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CHARACTERIZATION OF THE SOLAR DIFFUSE COMPONENT UNDER "PARRAL" PLASTIC GREENHOUSES

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Abstract

The diffuse and direct components of solar global radiation were measured during autumn months under a "parral" type greenhouse, commonly used in South East of Spain. For the covering material tested during this period (co-extruded three-layers film), the ratio of diffuse to global radiation (D/G) was significantly enhanced under the greenhouse. On sunny days, the inside diffuse radiation (D_i) can reach values as high as three o four times the outside diffuse radiation (D_0). The transmission of direct radiation (direct to direct) reached 0.21 on a daily average basis while the direct to diffuse transmission (β) was about double. It was found a significant correlation between the ratio D_i/D0 and the outside diffuse to global ratio, allowing to predict the greenhouse diffuse radiation from the knowledge of the outside solar radiation components.

Key words: *Greenhouse, cover material, solar radiation, diffuse radiation, transmission*

1. Introduction

Diffuse radiation represents an important fraction of the global solar radiation entering the greenhouse. It has special relevance with respect to the crop radiation use efficiency, RUE (Spitters, 1986). In greenhouse cultivation, the possibility of modifying the relative fraction of solar diffuse radiation by means of the cover material is an interesting possibility for:

- (i) reaching a higher spatial uniformity of the solar radiation that enters the greenhouse
- (ii) increasing the capacity of the crop for intercepting solar radiation, as it is well-known that diffuse radiation is more evenly distributed within the canopy than direct radiation

These two properties may be considered as key elements in the evaluation of the "quality" of greenhouse cover materials (Mermier and Baille. 1980). However, despite the relevance of the diffuse solar radiation in greenhouses, few information is available on this component, and of its magnitude with respect to the direct component (Baille and Tchamitchian, 1993). Most studies carried out "*in situ*" have dealt with the characterization of the greenhouse transmission (i.e. direct + diffuse) by measuring the outside and inside global solar radiation (G_0 and G_i respectively, W m^{-2}). The global greenhouse transmission derived from these measurements ($\tau_g = G_i/G_0$) is not a pertinent indicator of the cover material diffusing power. It is known that a greenhouse cover material, even transparent, increases significantly the amount of diffuse radiation inside the greenhouse, D_i, with respect to the outside, D_0 (Hanan, 1998), but no detailed investigation was performed until now about the diffuse radiation "enrichment" under greenhouse conditions. Recently, Montero et al. (2001) carried out laboratory measurements of the diffuse transmissivity of cover materials. It has to be stressed that the diffuse fraction not only depends on the diffusive properties of the material, but also on a certain number of other factors such as greenhouse structure and orientation, dust deposition and condensation droplets. Aging of the plastic material may also change the diffusive properties of the film.

The aim of the work, undertaken near the Spain Mediterranean coast of the Almería Province (Experimental Station "Las Palmerillas"), was to quantitatively characterize the amount of diffuse solar radiation within a classical "parral" type greenhouse, commonly used by the growers in this region.

2. Material and methods

2.1. Greenhouse and instrumentation

The experiments were carried out under a symmetrical E-W oriented "parral" greenhouse, with a ground area of about 500 m^2 (24m x 20.5 m), 1.9 m high under eaves and 10º roof slope. The cover material was a classical 3-layers co-extruded (PE-ld/EVA/PE-ld) film, 200 μm thick. Radiation measurements (W m^{-2}, or MJ m^{-2} d^{-1}) were performed by means of solarimeters (Model CM6 Kipp and Zonen, The Netherlands) located outside and inside the greenhouse. Two sensors were measuring the outside (G_0) and inside (G_i) global solar radiation, and two others, equipped with a shadow-band (Eppley, US), supplied the outside (D_0) and inside (D_i) diffuse component. Measurements were recorded on a data logger every 2 seconds and averaged over a 30 minutes period.

2.1. Data treatment

From the corrected values, the following parameters (Figure 1) were calculated:

- the ratio of diffuse-to-global radiation outside ($r_0 = D_0/G_0$) and inside ($r_i = D_i/G_i$)
- the *global* transmission coefficient, $\tau_G = G_i/G_0$
- the *diffuse* transmission coefficient, performed during completely overcast days, $\tau_{dif} = D_i/D_0$
- the *direct* transmission coefficient, calculated as $\tau_{dir} = I_i/I_0$, where $I_0 = G_0 - D_0$, and $I_i = G_i - D_i$
- the amount of direct radiation converted into diffuse radiation, D*, expressed as

$$D^* = G_i - \tau_{dif} D_0 - I_i \qquad (1)$$

allowing to derive the fraction of the outside direct radiation that enters the greenhouse as diffuse radiation, or direct-to-diffuse transmission, β:

$$\beta = D^*/I_0 = (G_i - \tau_{dif} D_0 - I_i)/I_0 \qquad (2)$$

The ratio D_i/D_0 and the coefficient β quantify the greenhouse diffuse radiation *"enrichment"*, and could be used as indicators of the diffusing power of the covering material under actual conditions of use, i.e. including the above mentioned effects of orientation, incidence angle, condensation, etc.

