Filtering Natural Light at the Greenhouse Covering – Better Greenhouse Climate and Higher Production by Filtering out NIR?

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Abstract

Wageningen UR investigated the potentials of several NIR-filtering methods to be applied in Dutch horticulture. NIR-filtering can be done by the greenhouse covering or by internal or external moveable screens. The objective of this investigation was to quantify the effect of different NIR-filtering methods on greenhouse climate, energy saving and growth and production of tomato and to estimate the amount of NIR to be blocked to get positive effects under Dutch climate conditions. In the research is shown that there are technical and economical potentials for filtering NIR by the greenhouse covering or to use a moveable screen, which does not limit ventilation. Tomato production can potentially be increased with 8-12% depending on the NIR-filtering materials used.

INTRODUCTION

Global radiation enters the greenhouse and can be divided into ultraviolet radiation UV (300-400nm), photosynthetic active radiation PAR (400–700nm) and near infrared radiation NIR (800–2500nm). PAR absorbed by the crop is important for growth and photosynthesis, NIR is less absorbed by the crop but it is absorbed by installations and construction elements of the greenhouse and increases air temperature. In Dutch greenhouses the heating effect caused by global radiation is desirable during winter, but during summer the temperature in the greenhouse can increase to undesirable levels. In fact, to prevent high temperatures or to reduce the cooling load in greenhouses during high temperature periods has been one of the most important problems to be solved in protected cultivation in most countries worldwide.

Since many years scientists and companies are working on greenhouse covering materials to reduce greenhouse inside temperature significantly. Since about 1939 water films have been used for the limitation of maximum temperature in glasshouses and it has been generally considered that the absorption of infrared radiation was the main method by which this was achieved (Brown, 1939). First detailed investigations on a greenhouse with a NIR-filtering liquid-roof were carried out by Morris et al. (1958). Investigations to optimise the liquid-roof-greenhouse by simulations and practical tests followed, also $CuSO_4$-solutions and other coloured solutions in fluid-roof-systems were used to reduce NIR more selectively (van Bavel et al., 1981; Gale et al., 1996). The liquid in the roof lowers the solar energy and can be used for heating and cooling purposes. Depending on the liquid and its concentration NIR is reduced more than PAR. However, since a reduction of PAR cannot be avoided, it is only beneficial in warm climates.

Recently the research focussed on developing solid materials with NIR-filtering, like plastic films as greenhouse covering (Verlodt and Verschaeren, 1997; Hemming et al., 2004; Abdel-Ghany et al., 2001) or moveable screens (Runkle et al., 2002; Tanaka, 1997). Also NIR-filtering shading paint is developed (von Elsner and Xie, 2003). The effectiveness of the NIR-filtering materials on the reduction of greenhouse air temperature and crop temperature and on the increase of crop production depends on several factors, though. Some authors point out that a high amount of NIR has to be kept out of the greenhouse to take effect. Moreover, the ventilation capacity of the greenhouse and the plant density and crop transpiration are important factors. Until now a detailed analysis of the potentials of several NIR-filtering methods is missing.

Therefore, Wageningen UR investigated the potentials of several NIR-filtering methods to be applied in Dutch horticulture. The first objective of this investigation was to quantify the effect of different NIR-filtering methods (covering material, moveable screens) on greenhouse climate, energy saving and growth and production of tomato and to estimate the amount of NIR to be blocked to get positive effects under Dutch climate conditions. The second objective of the research project was to investigate available NIR-filtering materials on their optical properties, and to define optimum material properties for the use in horticulture (not described in this paper).

MATERIALS AND METHODS

Model calculations of greenhouse inside climate and energy consumption were carried with the KASPRO model developed by de Zwart (1996). The dynamic simulation model KASPRO can simulate a full-scale virtual greenhouse based on the construction, the covering material, the set-points for inside climate, the greenhouse equipment and the Dutch outside climate. Output parameters are several climate parameters, such as air temperature, relative humidity, CO_2-concentration and energy consumption. The model is based on the computation of relevant heat and mass balances (Bot, 1983). The heat balances describe both the convective and radiative processes. The radiative heat exchange processes are computed from the Stefan Boltzman equation, taking into account the view factors and the emission and transmission coefficients of the radiating surfaces. The transmission of solar radiation (PAR and NIR) through the greenhouse covering is calculated based on Bot (1983). The interception of radiation by the crop is based on Goudriaan (1988). The convective heat exchange processes are based on standard heat exchange theory and incorporate the effect of wind speed. Outside weather conditions, such as solar radiation, air temperature, humidity and sky temperature, are described by the SEL-year (Breuer and van de Braak, 1989) and act as boundary conditions. The mass balances are constituted from exchange processes through leakage and ventilation (de Jong, 1990). They include canopy transpiration (Stanghellini, 1987) and condensation at cold surfaces. De mass balances around the CO_2-concentration are based on losses of CO_2 by ventilation and photosynthesis, and gains of CO_2 by CO_2-dosing and respiration. The inner greenhouse climate is controlled by a replica of commercially available climate controllers. The total set of differential equations is solved numerically (de Zwart, 1996).

