Filtering Natural Light by the Greenhouse Covering Using Model Simulations – More Production and Better Plant Quality by Diffuse Light?

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Abstract

Wageningen UR investigated the potentials of diffuse light for the use in Dutch horticulture. Light can be made diffuse by greenhouse covering materials. The transmission through the greenhouse covering is analysed. The penetration of diffuse light into the canopy is investigated for different crops in different growing stadiums under Dutch radiation conditions throughout the year. A plant growth model is used to calculate the effect of diffuse light on plant growth and development of several crops. Sweet pepper production can potentially be increased by 5-6% during summer months due to the use of diffuse greenhouse covering materials. There are good potentials for the development and use of diffuse greenhouse covering materials in Dutch horticulture.

INTRODUCTION

In Dutch glass greenhouses light is not distributed equally. Fruit vegetables like tomato and sweet pepper with a high leaf area index intercept a high quantity of light with the upper leaves, the lower leaves receive much less light and hardly contribute to photosynthesis and therefore to growth and production. Already in the past it was noted that a plant would benefit if upper leaves would intercept a lower proportion of the incident light and the lower leaves a greater proportion, so that a more uniform light interception over the foliage is achieved. This can be realized by light reflection back into the crop by the use of reflective ground covers or reflectors (Aikman, 1989; Critten, 1985, Sondern, 1962) and by making all incoming light into the greenhouse diffuse. From earlier investigations in ecosystems it is known that diffuse light is able to penetrate deeper into a plant canopy in comparison to direct light (e.g. Young and Smith, 1983) and that photosynthesis of forests is increased by diffuse light (Farquhar and Roderick, 2003; Gu et al., 2003). A better light penetration in agricultural crops, like apple trees (Lakso and Mussleman, 1976) and grass canopies (Sheehy and Chapas, 1976) is demonstrated by practical measurements. Hovi et al. (2004) showed that a higher amount of artificial light within a crop ("interlighting") is able to increase photosynthesis of the lower leaves significantly. Furthermore, several models exist to calculate the effect of diffuse light on crop photosynthesis (e.g. Goudriaan, 1977). However, an analysis of the effect of diffuse light on horticultural crops is lacking.

Wageningen UR investigated the potentials of diffuse light for the use in Dutch horticulture. Light can be made diffuse by greenhouse covering materials. The transmission through the greenhouse covering was analysed. The penetration of diffuse light into the canopy was investigated for different crops in different growing stadiums under Dutch radiation conditions throughout the year. A plant growth model was used to calculate the effect of diffuse light on plant growth and development of several crops. Also effects on greenhouse climate were modelled in a virtual greenhouse model. The potentials of diffuse light for Dutch sweet pepper production are given in this paper.

MATERIALS AND METHODS

The Dutch global radiation can be described with the SEL-year, which gives a typical year based on real climate measurements of the Royal Dutch Meteorological Institute (KNMI) in De Bilt between 1970 and 1986 (Breuer and Van de Braak, 1989). With the greenhouse transmission model developed by de Zwart (1993), the transmission of outside global radiation through the covering material is calculated. Several transparent covering materials were assumed with different optical properties. The reference material was clear horticultural glass, which is not able to transform any direct light into diffuse light. Furthermore, covering materials with different diffusing properties were considered, which were able to transform 30%, 60%, 80% or 100% of all incoming direct light into diffuse light. Traditional horticultural glass has a PAR transmission of 90%. Since new diffusing materials may have a reduced or increased PAR transmission, this variable was modified. PAR transmissions of 85%, 90% and 95% were considered. Results of the greenhouse transmission model were the amount of direct and diffuse PAR above the crop canopy for every hour of the year for the different cases. These data were used as input for the crop model to calculate the light penetration into a sweet pepper canopy.

The light penetration into the crop and crop production was modelled with INTKAM (Marcelis et al., 2000). The model calculated the photosynthetic speed on base of detailed biochemical comparisons (Farquhar et al., 1980), which take into account effects of radiation, temperature, CO_2-concentration and the water deficit of the atmosphere. Based on the distribution of dry matter between several plant organs, which is depending on relative sinks, the real growth speed of several plant organs was calculated. The increase of leaf area was calculated from the increase in leaf weight and the potential specific leaf area. The transpiration was calculated on basis of the Penman-Monteith comparison and the model of stomatal conductivity described by Nederhoff and de Graaff (1993). Photosynthesis and transpiration on crop level was obtained by integrating the photosynthetic speed of several crop layers. Potential photosynthetic activity was assumed to be equal for all crop layers. The quantity of light interception was calculated for six crop layers. While the first crop layer contained the most upper leaves, the sixth crop layer was representing the lowest leaves. The relative thicknesses of the layers were: 5%, 18%, 27%, 27%, 18% and 5% of the leaf area respectively. The light penetration into the crop canopy was based on the model of Goudriaan (1988). Sweet pepper was used as model plant. It was assumed that the crop was planted on 11th December and final harvest took place on 20th November in the next year. Greenhouse climate conditions were assumed to be according to Dutch horticultural practice.

