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SHADING METHODS FOR CROP PROTECTION UNDER GREENHOUSE IN MEDITERRANEAN AREAS

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ABSTRACT

Mediterranean areas are characterized by hot summers, which can determine unfavorable environment for the growth and quality of the crops which are cultivated inside a greenhouse. In order to control the greenhouse air temperature raise, one of the most common traditional solutions utilized by growers is the shading of the greenhouse against excessive solar radiation through the use of calcium hydroxide (i.e., slaked lime) or other paints applied on the greenhouse cover (so-called, whitening) with the aim to reduce the incoming solar radiation and limit the inside air temperature. More recently, the use of plastic shading nets is progressively affirming due to their cheaper price and photo-selective properties, as a way to effectively control the micro-climatic conditions inside greenhouses and tunnels. Thanks to a specific formulation of their chemical and physical properties, plastic nets may indeed combine the shading effect with some specific features useful for creating more favorable microclimatic conditions for the crop growth. With the aim to analyze the efficacy of the shading effect of plastic nets in different climates, two experimental trials have been carried out by comparing five identical small-scale tunnels; two installed in Southern Italy, and three in an arid climate (Saudi Arabia), in which the inside air and soil temperatures have been measured. The two tunnels were covered with EVAC plastic film, one of them also covered with plastic net, in contact with the external side the film. The three tunnels were covered with PE film; two of them were covered with two different plastic nets, fixed at 20-cm apart from the film cover. The radiometrical characteristics of the plastic films and nets were determined. The results obtained through these experimental trails enabled to start a comparative analysis of the performances of the tested net, highlighting the role that a selective filtering of solar radiation may play on crop protection from high temperatures and quality of light arriving to the crops.

Keywords: *plastic film, plastic nets, crop shading, radiometric characteristics, micro-climatic effect.*

INTRODUCTION

Agricultural production is progressively influenced by extreme meteorological phenomena, accompanied by big changes on a global scale, such as the increasingly sudden and frequent appearance of new types of insects, the transformation of food habits (*e.g.*, "*smart/super foods*"), *etc*. Thus, the concept of crop protection under a greenhouse, intended as a mere passive defense (from hail, sun, insects, wind, birds, *etc.*), is gradually being overcome: no longer an "*against*" or "*defending*" shelter, but rather a "*for*" or "*proactive*" smart structure. This building would be suitable to create ideal cultivation conditions thanks to a favourable microclimate, together with a greater diffusion of light, thanks to a more effective exploitation of solar radiation, as well as a better control of the general environmental conditions, enabling a reduction in use of pesticides as well. The plant and/or the fruits thus become healthier, more vigorous and characterized by higher concentrations of elements beneficial for human health (*e.g.*, antioxidants) thanks to a greater efficiency in the valorisation of natural resources and energy deriving from the sun.

Cladding materials employed for covering a greenhouse destined to protect crops may play a crucial role on the quality of light arriving to the crops, reducing in different ways the radiation, mostly within the Photosynthetically Active Radiation - PAR (400–700 nm) wavebands. Combination of wavebands in the incident light mixture may affect indeed plant growth, development, metabolism and morphology. This aspect may be at the base of the observed different agronomic results and antioxidant activity of the plant, since different cladding materials may influence the crop performance through a selective filtering which modifies the incoming radiation (Schettini et al. 2011; Vox et al., 2016). Mostly the UV-B component of the solar radiation may play a crucial role, as well as the green wavelength. This last component of the sun radiation in several cases may work against plant development, promoted conversely by the red and blue components (Folta and Maruhnich 2007).

