Effects of Misting Used to Improve the Microclimate and Productivity of a Screenhouse Crop

M. Romero-Gámez, E. M. Suárez-Rey and T. Soriano (IFAPA-Centro de Investigación y Formación Agraria, Granada, Spain)

Summary

One of the greatest challenges in screenhouse horticulture is the control of environmental conditions required to reduce the high vapour pressure deficits (VPD) recorded during most of the day in the summertime. This paper describes the results of the research conducted on evaluating the effect of low-pressure misting on the microclimate of a screenhouse on a green bean crop (Phaseolus vulgaris L. 'Festival') over two spring-summer production cycles in south-east Spain, together with a quantification of its water use efficiency (WUE). We compared a screenhouse equipped with a low-pressure misting system (SM), with a screenhouse without a misting system (S) and with conventional open-field crops (OF). The main effect of misting was a fall in the temperature of the plant canopy and of the maximum air temperature and VPD recorded at times of highest radiation and evaporative demand, and an increase in total and commercial productivity compared to the other systems. The misting reduced the light transmission with differences of 132.9 MJ m–2 in 2008 and 155.8 MJ m–2 in 2009 with respect to the S system. WUE was highest for the S system since SM required additional water for misting (29.3 % in 2008 and 45.5 % in 2009).

Keywords. global radiation – Phaseolus vulgaris L. – photosynthetically active radiation – plant canopy temperature – vapour pressure deficit (VPD) – water use efficiency (WUE)

Introduction

The screenhouse cultivation system is a promising technology in many countries with warm, tropical and subtropical climates, and in arid and semi-arid regions (Tanny 2010) such as Mexico, Italy, Israel or Spain. The expansion of screenhouses in inland areas of different regions in Spain could help to promote economic development, especially in areas in which there are few development options and which are falling behind coastal regions that have a better climate and a higher potential for economic growth.

The use of a greenhouse structure covered with woven netting that reduces incident radiation and the effects of the wind and increases the relative humidity of the air, would enable crop cycles from spring to autumn (the frost-free period) in these inland areas. These structures have a lower wind and rain load than plastic greenhouses, thus reducing manufacturing costs.

Screenhouses have certain limitations, the most frequent of which are: excessively high temperatures and low ambient humidity, excess shade at the end of the cycle (in crop-cycles that last until the autumn), extreme VPD levels at midday (Romero-Gámez et al. 2009) and in general the fact that it is difficult to control the environmental conditions inside them (Romero-Gámez et al. 2008). For this reason, although the microclimate of screenhouses has been analysed by various authors (Möller and Assouline 2007; Mutwiwa and Tantau 2009, among others), research is still required into different systems that could improve the microclimate inside these structures, due to their ever more frequent use in different parts of the world.

Excessively high temperatures and low humidity levels (high VPD) cause the plant to suffer periods of stress that affect its metabolism, leading to losses during fruit formation and thus, poorer production levels and quality of the crops produced, as has been documented for example in peppers (López-Marín et al. 2009a), tomatoes (Rosales et al. 2011) and beans (Romero-Gámez et al. 2009).

The installation of misting systems in screenhouses could be an interesting option for summer crops growing under conditions of low relative air humidity, high daytime temperatures and high VPDs. Low-pressure misting systems are a good, cost-effective way of alleviating these extreme conditions as they use poor-quality water and plastic pipes, which reduce considerably both installation and daily running costs (Gámez et al. 2010).

The objective of this study was to assess the effect of misting on the microclimate of a screenhouse and the
Materials and Methods

A screenhouse equipped with a low-pressure misting system (SM), with a screenhouse with no misting system (S) and with conventional open-field crops (OF) over two spring-summer crop cycles (2008 and 2009) were compared. The study was conducted at the Instituto de Investigación Agraria y Pesquera (Agriculture and Fisheries Research Institute), Centro “Camino de Purchil”, situated in the Vega of Granada, Spain (latitude: 37° 10’ 21” N; longitude: 3° 38’ 10” O; altitude: 600 m).

Description of the experimental plots

A trimodular screenhouse with a metal roof-end structure covering an area of 960 m², with the main axis running north-south was used. The roof was made of a natural, black-and-white polyethylene mono-filament screen of 9x6 strands cm⁻² (58 % porosity). The manufacturer of the shading material was Criado y Lopez, S.L. (Almería, Spain). The sides of the structure were covered with a black screen of 16x10 strands cm⁻² around the entire perimeter and air-impermeable plastic raffia.

The screenhouse was divided in two sectors (Sector 1 and Sector 2). In Sector 1 a low-pressure misting system was installed in order to characterize its cooling effect on the microclimate and on the development of the crop. This sector was separated from Sector 2, which had no misting, by a 38-μm clear plastic curtain along the central aisle of the screenhouse to separate treatments avoiding any effect on radiation transmission.

