Effects of Three Cooling Systems on the Microclimate of a Greenhouse with a Pepper Crop in the Mediterranean Area

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Keywords: greenhouse, whitening, forced ventilation, evaporative cooling,

Abstract

Control of the greenhouse microclimate during the summer is an important challenge in warm climate areas. Different cooling systems allow the limitation of high temperatures and/or low relative humidity levels inside the greenhouse. In the present work the microclimate conditions in three greenhouses with the same pepper crop and three different cooling systems were determined: mechanical ventilation; fog system and natural ventilation and plastic whitening with natural ventilation. The highest differences, between the systems, were measured in the first weeks after transplanting, when plants had a low leaf area index (LAI<1) and high temperatures occurred inside the greenhouse. The maximum temperature differences (weekly average of maximum temperatures) between inside and outside the greenhouses, were 8.4 ºC with mechanical ventilation, 4.1ºC with fogging and 5.1ºC with whitening. The maximum vapour pressure deficit values inside the greenhouses were 4.1 kPa, 3 kPa and 3.7 kPa for the three cooling methods respectively. To maintain the assigned climate settings, the fog system consumed 138 L m^{-2} of water and the electricity consumption of the forced ventilation system was 9.3 kWh m^{-2}. As the final yields were very similar in the three treatments (no significant differences were found), we consider that whitening of the plastic cover was the most efficient cooling system in terms of water and energy use.

INTRODUCTION

It has been recognised that there is a continuing need to adapt and improve greenhouse structures and equipment to enable the skilful management of the different aspects of the crop production system to achieve the objectives of expanding the seasonality of crops, increasing the cultivation period, and obtaining satisfactory levels of marketable and quality produce that will increase the net income of growers (Baille, 2001). Cooling the air inside a greenhouse is a problem of particular importance in warm climate areas, because the high temperatures potentially limit the correct growth and development of the crop, the quality of its production and the income generated.

In Almería, pepper is grown during the summer period (from June to August), thus making greenhouse climate management during this period one of the priorities in the horticultural sector. Good management of the climate control systems (ventilation, evaporative cooling and shading), can avoid episodes of physiological stress that are harmful to the plants and adversely affect the yield and quality of the final production (González-Real and Baille, 2000).

Nowadays, growers commonly use whitening of the plastic cover to reduce the amount of radiation entering the greenhouse, and this is used in combination with natural ventilation as the most common method to cool the greenhouse during the hottest periods.

During the 2004/2005 season the climate conditions experienced by a pepper crop grown in perlite with different cooling systems (mechanical ventilation, fog system with natural ventilation, and whitening with natural ventilation) in plastic multi-tunnel greenhouses were studied.

MATERIALS AND METHODS

Greenhouse and climate control devices

The experiments were carried out in three multi-span experimental plastic-covered greenhouses, E-W oriented, located near Almería (36º 47´ N, 2º 43´ W) on the coastal area of south-eastern Spain. The geometrical characteristics of the greenhouses were: 3 m height at the eaves, 4.5 m height at the ridge, total width 22.5 m, total length 28 m, ground area 630 m^2 and volume 2,923 m^3. The three cooling systems (Fig.1) were:

1. Greenhouse T1- Forced ventilation, with three fans located in the eastern gable, at 3 m height, with the entrance in the opposite gable. The maximum airflow rate was 40,000 m^3 h^{-1}, and temperature set points were modulated in the range 22-25 ºC depending on the humidity level. During the operation of the fans, the roof vents were opened to about 30% of their maximum aperture and the side vents were closed.
2. Greenhouse T2- Natural ventilation with evaporative cooling (high-pressure water fogging system). The set point of the air vapour pressure deficit, VPD, was fixed at 1.5 kPa.
3. Greenhouse T3 - Natural ventilation plus whitening, (about 30% reduction in greenhouse solar radiation transmission) during the first 2 months of the crop cycle, and only natural ventilation after washing off the whitening on September 17^{th}.

All actuators were connected to a commercial climate controller which maintained the desired set-points.

