Effect of Diffuse Glass on Climate and Plant Environment: First Results from an Experiment on Roses

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Abstract

High energy use in rose cultivation at higher latitudes is caused by the need for artificial light to supplement scarce sun radiation. On the other hand, since too high radiation levels are known to reduce flower quality, shading is widely applied during spring and summer, either through movable screens or seasonal whitewash. In both cases damage to the crop is avoided at the cost of reducing potential assimilation by reduction of (PAR) light. Recent research on cucumber has shown that diffusing cover materials have the potential of improving the uniformity of vertical light distribution in a crop, therefore decreasing the energy load on the uppermost crop layer to the advantage of underlying crop layers. Light diffusion, however, usually implies a loss of overall transmission. This drawback can be avoided by antireflection coatings, so that most recently diffusive glass covers have become available with the same transmissivity of standard glass. The application of such a cover on roses could decrease the need for shading so that a desired radiation sum could be achieved with less need for artificial light. Such an experiment is in progress on a crop of roses (cv Red Naomi) at the research station of Wageningen UR Greenhouse Horticulture in Bleiswijk, NL, in two compartments. One is covered with diffuse glass with anti-reflection coating with a light transmission of 93% perpendicular and 83% hemispherical and haze factor of 72%. The reference compartment is covered with standard glass. This paper describes the effect of a diffusing cover on the greenhouse climate (air- and plant-temperature, humidity and ventilation requirement) and water balance compared to a greenhouse covered with standard glass. It's showed that the effect on greenhouse climate is limited but flower temperature is reduced in the diffuse compartment which has effect on flower quality. It seems therefore that the material has potential for reducing leaf burning and if the use of shade screens or whitewash can be reduced there is a potential increase of yield with the same energy input.

INTRODUCTION

Light is not evenly distributed in greenhouses. In particular, tall crops such as cucumber, sweet pepper and tomato have a high leaf area index and intercept a large quantity of light with the upper leaves, while the middle and lower leaves receive much less light and contribute very little to photosynthesis, growth, and in the end, production. As the uppermost leaves may often be light-saturated, it can be argued that a more uniform light distribution would result in higher overall assimilation (Ellsworth and Reich, 1993). At least, if the lowermost leaves have enough photosynthetic capacity to take advantage of the additional light. This was proven by Hovi et al. (2004) who showed that a higher amount of artificial light within a crop−achieved by inter-lighting−significantly increased photosynthesis of the lower leaves of cucumber. Uniformity of light distribution can be realized by diffuse light. From earlier investigations in forests (Farquhar and Roderick, 2003; Gu et al., 2003), apple trees (Lakso and Mussleman, 1976) and grass canopies (Sheehy and Chapas, 1976) it is known that diffuse light is able to penetrate deeper into a plant canopy in comparison to direct light and that photosynthesis in forests is increased by diffuse light. There are also indications that plants have developed mechanisms to use diffuse light more efficiently

(DeLucia et al., 1996; Vogelmann, 1996).

Diffuse light can have advantages also for greenhouse cultivation of young plants and small plants like pot plants, as it could improve on the sub-optimal horizontal light distribution. Shadows cast from the greenhouse construction have a negative influence on the plant production. In order to realize a uniform production, the light distribution has to be uniform over the whole canopy. This can be achieved by diffuse light. Light can be made diffuse by modern covering materials (Hemming et al., 2008b). Such materials contain pigments, macro- or microstructures, which are able to scatter a fraction of direct light over an almost flat distribution of incidence angles (that is into diffuse light). This fraction is called the haze factor and quantifies the diffusive effect of the material. Efficient structures make the light diffuse without a significant reduction in light transmission. During the past six years Wageningen UR Greenhouse Horticulture has investigated the potential of diffuse covering materials used in Dutch greenhouses (Hemming et al., 2005a, 2008b). The suitability of several greenhouse covering materials and their optical properties (PAR transmission: τ–direct and τ–diffuse, haze) was investigated in laboratories, desk studies, using models and simulations, as well as in practice. Both in cucumber and potted plant crops (Hemming et al., 2005a, b) diffuse covers resulted in a more effective photosynthesis and better quality.

Therefore we investigated the effect of diffuse covering materials on light distribution, plant photosynthesis, plant growth and development of a rose crop, which has a more compact leaf pack and is in summertime often shaded to avoid burning damage of leafs and flower buds. We discuss here the preliminary results of a crop experiment in progress with roses in two greenhouse compartments, covered respectively with a diffuse and standard glass.

