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Relation between water vapour pressure difference and canopy temperature under different shading screen materials

Sammenhæng mellem damptryk og bladtemperatur under forskellige skyggegardin materialer.

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Summary

Water vapour pressure, canopy and air temperature were measured under three different shading screen materials (DGT4b, LS14 and LS16).

The highest average difference between air and canopy temperature was found under DGT4b. LS14 and LS16 had the same average difference between canopy and air temperature. The highest water vapour pressure difference betwen air and the intercellular spaces was found under DGT4b and the lowest under LS16. Different correlations between water vapour pressure difference and difference between air and canopy temperature could be found between the screen materials but also a variation during the day for the individual screen materials was found.

Key words: Air temperature, canopy temperature, *Ficus pumila,* water vapour pressure difference.
Abbreviations: T_a: air temperature, T_c: canopy temperature.

Resumé

Damptryk, blad- og lufttemperatur blev målt under tre forskellige skyggegardiner (DGT4, LS14 og LS16). Den største forskel mellem blad- og lufttemperatur blev målt under DGT4b, mens LS14 og LS16 havde lavere temperaturdifference. Den største damptryksforskel mellem luft og bladenes intercellulærrum blev målt under DGT4b og den mindste under LS16. Korrelationen mellem damptryk og temperatur difference var forskellig under de forskellige gardinmaterialer og varierede også over dagen.

Nøgleord: Bladtemperatur, *Ficus pumila,* lufttemperatur, damptryksforskel.
Forkortelser: T_a: lufttemperatur, T_c: bladtemperatur.

Introduction

The daily pattern in the relation between vapour pressure difference and T_a-T_c is very complex, because many factors are involved eg. irradiance, stomatal resistance, change in spectral reflection. Some of the factors are mutually dependent eg. vapour pressure and temperature. Transpiration decrease when stomata begin to close and as a result the inhibition of CO_2 diffusion through the stomata begins which affects the photosynthesis (12, 13, 14, 16).

The stronger the evaporative conditions around the leaf the sooner any obstruction to the leaf water supply will result in stomatal closing. Under greenhouse conditions it is very easy to keep plants well irrigated and peat which is used as a growth substrate has a high content of available water. The uptake rate of water through the roots and the resistance in the plant from root to leaves is the only limiting factor in the supply of the leaves with water (5).

The shading screen influences transpiration by a reduction in irradiance which reduces the amount of energy received by the canopy. The permeability of the screen material influences the air change rate and thus air temperature and humidity. A low air change rate in a greenhouse results in a high air temperature and water vapour pressure. Due to the characteristics of the screen materials air and canopy temperatures differs widely (1).

The relative humidity (RH) is very often used as an expression of the air humidity, even through it is an inane unit in plant physiology. The vapour pressure deficit of the air is very often used in research concerning drought conditions (8). The vapour pressure difference drives the diffusion of water vapour from the leaf. Therefore the best expression is the water vapour pressure difference between air and leaf because it describes the difference between the vapour pressure inside the intercellular spaces and the vapour pressure in the surrounding air (3).

The aim of this study was to determine the shading screen materials influence on the relation between water vapour pressure difference and the temperature difference between air and canopy (T_a-T_c) in regard to shade factor and air flow rate.

Effects on air, canopy and root zone temperature from the same experiment have previously been published in (1).

Materials and methods

Six enclosures covered with different shading materials were placed in a single span, east-west orientated greenhouse with a ground surface of 8 m x 20 m. The cladding material was PMMA (polymethylmetacrylate, double wall, 16 mm thich) and the greenhouse had continuous ridge ventilation. The set point for heating was 18°C and ventilation at 24°C.

The enclosures were made of a galvanized iron frame on which the shading screen materials were placed. The enclosures were placed in the southern side of the greenhouse on a bench covered with capillary mat. The capillary mat was covered with a perforated polyethylene film which reduce evaporation from the mat but ensure a steady water supply of the crop (4). The enclosures had a surface area of 1.5 m x 2.0 m with an overall height of 1.75 m. The slope of the enclosures roof was 25°C and was parallel to the greenhouse roof. The enclosures were covered with three different shading screen materials: DGT4b, LS14 and LS16. DGT4b (DGT/Volmatic, Farum, Denmark) is a woven acrylic fabric, LS14 and LS16 (Ludvig Svensson, Kinna, Sweden) are knitted fabrics consisting of 5 mm wide polyester strips. To obtain a certain shade factor, a specific number of the polyester strips are coated with a top layer of pure aluminium. By alternating transparent polyester strips with aluminized strips a specific shade factor can be obtained. LS14 consist of two strips of transparent polyester and one strip of aluminized polyester. LS16 have the opposite composition; two aluminized polyester strips and one transparent polyester strip. LS screens were mounted with the aluminium side facing upward to insure reflection of both short- and longwave heat radiation. In the present experiment the total shade factor (greenhouse construction and shading screens) for total short wave irradiance was 69, 70 and 79% for DGT4b, LS14 and LS16 respectively.

