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SPECTRO-RADIOMETRICAL ANALYSIS OF PLASTIC NETS FOR GREENHOUSE SHADING UNDER ARID CONDITIONS

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SUMMARY

The use of plastic nets in agriculture is now a consolidated reality all over the World. Plastic nets are used to protect orchards, flowers and vegetables thanks to the direct effect of crop protection against atmospheric agents (hail, wind, snow, heavy rain), birds and insects, as well as sand and saltiness, avoiding damages and/or dirtiness of the crop. Plastic nets perform indirect effects as well, when they are employed to close greenhouses and tunnels: due to their influence on the values of the main microclimatic parameters (temperature, relative humidity, carbon dioxide concentration, solar radiation, etc.), they could play a fundamental role on creating more favourable microclimatic conditions during the crop growth. The considerable success that plastic nets have registered in mild climate countries, as those located within the Mediterranean area, is currently pushing towards similar interesting application even in areas characterized by different climates - like the arid conditions usually found in Northern Africa and the Middle East - where greenhouse shading is essential in summer to reduce the solar radiation load.

In the present paper, the spectro-radiometrical properties of some different nets - white, black and thermal-screen - employed in Saudi Arabia to shade the roof and side-walls of a polycarbonate ventilated greenhouse, were measured in laboratory in the solar/PAR range and in the thermal Infra-Red wavelength. From the obtained results, it is clear that the absorbance of the black plastic net is very high, both in the solar (nearly 70%) and in the IR (over 75%), so their use inside the greenhouse should be avoided. On the other hand, the level of transmittance of the white plastic net (over 60%), joined to its significant reflectance – that generates mutual progressive reflections with the greenhouse cladding sheet, if it is installed inside the greenhouse – confirms once more that shading nets should be employed only outside the greenhouse, in order to fully *express their potential of shading the incoming solar radiation. Finally, the thermal screen seems very effective in blocking the IR radiation. This characteristic, joined with a high reflectance in the solar wavelength, makes this material very powerful for an effective contribution to an improvement in the energy balance of a greenhouse.*

Key words: *plastic net; radiometrical characteristics; shading; greenhouse; arid climate.*

INTRODUCTION

Plastic nets are widely used all over the World for agricultural application [Briassoulis et al., 2007]. Protection from heavy meteorological actions (*i.e.*, hail, wind, snow, or strong rainfall) in fruit-farming and ornamentals, as well as shading the solar radiation in greenhouse or modifying its micro-environment through the realization of a confined airspace with better microclimatic conditions, is the most common case. Besides protecting plants against excessive heat load, shading also significantly reduces the crop water consumption in arid regions [Al-Helal & Abdel-Ghany, 2011; Abdel-Ghany et al., 2015]. Plastic nets are also used as standalone cover, or in connection with structures for growing arboreal cultivation, for the protection against virus-vector insects and birds [Picuno P., 2014]. 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 construction parameters of the net. The choice often depends on empirical or economic criteria, and not on scientific considerations [Castellano et al., 2008/a].

In a large number of agricultural applications, the radiometric characteristics of the net are the most important parameter, which have to be taken into account by the growers. The radiometric properties of the permeable membrane influence the quality of the agricultural production and the aesthetic characteristics of the netting system. If the transmittance could be considered one of the main parameters involved in the choice of agronomic requirements of the netting system, the reflectance of the net is strictly involved in the aesthetic assessment of the net-house in the rural landscape, since the colour of the material and the light reflection - especially on the wavelengths visible for the human eye (*i.e.*, VIS = 380-760 nm) - determine the aesthetic value of the net structure and its environmental impact. Then, nets with lower values of reflectance should be chosen in order to reduce the visual impact of the building.

Nets with an expected shading factor should have a high transmission for diffuse light. Insect nets and anti-hail nets should have as high as possible light transmission. The colour of a net influences the spectral distribution of the radiation passing through the net absorbing their complementary colours, consequently the choice of the colour of the net combined with the radiation requirements of the plant could be strategic to optimize the production and, more generally, the performance required [Castellano et al. 2008/b]. According with these Authors, more research is needed to quantify the radiometric properties of nets and develop models to predict the light intensity and quality on crop level.