MATERIALS AND METHODS

The experiment is being carried out in 2 compartments (144 m^2) of a Venlo-type glasshouse, located in Bleiswijk (52°N, 4.5°E), western part of Holland. The greenhouse is E-W oriented. Each compartment is composed of 2 spans, each with north-south width of 4.8 m and east-west length of 15 m. The height of the gutter is 5.5 m and the roof angle is 22^o. The soil surface of each compartment is covered with anti-weed sheet, with the exception of a 1.2 m wide, concrete path situated along the entrance of the compartment. Each span is equipped with continuous roof vents, over the whole length, the flaps are 1.3 m wide. One compartment is covered with standard glass whereas the second compartment is covered (side walls included) with Vetrasol 503 diffuse glass with an Anti-Reflection coating (GroGlass) on both sides. The glass has in one side a prismatic structure, which is placed towards the inside of the greenhouse compartment. In Table 1 the overall properties of these glasses and of the compartments are shown. Figure 1 shows the solar radiation transmission spectra of the reference and diffuse glass panels.

Rooted cutting of cut roses (*Rosa hybrida* 'Red Naomi!') were May 28^{th}, 2010 planted in single production units (SPU) Rockwool blocks (Grodan) of 24×20×7.5 cm. After an extended propagation in comparable compartments, both with clear glass, the plants were transferred August 26^{th} (and mixed) to the experimental compartments with clear and diffuse glass and placed on E-W oriented gutters, with a plant density of 6.2 plants/m^2. The plants were grown following the 'bending' technique, which consists in bending the primary stem and all stems that are not considered useful to flower production. The plants were irrigated by means of a drip system, which was automatically controlled by a fertigation computer, water supply scheduling being based on outside solar radiation and crop age. Inside CO_2 concentration was controlled to 1000 ppm by CO_2 injection during daytime or if artificial lights were switched on. Artificial lights (170 μmol/m^2/s) were used during the night period and whenever the outside radiation dropped below 175 W/m^2 up to a maximum of 16 hours per day. Throughout the growth period, the following climatic data were recorded each 5 min by the greenhouse control computer system:

(1) The inside air temperature, relative humidity, water vapour deficit and CO_2

concentration were recorded by means of a measuring box, located 1.3 m above ground which is in between the flowering buds.

(2) The inside PAR light was measured by a Quantum sensor located above the canopy, 1.6 m above ground.

(3) The outside air temperature, relative humidity, solar radiation, wind speed and wind direction were recorded automatically by means of a weather station.

(4) The canopy temperature was measured with an IR thermometer above the canopy and for individual measurements by a handheld IR thermometer (Raytek Raynger ST).

(5) Position of the screens and ventilation opening area, the valves of the CO_2 supply, status of the artificial lighting and pipe temperatures were recorded as well.

Four load cells (model STC-250 kg, Celtron, USA) were installed in each compartment, supporting two coupled gutters, for a total of 10 plants per compartment. The trend of weight decrease allowed determining crop transpiration. As an additional check, the drain from the weighed gutters was recorded through an additional load cell. The cells were logged at 30 seconds interval by a dedicated system and subsequent filtering allowed to calculate crop transpiration on a 15 minute basis. Temperature of a large number of flower buds (at the stage just before harvest) was measured, during selected sunny and cloudy days, with a handheld IR camera. In addition to this, also images were taken with an infrared camera, only in the reference compartment.

Control of climate was in the winter period the same for both compartments. In spring/summer a 100 W/m^2 higher sun radiation threshold for closing the shading screen was maintained in the diffuse compartment. We limit the discussion here to the effect of the diffusing cover on the climate, crop water use and crop temperature (leaf and buds).

RESULTS AND DISCUSSION

The effect of diffuse glass on PAR radiation in the greenhouse at bud height is shown in Figure 2. On a clear day with a maximum global radiation of 650 W/m^2, pictured at left, artificial lighting is switched on at 03:30 and switched off at 11:00 when global radiation measured outside reached 300 W/m^2. At 20:00 hours, lights are switched on again till the pre-set darkness period which starts at 21:00. The PAR sensors are located exactly at the same position in the two compartments. It is easy to see the PAR radiation is much more variable in the reference compartment than in the diffuse compartment. This is an obvious consequence of the diffuse greenhouse cover. The peaks and troughs in the reference compartment are shadows of structural components (troughs) or direct light falling on the sensor (peak) as a result of light reflection. As azimuth and elevation of the sun varies through the day, it will be obvious that the shadow of construction parts move throughout the day. Cumulative PAR light received by the crop was 22.8 mol/m^2 and 22.4 mol/m^2 in the diffuse and in the reference compartment, respectively, the global radiation sum (outside) of that day being 1739 J/cm^2. No screen was used to reduce light intensity at crop level.

