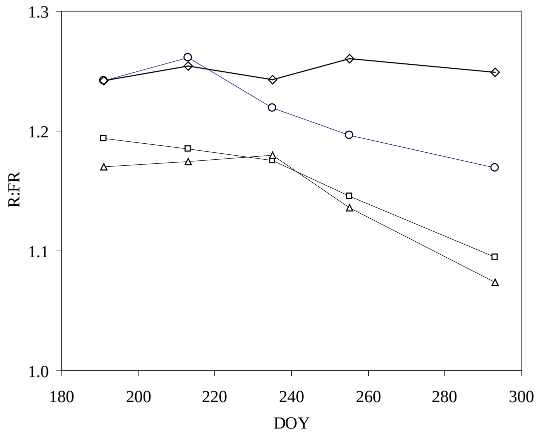

Fig. 3. Time evolution of the ratio red/far-red light (R:FR) throughout the observation period (Year 2011) under the three screenhouses and in the open-field. DOY = day of year. Triangles: GS-62; squares: IP-59; circles: IP-78; diamonds: open field.

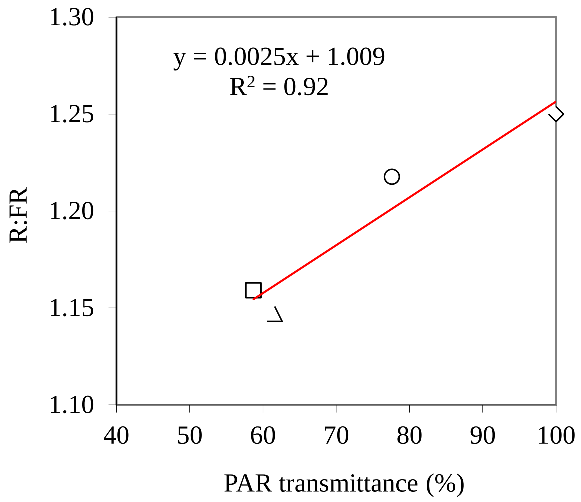

Fig. 4. Relationship between PAR transmittance (τPAR) and the ratio R:FR. Triangle: GS-62; square: IP-59; circle: IP-78; diamond: open field.

Table 2. Mean values of light quality parameters under the three screenhouses (IP-78, IP-59 and GS-62) and in open-field (OF). The standard deviation of the values is given in parenthesis. Means in the same line followed by different letters are statistically different (P < 0.05)

	IP-78	*IP-59*	*GS-62*	*Outside*
ζ	*1.24 (±0.011)b*	*1.20 (±0.006)c*	*1.24 (±0.025)b*	*1.27 (±0.003)a*
R:FR	*1.22 (±0.010)b*	*1.17 (±0.008)c*	*1.16 (±0.008)c*	*1.25 (±0.011)a*
B:R	*1.03 (±0.006)c*	*0.98 (±0.006)d*	*1.08 (±0.004)a*	*1.05 (±0.004)b*
B:FR	*1.25 (±0.012)b*	*1.15 (±0.005)c*	*1.25 (±0.029)b*	*1.32 (±0.005)a*

Wavelength bands: blue (B= 400-500 nm), Red (R= 600-700 nm) and far-red (FR= 700-800 nm) light and Photosynthetically Active Radiation (PAR= 400-700 nm). Phytochrome ratio, ζ = (655-665 nm)/(725-735 nm).

Although differing in colour, porosity and mesh size, the three screens shared several common characteristics in what refers to the changes they induced in light environment:

- A relative enrichment in NIR with respect to PAR and B light (Table 1, Fig. 2). The higher impoverishment in B light was observed under the two insect-proof screens, which have a low transmittance in this wavelength band (Fig. 1).
- An enrichment in FR light with increased shading intensity, which led to a decrease in all the FR-related parameters (ζ, B:FR and R:FR).
- The relative decrease in FR-related parameters was highly correlated with τPAR, especially the R:FR ratio.