3. Results and discussion

The results presented in this paper concern measurements obtained during the autumn period of 2001.The average transmission coefficient for diffuse radiation, measured during completely overcast sky, was $\tau_{dif} \approx 0.63$ (See Figure 3). This value was chosen for the calculation of D* and β (Equations 1 and 2).

Figures 2a-b present the values (30 min average) of the outside and inside diffuse radiation, for the month of October 2001, plotted against the outside global radiation G_0. It could be observed that the greenhouse significantly reduced the variability of the diffuse radiation with respect to G_0. By contrast, the inside diffuse radiation, D_i, showed a high scattering when plotted against the outside diffuse radiation D_0 (Figure 3), indicating that the latter was not the main factor that drived the amount of diffuse radiation in the greenhouse. The best correlation between D_i and the outside radiation variables was found with the diffuse-to-global ratio, D_0/G_0: when relating the enrichment ratio D_i/D_0 to D_0/G_0, a clear correlation was obtained (Figure 4). The ratio D_i/D_0 increased strongly when D_0/G_0 decreased, reaching values close to 400% when the ratio D_0/G_0 was at its minimum (about 0.15-0.20). The dependency was fairly described by a power function $D_i/D_0 = a\ (D_0/G_0)^{-n}$, with a = 0.57, n = 0.89, $r^2 = 0.97$. A better correlation ($r^2 = 0.99$) was even found for the daily average values, as shown in Figure 5, for the same month. Similar relationships were obtained for the other months (November and December). The daily average values of I_i and D* showed a clear linear dependence with respect to the outside direct radiation, I_0 (Figure 6). The slopes of the linear regression between D* and I_0, and I_i and I_0 were respectively 0.42 and 0.21. These values highlight that the fraction of direct radiation transmitted as diffuse radiation was about double the fraction transmitted as direct radiation. The sum of these two components was also linearly correlated with I_0 (Figure 7), with a slope equal to 0.63 ($r^2 = 0.99$), which is very close to the diffuse transmission above mentioned.

Figure 8 presents the daily trend of the direct-to-diffuse radiation, D*, and the inside direct radiation, I_i. It can be seen that, for both components, the transmitted radiation was not symmetrical with respect to solar noon. The diffuse component appeared to be higher on the morning while the direct component was higher in the afternoon. When plotting D* and I_i against sin (h), with h being the solar angle, it can be observed that these components presented an hysteresis, being clockwise for D*, and counterclockwise for the direct component I_i (Figure 9). The same hysteresis phenomena was found, although less pronounced, for the inside global radiation and for D_i. In fact, a more or less clear hysteresis was observed for all the inside radiation variable considered in this study, with a different temporal trend between the morning and the afternoon. A possible explanation may be the occurrence of condensation in the morning, and its progressive elimination after opening the vents. The presence of the droplets or water film increased the diffusion process, therefore increasing D* to the detriment of I_i.

4. Concluding remarks

The present study highlighted that greenhouse diffuse radiation can be quantified through two main characteristic parameters; the enrichment ratio, D_i/D_0, and the direct-to-diffuse conversion factor, β. It has been observed that the greenhouse diffuse radiation may be predicted from the knowledge of the outside components of the solar radiation, G_0 and D_0. Considering mean daily radiation values, β and the direct-to-direct-transmission τ_{dir} were found to be 0.42 and 0.21, respectively. The sum of the two transmissions gives a total direct transmission of 0.63, which means that, for the parral greenhouse studied in this work, the direct transmission was quite similar to the diffuse transmission.