In the day pictured at right in Figure 2 (April 30th) a shade screen was used during mid-day. Again we see a smoother distribution of light in the diffuse than in the reference compartment. Our management of the screen accounted for the lack of radiation peak, and was controlled at a 100 W/m^2 higher light level (global radiation outside) than in the reference compartment. The light reducing effect of the screen in the reference compartment is therefore approximately 1.5 hours longer than in the diffuse compartment. This resulted in a higher PAR radiation sum in the diffuse compartment compared to the reference compartment with a potential additional positive effect on photosynthesis. In the diffuse compartment PAR light received by the crop (global radiation sum outside was 2335 J/cm^2) was 23.1 mol/m^2 and 22.0 mol/m^2 in the reference compartment.

Crop transpiration is mainly controlled by radiation (energy) on the crop, vapour deficit, leaf area and leaf temperature which is nearby the air temperature of the compartment. On April 30th (shown in the right panels of Fig. 3) greenhouse air temperature was the same in both compartments (data not shown). With respect to crop development, the leaf area (LAI) in the diffuse compartment was slightly smaller, as harvest had started a few days in advance of the reference compartment (Garcia Victoria et al., 2011). The vapour deficit was similar in both compartments (Fig. 3, top right). Crop transpiration (Fig. 3, bottom right) shows only some minor differences between the compartments at daytime. The opening and closing of screens at different times is hard to find in the figure, in spite of the fact that less radiation will reduce the transpiration. The daily sum of transpiration was reduced down to 7.2 kg/m^2 in the diffuse compartment vs 7.4 kg/m^2 in the reference. On April 10 (pictured left in Fig. 3), sun radiation reached the threshold for closing the screen in the reference compartment (between 12:30 and 16:15), but not the threshold for the diffuse compartment. Figure 3 (bottom left) shows that during that time, crop transpiration decreases in the reference compartment but not in the diffuse one. Total transpiration in the diffuse compartment was 6.2 kg/m^2 and in the reference 5.2 kg/m^2. The reduced transpiration in the reference has no effect on the vapour deficit. Because the screen is closed for about 80%, the air exchange between the outside and crop area is slightly reduced. Because of the lower radiation dose, the temperature hardly increased in comparison with the diffuse department.

The effect of the diffuse glass on bud temperature is shown in Figure 4. The temperature difference between bud and air temperature is in the reference higher than in the diffuse compartment. This effect is more evident on sunny than on cloudy days. It may surprise that in the last points of Figure 4 (April 8), bud temperature in the diffuse compartment is suddenly warmer than in reference. This day the shadow screen was closed in the reference compartment but not in the diffuse one. Closing the screen, has therefore an obvious effect on bud temperature. This is made clear by Figure 5, showing images of the infrared camera during a sunny day in the reference compartment. Around noon (Fig. 5, left), the temperature of the bud (on the sunny side), reaches over 42 degrees, with a greenhouse air temperature of 25°C, whereas the side on the shadow is some 10°C cooler (darker of collar). There are also clear temperature differences among the leaves. The most exposed leaves, the youngest ones, have a higher temperature which, in turn, may well be compatible with burned leaves which is an quality aspect of great importance while the whole stem is sold. In the diffuse compartment less burned leaves are observed and a production increase of about 4% was found (Garcia Victoria et al., 2011). In the evening (Fig. 5, right), when the greenhouse air temperature slowly drops to 15°C and artificial lighting is switched off, temperature differences within the bud are within approximately 1°C.

On the other hand, no effect of the cover was found on greenhouse climate variables such as temperature, ventilation requirement and humidity. In an earlier study, with a cucumber crop Hemming et al. (2008a) obtained comparable results although they found difference in greenhouse climate as well. This may be caused by the way the compartments were controlled or a difference in transmissivity of the compartments, meaning a difference in heat load and so on an effect on the climate. In this experiment with roses the transmissivity of the compartments were nearly the same as is shown in Table 1. Presumably, the glass cover would have influenced the greenhouse climate when the excess radiation would not have been excluded from the greenhouse by the shade screens. Hemming's experiment was conducted with vegetable crops, whereas to produce a good quality marketable rose of this variety, screening of excess radiation has proven inevitable. The results suggest that the diffuse cover might make possible to cultivate rose varieties less sensitive to leaf-tip burning and blue petal edges with an even higher screening threshold or even to cultivate them unscreened.

