48. ACTUAL TASKS ON AGRICULTURAL ENGINEERING

Preliminary communication

EFFECTS OF GREENHOUSE LIME SHADING ON FILTERING THE SOLAR RADIATION

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ABSTRACT

Protecting crops under a greenhouse allows their optimal management all over the year. Mostly during summer, in order to limit the indoor temperature and create suitable internal growing conditions, a common traditional solution is whitening the external side of the cladding material with slaked lime (calcium hydroxide– $Ca(OH)_2$). The benefits of whitewashing reported in the literature confirm that it has positive effects both on the microclimate and on the development of crops. This paper shows the results of a research, performed by using spectrophotometers in the Laboratory for Testing Materials of the University of Basilicata (Italy), aimed to analyse different types of calcium hydroxide solutions. The analysis verified the variation of radiometric properties and shading effect. The whitening concentration was a fixed dose of simple calcium hydroxide, diluted in two different water concentrations, then painted on an EVAC plastic film. Moreover, an unpainted transparent EVAC plastic film was considered as a reference. The radiometric measurements on the samples were carried out to measure transmittance, reflectance and absorbance on all wavelengths of the Photosynthetically Active Radiation (PAR). The results have given information on the effect of different dilutions of slaked lime on the selective filtering of the solar radiation. These conclusions may be useful to compare similar results with more recent solutions for greenhouse shading, such as the use of plastic nets.

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

INTRODUCTION

Continuous climate changes involve many sectors, among which agriculture seems to be the most affected. Climate management is essential to increase crop productions and improve their quality. Protected crops are widely used forms of intensive production, with yields higher than the traditional field crops. A greenhouse must guarantee optimal microclimatic conditions for the growth of crops, by using well-performing covering materials, which are the most important elements. Indeed, they protect from atmospheric agents, at the same time influencing the transmission of incident solar radiation - according to the radiometric properties of the material - and reducing the energy losses (Castronuovo et al., 2017; Castronuovo et al., 2019).

The ability of covering materials to modify the microclimate depends on their radiometric properties, mainly on their transmittance (Vox et al., 2010), as well as reflectance and emissivity/absorbance (Papadakis et al., 2000). Solar radiation is the primary source of energy flows reaching the earth's surface. Solar radiation has its peak at a wavelength of 500 nm. The visible range (380 - 760 nm) is nearly coincident with the Photosynthetically Active Radiation (PAR), having a wavelength ranging from 400 nm to 700 nm (Papadakis et al., 2000; Castellano et al., 2008). Within PAR, the green wavelength can play an important role, because it is antagonistic to plant development, when compared to the red and blue components, that instead promote plant development (Folta and Maruhnich, 2007). Excessive solar radiation levels can affect crops negatively, altering the production and creating an unhealthy environment for the agricultural workers to carry on their work. The combination of different wavelengths can influence the morpho-physiological development of plants. Different roofing materials through selective filtering of incoming solar radiation can influence the productive aspects of the plant (Schettini et al., 2011). In addition, adverse temperatures and excessive radiation can significantly reduce the photosynthetic process with photo-inhibition (Moreno-Teruel et al., 2020). Therefore, the solution would be to use shading devices (Castronuovo et al., 2017; Abdel-Ghany et al., 2016), capable of controlling the temperature inside the greenhouse, in order to reach an environment suitable for crops. Different cooling strategies can be used, such as evaporative cooling systems and forced ventilation, or by means of shading methods. Within these methods, the most currently employed is the traditional whitening of the external side of the plastic film with slaked lime (calcium hydroxide – $Ca(OH)_2$). More recently, the use of shading nets - with fairly high photo-selective properties, with equally large shading factors (Abdel-Ghany and Al-Helal, 2020) - has been affirmed, thanks to their properties to selective filtering the solar radiation, when applied outside the greenhouse.