Spectro-radiometrical characteristics of greenhouse shading plastic nets

Shading the roof of a greenhouse is usually performed by various conventional methods such as: whitening by spraying the exterior cover surface with an aqueous solution of hydrated Calcium oxide [$Ca(OH)_2$], external shade cloths, deploying movable refractive screens or curtains and plastic nets of various types and colours [Kittas et al., 2009]. Whitening the roof is nearly inexpensive; it can be used for reducing the heat load during summer. However, it reduces the average greenhouse transmittance to solar radiation by about 50%; it is washed away if rains falling over the greenhouse, and its shading density cannot be changed once applied [Baille et al., 2001]. However, no scientific contribution was proposed so far within the international relevant literature for the quantification of the shading effect of roof whitening with hydrated Calcium oxide.

An external or internal shade can be obtained by using movable plastic nets, curtains or refractive screens applied above or below the roof of the greenhouse. Some previous studies [Briassoulis et al., 2007; Kittas et al., 2009] evaluated shading nets either independently, or investigated their influences on greenhouse macroclimate (*e.g.*, air temperature, relative humidity and solar radiation). All shading methods are aimed to regulate the amount of solar energy entering the greenhouse and reduce the heating load in summer. Thermal screens are used inside the greenhouses in order to limit both convective and thermal radiative heat losses, especially during cold winter nights. Usually this kind of application requires aluminium colour nets to increase the reflection of heat radiation emitted from inside the greenhouse.

Nets are, unlike other covering materials, three-dimensional structures: the whole construction parameters of the net, combined with the shape of the structure, the position of the sun and the sky conditions affect the radiometric performance of the permeable structure [Castellano et al., 2008/a]. The colour of a net influences the spectral distribution of the radiation passing through the net, absorbing its complementary colours, consequently the choice of the colour of the net combined with the radiation requirements of the plant could be strategic to optimize the production and, more generally, the performance required to the net.

Previous experimental studies [Sica & Picuno, 2008; Schettini et al., 2011] have showed that, as expected, the transmittance of nets decreases when the mesh net becomes more close. Even so, the definition of a relationship between porosity and transmittance of a net appears hard to obtain. Porosity is not a parameter sufficient to quantify the shading effect, that is influenced by many other factors (polymer, thickness, colour, distance between the net and the plan receiving the radiation, additives, shape and diameter of the thread, *etc.*). Anyway, it’s a matter of fact that, at present, only the global shading factor is usually reported by the industries as a technical information on the leaflet that accompanies the material, while the information about the transmittance value of the net in the principal wavelength ranges (solar: 200-2.500 nm; Phosynthetically Active Radiation (PAR): 400-700 nm; Thermal Infra Red: 7,5-25,0 μm) seems very meaningful, taking into account the different effects on the crops and on the protected environment. Transmittance coefficients at the different wavelength ranges appear therefore as an indispensable tool, able to classify the covering material in relation with the micro-climatic parameters of the protected environment, the quality of the radiation, the temperature and the air flow. First spectro-radiometrical tests have shown that the nets determine effective qualitative changes in the incoming solar spectrum, that is the variation of the distribution of the radiant energy at different wavelengths. Unfortunately at present there is a lack of a specific Standard defining the spectro-radiometrical characteristics that agricultural nets should demonstrate, in order to adequately perform the application for which they are designed [Sica & Picuno, 2008].

Also the durability on time of a plastic net is strongly connected to its spectro-radiometrical properties. UV stabilizers increase the resistance to commercial nets against solar radiation up to 400 – 800 kLy [Castellano et al., 2008/b], which corresponds to a durability of the polymer of 5 to 6 years in mild climates - such as the Mediterranean basin (100-120 kLy/year) - or 3 to 4 years in arid areas (140-160 kLy/year). In this view, the formulation, through a set of specific experimental tests, of a mathematical algorithm able to predict the useful lifetime of a plastic material depending on the main climatological and environmental characteristics of the location where it will be used, in order to govern the chemical formulation of the basic polymer and/or quantity and quality of its additives, still appears an interesting option [Picuno P., 2014].

