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Effect of Greenhouse Cooling Method on the Growth and Yield of Tomato in the Tropics

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Abstract

Cooling greenhouses in the humid tropics is especially challenging due to the high intensity of solar radiation and humidity prevalent in these regions. The effect of natural ventilation and evaporative cooling on the greenhouse microclimate, growth and production of tomato *Solanum lycopersicum* cv FMTT260 were evaluated. The research was carried out in two greenhouses (measuring 20 m long by 10 m wide) at the experimental site of the "Protected Cultivation Project" on the campus of the "Asian Institute of Technology" (AIT), situated 44 km north of Bangkok in Khlong Luang, Pathum Thani, central Thailand, (14° 04' N, 100° 37' E, altitude 2.3 m). The naturally ventilated greenhouse was covered with a UV-absorbing plastic film on the roof and a 50-mesh insect proof net on the sidewalls and roof ventilation opening. The evaporative cooled greenhouse was completely covered with the UV-absorbing plastic film and was equipped with a fan and pad cooling system. In each greenhouse, 300 tomato plants were grown at a density of 1.5 plants m^{-2} and maintained for 15 to 20 weeks. Results from two seasons show that the cooling method influenced the greenhouse microclimate, plant growth and yield. Although evaporative cooling lowered greenhouse temperature, the unwanted increase in humidity resulted in fungi infections and reduced transpiration. Plants grown in evaporatively cooled greenhouse were 30 cm to 45 cm shorter than those grown in naturally ventilated one. Differences were also noted in flowering, leaf area, dry matter partitioning and harvested yield. The significance of cooling method and greenhouse covering material on plant growth and production in protected cultivation systems in the tropics is discussed.

Key words: *Greenhouse, Natural ventilation, evaporative cooling, nets, microclimate, tomato, tropics*

Introduction

Temperature is one of the most crucial environmental factors influencing plant growth especially in protected cultivation. For tomato (*Solanum lycopersicum L.)*, maximum growth occurs at a day and night temperature of 25 °C (Papadopoulous, 1991). There are various methods for cooling greenhouses, among them evaporative cooling, shading and natural ventilation. Natural ventilation relies more on the prevailing conditions (especially wind) and the size of the ventilation area (Kittas et al., 1996). Covering ventilation openings with insect-proof screens that physically block (Bethke, 1994) or optically prevent (Antignus et al., 1998) the entry of insects into and their distribution within the greenhouse is a common practice nowadays. However, these screens reduce air exchange rates depending on the size of the pore openings (Harmanto et al., 2006) and also influence the light quantity transmitted into the greenhouse (Klose and Tantau, 2004). Fan and pad cooling systems are efficient in reducing the heat load inside greenhouses through the conversion of sensible heat into latent energy, improving the microclimate for plant growth. The objective of this study was therefore, to investigate the effect of natural ventilation and fan and pad cooling on greenhouse microclimate, growth and production of tomato in the humid tropics. The results of this study may contribute to the development of adapted greenhouses for sustainable vegetable production in these regions.

Materials and Methods

The research was carried out at the greenhouse complex at the Asian Institute of Technology (AIT) Thailand, (14° 04' N, 100° 37' E). Greenhouses dimensions were 20 m long by 10 m wide with height of 6.8 m at the ridge and 3.4 m to the gutter. The roof of both greenhouses was covered with the 200 μm thick, anti-dust and anti-fog UV-absorbing PE film (Wepelen™, FVG, Dernbach, Germany). For the naturally ventilated greenhouses (NV), the sidewalls were covered with the UV-absorbing PE film up to a height of 0.8 m above the ground while the remaining portion was covered with a 50-mesh insect-proof net (BioNet, Klayman Meteor Ltd, Petach-Tikva, Israel) up to the gutter (3 m above the plastic film). The greenhouse cooled with the fan and pad system (FP) was completely covered with the UV-absorbing plastic film. The dimensions of the cooling pad were as follows: length: 9.7 m, height: 1.8 m and thickness: 0.15 m. Inside the greenhouses, one horizontal airflow fan was positioned 4 m away from the pad (6 m above the floor of the greenhouse). Three exhaust fans were positioned on the side opposite to the pads i.e. western end and directly opposite the HAF inside the greenhouse. In all the greenhouses, tomato, *Solanum lycopersicum*, cv FMTT260 (AVRDC, Shanhua, Taiwan) were grown in pots at a density of 1.5 plants m^{-2}. The double stem technique for tomato production recommended by Chen and Lal (1999) was adopted. A drip system was used to deliver water and fertilizer to the plants.

