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The influence of shading screen material on air, canopy, and root zone temperature

Gardinmaterialets indflydelse på luft-, blad- og substrattemperatur

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Summary

Air, canopy, and root zone temperature were measured under different shading screen materials with specific characteristics. The surface temperatures of the screen materials were also measured.

The temperature of the air, and plant canopy depended on the specific environment under the screen material. The root zone temperature was independent of the screen material and the temperature of the screen material is assumed not to influence the canopy temperature.

Key words: Air temperature, artificial shade, canopy temperature, root zone temperature, screen temperature, shade factor.

Resumé

Luft-, blad- og dyrkningssubstratets temperatur blev målt under tre forskellige skyggegardiner.

Gardinernes overfladetemperatur blev også målt, men antages ikke at have indflydelse på bladtemperaturen. Derimod var luft- og bladtemperatur påvirket af klimaet under det specifikke gardin. Der kunne ikke påvises nogen sammenhæng mellem gardinmateriale og dyrkningssubstratets temperatur.

Nøgleord: Bladtemperatur, gardintemperatur, lufttemperatur, skyggefaktor, skyggegardin, substrattemperatur.

Introduction

Shading screens are used for a number of purposes in greenhouses. Their primary function are to reduce irradiance and mitigate the rise of air temperature and create the right environment for optimal plant production.

Shading screens are also used as thermal screens at night but the properties of shading and thermal screens are not the same.

The ideal shading screen should reflect the sun's infra-red spectrum (760–2500 nm), and have a high transmission in the wavelength range 300–760 nm. Screens with such properties are difficult to develop. Using a combination of aluminium, which is highly reflective, and polyester which has a low absorbtion and high transmission approach the ideal screen.

The practical results with these screens differ from the result that the growers might expect.

Closing the screens totally results in an undesirable increase in air temperature. Overcoming this problem by closing the screens only 80 or 90%, results in sunny strips across the greenhouse in which plants are unshaded.

Methods for measuring and calculating radiometric properties of greenhouse materials are available (8, 9). In these papers only the properties of the materials are described but not their influence on greenhouse climate.

This paper deals with the influence of screen material on air, canopy, and root zone temperatures in permanently shaded enclosures.

Materials and methods

Six enclosures covered with different shading materials were placed in an unshaded single span east-west orientated greenhouse with a ground surface of 8 m × 20 m. The cladding material was PMMA (polymethylmetacrylate, double wall, 16 mm thick) and the greenhouse had continuous ridge ventilation. The set point for heating was 18°C and ventilation started at 24°C. The air temperature in the greenhouse was measured with a Pt100 sensor placed in an aspirated screen.

The enclosures were made of a galvanized iron frame, on which the shading screen materials were placed. The enclosures had a ground area of 1.5 m × 2.0 m with an overall height of 1.75 m.

The volume of the enclosure was 5.2 m^3 (1.7 m^3 per m^2). The slope of the roof was 25° and parallel to the greenhouse roof. The distance between the upper side of the enclosure and the inner side of the greenhouse roof was 1.4 m. The shading screen material covered the roof, the southern wall, and the two gables leaving the northern wall of the enclosure open. The enclosures were placed randomly in the southern side of the greenhouse 0.4 m from the wall. The enclosures were placed on an unheated bench covered with a dry capillary mat. In each enclosure were placed 105 *Ficus pumila* L. The rest of the greenhouse was filled with six and a half month old *Ficus benjamina* L.

The enclosures were covered with three different shading screen materials: DGT4b, LS14 and LS16. DGT4b (DGT/Volmatic, Farum, Denmark) is a woven acrylic cloth, LS14 and LS16 (Ludvig Svensson, Kinna, Sweden) is a knitted cloth consisting of 5 mm width polyester strips. To obtain a certain shade factor, only a part of the polyester strips are coated with a top layer of pure aluminium on one side of the polyester. The top side of the screen has a high reflectivity and the under side a lower one due to the polyester base. The shade factor is provided by alternating clear polyester strips with aluminized strips. LS14 consists of two strips of clear polyester for each strip of aluminized polyester. LS16 has the opposite composition; two aluminized polyester strips for each clear polyester strip. LS screens were mounted with the aluminium side facing upward to insure reflection of both solar and heat radiation.

For determination of shade factors for solar radiation (300–2500 nm) for the screen materials, a solarimeter (Kipp and Zonen, Delft, Holland) was used. One sensor was placed at plant height in the enclosure, and one was mounted on a revolving rod of 0.5 m placed over the top heating. A third sensor was placed outside the greenhouse. The shade factor is calculated from measurements between 11 a.m. and 2 p.m. where the materials transmit near-parallel radiation. Change in shade factor due to a lower sun elevation in the morning and afternoon is not taken into consideration (12).

