Cover Materials Excluding Near Infrared Radiation: What is the Best Strategy in Mild Climates?

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Abstract

Only about half of the energy that enters a greenhouse as sun radiation is in the wavelength range that is useful for photosynthesis (PAR, Photosynthetically Active Radiation). Nearly all the remaining energy fraction is in the Near InfraRed range (NIR) and only warms the greenhouse and crop and does contribute to transpiration, none of which is necessarily always desirable. Materials or additives for greenhouse covers that reflect a fraction of the NIR radiation have recently become commercially available.

Besides lowering greenhouse temperature, a NIR-excluding cover has quite a few side-effects that may become quite relevant in the passive or semi-passive greenhouses typical of mild climates. For instance, the ratio of assimilation to transpiration (the water use efficiency) should increase. On the other hand, by lowering the ventilation requirement, such a cover may hinder in-flow of carbon dioxide, thereby limiting the photosynthesis rate. In addition, there are obviously conditions where the warming up caused by NIR may be desirable rather than a nuisance.

NIR-reflecting materials are becoming available in forms that are suitable for various types of applications, such as permanent, seasonal or mobile. By means of a simulation study, we discuss in this paper the best form of application in relation to the external climate and climate management options available.

INTRODUCTION

Global radiation that enters the greenhouse can be divided into ultraviolet radiation (UV, 300-400nm), photosynthetic active radiation (PAR, 400–700nm) and near infrared radiation (NIR, 800–2500nm). PAR is almost completely absorbed by the crop and is the source for photosynthesis and thereby crop growth. NIR is partly reflected by the crop but it is absorbed by installations and construction elements of the greenhouse and increases air (and crop) temperature, as well as the energy in the PAR range not used for photosynthesis. The heating effect in greenhouses caused by global radiation is desirable during cold periods, but in warm periods the temperature in the greenhouse can increase to undesirable levels so that crop growth and production will be affected or even become impossible. To prevent high temperatures the heat load of the greenhouse has to be reduced or the cooling capacity has to be increased.

Research focus is now more on developing solid materials with NIR-filtering, like plastic films or glass for greenhouses (Verlodt and Verschaeren, 1997; Hemming et al., 2006; Abdel-Ghany et al., 2001) or sheets to be used as moveable screens (Runkle et al., 2002). Also NIR-filtering white wash has been developed (von Elsner and Xie, 2003).

It seems reasonable that it is the combination of external climate conditions and type of greenhouse that determines the most appropriate form of application in a given place. All these factors have been taken into account in the simulation study that we present here, where we quantify the expected benefits (in terms of productivity, water use efficiency and lengthening of the growing season) of each of the three forms of application of the NIR-filter in a semi-passive greenhouse in the Mediterranean basin. We

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compare such analysis with the results obtained for a highly controlled greenhouse under Dutch climate conditions to determine a strategy for selecting the most appropriate application of a NIR-selective filter, in view of the prevailing climate and the available ambient management option.

MATERIALS AND METHODS

The use of models makes comparison of the effect of several types and levels of NIR reflection on the greenhouse climate possible. For the Dutch greenhouses the climate model KASPRO (de Zwart, 1996), which has been validated for the Venlo type greenhouse was used to analyze the effects of NIR-filtering materials on greenhouse climate parameters, while Vanthoor's (2008) model for a simpler, passive greenhouse, has been used for the Mediterranean calculation. Calculations have been done with a simulated NIR reflection coefficient of 0, 0.5 and 1 is introduced where 0 is non reflective, assumed to be the reference. We have assumed that the PAR transmission is not affected by the NIR filtering. The reflection reduces the heat load of the greenhouse. Calculation of the indoor climate, temperature, humidity, transpiration and CO_2 concentration for a tomato crop is presented. For the Dutch case it has been assumed that the climate control system is able to deliver the desired set-points of (minimum) temperature and CO_2 concentration (1000 PPM), whereas the "Mediterranean" greenhouse is fully passive. The results have been grouped for a typical winter period (December 1th – March 1th) and a spring-summer period (April 15th July 15th), comparing the effects of NIR reflection on indoor climate parameters of northern Europe to Mediterranean. In the calculations for the Mediterranean basin a white wash is introduced during the summer, in accord to common practice there.