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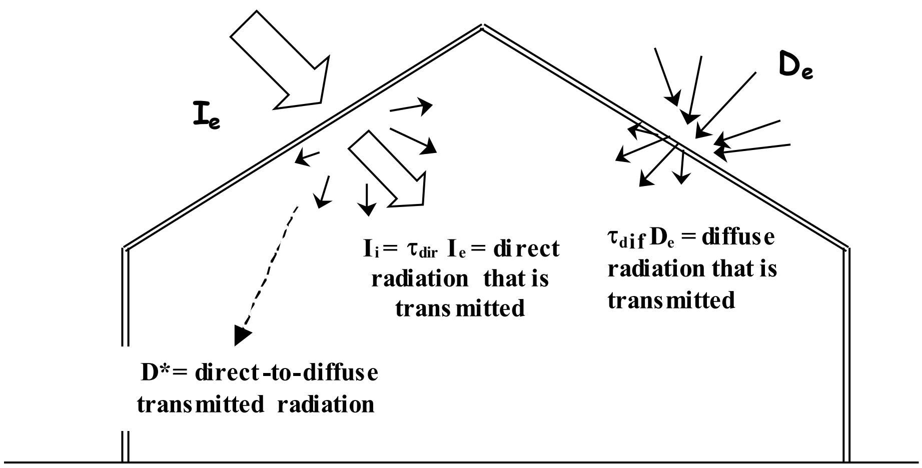

Figure 1. Scheme of the components of solar radiation entering a greenhouse

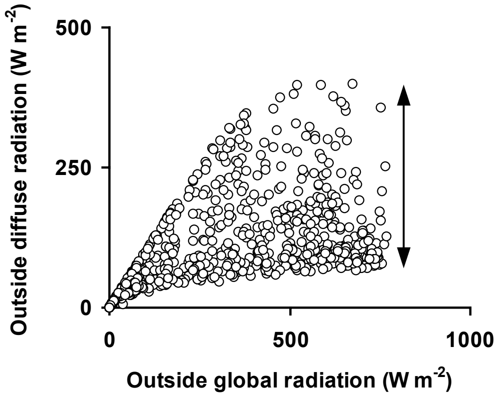

Figure 2a. Outside diffuse radiation vs. outside global radiation, 30 min average, October 2001.

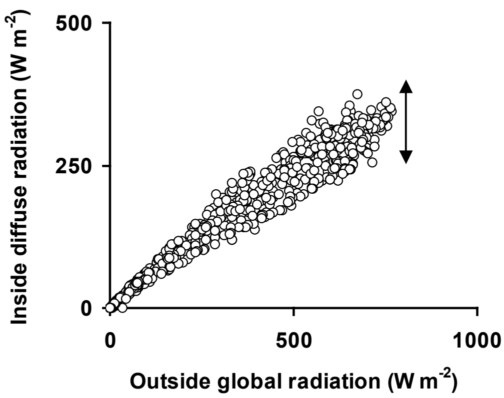

Figure 2b. Inside diffuse radiation vs. outside global radiation, 30 min average, October 2001

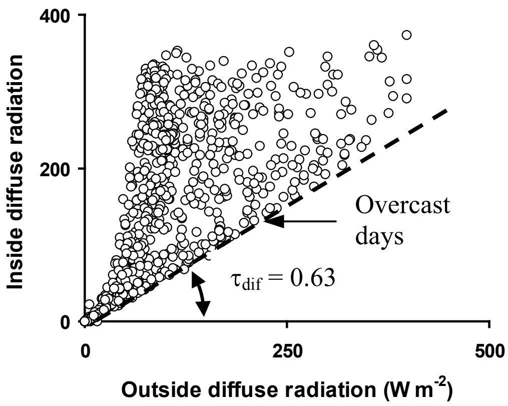

Figure 3. Inside diffuse radiation, D_i, vs. outside diffuse radiation D_0, 30 min average, October 2001

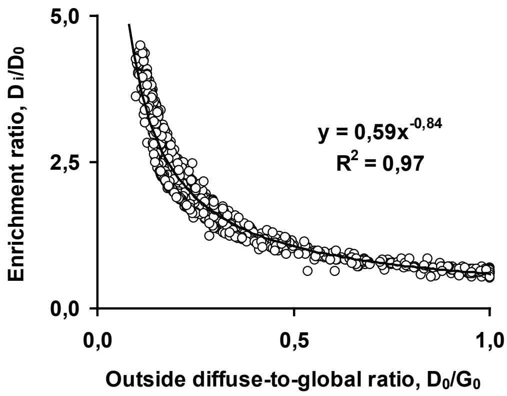

Figure 4. Enrichment ratio (D_i/D_0) vs. outside diffuse to global ratio, D_0/G_0, 30 min average, October 2001

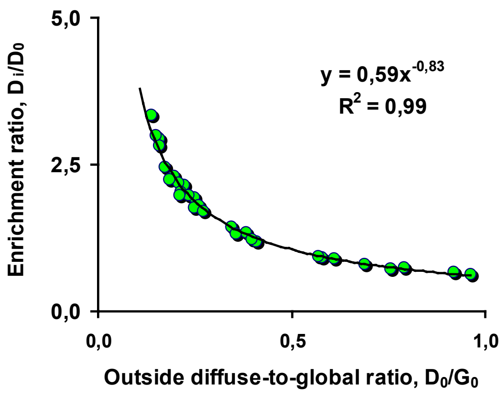

Figure 5. Enrichment ratio (D_i/D_0) vs. diffuse to global ratio, D_0/G_0. Daily average, October 2001