MATERIALS AND METHODS

In order to analyse the radiometric characteristics of some of the most diffused plastic nets in arid regions, three different plastic nets - that were employed in Saudi Arabia to shade the roof and side-walls of a polycarbonate ventilated greenhouse [Abdel-Ghany et al., 2015] - were analysed in the Laboratory of Material Tests of the SAFE School of the University of Basilicata (Italy). The spectro-radiometrical characteristics of these three nets were determined through a Jasco V-570 spectro-radiometer in the UV-VIS-NIR wavelength, and a Jasco FT/IR-430 spectro-radiometer in the LWIR wavelength.

Figure 1 The three analysed plastic nets: white net (left), black net (centre), aluminized thermal screen (right).

The following three nets (fig. 1) were analysed:

- white plastic net - 185 µm thickness, 50% porosity, 30% shading factor, (Saudi Yarn & Knitted Technology Factory-SYNTECH);
- black plastic net - 250 µm thickness, 30% porosity, 50% shading factor, (Saudi Yarn & Knitted Technology Factory-SYNTECH);
- plastic aluminized thermal screen - 183 µm thickness, 15% porosity, 70% shading factor, (Ludvig Svensson, China).

RESULTS AND DISCUSSION

The results of the spectro-radiometrical analysis over the tested materials are reported in Tables 1, 2 and 3, in terms of the main characteristics measured in the solar/PAR range, as well as in the Thermal Infra-Red wavelength.

Table 1 Results of the spectro-radiometrical analysis on the white plastic net

Range	Wavelength [nm]	Transmittance [%]			Reflectance
		Total	Direct	Diffuse	[%]
Solar	200 – 2.500	61,0	43,4	17,7	24,1
PAR	400 – 700	62,6	42,0	20,6	24,0
Solar IR	700 – 2.500	62,1	46,1	15,9	24,6
UV	280 – 380	8,0	5,6	2,4	12,7
UVA	320 – 380	8,2	5,7	2,5	12,6
UVB	280 – 320	0,5	0,3	0,3	14,8
Thermal IR	7.500 - 12.500	7,9			2,8

Table 2 Results of the spectro-radiometrical analysis on the black plastic net

Range	Wavelength [nm]	Transmittance [%]			Reflectance
		Total	Direct	Diffuse	[%]
Solar	200 – 2.500	27,9	26,1	1,9	3,5
PAR	400 – 700	27,5	26,6	0,9	3,7
Solar IR	700 – 2.500	28,3	25,6	2,7	3,3
UV	280 – 380	27,7	27,0	0,7	4,1
UVA	320 – 380	27,7	27,1	0,6	4,1
UVB	280 – 320	27,8	27,1	0,7	4,1
Thermal IR	7.500 - 12.500	23,2			0,9

Table 3 Results of the spectro-radiometrical analysis on the thermal screen

Range	Wavelength [nm]	Transmittance [%]			Reflectance
		Total	Direct	Diffuse	[%]
Solar	200 – 2.500	26,1	13,4	12,7	55,2
PAR	400 – 700	26,3	12,8	13,6	55,4
Solar IR	700 – 2.500	27,0	14,4	12,5	55,4
UV	280 – 380	3,7	2,1	1,7	46,0
UVA	320 – 380	3,8	2,1	1,7	45,8
UVB	280 – 320	0,4	0,2	0,2	53,6
Thermal IR	7.500 - 12.500	4,7			87,0

In the case of the white plastic net, its level of transmittance (over 60% - Table 1), joined to its significant reflectance – that generates mutual progressive reflections with the greenhouse cladding sheet inside the greenhouse – confirms once more that shading nets should be employed only outside the greenhouse, in order to fully express their potential of shading the incoming solar radiation.

On the other hand, from the reported results it is clear that the absorbance of the black plastic net (Table 2) – equal to the part complementary to 100% of transmittance + reflectance - is very high, both in the solar (nearly 70%) and in the IR (over 75%), so their use inside the greenhouse should be avoided.