Two misting feed-lines were installed in each module of the greenhouse. These lines were 4 m apart from each other and 2 m from the misting line (Fig. 1). The lines were installed at a height of 3.5 m. The misting system operated at a pressure of 450 kPa with 7 L h⁻¹ nozzles placed with a density of 0.125 nozzles m⁻².

A control unit to operate the misting system was used in this experiment (IRTA-IFAPA®). This device controls the operation of the nozzles on the basis of a preset value for VPD, in our case 2.5 kPa. The time interval between the pulses was set at 90 seconds and the system was run for six hours around solar midday (from 10:00 to 16:00 solar time). The control unit was switched off for the rest of the time to minimize water consumption.

The open-field study was conducted on a plot of 494 m². All three experimental sites had a usable cultivated area of 336 m². The beans were trained with polyethylene raffia tapes positioned at a height of 2 m. The soil was mulched with polyethylene black raffia to prevent loss of moisture from the soil and weeds from growing.

The chosen crop was a green bean of the ‘Festival’ variety. The beans were sown in paired north-south lines, four plants per spot. Planting density was 21.33 pl m⁻². Sowing took place in the first week of May. Shoots emerged approximately ten days after sowing (d.a.s.). In both cycles harvesting began at approximately 60 d.a.s. In the 2008 cycle, harvesting finished at 109 d.a.s. in OF (interrupted by a problem with the irrigation system) and 164 d.a.s. in S and SM. In the 2009 cycle harvesting in all the systems finished 135 d.a.s.

Study of the Microclimate

To characterize the microclimate conditions air temperature and humidity probes (HMP45C, Vaisala, with values
in °C and %), soil temperature sensors (107, Campbell Sci., with values in °C) at a depth of 10 cm, global radiation sensors (SKS1110, Sky Instruments, with values in W m−2) and photosynthetically active radiation sensors (SKP215/S, Sky Instruments, with values in μmol m−2 s−1) were installed (two sensors of each type per crop system). The sensors were connected to a datalogger (Campbell Sci. CR10X). Weekly leaf-temperature measurements (halfway up the plant) on both the upper and the underside of the leaf were also performed with an infrared thermometer (PCE GROUP) with six repetitions per treatment.

Relative Chlorophyll Content

Weekly measurements of the relative leaf chlorophyll content were taken in the central part of the plant at 08:00 solar time with six repetitions per treatment, with an SPAD 502 meter (Soil Plant Analysis Development, Minolta).

Fertigation System

Irrigation at all the sites was regulated by automated drip watering. Two feed lines above each crop line with emitters with a flow rate of 3 L h−1 were installed. The operating pressure was 180 kPa. Irrigation was programmed with soil-moisture sensors (ECH2O EC-5, Decagon devices) so as to maintain soil volumetric water content values of 20–30 % in the root zone.

The doses of fertilizer were calculated according to the particular characteristics of each trade formula, the amounts of irrigation water being supplied and the needs of the crop (CASAS 1999). Fertilizing was programmed for a conductivity of 0.8 mS cm−1 and a pH of 6.5.

Water Use Efficiency

The water use efficiency (WUE, g L−1) was calculated according to the commercial production obtained (g m−2) relative to the amount of water supplied by irrigation (L m−2). Calculations for the SM system included the water used by the misting system. MONTERO et al. (2003), REINA-SANCHEZ et al. (2005) and GARCÍA (2007) obtained the water use efficiency in commercial greenhouses for Mediterranean conditions.

Statistical treatments and design

An analysis of variance and the Minimum Significant Difference (MSD) Test (GÓMEZ and GÓMEZ 1984) were calculated as part of a statistical study of the results for leaf and air temperature, VPD, chlorophyll and production. The statistical design used for each year was multi-factor with nested factors and three repetitions. The principal factor was the crop system: a screenhouse (S), a screenhouse with a misting system (SM) and an open-field control (OF), and the nested factor was the eastern (E) and western (W) side of each system. There were 3 repetitions of each of the 6 treatments: SE, SME, OFE, SW, SMW and OFW. The factor ‘year’ was taken as a source of variation crossed with the crop systems.

Results and Discussion

Radiation

The microclimate inside the screenhouse is characterized by a substantial decrease in the average daily values for global radiation (Table 1) due to the density of screen. The fall in the integral for global radiation measured in the S crop system was 1997.5 MJ m−2 in 2008 and 1209.2 MJ m−2 in 2009, compared to the integral measured in OF. The higher decrease in radiation observed the first year was possibly explained by some dust accumulation on the screen surface as a result of field works adjacent to the screenhouse in 2008.

The drops of water dispersed by the misting system reduced this value even further with differences of 132.9 MJ m−2 in 2008 and 155.8 MJ m−2 in 2009 between the SM and S systems.