The main differences among the insect-proof screens (IP-78 and IP-59, of pearl and white colour, respectively) and the green shade screen (GS-62) is that the formers have a lower transmittance in the B-band than GS-62, whereas in the green and red bands GS-62 has, respectively, a slightly lower and higher transmittance than IP-78 and IP-59 (Fig. 1). Despite these differences, all the screens exhibited values of PAR-transmittance (i) lower than those of NIR and global solar transmittance and (ii) higher than the values of B-transmittance. An important finding related to light quality parameters is that all screens promoted a relative enrichment in FR light, therefore inducing a decrease in the R:FR ratio that was highly correlated with PAR-transmittance.

3.3 Effect of screens on microclimate

Values of air temperature and humidity-related variables (e.g. vapour pressure deficit, VPD) did not show significant differences among the screenhouses (Figs. 5a and b).

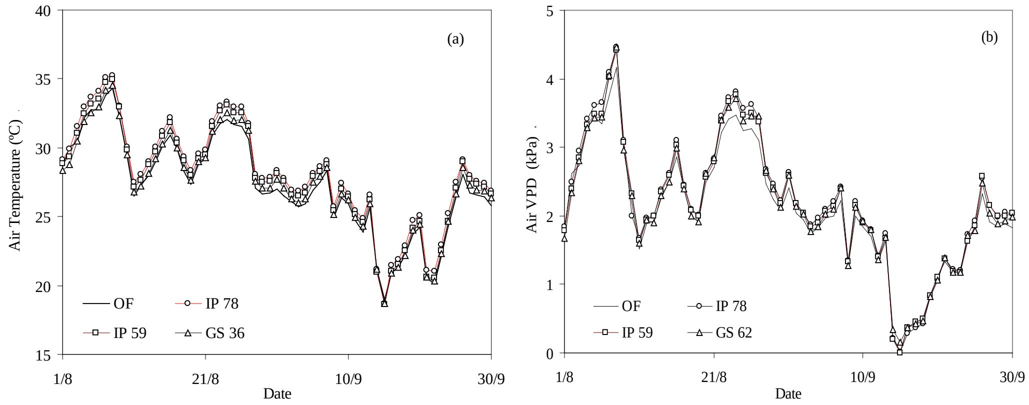

Fig. 5. Time evolution of (a) air temperature (Ta, ºC) and (b) vapour pressure deficit (VPD, kPa) in the open field and under the screenhouses, over the period August 1 to September 30, year 2012. Triangles: GS-62; squares: IP-59; circles: IP-78; clear line: open field.

On average over the period of observation, the daily mean air temperature and the corresponding values of VPD at 1.5 m aboveground did not differ by more than ± 0.5ºC and ± 0.2 kPa, respectively, among screenhouses. The IP-78 screenhouse presented generally slightly higher air temperature than the two other ones. Similar results were reported by Shahak (2008) for the pearl and white insect proof nets and by Holcman & Sentelhas (2012) for coloured nets. This observation suggests that air temperature and VPD are not likely to explain any possible differences in biomass and yield observed among screenhouses, neither between screenhouses and open field.

4 Conclusions

It was found that the screens used in the present study did not significantly affected the screenhouse air temperature and vapour pressure deficit conditions since the consitions observed in the screenhouse were similar to those observed under open field. However, all screens affected incoming light quality since induced impoverishment in the blue wavelength band (B, 400-500 nm) and enrichment in near-infrared broadband (NIR, 700-1100 nm) with respect to PAR (400-700 nm), and modified photomorphogenetic parameters such as the ratios B:FR (Blue *vs* Far-Red), R:FR (Red *vs* Far-Red) and the phytochrome ratio, ζ. Seasonal changes in beam incidence angle, dust accumulation and ageing induced a slight downward seasonal trend throughout the two periods of observation in all broadband ratios.

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