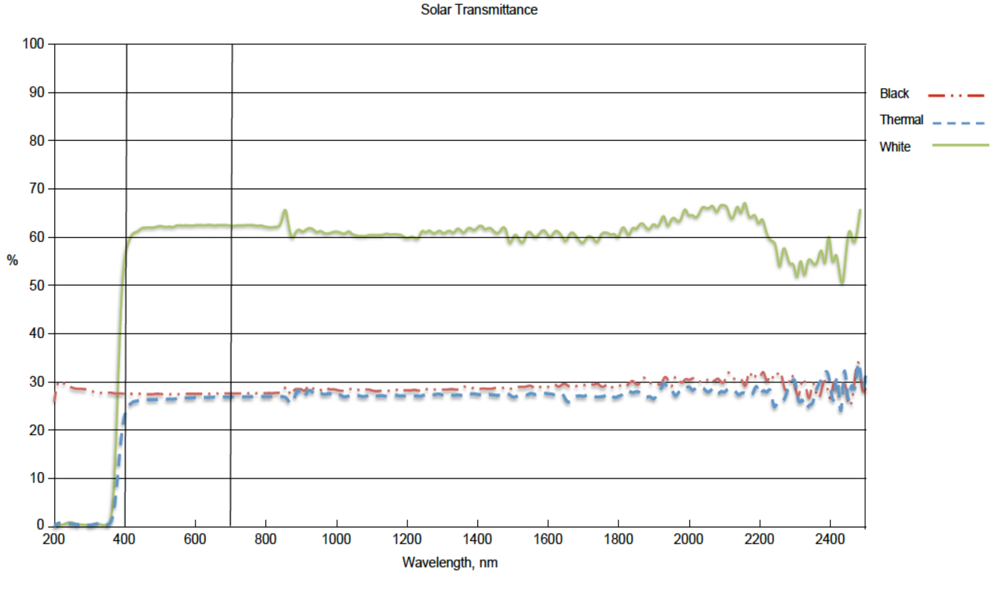

Figure 2 Transmittance of the three nets in the UV-VIS-NIR wavelength

Finally, the thermal screen (Table 3) seems very effective in blocking the IR radiation. This characteristic, joined with an high reflectance in the solar wavelength, makes this material very useful for an effective contribution to the improvement in the energy balance of a greenhouse.