Crop and cultural practices

The rows of sweet peppers (cv. Melchor) were transplanted on 21^{st} July 2004 in bags (40 L volume) filled with perlite. Plant density was 2.97 plants m^{-2}. The distance between rows was 1.60 m, and the distance between plants was 0.21 m. Water and fertilisers were supplied by means of a drip irrigation system which was automatically controlled by a fertirrigation computer. The plants were managed following the "trellis" technique, which consists of keeping two main stems per plant and pruning all auxiliary shoots.

Measurements

The relevant climatic variables were continuously monitored outside and inside the three greenhouses. Air temperature, Ta (ºC), and VPD (kPa), were measured by aspirated psychrometers, located 1.5 m above the ground, and solar radiation, Rs (W m^{-2}) by a solarimeter. The CO_2 concentration was measured from 5^{th} December by a CO_2 analyzer (model APBA-250E, HORIBA, Germany). Climate control and management was made from 30 s measurements averaged every 5 minutes, by means of a climate controller. With the aim of easing the analysis and understanding of the climate data, they were grouped in weeks and the growing cycle was divided in two periods, period 1, from the beginning of the crop to the removal of the whitening during week 9 (58 days after transplanting (dat)) and period 2, from week 10 until the end of the crop cycle.

In each greenhouse the transmissivity of the covering material for PAR radiation was determined by measuring with a linear sensor (LICOR Inc, Lincoln, Nebraska, USA), on clear days at 12:00 (GMT time). In each greenhouse, 4 Pt-100 sensors were placed on two plants, to measure the average temperature of the crop.

RESULTS AND DISCUSSION

During period 1 (when cooling systems were more active), temperature values above 36ºC occurred with fan ventilation, giving this greenhouse maximum temperatures 2 ºC above the other two treatments. Therefore, we can observe in Fig. 2, during weeks 2 and 3 that the fog and whitening treatments show temperatures 3.5-4 ºC below those in the fan ventilation treatment.

The maximum temperature differences (average per week) between the three treatments and the outside, represented in Fig. 3, show a decrease as the plants grow, going from initial values of up to 8 ºC in the fan ventilation treatment with a young crop to values of 1.5 ºC with a fully developed crop. This shows, therefore, that a well developed crop with high light interception and with good irrigation is the most important cooling agent in the greenhouse, when combined with ventilation.

From week 5, the whitening became the most efficient method of controlling temperature inside the greenhouse, although the differences with the fog system treatment were minimal, confirming that with a fully developed crop the combination of shading plus natural ventilation and high transpiration rates provides the most efficient or appropriate cooling strategy. These results agree with those obtained in similar experiments (Matallana and Montero, 1989; Francescangeli et al., 1994; Peréz Parra et al., 2005).

In order to analyze the efficiency of the three cooling treatments, the ambient temperatures, VPD values and leaf to air temperature differences were compared (Fig. 4) for the 24th August (34 dat). In the forced ventilation greenhouse temperatures above 40 ºC were achieved, with the maximum values for the fogged and whitened greenhouses being 2 ºC and 3.5 ºC lower respectively. The maximum diurnal VPD values also occurred with forced ventilation (4.1 kPa), compared to 2.3 kPa with whitening and 2 kPa with fogging. On the other hand, leaf temperature had a different behaviour, the highest values were reached in the fog system greenhouse (35.8 ºC), against 34.1 ºC in the forced ventilation greenhouse and 33.2 ºC in the whitened greenhouse. The leaf to air temperature difference shows the capacity of the leaf to cool itself. Figure 4c shows the forced ventilation and whitening treatments achieved the most negative values, below -6 ºC, whereas in the fog system greenhouse only -4 ºC was achieved, which might indicate that the low VPD values maintained with the fog system may have limited the transpiration rate. Baille et al. (2001) observed that the effect of shading was quite noticeable in decreasing leaf temperature which reduced the water stress suffered by the crop and, as a consequence, it may induce an improvement in the stomatal behaviour.