Cladding materials and shading strategies may be proactively selected and implemented in many Mediterranean areas, as well as in other hot regions (*e.g.*, arid regions) in which the solar radiation levels arriving during spring/summer season are often too high for a correct management of the greenhouse, even to avoid undesirable effect on the crop, *e.g.*, sunburn. Sunlight can affect indeed more than the opening and closing of plant stomata. While some plants have specialized proteins that protect them from sunburn, others do not, and intense solar radiation can damage their leaves. Plants that are not adapted to full or intense sunlight can develop heat stress. Many plants are susceptible to leaf scorch, where parts of the plant die due to excessive water loss through transpiration. In addition to slowing or halting photosynthesis, heat stress and leaf scorch can make plants more susceptible to disease or insect infestations. Most of these negative effects may be avoided, mostly in the case of crop protection under greenhouse, when some suitable shading devices are properly employed (Castronuovo et al., 2015; Dehbi et al., 2017). In order to control air temperature inside greenhouse, one of the most common traditional solution utilized by growers in Southern Europe is the shading of the greenhouse against excessive solar radiation through the application of calcium hydroxide (*i.e.*, slaked lime) or other chemicals on the cover of the greenhouse (so-called, *whitening*) to create some shade and then limit the raising of the air temperature (Castellano et al., 2008).

More recently, the use of plastic shading nets is progressively affirming, thanks to a cheaper price and improved photo-selective properties, as a way to more effectively control the late spring and summer micro-climatic conditions inside close greenhouse and tunnel (Picuno et al., 2008). Plastic nets are usually characterized by a shading factor, ranging from 10% to 90%, which represents the capacity of the net to reduce the incoming solar radiation, related to the average value of the transmissivity of the net in the solar wavelength band from 200 nm to 2500 nm (Schettini et al., 2012). A plastic net performs indirect effects as well, when it is employed to cover close greenhouse and tunnel. Due to its influence on the values of the main microclimatic parameters (temperature, relative humidity, carbon dioxide concentration, solar radiation, *etc.*), it could play, if used as standalone cover or even in synergy with a cladding plastic film, a fundamental role on creating more favourable microclimatic conditions during the crop growth (Picuno & Abdel-Ghany, 2016; Dehbi et al., 2018). Thanks to a specific formulation of their chemical and physical properties, plastic nets may indeed combine the shade effect with some specific features useful for creating suitable conditions for the crop growth and to guarantee healthy conditions for workers. Each plastic net modifies the solar radiation that arrives on the crop, by reducing the light flow and varying the available radiant spectrum. Apart from the net structure, the spectrum of the transmitted radiation is also influenced by the diameter of the thread, color and thickness of the net, and the radiometric properties (absorbance, transmittance and reflectance) of the plastic material (Sica & Picuno, 2008). Plastic covers play a critical role not only towards the internal environment, influencing the crop growth, but also towards the external surrounding landscape, strongly influencing the visual aspect of the rural land (Tortora et al., 2015). From this point of view, a suitable landscape planning approach appears necessary, in order to consider in a holistic way all aspects connected to the use of plastic nets in agricultural application (Statuto et al., 2016). Despite their widespread use, however, neither growers nor net producers have clear ideas about the relationship between the net typology optimization for a specific application and the technical characteristics of the net. The choice often depends on empirical or economic criteria, not on scientific considerations (Castellano et al., 2008; Shahak, 2008).

The analysis of different shading strategies was performed by Abdel-Ghany et al. (2015), who showed through experimental tests that the internal position of the shading net drastically increases the generated thermal radiation within the greenhouse and the internal air temperature during the day, so the outside position for the shading net should anyway be preferred from a general thermodynamic point of view (Abdel-Ghany et al., 2016). Despite the importance of the spectral radiative properties during the lifetime of a plastic material used to crop protection, very few studies have been performed so far to analyse the degradation behaviour of these materials, in terms of their spectro-radiometrical characteristics (Emekli et al., 2016). Particularly Abdel-Ghany et al. (2018) have investigated the degradation behaviour of spectral transmittance and reflectance in the solar spectrum range of a 200 μm thick, PE-LD film-covered greenhouse model, resulting that the 1-year exposure drastically reduced the spectral and total transmittance of the cover film to global and PAR solar radiation by about 32% and increased the spectral and total reflectance by about 19% compared to new film. Degradation of the radiative properties of the film did not affect the light quality or the transmission ratios of light into the greenhouse.