RESULTS AND DISCUSSION

NIR-reflection influences the greenhouse air temperature. In Fig. 1 the course of the average air temperature (T air) during the day in a winter period (December 1st – March 1st) of a greenhouse in the Mediterranean basin is showed. The average maximum temperature decreases at a NIR-reflection of 100% with 3.6 ^{o}C in relation with no NIR reflection at all. At a NIR-reflection of 50% the decrease is 1.4 ^{o}C. It is important to observe the decrease also of the minimum temperature with 1.1 ^{o}C at 100% NIR-reflection, which is the result of a lower day time temperature, hence a lower heat release by "warm" structures (mainly the soil) in the night. The lower air temperature will lower the ventilation requirement, which will affect the CO_2 level. During day time the CO_2 concentration decreases with higher NIR-reflection, since outside air entering the greenhouse via the opened ventilators is the only CO_2 source. The opposite effect of "keeping inside" the CO_2 released by respiration at night will be offset by assimilation soon after sunrise, so it will not compensate for the much larger opposite effect at daytime (Fig. 1 - CO_2).

The reduced heat load at high NIR-reflection rates decreases the transpiration (Fig. 1 - transpiration), substantially in wintertime. The transpiration is reduced by 20 and 50% with a NIR-reflection of respectively 50 and 100%. The reason for non linearity is the difference in ventilation and therefore in humidity (Fig. 1 - RH).

In summer the reference is a whitewash reflecting equally NIR and PAR by 40 %. The overall transmission decreases with whitewash more than with the NIR-reflecting covers of 50 and 100%. For this reason the air temperature of the white washed greenhouse is the lowest of all (Fig. 2 - T air). The average maximum air temperature decrease from 31.6 ºC for the greenhouse with a NIR reflection of 0% to 29.1, 26.1 and 25.0 ^{o}C for respectively the greenhouse with NIR reflection of 50 and 100% and the white washed. In the night differences in minimum temperature are. The differences in ventilation requirement of the greenhouses due to the differences in heat load affect the CO_2-levels in the greenhouse as well (Fig. 2 - CO_2). During daytime (08:00-18:00) with a NIR-reflection of 100% the CO2-level decreases down to an average level of 320 ppm which is about 40 ppm below outside level. It's clear that limitation of the ventilation influences the CO_2-concentration in a negative way. The comparable CO_2 concentration of the white washed greenhouse with the reference and the greenhouse with 50% NIR-reflection will also be a consequence of the lower CO_2 uptake by the crop due to the reduced PAR-transmission of the white washed greenhouse.

The transpiration decreases when NIR-reflection increases (Fig. 2 - transpiration). The decrease of transpiration at noon with a NIR reflection of 50 and 0% is a consequence of the introduction in Vanthoor's model of a crop stress factor when air temperature goes beyond a given level. Transpiration of the whitewashed greenhouse is reduced by 36%. Because the stress factor influences the transpiration at a NIR reflection of 50% the transpiration decreases only with 6% in relation to the reference while the reduction is 26% with 100% NIR-reflection. The combination of lower transpiration and higher temperatures has consequences for the humidity (Fig. 2 - RH). The minimum RH is 25% lower at a NIR reflection of 0 then the whitewashed greenhouse and 20% with a NIR-reflection of 100%. Because whitewashing affects the PAR-transmission, the PAR radiation sum of the summer period decrease from 650 MJ of the NIR-reflecting greenhouses back to 250 MJ for the white washed one. This will affect the crop production in a negative way.

In Fig. 3 and 4 the results for the north European area are shown. Main difference with the Mediterranean basin is the heating which is required in winter time. While there is no lack of CO_2 during winter time, in Fig. 3 gas use is shown instead of CO_2-concentration. Because of the heating system during night time the air temperature is on the set point temperature (Fig. 3 - T air). During daytime only small temperature differences occur. Because set point ventilation is 23 ^{o}C the ventilators are open seldom. Also the humidity (Fig. 3 - RH) is in this period hardly affected by NIR-reflection. Please observe that the scale of the humidity graph is half of the scale of Fig. 1. Humidity levels are low because of the young crop and the lack of light, so that crop growth is low. Only at the end of this winter period will first fruits be harvested. Main differences in energy use are shown in Fig. 3-gas use. During night there are hardly any differences because the NIR-reflection has no influence on the greenhouse climate when there is no NIR radiation. Beside avoiding heat loss during night-time or even during daytime if out side temperatures are to low a transparent screen is closed. During day time the NIR-reflection reduces the heat load of the greenhouse and often this reduction of heat load has to be added by the heating system. The energy use increases during winter with 4.5 and 9.8 % compared to the reference for respectively 50 and 100% NIR-reflection. Because of the young crop absolute transpiration levels are low. Transpiration is decreased by 6 and 11% for respectively NIR-reflection of 50 en 100%.