Among the most inexpensive traditional techniques, the whitening of greenhouse covering materials is quite easy to apply, with relatively low costs and satisfying results on crops and the maintenance of the microclimate inside the greenhouse. For example, in the Mediterranean area, especially during the summer period, natural ventilation is not always sufficient to limit the high temperatures, so whitening is used as a possible cooling technique (Valera et al., 2016). Then, an effective lime removal takes place naturally, with the help of autumn rains. Baille et al., (2001) described how the whitening of the greenhouse covering material could influence the behaviour of the microclimate inside a greenhouse. The greenhouse observed was located in a coastal area of eastern Greece. Whitewashing reduced the average greenhouse transmission coefficient of solar radiation from 0.62 to 0.31. The conclusions from the use of whitewashing method provided important information on the economic benefits of the technique (Goudriaan and Laar, 1994; Mashonjowa et al., 2010; Abdel-Ghany et al., 2012). Also, positive effects on both the behaviour of the crops and the effectiveness of the practice have been observed. Hence, this simple technique turned out to be an ideal mean to overcome the high summer temperatures in warmer countries, thus limiting the heat generated by the incident solar radiation, by reflecting it to a large extent (Picuno et al., 2011; Ahemd et al., 2016). Tests on peppers in southern Spain have shown that the use of whitening has increased the quality of the product with a significant reduction in sunburn. (López-Marín et al., 2011). Positive influences on water stress limitation have been verified as well. The whitening was also compared with different aluminised screens with different transmittance rates and showed, on tomato crops, to keep the temperature of the greenhouse lower (Callejón-Ferre et al., 2009). The degree of transmittance of solar radiation influences the energy balance with alteration of the temperature inside the greenhouse, which can vary depending on the percentage of whitening (Reyes-Rosas et al., 2017). Experimental trials in Jordan have shown that whitening the plastic material, compared to green shading, produced a higher yield of fruit (Abu-Zahra and Ateyyat, 2016).

Plastic nets are progressively affirming as “smart” solutions for shading greenhouse. 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 (Picuno & Abdel-Ghany, 2016). From the obtained results, it was reported that the absorbance of the black plastic net was very high, both in the solar (nearly 70%) and in the IR (over 75%), confirming that their use inside the greenhouse should be avoided. The thermal screen seemed 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. On the other hand, the level of transmittance of the white plastic net (over 60%), joined to its high reflectance – that generates mutual progressive reflections with the greenhouse cladding sheet, if it is installed inside the greenhouse – confirmed 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. The application of nets or screens inside the greenhouse, under the roof, should be therefore avoided, as they would reduce the benefits of natural ventilation by altering the microclimate of the greenhouse and absorb solar radiation by releasing heat, thus increasing the air temperature inside the greenhouse (Abdel-Ghany et al., 2015; Abdel-Ghany et al., 2019).

With the aim to analyse the efficacy of different greenhouse shading techniques, an experimental trial was carried out by comparing two commercial plastic nets characterized by different shade effects, respectively equal to 60 % and 36% (Statuto & Picuno, 2017). These two plastic nets were tested in laboratory, where their radiometrical characteristics were determined. The same plastic nets were then installed on two different small-scale tunnels located in Southern Italy, in which inside air and relative humidity were measured during some late-spring days. The results obtained through these experimental trails enabled to start a comparative analysis of the performances of the two tested shading nets, highlighting the role that a correct selection of the most suitable net may play on the final results in terms of crop protection from high temperatures and sunburns. With the aim to analyse the efficacy of the shading effect of plastic nets in different climates, further experimental trials have been then carried out (Statuto et al., 2019; Statuto et al., 2020) on some identical small-scale tunnels installed in two different locations, one in the Mediterranean area (Acerenza—Southern Italy) and one in arid conditions (Riyadh—Saudi Arabia). These tunnels were covered with a plastic film and shaded with a white plastic net installed either in contact or at a distance of 20 cm over the cladding film. The radiometrical characteristics of the plastic film and nets have been determined through laboratory tests, while the internal microclimatic conditions have been monitored inside these experimental tunnels in both locations. The obtained results have been taken as the base for a comparative analysis to evaluate the performance of different nets, and to explore the role of shading on the temperature reduction and quality of light in different climates.

The present work aims to show the main results of a laboratory research aimed at analysing the effect of greenhouse shading with different types of calcium hydroxide concentrations. This experimental analysis was carried out to verify the variations in terms of radiometric properties (transmittance, reflectance, absorbance) and shading effect, so as to compare these results with plastic nets.

MATERIALS AND METHODS

The concentration of the whitening solution used for this analysis (Table 1), is a fixed dose (100 g) of simple calcium hydroxide (Roca et al., 2016), which was diluted in two different concentrations of water (50 ml and 30 ml) and then whitened on a 200µm thick EVAC transparent plastic film (fig. 1). An untreated EVAC plastic film was also analysed as a control. The experimental activity was carried out at the Laboratory for Testing Materials of the SAFE School of the University of Basilicata (Italy), by determining the radiometric properties – *i.e.*: transmittance, reflectance and absorbance - thanks to the use of spectrophotometers (Jasco V-570®), which allowed to test the different samples and to analyse these characteristics for all the wavelengths along the PAR.