RESULTS AND DISCUSSION

To estimate the potentials of diffuse greenhouse covering materials, the amount of natural global radiation has to be known. The Dutch climate is characterised by 3650 MJ/m^2 global radiation per year. The radiation sum during summer months is ten times higher than during winter months (Table 1). The amount of direct radiation is in average 20% during winter, while it is 40% during summer. The amount direct radiation during winter is 200 MJ/m^2 (5.5% of total radiation sum), during summer it is 880W/m^2 (24.1%). Because the amount of direct radiation, which can potentially be transformed into diffuse radiation, is smaller during winter (Table 1), it can be suspected that a diffuse covering material will give more advantages during summer months.

Model calculations with INTKAM showed that diffuse light is able to penetrate deeper into the crop canopy. (Fig. 2.). Especially during the first period of crop production, from December until the end of February, more PAR is penetrating into the lower crop layers. In a young crop PAR can obviously enter easily into all layers of the canopy. During summer months the middle crop layers get more PAR, while light is obviously not able to penetrate into the lowest crop layers anymore. Fig. 3 shows the amount of absorbed PAR by the sweet pepper canopy under a diffuse greenhouse covering material compared to clear reference material. In the winter months more PAR is available for the lowest crop layers (Fig. 2.), however, the crop is too small to intercept all the light. From April until October the middle crop layers intercept more PAR, while the upper two layers absorb less PAR (Fig. 3).

Fig. 4 shows the photosynthesis of the different crop layers during the production period. Again, a diffuse greenhouse covering material is compared with a clear reference material. During the winter months a slight decrease in photosynthesis can be observed. This is probably related to a lower PAR absorption due to the fact that there is more PAR available but the plant is too small to intercept all that light. It can be concluded that diffuse light seems to have to advantage in these months. During the summer months an increase in photosynthesis can be observed in almost all crop layer, except the upper layer. The highest increase can be noticed in the middle layers, which also receive and absorb more light. Though, the first and second crop layers absorb less light, no reduction of photosynthesis can be observed. Obviously photosynthesis in the upper layers is close to the light saturation point, a reduction of PAR has almost no effect on photosynthetic activity. On the other hand, photosynthesis in the lower layers is highly increased by only a little bit more PAR. The higher photosynthesis of the middle crop layers also affects sweet pepper fruit production. The production under a highly diffusing covering material (100% of all incoming light is made diffuse) compared to a clear reference material is increased by 5-6% per year. The production increase is depending on the diffusing properties of the covering material. A material that is able to make 80% of all incoming light diffuse leads to a higher production increase than a material that is only able to make 30% of the incoming light diffuse (Fig. 1). There is an interaction between the amount of diffuse light and the total amount of PAR available for the crop on crop production. A covering material that is able to make 80% of the incoming light diffuse but at the same time reduces PAR transmission to 85% has no advantages anymore according to the model calculations described here. On the other hand, a diffuse covering material that at the same time increases PAR to 95%, is able to increase sweet pepper production under Dutch climate conditions during summer months with about 7% on yearly base.

The results of the model calculations still have to be confirmed by practical data. Also more information has to be gained for other important horticultural crops. First results show that there are good potentials for the development and use of diffuse greenhouse covering materials in Dutch horticulture.

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Tables

Table 1. Total, direct and diffuse global radiation in The Netherlands during the year, based on the SEL-year (Breuer and van de Braak, 1989).