In this paper, the results of an experimental trial carried out on the basis of some previous experimental tests (Statuto & Picuno, 2017) are reported. This new analysis was performed in order to start a systematic approach aimed to analyze the effect of a shading net on the internal microclimate of a greenhouse depending on its radiometrical properties, as well as to analyze different shading strategies on a selective filtering effect of the solar radiation.

MATERIALS AND METHODS

Two identical small tunnels (Fig. 1) were realized in the experimental area of an agricultural farm located in the municipality of Acerenza (Southern Italy - 40° 82′ N latitude; 15° 96′ E longitude). These small-scale tunnels, both covered with an EVAC plastic film, were left without any cultivation inside. One of them was covered with a plastic shading net overlapped on the external side, in contact with the plastic film. The tested plastic net was a BIORETE 50 MESH, 100% PE-HD monofilament net produced by the Italian industry Sachim-Arrigoni. It was a semi-transparent milky-white colour woven net, with a hole dimension of 0.27-mm × 0.83-mm and a weight equal to 130g/m^2. The producer declares a shading effect for this net of 13%. Both the shading plastic net and the EVAC plastic film were analyzed in the UV-VIS-NIR wavelength ranges by using a Jasco V-570 spectro-radiometer, at the Laboratory of Material Tests of the SAFE School of the University of Basilicata, Italy.

The temperature of the external and internal air and soil were recorded by CS500-L probes (modified version of Vaisala's 50Y Humitter, Campbell Scientific Inc, Utah, USA). The relevant data were recorded by a CR10X data-logger (Campbell Scientific Inc, Utah, USA).

Figure1 Small-scale tunnels covered with plastic film (left) and plastic film+net (right).

In parallel, another experiment was conducted in an arid climate (at King Saud University campus, Riyadh, Saudi Arabia - 24° 39′ N latitude; 46° 47′ E longitude) using three identical small tunnels, having the same dimensions as those two in Figure 1. These three tunnels were covered with a PE-LD plastic film, 200-µm thick. One tunnel as a control and the other two include an additional frame used to fix a plastic net cover at a distance of 20 cm apart from the film cover. The nets colors were white and black, each one of 50% nominal shading factor, as they were provided by the supplier. The radiometric properties of the PE-LD plastic film and of the white and black nets used in Riyadh experiment have been reported by Abdel-Ghany et al., (2018) and Abdel-Ghany & Al-Helal (2012).

RESULTS AND DISCUSSION

The results of the spectro-radiometrical analysis of the materials used in the experimental trials performed in Acerenza are reported in Tables 1 and 2, in terms of the main characteristics measured in different significant ranges within the solar spectrum, both for the plastic film and for the joint combination (coupling) plastic net + EVAC film. From the results of this spectro-radiometric analysis performed in the solar range, it could be deduced that the shading effect that was detected (*i.e.*, the complement to 1 of the transmissivity coefficient) into the different wavelength ranges (UVB, UVA, PAR, *etc.*) may give further information about the effective capability of the net to protect the crop from excessive solar radiation. The overlapping of the plastic net in contact with the cladding film has indeed increased the shading effect in the solar range of around 11% (from 33,86% to 44,8%) that is, somewhat, lower than the shading effect of the net alone (13%), as it is reported by the net producer.

Table 1 Results of the spectro-radiometrical analysis on the plastic EVAC film.

Range	Wavelength	Transmittance	Reflectance	Absorptivity	Shading effect
	nm	%	%	%	%
Solar	200 - 2500	66,14	8,75	25,11	33,86
PAR	400 - 700	67,14	12,19	20,67	32,86
Solar IR	700 - 2500	72,06	8,53	19,41	27,94
UV	280 - 380	10,45	4,86	84,69	89,55
UVA	320 - 380	16,78	5,26	77,96	83,22
UVB	280 - 320	0,64	4,24	95,12	99,36

Table 2 Results of the spectro-radiometrical analysis on the coupling plastic net + EVAC film used in the Acerenza experimental trials.