During period 1, the maximum VPD values were achieved with forced ventilation (up to 4.1 kPa), while those in the other treatments were approximately 1 kPa lower. In period 2 the values decreased noticeably, but the relationships between the three treatments were similar (Fig. 5). The fog system provided VPD values lower than those obtained in the whitened greenhouse during the first five weeks of the crop cycle. From week 6, it was observed that as leaf area increased (LAI>1) and external radiation fell below 20 MJ m^2 d^{-1}, the whitening treatment was able to maintain a lower VPD, even lower than the fog system greenhouse set point.

Figure 6 shows the evolution of the average diurnal global radiation integral outside and inside the three greenhouses, through the crop cycle. The outside global radiation decreased as the crop developed, beginning at 26 MJ m^{-2} d^{-1} (week 2) and reaching a value of 4 MJ m^{-2} d^{-1} (week 20) at the winter solstice.

The average transmissivity values at noon in the whitened greenhouse (around 30%) are of the same magnitude of those cited in experiments by Francescangeli et al. (1994) (35%), Morales et al. (1998) (34.1%), Fernández-Rodríguez et al. (1998) (31.2%), Baille et al. (2001) (31%), Sánchez (2003), Aroca (2003) (35 %) and Maillo (2005)(34%).

The forced ventilation treatment was the best strategy for maintaining high values of CO_2 concentration inside the greenhouse it increased the minimum CO_2 concentration in relation to the other cooling techniques by up to 50 ppm (values not shown).

The total water use by the fog system treatment to maintain the minimum VPD set point of 1.5 kPa, was 138 mm; which is similar to the value reported by Maillo (2005) for the 2003/2004 season with the same VPD setpoint of 1.5 kPa, but lower than the value obtained by Aroca (2003), for a setpoint of 0.9 kPa. At the end of the crop cycle (232 days), the electricity consumption of the forced ventilation system was 9.3 kWh m^{-2}, which is similar to that obtained by Maillo (2005) in the 2003/2004 season, for similar conditions.

CONCLUSIONS

The general conclusions from this comparative study are:

1. During the first crop period, with LAI<1, mechanical ventilation was the least effective cooling technique, as it gave the highest air temperatures and VPD values.
2. For LAI>1, the crop was the most important cooling factor and therefore mitigated the differences between treatments.
3. The whitening treatment was the most effective in reducing crop temperature.
4. For an autumn-winter cycle pepper crop the combination of whitening and natural ventilation was the most efficient cooling strategy. This conclusion justifies the common use of this technique by the growers in the area. However, it is necessary to optimize its use, by determining the efficiency of the different whitening products, the optimum dose, and establishing physiological criteria to determine the best date for washing it off.