Month	**Global radiation total [MJ/m^2]**	**Global radiation direct [MJ/m^2]**	**Global radiation diffuse [MJ/m^2]**	**Direct part [%]**	**Diffuse part [%]**
January	62.6	12.8	49.7	20.5	79.5
February	104.7	15.8	89.0	15.0	85.0
March	314.6	95.0	219.6	30.2	69.8
April	299.1	41.5	257.6	13.9	86.1
May	568.0	162.2	405.8	28.6	71.4
June	551.5	159.0	392.5	28.8	71.2
July	597.4	244.7	352.8	41.0	59.1
August	502.5	148.1	354.4	29.5	70.5
September	342.3	124.0	218.3	36.2	63.8
October	163.7	37.9	125.8	23.1	76.9
November	89.9	26.0	63.9	28.9	71.0
December	54.0	14.4	39.7	26.6	73.4
Total	**3650**	**1081**	**2569**	**100.0**	**100.0**
Winter	**789**	**202**	**588**	**5.5**	**16.1**
Summer	**2861**	**880**	**1981**	**24.1**	**54.3**

Figures

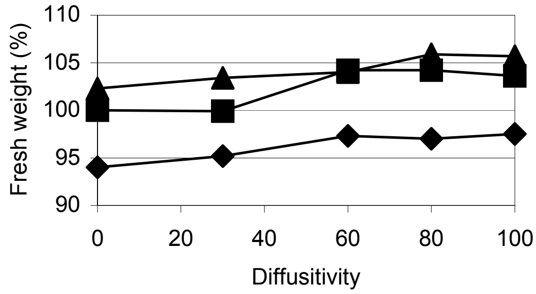

Fig. 1. Dry matter production of sweet pepper depending on the diffusing properties and the PAR transmission of the greenhouse covering material, based on model calculations with INTKAM.

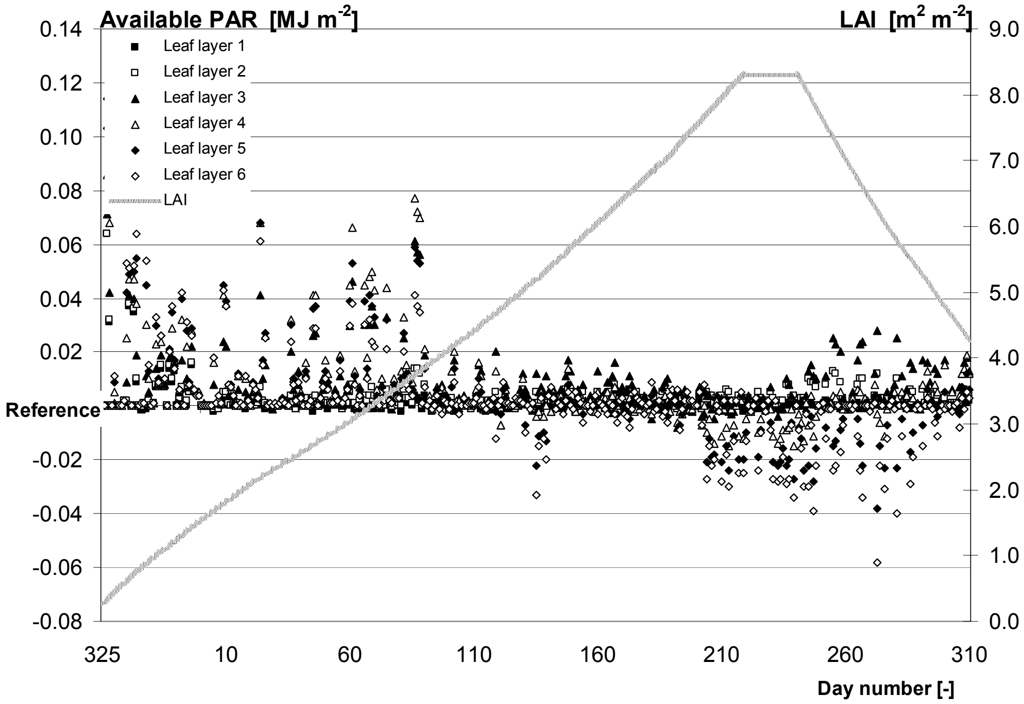

Fig. 2. Available PAR in different crop layers (1 = upper leaves, 6 = lower leaves) of sweet pepper under a highly diffusing greenhouse covering material compared to a clear reference material per day during the year, based on model calculations with INTKAM.