Range	Wavelength	Transmittance	Reflectance	Absorptivity	Shading effect
	nm	%	%	%	%
Solar	200 - 2500	55,20	15,72	29,08	44,80
PAR	400 - 700	57,54	20,33	22,13	42,46
Solar IR	700 - 2500	60,03	15,98	23,99	39,97
UV	280 - 380	7,01	5,87	87,12	92,99
UVA	320 - 380	11,34	6,91	81,75	88,66
UVB	280 - 320	0,30	4,25	95,45	99,70

In figures 2 and 3, the diagrams of the solar transmittance and reflectance respectively of the plastic EVAC film and the joint combination (coupling) plastic EVAC film and the shading plastic net along the whole UV-VIS-NIR wavelength [200–2500 nm] are illustrated. The difference did not seem to have significant influence on the air and soil temperature within the two different small-scale tunnels located in Acerenza during the testing period. As shown in figure 4, in fact, temperatures within these close small structures were almost the same, but it is possible to notice a lower air temperature (difference about 1°C) in the tunnel shaded with the plastic net.

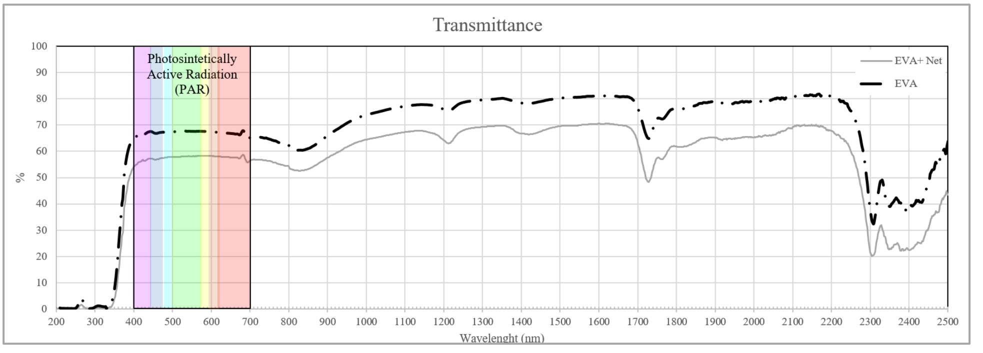

Figure 2 Transmittance in the UV-VIS-NIR of plastic film and coupling film + net.

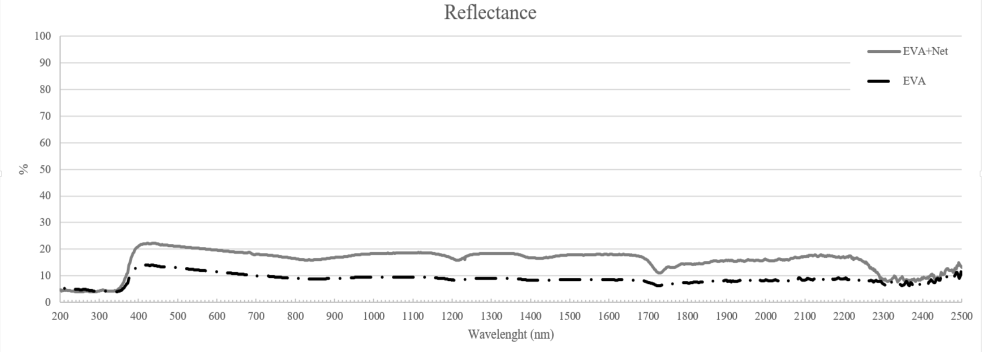

Figure 3 Reflectance in the UV-VIS-NIR of plastic film and coupling film + net.

In the case of the experimental trials performed in an arid climate on the identical experimental tunnels, however, a reduction of around 5-7ºC was observed when the shading nets installed apart from the film cover (Fig. 5). Despite of the nominal shading factor is the same (50%), the black net showed higher shading effect than the white net because the white colour increases the forward scattering of solar beam and consequently enhances the transmitted solar radiation into the tunnel.