The plant canopy and screen surface temperature was measured with an infra-red thermometer (Heimann KT15, Heimann GmbH, Wiesbaden, West Germany). Measuring the plant canopy temperature detector A and lens type M was used. The infrared thermometer was held 0.4 m above the plant canopy and pointed downwards at an angle of about 45° from horizontal. The area measured was 0.06 m^2.

Measuring the screen temperature detector A and lens type K was used. The infra-red thermometer was held 1.3 m from the inner side of the screen at an angle of about 35° from horizontal. The area measured was 0.01 m^2. The air temperature and humidity of the enclosures were measured with a Hygromer sensor (Rotronic-Hygromer HT, Rotronic AG, Zürich, Switzerland). The sensor was screened for direct radiation exposure.

The root zone temperature was measured with a Pt100 sensor placed in the same area where canopy temperature was measured.

The plants were automatically irrigated with water containing fertilizer (0.94 g/l, 10.2 N – 1.3 P – 14.3 K and micronutrient). The plants were irrigated when 1 mm of evaporation had occurred.

The experiment was conducted from 8 June to 8 August.

Results

The shading factor for DGT4b and LS14 was identical (Fig. 1) and LS16 had the highest shading factor.

The air temperature in the surrounding greenhouse was lower than the air temperature in the enclosures during the day (Figs. 2, 3, and 4).

During night the air temperatures were close to each other in both greenhouse and enclosures. The highest air temperature in the enclosures was found under LS14 (Fig. 3). The air temperatures were similar under LS16 and DGT4b (Figs. 2 and 4) and was 1.5°C lower than under LS14.

The highest screen temperature was observed on LS16 (Fig. 4) and the lowest on DGT4b (Fig. 2).

The differences between screen temperatures were greater than the differences between air temperatures even though the difference between LS14 and LS16 was similar to the one for air temperature. The highest canopy temperature was found under LS14 during the day (Fig. 3) and the lowest under DGT4b (Fig. 2).

Only a small difference in root zone temperature was found between the different screen materials. The maximum root zone temperature was reached 1.5–2.5 h after the maximum for air, screen and canopy temperature depending on screen material. The greatest delay was found under DGT4b (Fig. 2) and the shortest under LS14 (Fig. 3). Also a small lag in the maximum for air, screen and canopy temperature was observed between the screen materials.

Discussion

At high air temperature greenhouses are cooled by natural ventilation only. When the shading screen is closed, the air change through the screen material is a limiting factor in natural ventilation. Movement of air through the screen occurs because of the different density of the air, resulting from differences in air temperatures above and below the screen. The LS screen materials used in the experiment have a very low permeability in comparison to DGT4b (*O. Skov* pers. com., 1990). The highest air temperature was also observed in the enclosures covered with the LS14 screens. A screen material with low permeability restricts the convective heat transfer of both sensible and latent heat. It is concluded that the air temperature under a shading screen solely depends on heat loss by convection. The air temperature under LS16 is lower than under LS14 due to a lower transmission because the permeability of both screen materials are identical (*O. Skov* pers. com., 1990).

The temperature of the screen material depends on the absorbtion of radiation, reradiation, and convection. IR-thermometry expresses the

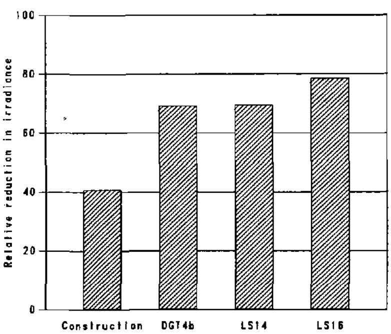

Fig. 1. The relative reduction in natural irradiance for greenhouse construction and three different shading screen materials. In the relative reduction for the shading screens the reduction from construction is included.

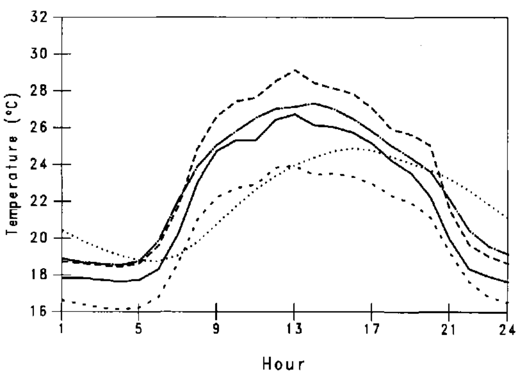

Fig. 2. The temperature profile for air (– –), canopy (- -), root zone (···), and screen (—) under DGT4b and air temperature in the surrounding greenhouse (-··-).