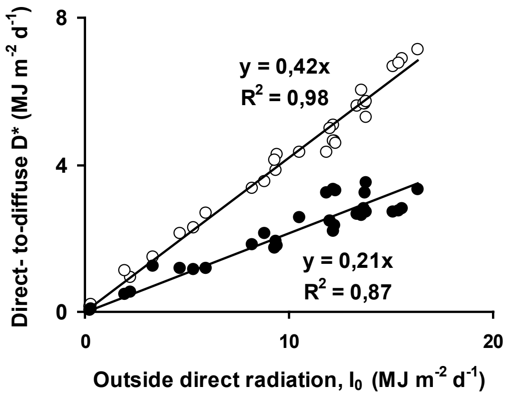

Figure 6. Inside direct, I_i (●) and direct-to-diffuse D* (○) vs. outside direct radiation, I_0. Daily average, October 2001

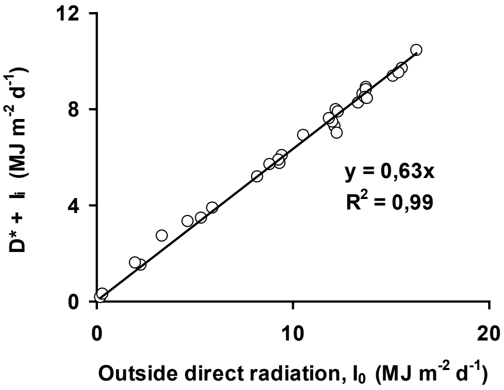

Figure 7. Sum of direct-to-diffuse (D^*) and direct radiation (I_i) entering the greenhouse vs outside direct radiation, I_0. Daily average, October 2001

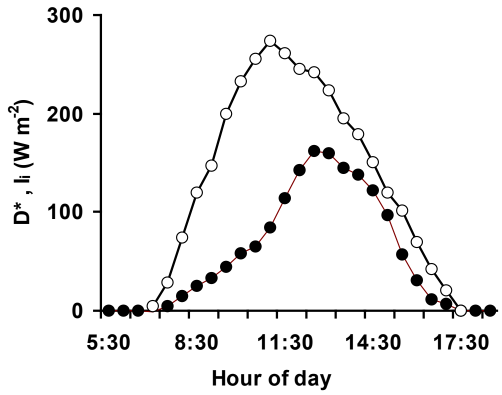

Figure 8. Direct-to-diffuse radiation, D^* (○) and inside direct radiation. I_i (●) vs. time. 30 min. average (25/10/2001, sunny day)

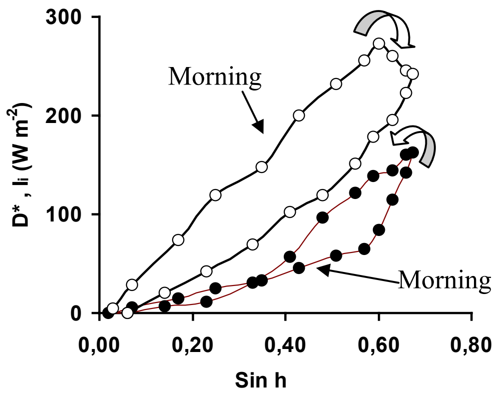

Figure 9. Direct-to-diffuse transmitted radiation, D^* (○) and inside direct radiation. I_i (●) vs. sin h. 30 min. average (25/10/2001, sunny day)

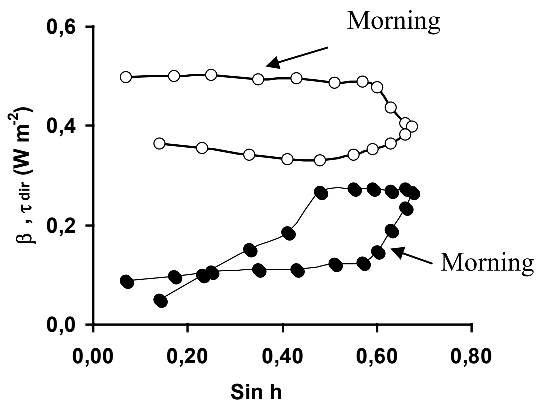

Figure 10. Direct to diffuse transmission, β (○) and direct transmission. τ_{dir} (●) vs. sin h. 30 min. average (01/12/2000)