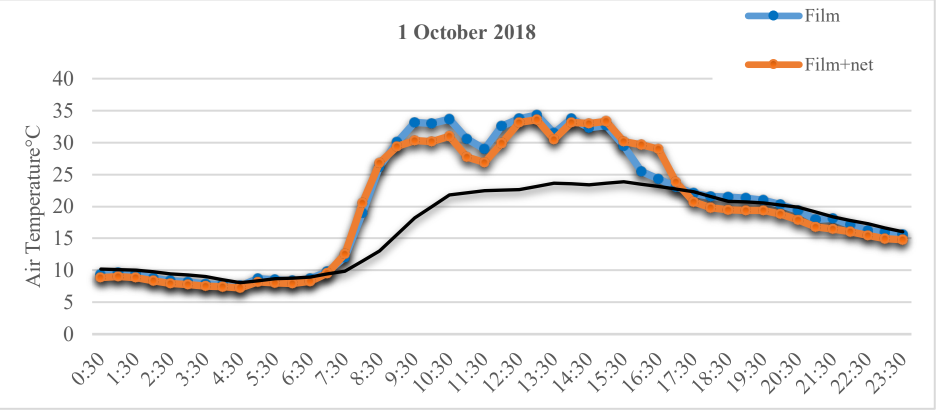

Figure 4 Air temperature detected in the trial tunnels installed in Southern Italy.

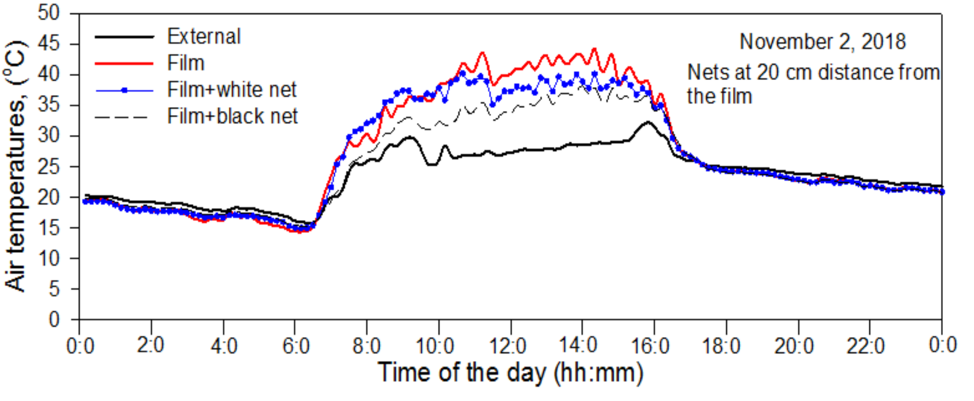

Figure 5 Air temperature detected in the trial tunnels installed in the arid climate.

In the Acerenza experiment, the same situation appears when considering the soil temperature at the centre of each tunnel, at a depth of 10 cm. Also, in this case the temperature recorded in the case of film with net is slightly lower, during the day, than in case of plastic film only (Fig.6). This observation is mainly attributed to the low shading power of the net (≅11%) and its colour which enhances the transmitted radiation into the tunnel and reduces the shading effect.

Under arid climatic conditions and existing a sandy soil below the three tested tunnels, however, the effect of shading reduced the in-depth (at 10-cm) soil temperature by about 3°C lower than that under the un-shaded tunnel (Fig. 7). The maximum reduction in Figure 7 was shifted from solar noon to 4:00 PM due to the thermal inertia of soil, which delayed the response of soil to the environment over the soil surface. During night time, shading is expected to warm up the microclimate and the soil below the tunnels; however, this effect is not clearly recognized in the present study because the size of the tested tunnels was small. Significant effects are expected with full scale and commercial greenhouses.