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Figures

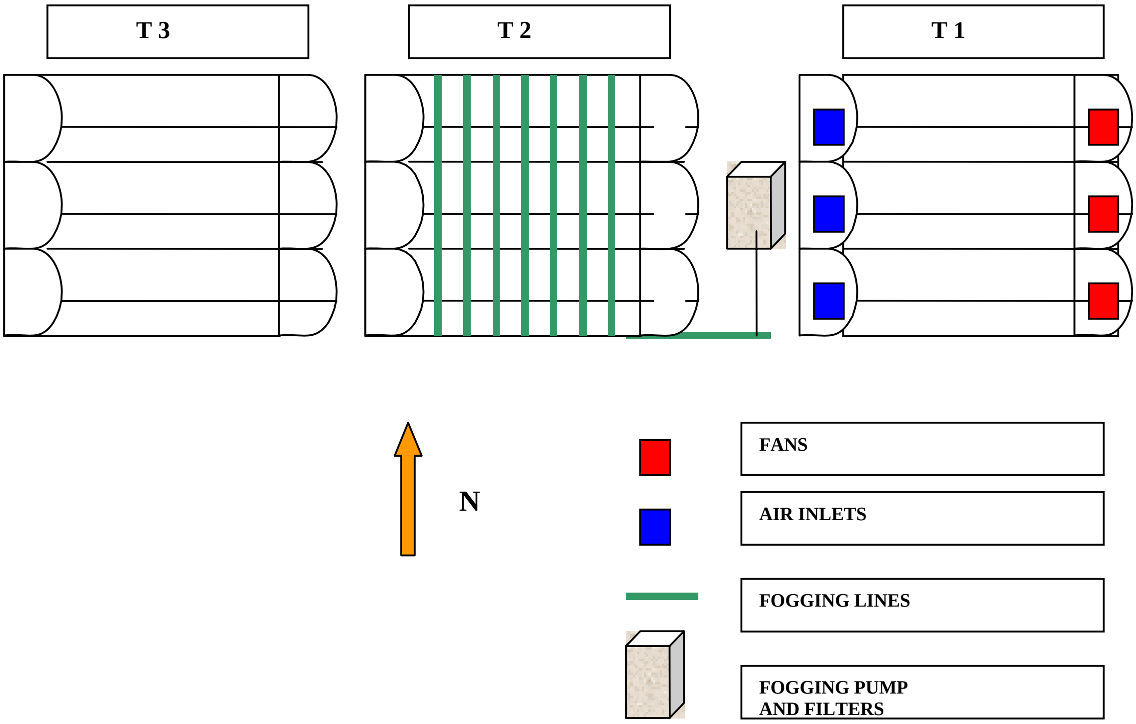


Fig. 1. Schematic diagram of the three experimental greenhouses: (T1) forced ventilation, (T2) high pressure fogging and (T3) whitening.

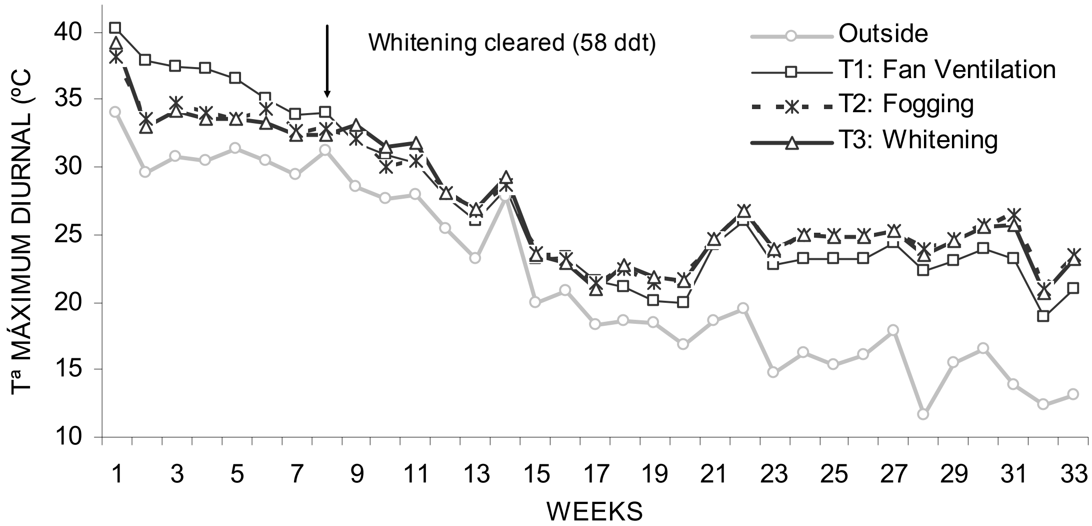


Fig. 2. Evolution of the greenhouse and outside air temperatures. Weekly averages of the diurnal maximum values.