CONCLUSIONS

The diffuse- anti reflection coated greenhouse glass cover made the light incidence inside the greenhouse smoother, with less moments of extreme high and extreme low values. The smoother light did not result in differences in daily light sum, but it reduced the need for screening (required to avoid leaf tip burning and blue flower edges) with 100 W/m^2 as compared to the compartment with normal float glass. This difference in screening regime have led to differences in total light integral in the spring and summer that varied between 0 and 1.5 mol/m^2 per day. Although the limited data on production up to now do not allow final conclusions, we have shown that the effect of diffuse light on climate and crop processes of a rose crop should improve production and quality (Garcia Victoria et al., 2011). This is explained by a change in light distribution within and over the crop. Diffuse roof material results thus in a lower flower bud temperature with as side effect a reduction of burned leaves which is from quality point of view very important. The differences in crop transpiration that were observed follow from our management of the shadow screen. Our data seem to endorse the hypothesis that there is less need for shadowing/whitewash under a diffusive cover, less shadow is alone enough to warrant higher assimilation. In our opinion, a diffuse roof material for greenhouses might be profitable, provided there is no loss of light transmission. A lower light transmission will result in a loss of production, especially in the winter when light is the limiting factor. This cannot be balanced by any beneficial effect of diffusion, since most natural light is already diffuse in winter, at least at the latitude of The Netherlands. The largest potential for diffusing cover is in the seasonal and geographical conditions that ensure that a large fraction of sunlight is direct, and for crops that suffer from exposure to high light intensity.

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Tables

Table 1. Transmission (perpendicular and hemispheric) and haze of the two cover materials and the overall transmission of the greenhouse compartment fitted with each one.

Material	τ Perpendicular	τ Hemispheric	Haze	τ Compartment
Reference	90	83	0	59
Diffuse	93	83	72	60

Figures

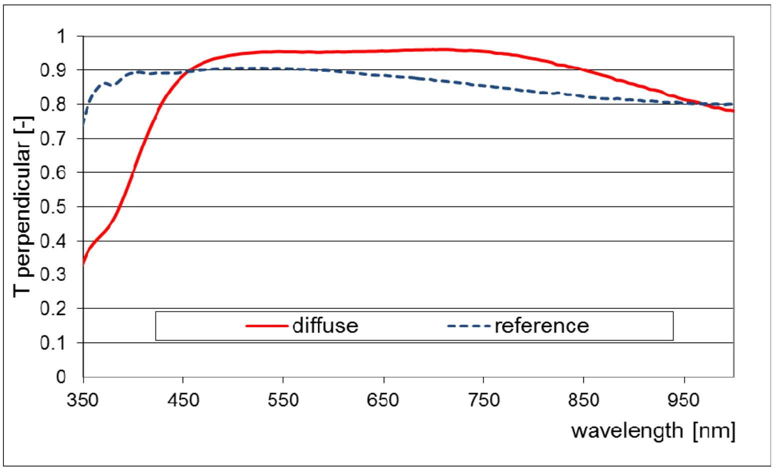

Fig. 1. Solar radiation transmission spectra (only perpendicular) of the two glass types.

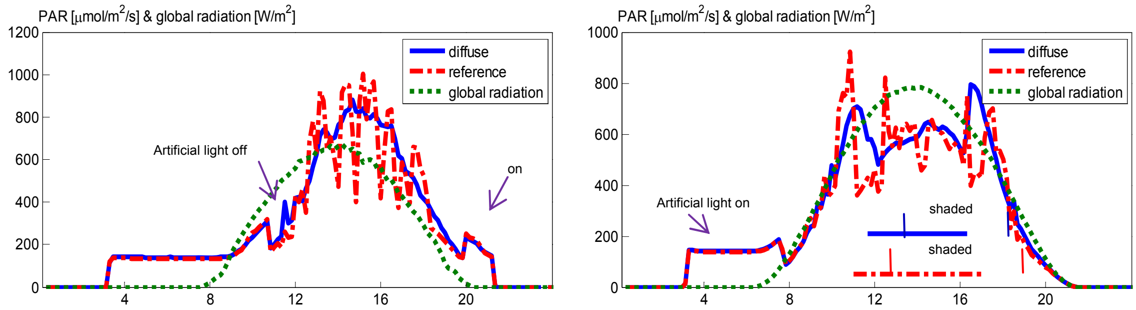

Fig. 2. Outside global radiation and inside PAR radiation on March 29th (left) and April 30th (right).