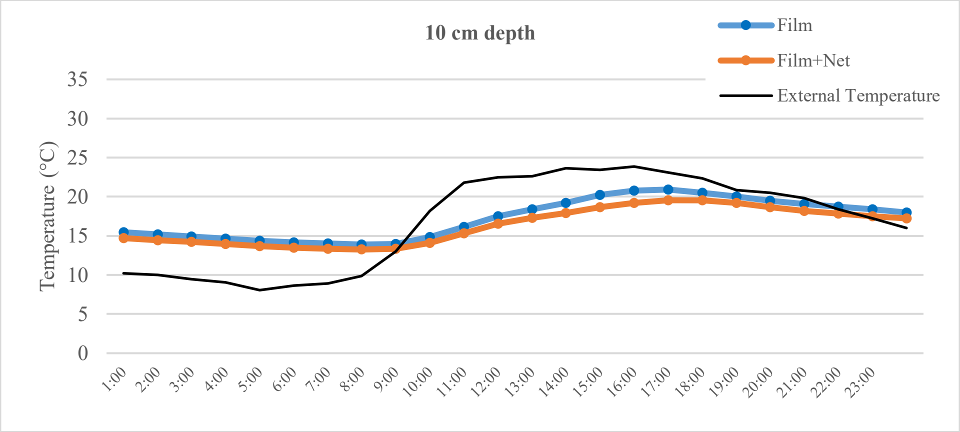

Figure 6 Soil temperature detected in the trial tunnels at 10 cm depth (Acerenza).

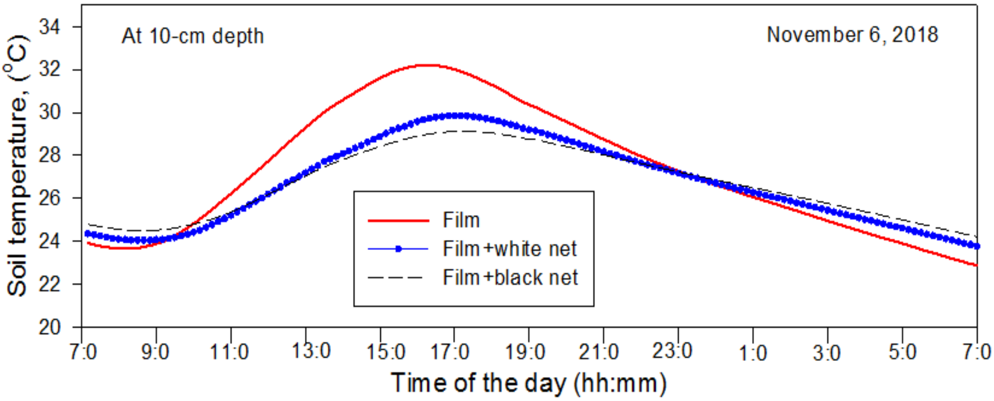

Figure 7 Soil temperature detected in the trial tunnels at 10 cm depth (arid climate).

From the results of these first trials, it can be concluded that an accurate evaluation of shading effects of a plastic net for different wavelength ranges (e.g., UVA, UVB, PAR, etc.) may give useful hints for the evaluation of the technical performance, in terms of real efficacy in protecting the crops from excessive sun radiation and possible consequent damages to the crop, *e.g.*, sunburn, scorch, *etc.* Transmittance coefficients, detailed at the different wavelength ranges playing a role in the crop growth, appear as an indispensable tool, able to classify the covering material in relation to the micro-climatic parameters of the protected environment, the quality of the radiation, the temperature and the air flow.

CONCLUSIONS

Nets are currently often employed as covering elements without any proper design, only basing on the knowledge of some technical characteristics. The lack of a specific Standard for determining the spectro-radiometrical characteristics of agricultural nets - with the consequence that laboratory test may be conducted on the basis of Standards applicable to different materials (*e.g.* glass, or transparent film) - still asks further investigations aimed to support an improvement of the technical properties of the plastic nets, in order to make them more finalized to the biological necessities of the crop.

From the present research, it can be concluded that nets should be accompanied by technical information about the shading factor along the whole solar range even when they have a different function than the shading. This specific information about the shading factor in the principal wavelength ranges - mostly in the Phosynthetically Active Radiation and UVA/UVB bands - seems very meaningful, taking into account the different effects on the crop as well as on the protected environment. More research is anyway needed to characterize different types of nets for specific purposes, as well as to quantify the effects of the shading effect on the greenhouse internal climate and crop response. Also, the duration of a plastic net, depending on the site and condition of application still needs further investigations.

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