In each enclosure 105 *Ficus pumila* L. were placed. The rest of the greenhouse was filled with six and a half month old *Ficus benjamin* L. The plant canopy surface temperatures were measured with a infra-red thermometer (Heimann KT15, Heimann GmbH, Wiesbaden, Germany) with detector A and lens type M. The infra-red thermometer was held 0.4 m above the plant canopy and pointed downwards at an angle of about 45° and the area measured was 0.06 m^2.

In the enclousures air temperature and humidity was measured with a Hygromer sensor (Rotonic-Hygromer HT , Rotronic AG, Zürich, Switzerland). Under the assumption that the surface temperature is an expression of the tissue temperature and that there is saturated vapour

Table 1. Regression lines and correlation coefficient for the relations between water vapour pressure difference and T_a-T_c under three different shading screen materials.

Screen material	Morning	R^2	Afternoon	R^2
DGT4b	y=1.3x+3.1	0.61	y=1.1x+3.0	0.43
LS14	y=2.3x+0.4	0.84	y=1.8x+0.4	0.65
LS16	y=2.1x+1.0	0.71	y=1.9x+0.9	0.44

pressure conditions in the intercellular spaces (7), the water vapour pressure difference between air and canopy can be calculated (2, 18).
The plants were automatically irrigated with water containing fertilizer when 1 mm of evaporation had occurred.
The experiment was conducted from 8 June to 8 August 1989.

Results

The highest difference between air and canopy temperature (T_a-T_c) was found under DGT4b (Fig. 1). The average T_a-T_c was nearly identically for LS14 and LS16 and only in the middle of the day was a slightly higher difference observed under LS16. For all the screen materials T_a-T_c tended to be stable over a period of 3 to 5 h in the middle of the day, but T_a-T_c was higher at the end of the day than in the morning.

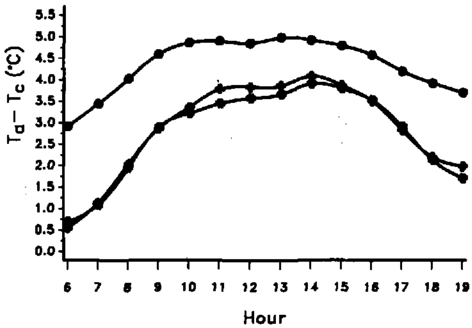

Fig. 1. The profile of T_a-T_c for three different shading screen materials; DGT4b (o), LS14 (*) and LS16 (+).

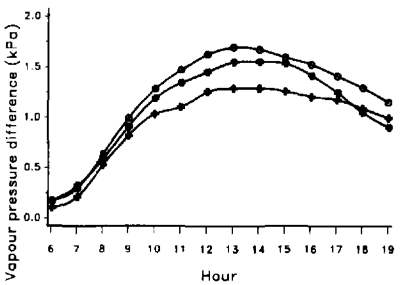

Fig. 2. The profile of the vapour pressure difference for three different shading screen materials; DGT4b (o), LS14 (*) and LS16 (+).

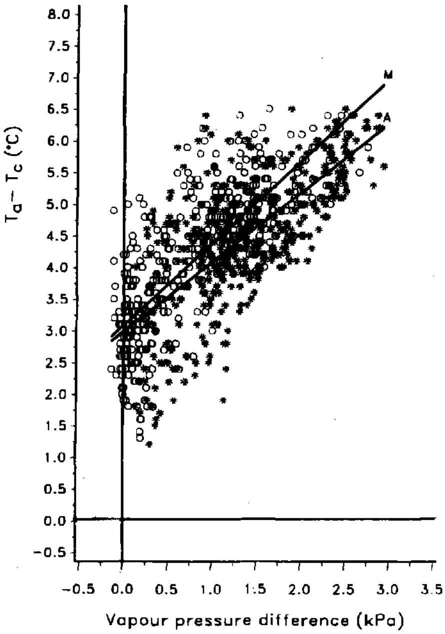

Fig. 3. The calculated water vapour pressure difference vs. T_a-T_c for DGT4b (morning (o) afternoon (*). M and A indicate the regression lines for morning and afternoon respectively.