Crop production is calculated with the model INTKAM (Marcelis et al., 2000). The model calculates 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. The greenhouse climate parameters obtained with KASPRO serve as input for INTKAM. Photosynthesis and transpiration on crop level is obtained by integrating the photosynthetic speed of several crop layers. The crop development is calculated on daily base via temperature depending development of internodes, which consist of a bunch and three leaves. Tomato is chosen as model crop. Plant datum is 11th December; last harvest takes place on 20th November next year. Climate set points are according to Dutch horticultural practice. The production takes place in a standard Venlo glass-greenhouse of 4ha with a standard energy screen.

Different NIR-filtering methods are investigated: A greenhouse covering material filtering out 100% or 50% of the NIR energy; a transparent moveable screen installed inside the greenhouse horizontally and filtering out 100% or 50% of the NIR energy, which is closed at 200, 450 or 600 W/m^2 outside radiation; and a transparent moveable external screen, which does not limit the ventilation capacity of the greenhouse, filtering out 100% or 50% of the NIR energy, which is closed at 200, 450 or 600 W/m^2 outside radiation. The PAR transmission of the greenhouse covering is 90% for direct radiation and 83% for diffuse radiation, the PAR transmission of the screens is 90% or 95% for direct radiation and 83% or 88% for diffuse radiation. NIR is filtered out by reflection.

RESULTS AND DISCUSSION

The different NIR-filtering methods (greenhouse covering, moveable screens) influence greenhouse climate parameters and crop parameters. A greenhouse covering material, which is assumed to filter out all incoming NIR is able to increase the production of tomato, because of the following factors: 1. A lower greenhouse inside air temperature is the result of less incoming radiation energy due to NIR-filtering. The air temperature is during summer months in average 1^{o}C lower than in the reference greenhouse, during hours with high irradiation it can even be 2^{o}C lower. 2. Also the crop temperature is during summer months in average 0.8^{o}C lower, during hours with high irradiation it can be even 2^{o}C lower. 3. Due to lower air temperatures the greenhouse ventilation openings can be kept close for a longer time, which can be up to 20% of the hours compared to the reference. 4. More closed ventilation openings cause a higher CO_2-concentration in the greenhouse, which is in average 100ppm higher than in the reference greenhouse, especially during midday hours, when CO_2 can be used most efficiently by the crop. 5. Moreover the crop transpiration is lower during summer months, which is a sign, that less transpiration is necessary during periods with high irradiation to keep the crop temperature on an optimum level (Fig. 2 and Fig. 3).). These parameters lead to an increased daily dry matter production, especially from the end of March until the end of September. The production of tomato is increased by 8.6% during summer months (Fig. 1). A covering material that is able to reflect only 50% of the NIR is less effective, since greenhouse climate effects are smaller than described above. This will result in a production increase of about 4.9% during summer months. Since currently available NIR-filtering materials are able to reflect 50% NIR without reducing PAR, this figure is realistic to be reached on a short-term. However, an even higher production increase can be reached, if optical properties of currently available materials are optimised for the use in horticulture and NIR-filtering is further increased. Potentially we estimate the production increase for a tomato crop with 10-12% compared to the production under traditional glass, if a NIR-filtering coating on glass is used in addition to an anti-reflection coating, PAR-transmission can be increased to 95% and almost 100% NIR-filtering can be achieved. However, such materials are not available yet, though an economical study showed that new materials may cost 4-5 times more than traditional glass.