Results and Discussion

The intensity of global radiation inside the greenhouses was influenced by the covering material. More radiation was recorded inside FP than NV probably as a result of slight differences in the spectral properties of the UV-absorbing insect-proof net and UV-absorbing PE film, and /or the adherence of dust on the insect-proof nets (Fig. 1A). There was no difference in the intensity of photosynthetic active radiation (PAR) inside both greenhouses. Air temperature was lower in FP than NV. On a representative sunny day during the rainy season (04.07.2006), air temperature increased with increase in global radiation to reach a maximum of 31.3 °C, 29.0 °C, and 32.1 for ambient, FAP and N50, respectively (Fig. 1B). There was no significant difference in the air temperature between the two greenhouses at night. The large ventilation openings in NV increased air exchange hence ventilation thereby lowering air temperature (Harmanto et al., 2006). Temperature gradients were observed in FP with air temperature increasing from the pad to the fans corroborating the results of other authors (Arbel et al., 2003; Kittas et al., 2003). Mean temperature difference from the pad to the fans was 5.1 °C. A slight increase in air temperature was realized in the evening after the fans were switched off. High and low air exchange during the day and night, respectively, led to a higher concentration of CO_2 in FP. Maximum CO_2 concentration was 687 μmol mol^{-1} and 445 μmol mol^{-1} in FP and NV, respectively, recorded just before daybreak. The fan and pad cooling system increased the water content of the air and decreased vapour pressure difference (VPD). The mean value for ***VPD*** in the rainy season was 1.3 kPa, 0.4 kPa and 1.2 kPa, for ambient, FP and NV, respectively.