The highest vapour pressure difference was found under DGT4b and the lowest under LS16 (Fig. 2). As for T_a-T_c the water vapour pressure difference was higher at the end of the day than in the morning.

A correlation between vapour pressure difference and T_a-T_c could be found, but a better description of data was obtained by dividing the data sample in to groups one in the morning and one in the afternoon. The data were divided into two groups by method of least squares and two

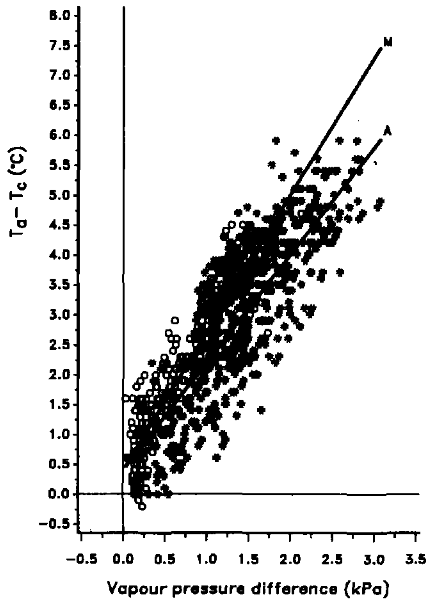

Fig. 4. The calculated water vapour pressure difference vs. T_a-T_c for LS14 (morning (o) afternoon (*)). M and A indicate the regression lines for morning and afternoon respectively.

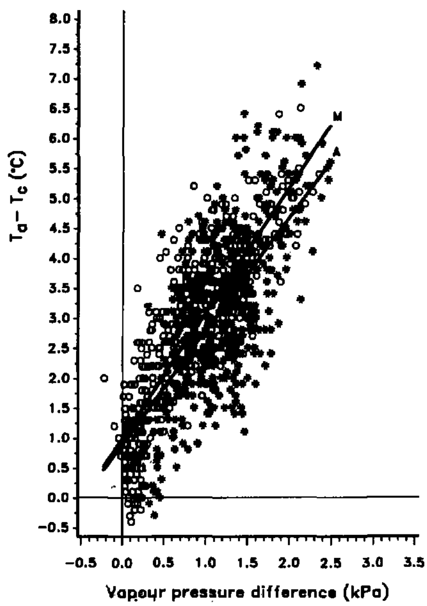

Fig. 5. The calculated water vapour pressure difference vs. T_a-T_c for LS 16 (morning (o) afternoon (*)). M and A indicated the regression lines for morning and afternoon respectively.

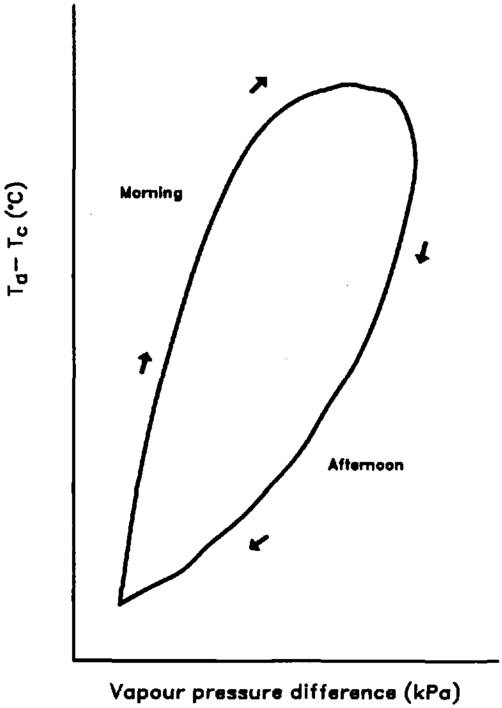

Fig. 6. The generalized relationship between vapour pressure difference and T_a-T_c.

significant different correlations were found between morning and afternoon for each screen material (Figs 3, 4 and 5). For DGT4b and LS16 the first group was between 6.00 to 12.00 hours and the second between 12.00 to 19.00 hours.