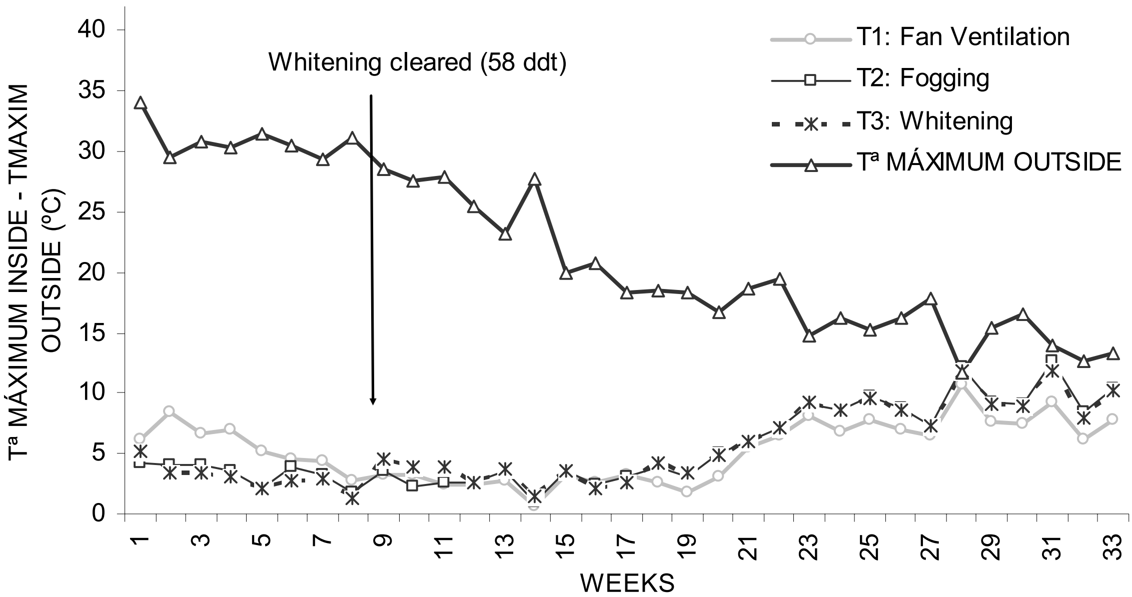
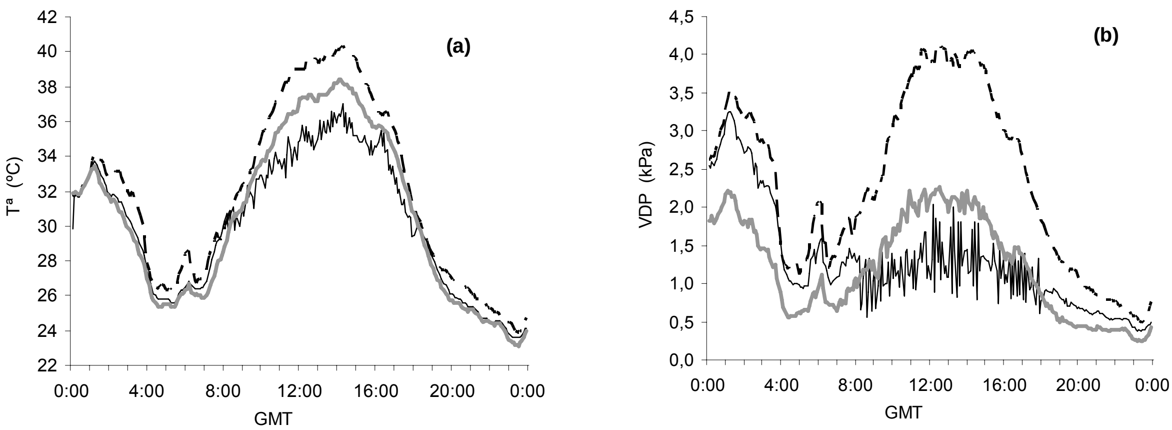
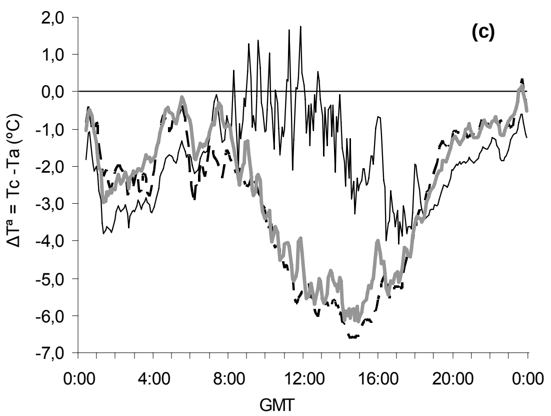


Fig. 3. Evolution of the inside-outside the greenhouse temperature difference for the three cooling treatments.