Table 1 Concentrations used in the experimental activities.

Treatment	Name treatment	White lime dose (g)	Water dose (ml)
White	A1	100 g	50 ml
	A2		30 ml
Control	T_0	---	---

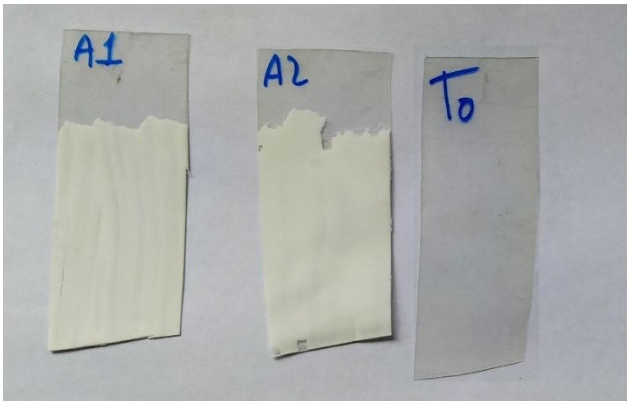

Figure 1 EVAC film tested during the experimental activity.

RESULTS AND DISCUSSION

The spectro-radiometric analyses provided data in terms of shading along the PAR. It can be inferred that the shading effect will be able to provide further information on the actual ability of the whitewashed film to protect crops inside the greenhouse. These analyses can provide, with more in-depth analysis, further information on the actual ability of the whitewashed film to protect plant crops under the covering material from excessive solar radiation. The use of EVAC plastic film whitened with lime has significantly increased the shading effect at PAR (Tab.2).

Table 2 Results of spectro-radiometric analyses of shading effect in different test.

Range	Wavelength nm	Transmittance %	Reflectance %	Absorbance %	Shading effect %
T_0	400 - 700	88.40	10.10	0.06	10.15
A1	400 - 700	19.75	80.69	0.73	81.42
A2	400 - 700	13.48	85.88	0.89	86.77

The results show that there are clear differences between samples whitened with calcium hydroxide. Among these, sample A2 - *i.e.,* the least diluted sample - showed a slightly lower transmittance than the most diluted sample, *i.e.* A1. Reverse situation for reflectance, which has – as expected - significantly higher percentages on the whitened samples, compared to the T control (Tab. 2). Among the whitened samples, the one with the highest reflectance is A2, *i.e.,* the less diluted sample with water, followed by A1. The reflectance, like absorbance, respects the dilution trend, from lowest to highest. The absorbance shows indeed almost similar results in the whitened films, being higher than in the case of the non-whitened film (Tab. 2).

The effect of whitewashing on the radiometric characteristics along the PAR, has been then further assessed through the analysis of their change along the different colours/wavelengths in the range from 400 to 700 nm (tables 3, 4 and 5).

Table 3 Results of spectro-radiometric analysis on the transparent EVAC film (T_0).

Range	Wavelength nm	Transmittance %	Reflectance %	Absorbance %	Shading effect %
VIOLET	400 - 435	86.87	11.28	0.06	11.34
INDIGO	435 - 500	87.73	10.77	0.06	10.83
BLUE	500 - 520	88.22	10.35	0.06	10.41
GREEN	520 - 565	88.83	9.70	0.05	9.75
YELLOW	565 - 590	88.74	9.76	0.05	9.82
ORANGE	590 - 625	88.95	9.57	0.05	9.62
RED	625 - 700	89.35	9.27	0.05	9.32

Table 4 Results of spectro-radiometric analysis on EVAC film whitened with calcium hydroxide (A1).

Range	Wavelength nm	Transmittance %	Reflectance %	Absorbance %	Shading effect %
VIOLET	400 - 435	15.69	81.32	0.85	82.17
INDIGO	435 - 500	18.13	82.40	0.77	83.17
BLUE	500 - 520	19.29	81.90	0.74	82.64
GREEN	520 - 565	20.97	80.20	0.70	80.90
YELLOW	565 - 590	20.73	80.45	0.71	81.15
ORANGE	590 - 625	21.26	79.79	0.69	80.48
RED	625 - 700	22.30	78.68	0.67	79.36

Table 5 Results of spectro-radiometric analysis on EVAC film whitened with calcium hydroxide (A2).