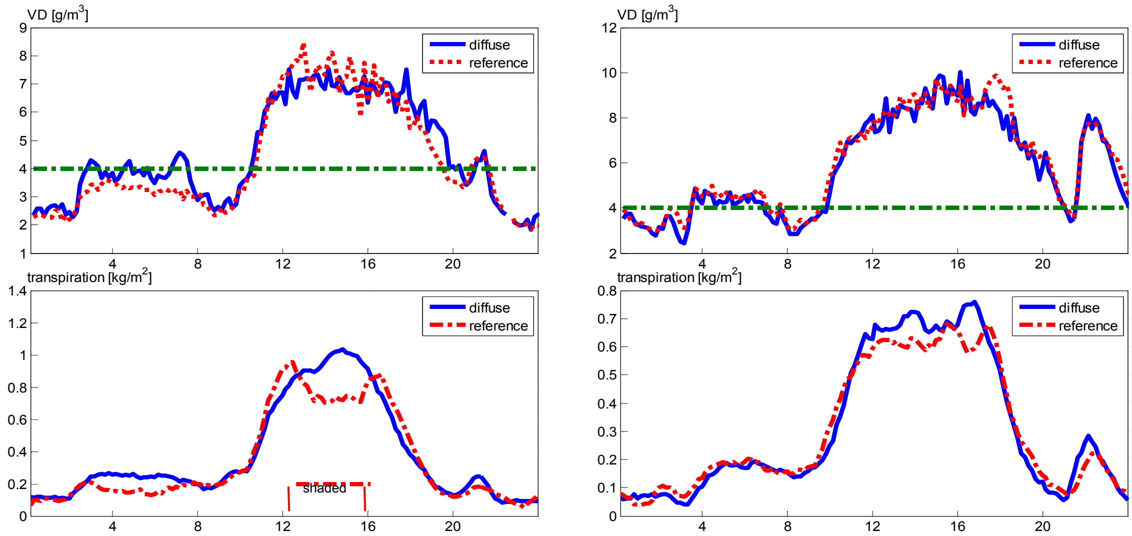

Fig. 3. Vapour deficit (top, green slash-dot line is the setpoint; for both compartments the same) and crop transpiration (bottom) on April 10th (left) and April 30th (right).

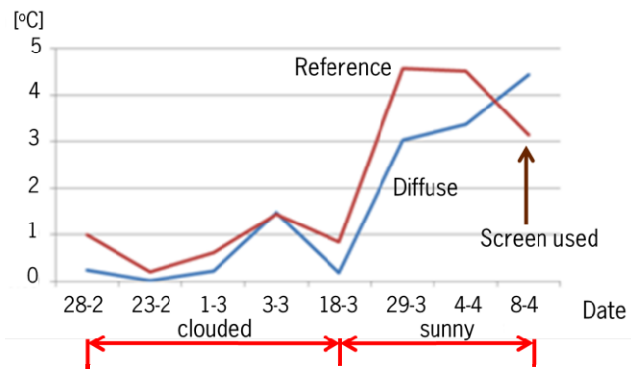

Fig. 4. Average difference between bud- and greenhouse-temperature on different time-points. Time points are means of 20-40 measurements of nearly harvest-ripe buds.

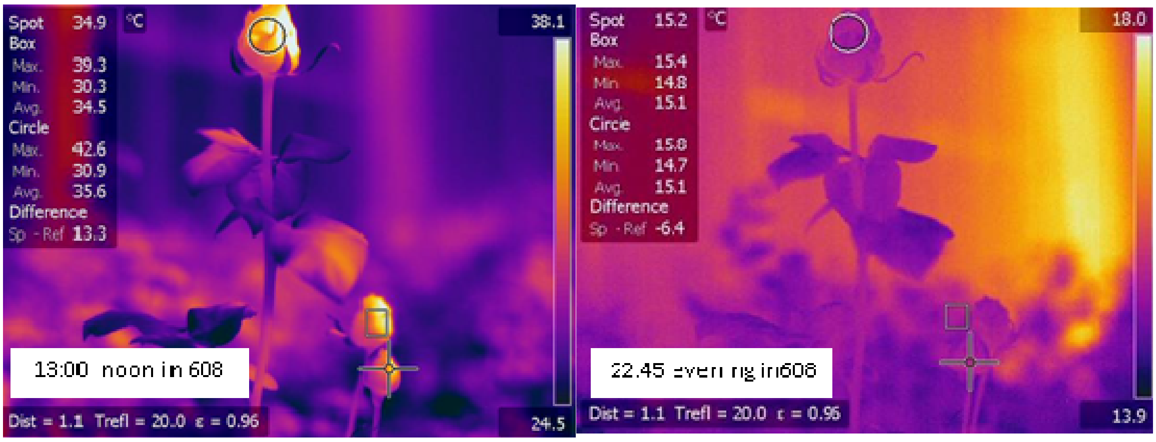

Fig. 5. Bud and leaf temperatures in the reference compartment at noon (left) and in late evening (right).