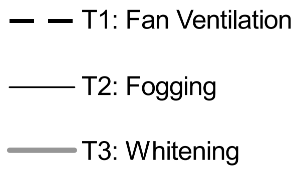


Fig. 4. Hourly evolution of the air temperature (a), air VDP (b) and the canopy-to-air temperature difference (c) at DAT=34 (24 August).

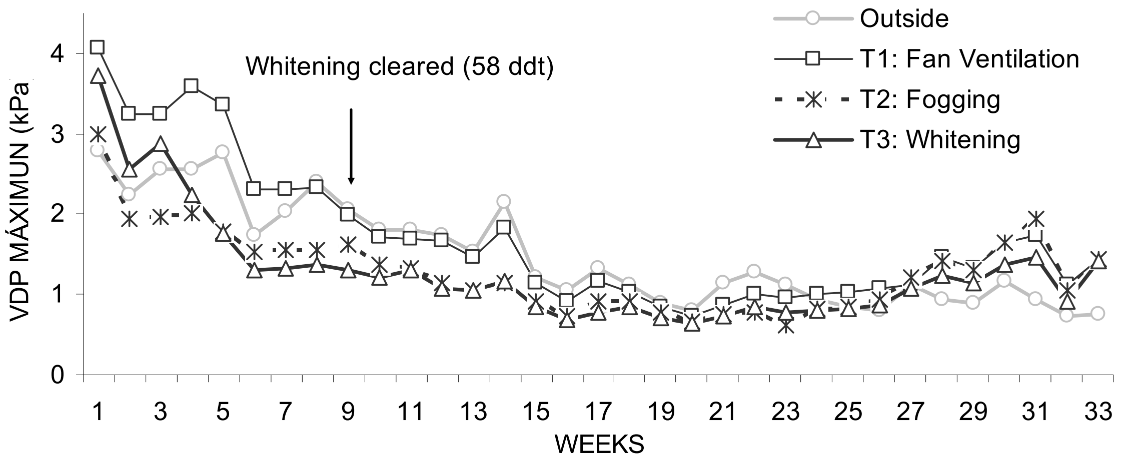


Fig. 5. Evolution of the VPD (kPa) in the three greenhouses and outside. Weekly averages of maximum diurnal values.

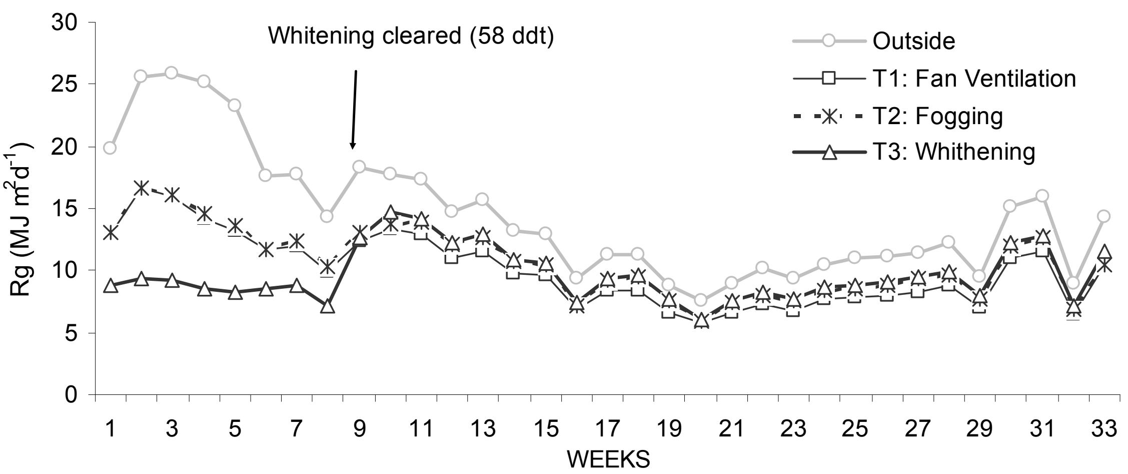


Fig. 6. Weekly averages of diurnal global radiation integral (MJ m^{-2} d^{-1}) for the three cooling treatments.