Range	Wavelength nm	Transmittance %	Reflectance %	Absorbance %	Shading effect %
VIOLET	400 - 435	9.20	84.63	1.07	85.70
INDIGO	435 - 500	11.82	86.95	0.94	87.89
BLUE	500 - 520	13.02	86.95	0.90	87.85
GREEN	520 - 565	14.68	85.93	0.84	86.77
YELLOW	565 - 590	14.50	86.15	0.85	87.00
ORANGE	590 - 625	14.96	85.64	0.83	86.47
RED	625 - 700	15.85	84.78	0.81	85.59

From these results, it is possible to deduce that the reduction in the transmittance of the plastic film, depending on the level of painting concentration, is higher as long as shorter wavelengths are considered. Indeed, as shown in figure 2, the reduction of the transmittance is progressively increasing from red to violet. This last colour/waveband has a significantly lower transmittance in all samples with EVAC film whitened with lime, respectively 9.20% in A2 (Tab. 5) and 15.69% in A1 (Tab. 4), while the control has an approximately uniform transmittance throughout the PAR. The red colour, on the other hand, is significantly higher than the other colours/wavebands in all tests, by 15.85% in A2 (Tab. 5) and 22.30% in A1 (Tab. 4). Indigo and blue have intermediate transmittance values.

The reflectance results show that in A2 violet (84.63%) and red (84.78%) are significantly lower than the other colours. In the control the results show decreasing data from violet to red (Fig. 3). The absorbance, instead, presents significantly higher results from violet, 1.07% in A2 and 0.85% in A1, to red, 0.81% in A2 and 0.67% in A1 (Fig. 4).

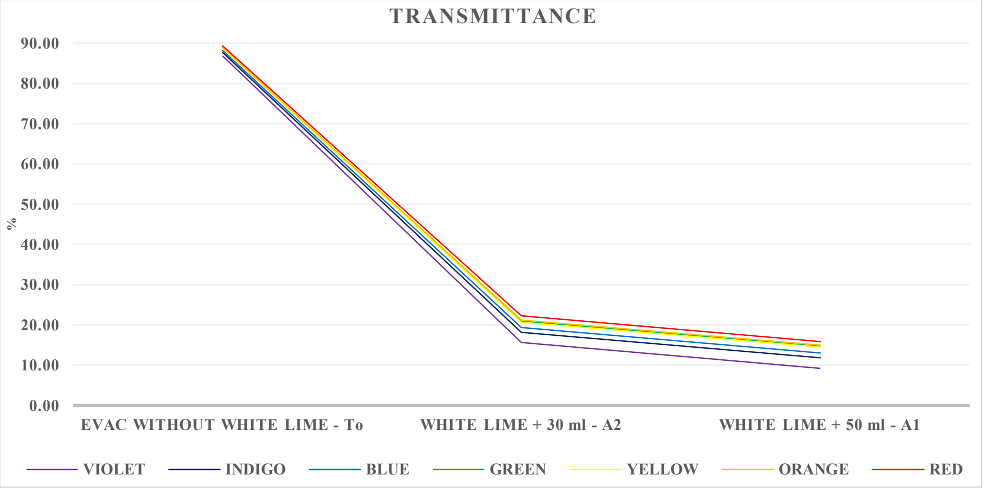

Figure 2 Transmittance along the PAR wavelengths of the three tested EVAC plastic films.

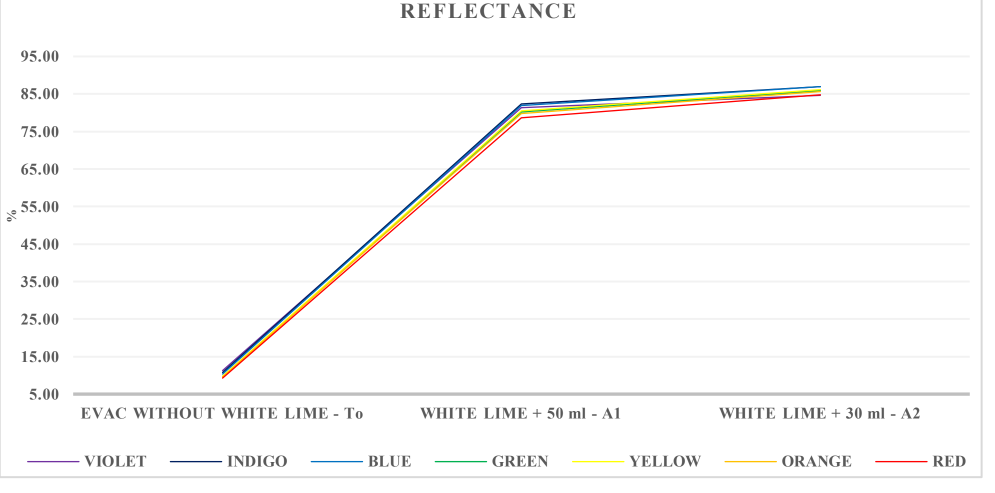

Figure 3 Reflectance along the PAR wavelengths of the three tested EVAC plastic films.