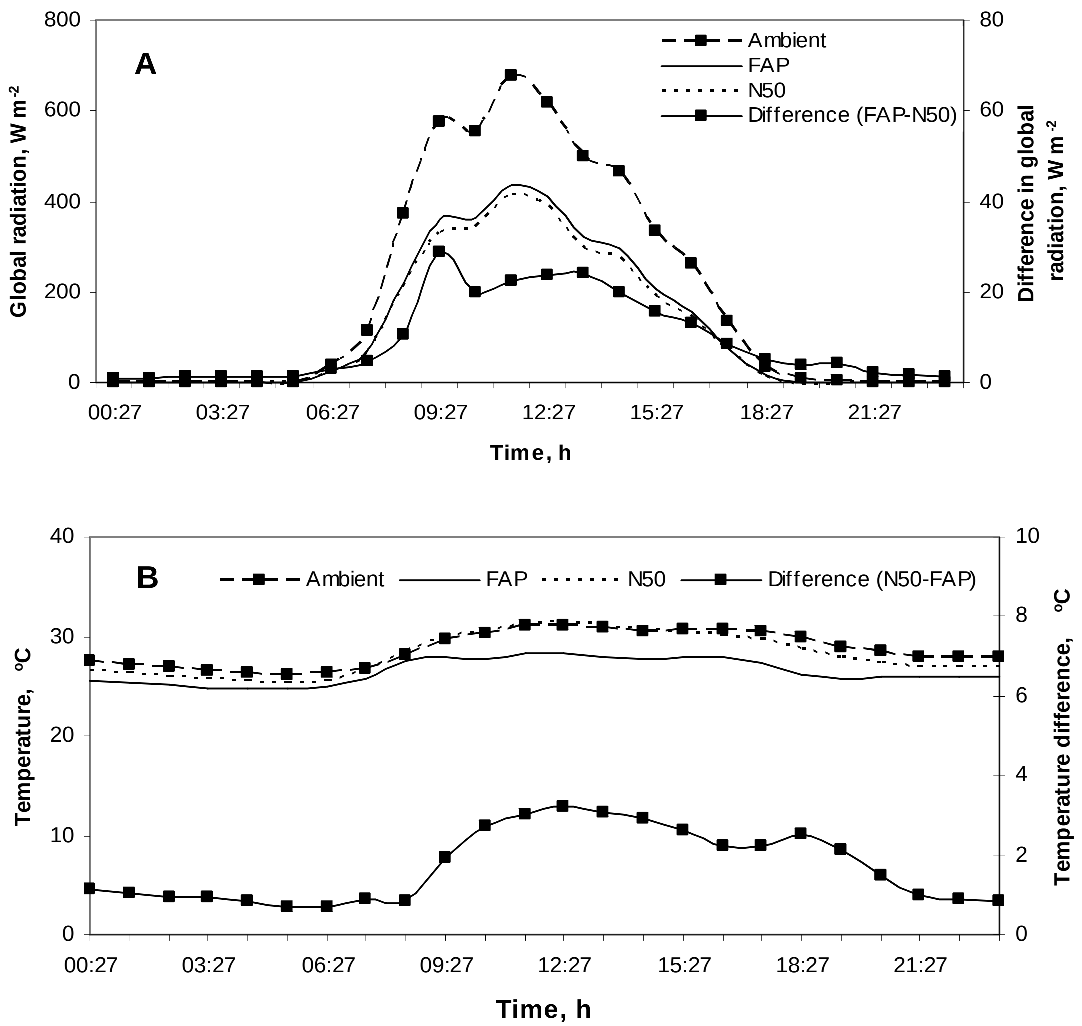

Figure 1: Intensity of global radiation (A) and diurnal temperature (B) profiles recorded inside and outside the evaporatively cooled (FAP) or the naturally ventilated (N50) greenhouse on a representative sunny day (04.07.2006) during the rainy season.

Cumulative water requirement during the rainy season in NV from 4 WAT to 16 WAT was almost double (24.86 L plant^{-1}) that of plants in FP (13.40 L plant^{-1}), indicating low transpiration in the latter. Moreover, during both seasons, plants in FP had a better water use efficiency (WUE) compared to those in NV. Calculated on the total harvested yield and cumulative water consumption between 4 WAT to 16 WAT, WUE was 0.553 kg L^{-1} and 0.349 kg L^{-1} for FP and NV, respectively during the dry season. WUE during the rainy season was 0.147 kg L^{-1} and 0.094 kg L^{-1} for FP and NV respectively. Maximum height at 16 WAT during the rainy season was 295.3 cm and 321.2 cm in FP and NV, respectively. Furthermore, plants in FP allocated more resources to leaves and fruits compared to NV. Leaf area index (LAI) was only significantly different during the dry season, being higher in FP.

These results indicate that the kind of cooling systems installed in a greenhouse influences the overall greenhouse microclimate. This has a significant effect on plant growth, disease infestation and crop water requirement. Temperature reduction by the fan and pad cooling system may improve fruit set for tomatoes (Peet et al., 1997) but the accompanying high humidity increases the risk of fungal infection. Max et al., (2007) reported an increase in the number of fruits affected by blossom-end rot (BER) in FP compared to NV. This was attributed to a decrease in calcium transport caused by a low transpiration in FP (Ho et al., 1989). The higher air exchange of the FP enhances replenishment of CO_2 thereby boosting photosynthesis. Small difference between day and night temperatures (DIF) in FP resulted in shorter plants possibly due to shorter internodes (Berghage, 1998). Large DIF increases cell elongation instead of cell number thus taller plants with a slightly lower leaf area were recorded in NV, while the converse was true in FP.

Conclusions

There was a better microclimate (air temperature and CO_2 concentration) in FP compared to NV. However, small DIF led to the production of shorter plants while high humidity increased fungal infestations and BER incidences. Plants grown in NV had a higher transpiration hence higher crop water requirement and a lower WUE during both dry and rainy season. The results imply that none of the two methods investigated could adequately provide an optimal microclimate for plant growth. High ambient relative humidity limits the efficiency of evaporative cooling systems in these regions. On the other hand high ambient temperatures (due to high solar radiation) limit the performance of natural ventilation. A combination of natural ventilation and filtration of near infra-red radiation may provide better conditions for plant growth in the regions.

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