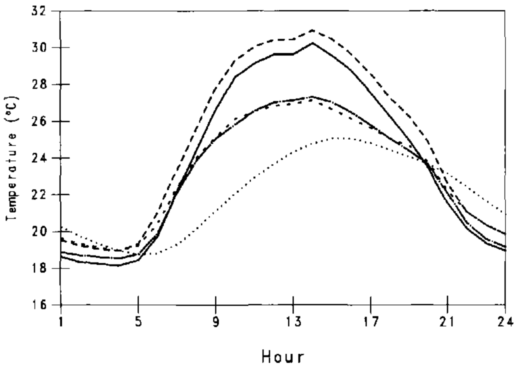

Fig. 3. The temperature profile for air (– –), canopy (- -), root zone (···), and screen (—) under LS14 and air temperature in the surrounding greenhouse (-··-).

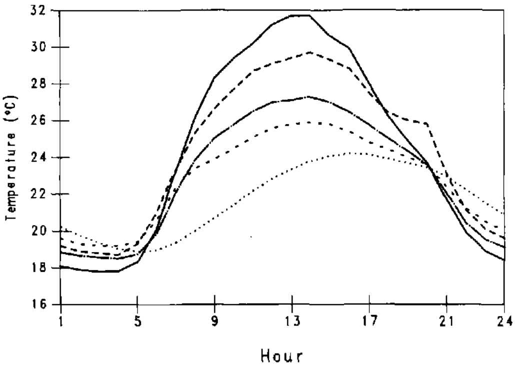

Fig. 4. The temperature profile for air (– –), canopy (- -), root zone (···), and screen (—) under LS16 and air temperature in the surrounding greenhouse (-··-).

surface temperature and is in this case a combination of transmission and emission. The measurement of the screen temperature combined with irradiance is a good expression for the amount of energy the plants receive.

The air temperature is higher than the screen temperature for DGT4b and LS14 during the day. For LS16 the screen temperature is higher than the air temperature.

Polyester has a low absorbtion approximately 5% (9) and low thermal conductivity (0.45 W/m^2 K) (8). Even though aluminium has a high thermal conductivity (211 W/m^2 K) the convective loss is low because of low air speed.

LS16 has the highest reflection but also the highest surface temperature. *Amsen* and *Nielsen* (1) found a higher surface temperature on a thermal screen than the air and canopy temperature during night. The thermal screen was made of polyethylene with a top layer of aluminium. The higher temperature of the screen was due to radiation from the top heating system. *Mellor et al.* (7) found that 32 to 75% of the energy lost by a leaf was by transpiration, 5 to 12% by convection and 13 to 63% by radiation depending on air temperature, wind speed, humidity and irradiance. A part of the energy lost by radiation from the canopy is reradiated back to the screen increasing its temperature.

Due to heat loss by radiation during night the screen temperature is lower than the air temperature independent of the screen material.

Many factors affect the heat balance of the leaf and thus also the leaf temperature. The heat balance depends on air temperature, transpiration rate, vapor pressure deficit, wind speed, convection, reflection, radiation and reradiation. The canopy consists of leaves of different ages, sizes and leaf angles, sunlit and internal shaded leaves resulting in individual transpiration rate and temperature. IR-thermometry expresses the average surface temperature of the canopy. The relation between canopy and air temperatures under the same shade factor (DGT4b and LS14) was different. This indicates that air temperature in this case has the strongest influence on canopy temperature. The difference between air and canopy temperatures under the same permeability but with different shade factors (LS14 and LS16) was equal. It is supposed that radiation has the strongest influence on canopy temperature in this case because the shade factor is different.

From Wien's displacement law the wavelength at which energy is emitted at a certain surface temperature can be calculated. The emission of energy from the screens occurs in the wavelength range 1002–1079, where green leaves have high transmission and reflection (10). The temperature of the shading screen only faintly influences the canopy temperature.

Minimum root zone temperatures up to 25°C increase transpiration (4), reduce production time (5,11) and reduce plant height (5). The root zone temperature has a delay in reaching the maximum temperature compared to air temperature. A similar observation has been made by *Amsen* and *Nielsen* (2). *Keever* and *Cobb* (6) found a slower rise in root zone temperature in growth medium with high moisture content compared to a medium with low moisture content. The decrease in root zone temperature was also slower with high moisture content. The change in growth medium temperature is strongly influenced by the specific heat of water (6). The heat transfer to the root zone occurs in two ways. The leaf absorbs, emits and transmits solar radiation and exchange thermal radiation with the growth medium (3) and as convective heat transfer. In the present experiment the direct exposure of the pot and growth medium to solar radiation is so small that it is a negligible factor in heating the growth medium.

The screen material will reduce the direct radiation and the architecture of the canopy will shade the pot surface and growth medium. The differences between the root zone temperature under the screen materials is very small and in this case it is concluded that the root zone temperature is independent of the screen material. The small differences observed in time to reach maximum temperature under DGT4b result from a lower canopy temperature and are an indirect effect of the screen material.

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