The results show that the different dilution of the whitening formulation can significantly alter the different wavelengths taken into account compared to the untreated control. The difference between the two whitened samples is quite obvious compared to the T control. The whitening of the EVAC film significantly reduced transmittance compared to the control, affecting the film's ability to transmit solar radiation (Tab. 2). The reduction in transmittance is slightly decreasing as the wavelength increases. This reduction corresponds to an increase both of reflectance and absorbance. Therefore, we could conclude that the more we go from red towards ultra violet, the more the ability of the covering material to filter solar radiation at lower wavelengths, increases.

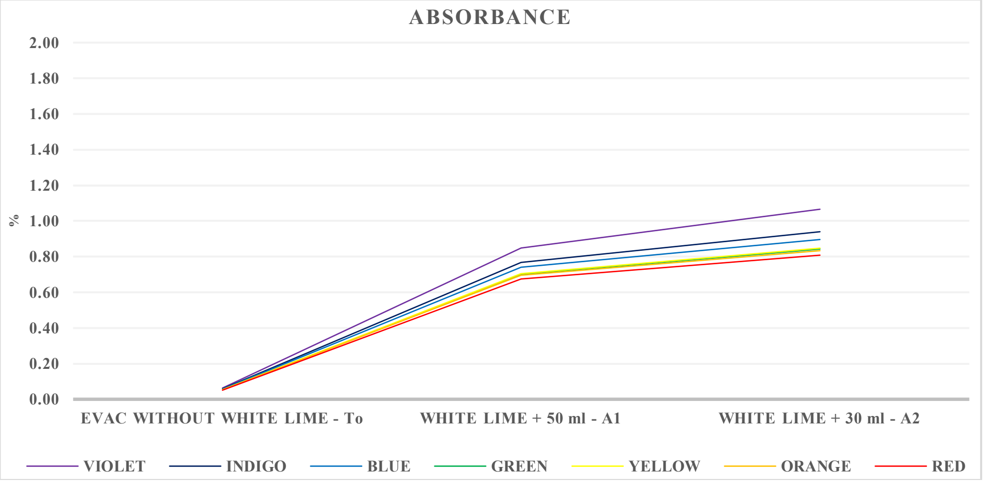

Figure 4 Absorbance along the PAR wavelengths of the three tested EVAC plastic films.

Further evaluation of the shading effects of calcium hydroxide on different wavelength ranges (*e.g.,* UVA, UVB, IR, *etc.*) would be then necessary. Comparing this selective filtration performance of whitened plastic films with other shading techniques - such as the use of plastic nets, which are progressively used today in protected agriculture - should be investigated as well.

CONCLUSIONS

Calcium hydroxide as a shading technique is mainly used thanks to its cost-effectiveness, as well as its ease of use. It is not a highly technological solution, but it is still frequently used, especially in the Mediterranean areas. It would be of great importance to use current scientific knowledge to support further experimentation in order to compare and develop new shading technologies, such as shading nets. The lack of a specific standard does not allow to determine the spectro-radiometric characteristics of shading roofing materials, such as nets, which requires further laboratory tests. The determination of the spectro-radiometric properties of plastic films whitened with calcium hydroxide is difficult. The dose of calcium hydroxide and the dilution of the whitening formulation, as can be seen from this research, presents very different results on transmittance characteristics. This research also shows that the different dilutions of the whitening formulation do not affect the general transmittance properties and individual wavelengths, so it may not be convenient to use a large amount of lime, while a higher dilution of the whitening formulation would be sufficient and, above all, economically convenient. This research leads to the conclusion that further research on shading materials is needed, which must be accompanied by technical information on the shading factor throughout the solar range, even when they have a function other than shading. This specific information on the shading factor in the main wavelength ranges seems to be very significant, taking into account the different effects on the protected environment.

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