In summer differences in greenhouse air temperature are much smaller than in the Mediterranean basin (Fig. 4 - Tair). Outside climate is unstable and cooler so on some days ventilators are hardly open. This decrease of ventilation influences the CO_2-concentration in the greenhouse (Fig. 4 - CO_2), which the injection system is able to maintain higher. The CO_2-concentration increases during daytime by 100 PPM from 670 PPM (reference) up to 770 PPM at a NIR-reflection of 100%. This increase can partly be explained by the increase of the gas use which means more CO_2 from flues is available. Even during summer increase of NIR-reflection leads to an increase of the gas use. This increase is not only caused by the decrease of NIR energy into the greenhouse but by the increase of de-humidification as well. The decrease in ventilation leads into an increase of humidity (Fig. 4 - RH). At a humidity level of 85 % (set point) active de-humidification is started. In spite of this during summer the number of hours with a humidity level of over 90% increases from 360 (reference) up to 810 at a NIR-reflection of 100%. Differences in heat load humidity and ventilation leads to a decrease of transpiration by 16 and 33% (Fig. 4-transpiration).

CONCLUSION

There is a good potential for application of NIR-reflective filters in greenhouse covers. However, this desk-study shows that a permanent filter may be unsuitable both for the heated greenhouse of Northern regions and for the passive greenhouses of mild-winter conditions. A year-round screen is bound to increase the [fossil] energy requirement of heated greenhouses and lower the winter-time mean temperature in passive greenhouses. In addition, the reduced ventilation requirement may affect negatively CO_2 concentration (hence productivity) in this latter case. Application of a NIR filter (whether movable or seasonal) should be coupled to a CO_2 fertilization facility, to be profitable.

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Figures

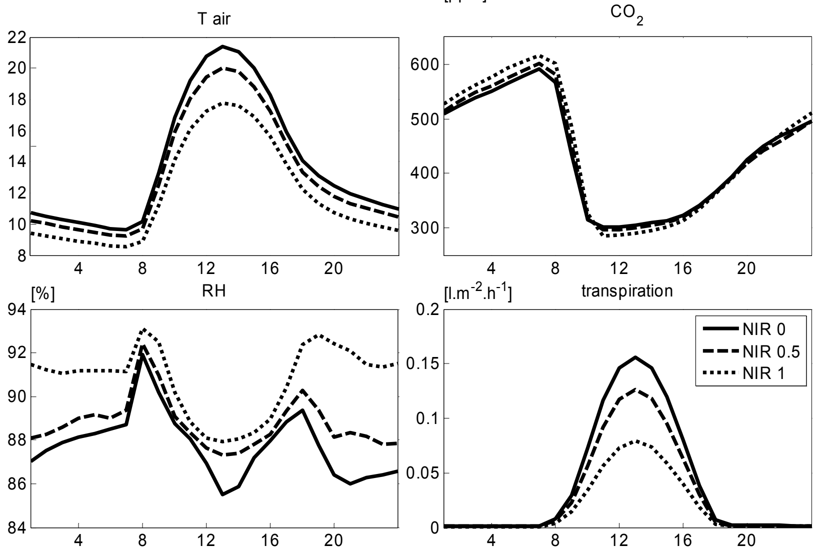

Fig. 1. Cycle mean of the greenhouse air temperature (Tair), CO_2 level (CO_2), relative humidity (RH) and the crop transpiration (transpiration) of the winter period in the Mediterranean basin.