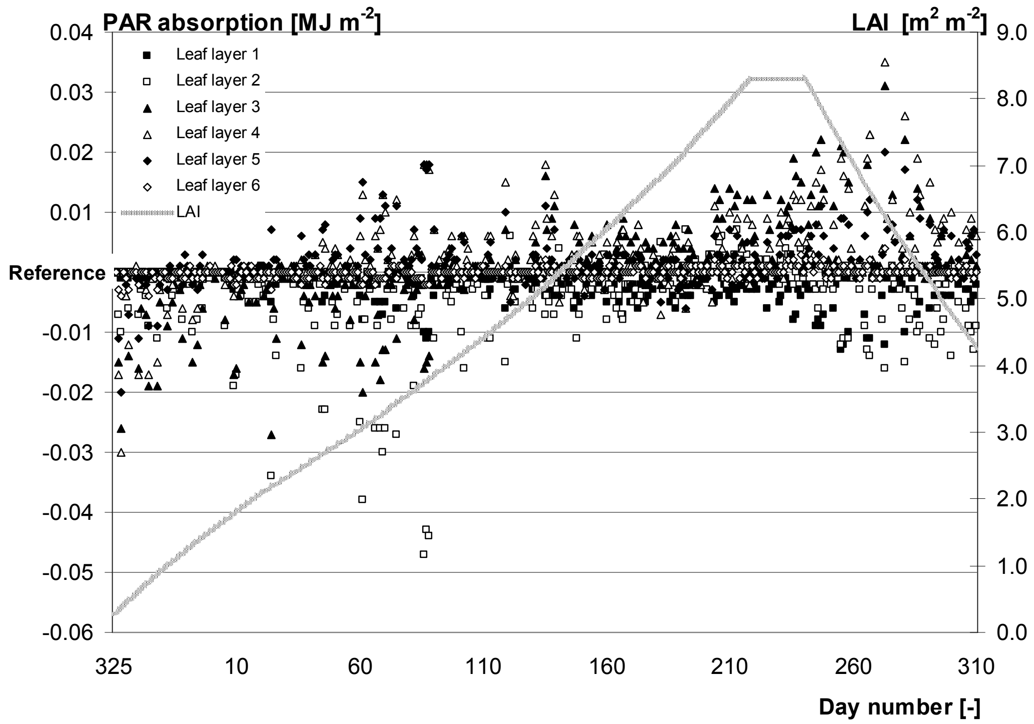

Fig. 3. Absorbed PAR by different crop layers (1 = upper leaves, 6 = lower leaves) of sweet pepper under a highly diffusing greenhouse covering material compared to a clear reference material per day during the year, based on model calculations with INTKAM.

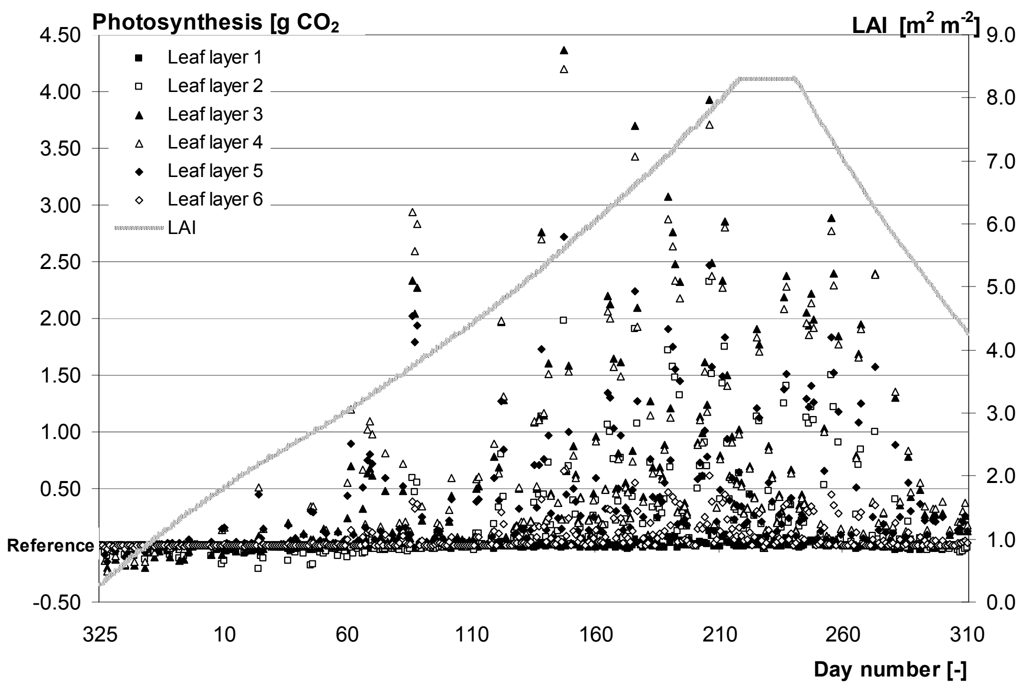

Fig. 4. Photosynthesis in different crop layers (1 = upper leaves, 6 = lower leaves) of sweet pepper under a highly diffusing greenhouse covering material compared to a clear reference material per day during the year, based on model calculations with INTKAM.