For LS14 the first period was between 6.00 to 10.00 hours and the second from 10.00 to 19.00 hours. The relative low correlation coefficient imply that the relation between temperature difference and vapour pressure difference is not linear (Table 1). This could be due to the change in both temperature and irradiance during the day. The data for the morning situation is characterized by increasing irradiance and temperature. The opposite situation occurs in the afternoon where irradiance and temperature decrease. The proposed relation between vapour pressure difference and T_a-T_c is indicated in Fig. 6.

Discussion

The high T_a-T_c under DGT4b is due to the low air temperature under this screen material. LS14 has a lower air change rate which results in high air temperature and convective heating of the canopy occurs. LS16 has the same air change rate as LS14, but a higher shade factor, which results in an air temperature similar to DGT4b. The higher shade factor results in a lower transpiration which reduced the difference between T_a and T_c.

The shade factor has only a slight influence on T_a-T_c at same air change rate (LS14 and LS16). At different air change rate but with the same shade factor (DGT4b and LS14) a small difference in water pressure difference resulted in distinct T_a-T_c values. In long term experiments with shade, acclimation to the light conditions occurs (10). *Fails et al.* (6) found a higher number of stomata per leaf in shade grown *Ficus benjamin* L. *Kappel and Flore* (9) found no differences in stomata resistance in *Prunus persica* L. grown under different shade levels.

Rawson et al. (14) found an increase in transpiration with increasing water vapour pressure difference, while the photosynthesis was unaffected. The measurement was made on individually attached leaves. In the same experiment measurements on whole plants showed that photosynthesis decreased with increasing water vapour pressure difference. The change in the slope of the regression line between morning and afternoon for the three screen materials is due to a decrease in transpiration during the day (5, 16, 17). The specific change in slope of the regression lines for the shading screens is due to their characteristics, which have different evapotranspirative conditions.

The stomatal aperture depends on the humidity and it decreases with decreasing humidity (11). *Hall et al.* (7) found a slight decrease in leaf resistance when leaf temperature increased, if the water vapour pressure difference was kept constant. If the water vapour pressure difference increased, the leaf resistance increased resulting in an increasing leaf temperature. *Lorenzo-Minguez et al.* (12) found a linear decline in leaf temperature with increasing water vapour pressure difference due to a increase in transpiration; however, the leaf resistance increased with increasing water vapour pressure difference. In general DGT4b has the lowest slope for both regression lines, which could indicate that the plants have a high resistance to transpiration. However, the air temperature was lowest (1) and vapour pressure difference highest under DGT4b, therefore the exigency transpiration is lower to keep a high T_a-T_c. Under LS14 the greatest change in the slope of the regression line between morning and afternoon was found. This could be due to the high air temperature under this screen,which results in high transpiration demand.

The variation in data is higher for DGT4b than for the LS screens, indicating that the higher air change rate makes the climate under the screens more dependent on the climate in the surrounding greenhouse.

The daily pattern in the relation between vapour pressure difference and T_a-T_c has been suggested in Fig. 6. The figure is based on analysis of data and assumptions which are described in the following.

In the morning a low vapour pressure difference is able to give a high T_a-T_c due to a decrease in stomatal resistance, increase in irradiance, transpiration and air and canopy temperature. At the end of the morning the maximal transpiration rate is reached and the water uptake begins to be a limiting factor and stomatal resistance increases. The increase in stomatal resistance results in an increase in canopy temperature which also leads to an increase in air temperature. At lower transpiration rates a greater proportion of the radiation is dissipated as sensible heat resulting in an increase in air temperature. The lower transpiration and the elevation in air temperature increase the vapour pressure difference. In the afternoon the irradiance, air and canopy temperature decrease, which results in a lowering of vapour pressure difference, but the stomal resistance will still be high until the full turgidity is reached. Under conditions where transpiration reduces, the spectral reflection of the canopy increases (15) which moderates increase in canopy temperature. A change in spectral reflection has not been measured in the present study, but it is a factor that cannot be neglected.

Similar observations as suggested in Fig. 6, have been made by *Singh et al.* (16) for evapotranspiration and photosynthetically active radiation and photosynthesis and photosynthetically active radiation.

The results presented here are not fully in agrement with results obtained under short term experiments (12, 14). In contradiction to short term experiments the present study covers the diurnal variation in irradiance, humidity, air and canopy temperature. From the present study it is concluded that the relation between water vapour pressure difference and difference between T_a and T_c depends more on the air flow rate through the shading screen material than the shade factor of the screen material.

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