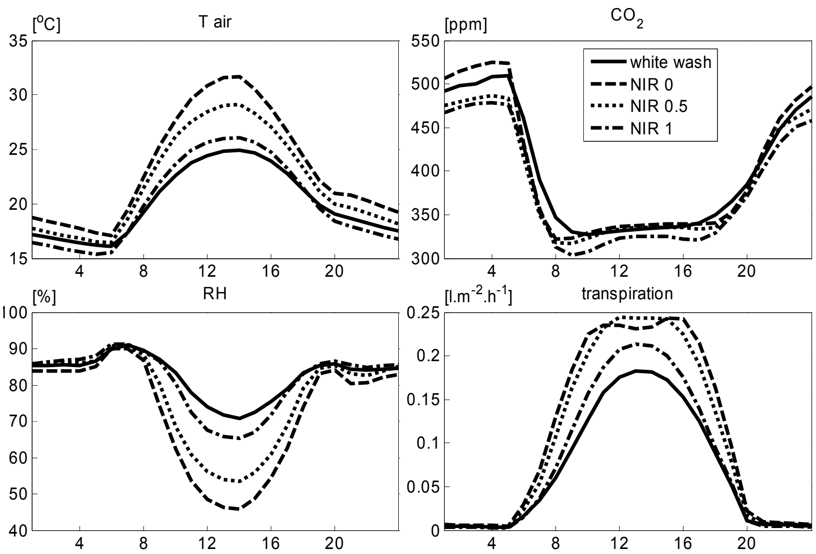

Fig. 2. Cycle mean of the greenhouse air temperature (Tair), CO_2 level (CO_2), relative humidity (RH) and the crop transpiration (transpiration) of the summer period in the Mediterranean basin.

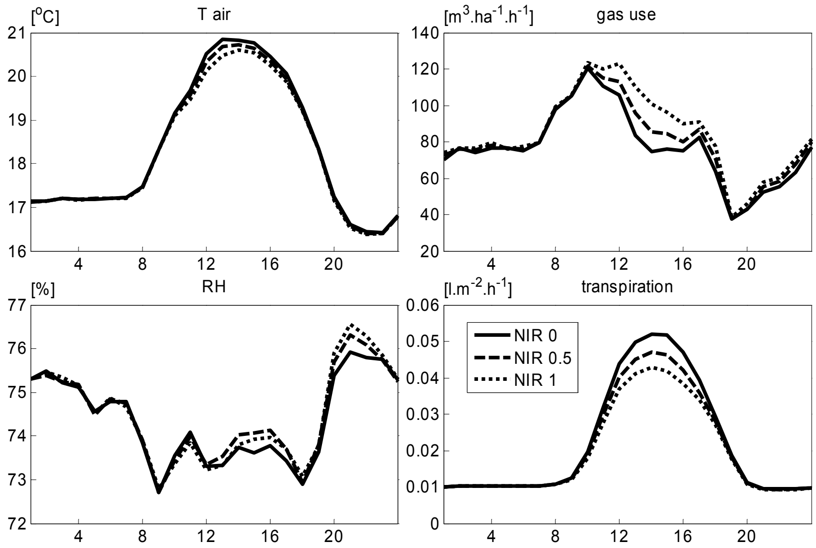

Fig. 3. Cycle mean of the greenhouse air temperature (Tair), natural gas input for heat demand (gas use), relative humidity (RH) and the crop transpiration (transpiration) of the winter period in the Netherlands.

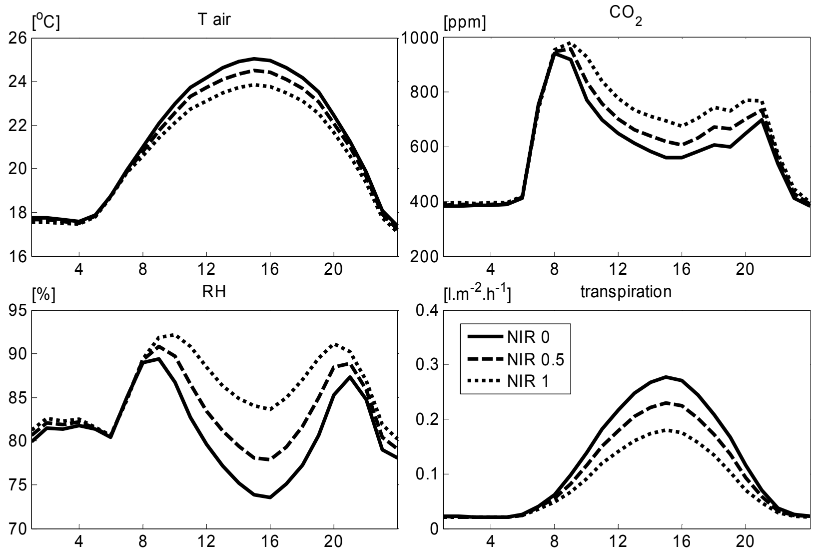

Fig. 4. Cycle mean of the greenhouse air temperature (Tair), CO_2 level (CO_2), relative humidity (RH) and the crop transpiration (transpiration) of the summer period in the Netherlands.