Another option is to use a moveable NIR-filtering external or internal screen. Greenhouse climate calculations have shown, that a NIR-filtering internal, horizontal screen has no advantages. The goal to decrease inside air temperature cannot be reached with any screen strategy. In the opposite, air temperature increases about 1-2^{o}C in average during summer months (Fig. 2), and can reach even higher values up to 5-6^{o}C during clear summer days at noon (Fig. 3). The closed screen limits the air exchange with outside. Obviously the NIR-filtering effect of the screen is not able to compensate this limitation. The radiation energy in the PAR region is still enough to increase inside air temperature. Also crop production is not increased by the use of an internal screen. Due to high temperatures during summer months, bud abortion and a reduced setting of fruit follow. Better is the use of screens, which do not limit free airflows, e.g. an external moveable screen. An external screen is able to decrease greenhouse air temperature with about 2^{o}C on hot summer days, to decrease crop temperature and to increase CO_2-concentration. The right screen strategy seems to be important (data not shown), also the optical properties of the film. A screen that reflects only 50% of the NIR has less effect than a screen that reflects 100%. A screen, which is closed more often, has more effect than a screen that is closed at higher outside radiation levels. Additionally, the film has to have a very high PAR-transmission (at least 90%, better 95%), since a screen always creates a second light-intercepting layer in the greenhouse and decreases the amount of PAR for the crop. Such NIR-filtering screens are able to increase crop production of tomato with 2-8% depending on the optical properties and the screen strategy (Fig. 1). Potentially a NIR-filtering screen has less effect on crop production than a NIR-filtering greenhouse covering, because it always will reduce the amount of PAR when it is closed.

Since NIR-filtering leads to less solar energy in the greenhouse, it is only advantageous during summer. Filtering out NIR during winter leads to an increased use of heating energy in heated greenhouses (data not shown) or to a drop of air and crop temperature in unheated greenhouses. The use of moveable external screens should be preferred above the use of a NIR-filtering greenhouse covering, if energy has to be conserved. However, the production increase will be less in the first case. In a closed air-conditioned greenhouse the reflection of NIR is a very important factor to reduce cooling capacity during summer. Filtering out 100% of the NIR will lead to a 50% reduction of the cooling capacity (data not shown). The overall analysis of greenhouse climate and crop growth and production parameters has shown, that there are advantages and economical potentials to reduce greenhouse inside air temperature during summer and to increase tomato production by reflecting NIR by the greenhouse covering or to use a NIR-reflecting screen, which does not limit greenhouse ventilation in Dutch horticulture.

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Figures

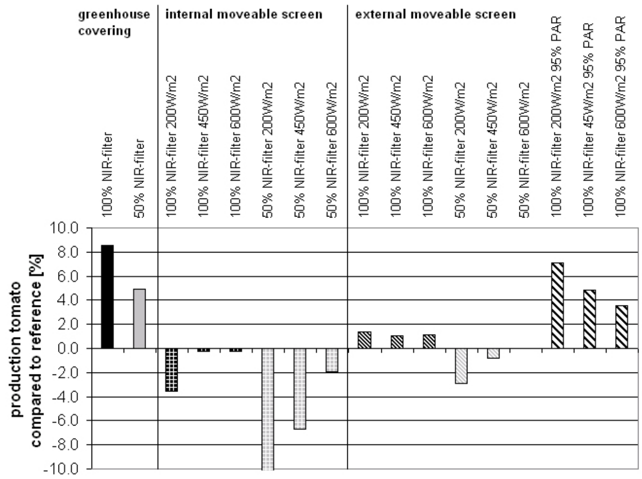

Fig. 1. Effects of several NIR-filtering methods on production of tomato in relation to the reference, based on calculations with INTKAM.