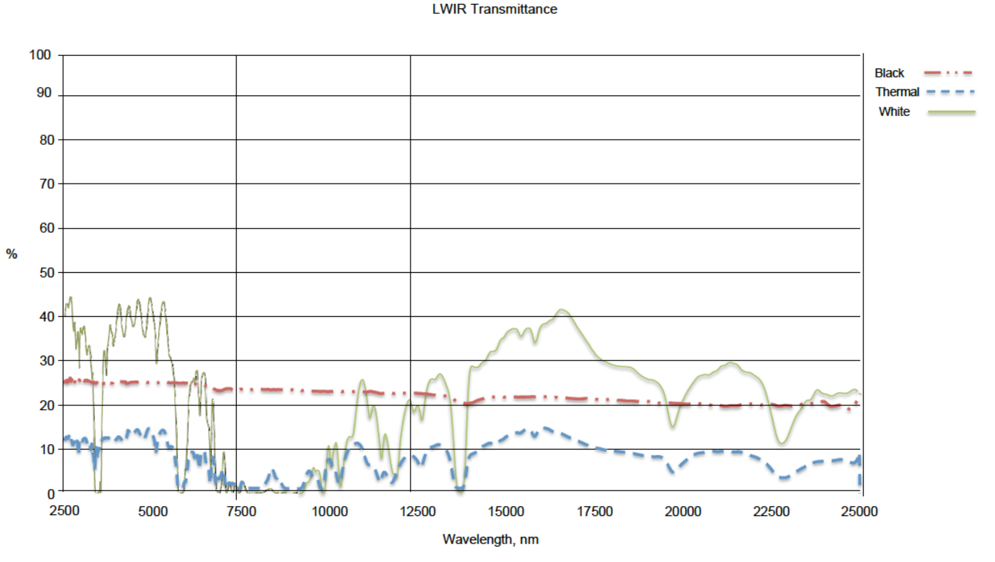

Figure 3 Transmittance of the three nets in the LWIR wavelength

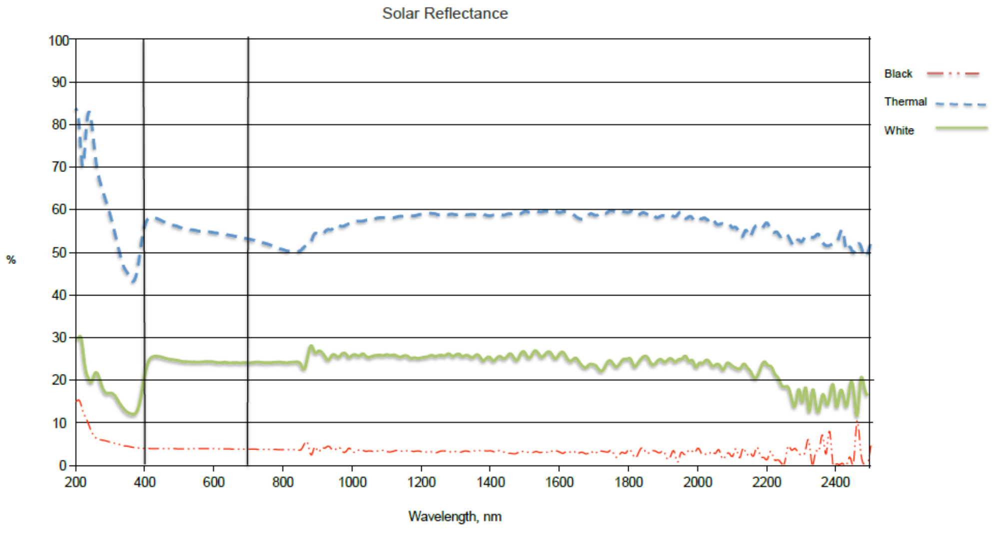

Figure 4 Reflectance of the three nets in the UV-VIS-NIR wavelength

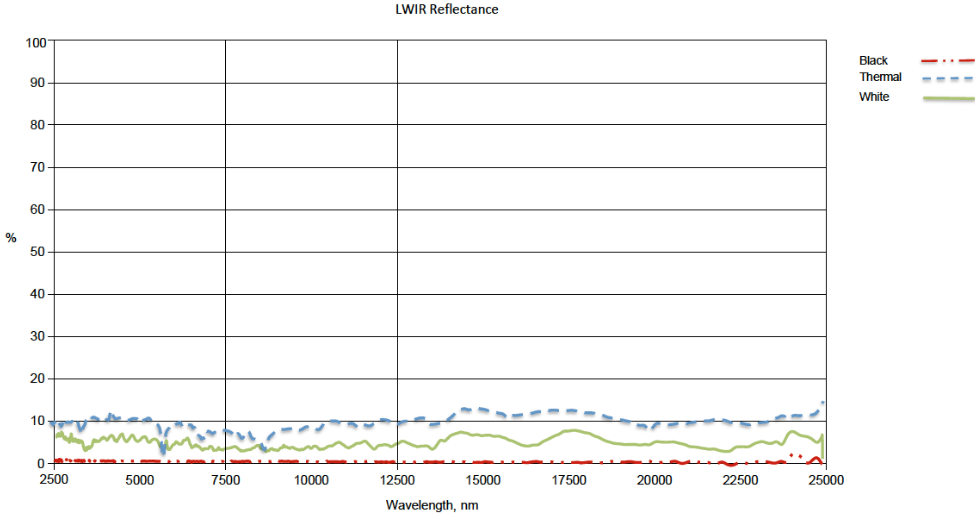

Figure 5 Reflectance of the three nets in the LWIR wavelength

In figures n. 2 and 3 the diagrams of transmittance of the three nets are reported, respectively in the UV-VIS-NIR wavelength and in the LWIR wavelength, while the corresponding diagrams of reflectance are reported in figures 4 and 5.

CONCLUSIONS

In the last years an extensive use of agricultural plastic nets in protected agriculture was recorded thanks to their beneficial effects on the crop. However, their use sets some technical problems connected with their spectro-radiometrical characteristics and the consequent microclimatic performance. Nets are often employed as greenhouse elements without any engineering design, only basing on the knowledge of some technical characteristics that, in some cases, are determined through laboratory test conducted on the basis of Standards applicable to different materials (*e.g.*, glass, or transparent film). Suitable criteria for an objective comparison, comprehensible and usable by the farmers, are therefore still impossible to define.

More research is therefore needed to characterize different types of nets for specific purposes, as well as to quantify the effects of the net colour 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 analysis.

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