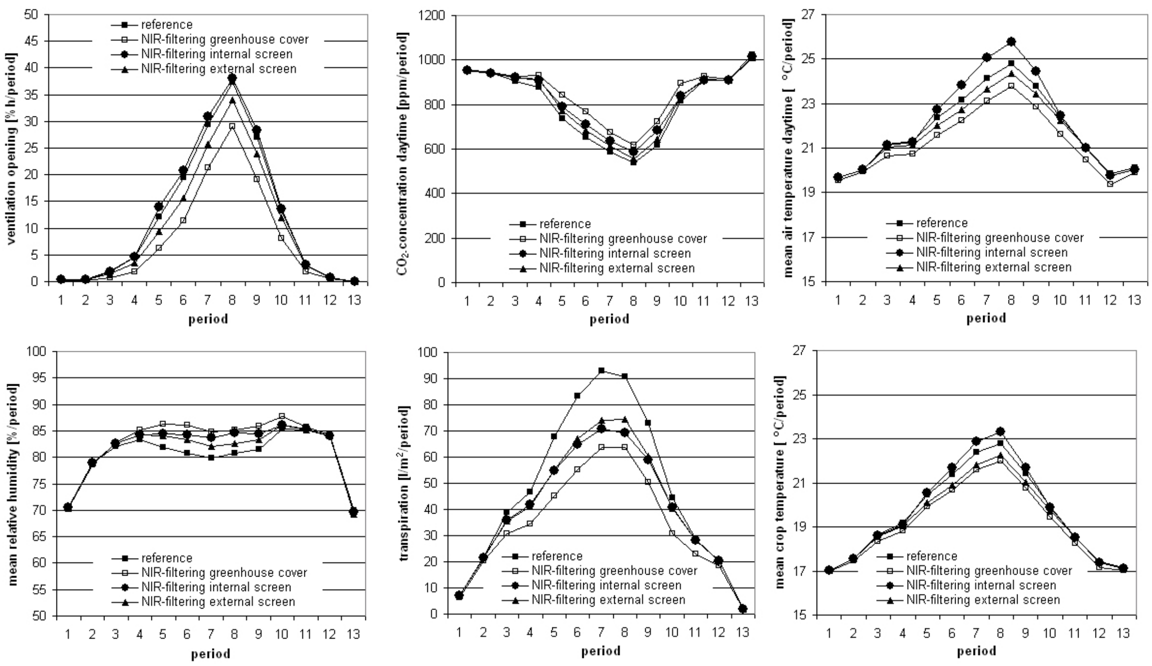

Fig. 2. Effect of several NIR-filtering methods on greenhouse climate per period of 4 weeks during the year, based on calculations with the KASPRO-model (100% NIR-filtering, moveable screens close at 450 W/m^2 outside radiation).

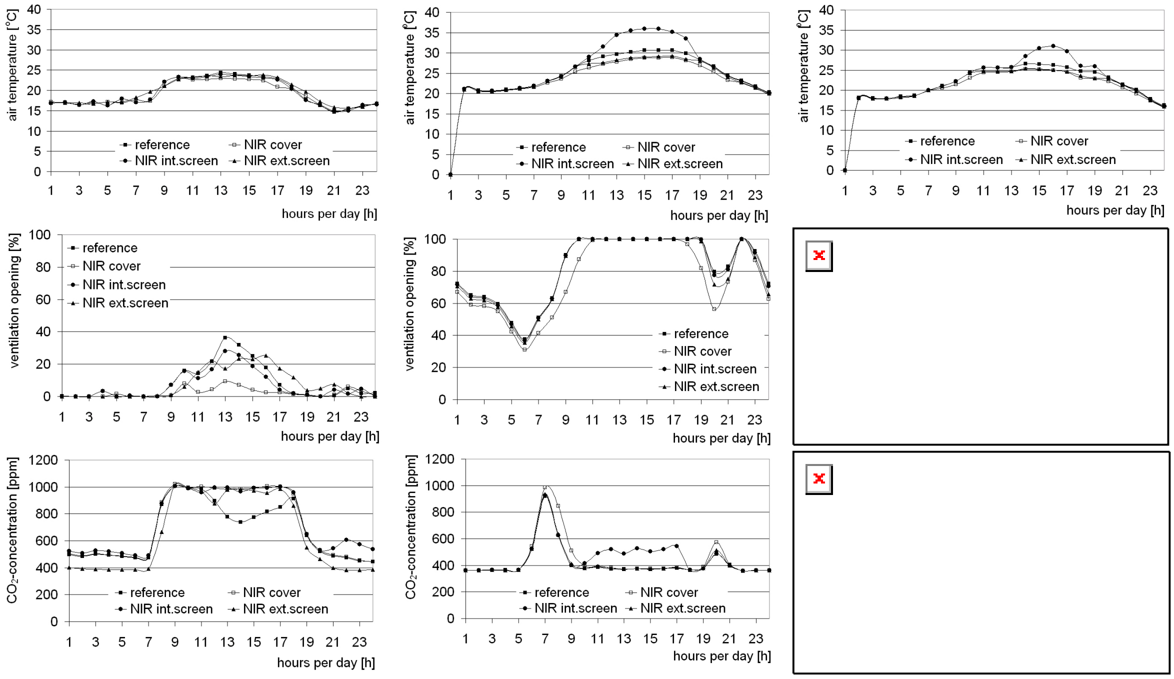

Fig. 3. Effect of several NIR-filtering methods on mean air temperature, greenhouse ventilation opening and CO_2-concentration on selected typical days (left: springtime March, 27th; middle: hot clear summer day July, 30th; right: warm clouded summer day June, 24th of SEL-year) based on calculations with the KASPRO-model (filtering of 100% NIR, greenhouse covering installed permanently, moveable internal and external screen close at 450 W/m^2 outside radiation).