The microclimate created inside the screen was also characterized by a substantial reduction in the maximum PAR value compared to OF (approximately 1200 μmol m−2 s−1 in S, on a sunny day and at the time when the sun was highest in the sky (12:00 solar time) compared to approximately 1800 μmol m−2 s−1 in OF) (Fig. 2). Misting also reduced the incident PAR on the plants with differences at 12:00 solar time of more than 150 μmol m−2 s−1 compared to S. According to URBAN and LANGELEZ (1992), the fall in PAR induced by the misting system may be considered a negative effect, but this effect is much smaller than that caused by other cooling systems such as whitewashing or shading in plastic greenhouses.

Table 1. Cumulative and relative global radiation during the 2008 and 2009 cycles inside the screenhouse without a misting system (S), the screenhouse with a misting system (SM) and in the open-field (OF).

<table>
<thead>
<tr>
<th>Cycle</th>
<th>d.a.s.</th>
<th>System</th>
<th>Radiant Exposure (MJ m−2)</th>
<th>Relative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>169</td>
<td>OF</td>
<td>3879</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>1873</td>
<td>48.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SM</td>
<td>1749</td>
<td>45.1</td>
</tr>
<tr>
<td>2009</td>
<td>135</td>
<td>OF</td>
<td>3542</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>2349</td>
<td>66.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SM</td>
<td>2184</td>
<td>61.7</td>
</tr>
</tbody>
</table>

d.a.s. (days after sowing)
houses. In our case, given the time of year in which the crop is growing, this loss of radiation was offset by the beneficial effects of the fall in temperature and VPD, the main limiting factors in plant development.

Relative Chlorophyll Content

The relative chlorophyll content in the leaves of the green beans during the 2008 and 2009 crop cycles was relatively higher in the OF system but not significantly, than in the screenhouse (Table 2). High radiation levels may cause a lower chlorophyll content and possibly even to the photo-destruction of chlorophyll, known as ‘bleaching’ (CASTILLA 2007). OLAV and ASBJORN (1998) found in laboratory tests that higher relative chlorophyll contents (measured in SPAD values) were proportional to lower PAR values. In our case, radiation was not a limiting factor in the screenhouse, and the plant did not require any increase in its chlorophyll content. There was no significant difference between crop systems from one year to the next and neither was there any significant difference within each crop system.

Air temperature and VPD

Table 2. Average relative chlorophyll content (measured in SPAD values) of green beans inside the screenhouse without a misting system (S), the screenhouse with a misting system (SM) and in the open-field (OF) during the 2008 and 2009 cycles (Standard error for comparison = 1.80). There were no significant differences nor among treatments any given year nor between years.

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Chlorophyll</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
</tr>
<tr>
<td>2008</td>
<td>44.9</td>
</tr>
<tr>
<td>2009</td>
<td>47.8</td>
</tr>
</tbody>
</table>

Fig. 3 shows that there were only small differences in temperature and VPD between S and OF in the hours when the sun was highest in the sky on a hot day in the 2008 (Fig. 3a) and 2009 (Fig. 3b) cycles. Two days that represented mean weather conditions were chosen. In general, air temperatures and VPD differences of up to approximately 2.5 °C and 0.5 kPa respectively, were reached in both cycles. These differences were higher between the third (summer solstice) and eighth fortnight of the cycle, coinciding with maximum values for air temperature and VPD in OF.

The change in air temperature and VPD caused by switching the misting system on and off as required was around 3 °C and 1.5 kPa respectively for the 2008 and 2009 cycles. The temperature change also matches that observed by HIRAI et al. (2008) in studies with green tea grown in a screenhouse with a misting system that was activated intermittently from 12:00 h to 14:00 h on 17 August (latitude 33°N), obtaining temperature differences of 3 °C (35 °C in the screenhouse with a misting system at 14:00 and outside temperature of 38 °C). However, the temperatures are higher inside of plastic greenhouses (37 °C at latitude 36.5° N on a summer day at 14:00 h) with similar cooling techniques (outside air temperature of 34 °C) (KATSOLAS et al. 2006, GÁZQUEZ et al. 2010). During the period that the misting system was on, maximum VPD differences of around 2 kPa and 1.3 kPa in 2008 and 2009 respectively were obtained, compared to the S and OF treatments.

In spite of this reduction in VPD and temperature, the misting control unit was unable to maintain the preset target of 2.5 kPa during the midday hours. The high tem-
peratures and low humidity levels outside (40–41 °C and 10–15 % humidity) combined with the type of screen used (9x6 strands cm⁻²) favoured that part of the water escaped from the screenhouse through the screen pores to the outside air. The use of thicker screens that might limit ventilation may result in greater reductions in VPD and lower water consumption. These screens would, however, restrict the radiation reaching the plants and limit ventilation during times when the misting system is not operating, and this could lead to overheating the air inside the screenhouse (MAJDOUBI et al. 2007). Thus, it would be a good alternative to try different pulse durations with the purpose of improving control of the VPD in the middle of the day.

Soil temperature

The soil temperature in the screenhouse systems showed a similar pattern, with the greatest differences being observed when compared to the open-field system, which always showed higher average temperatures (around 25 °C in OF and 22 °C in S and SM), maximum temperatures (27 °C in OF and 25 °C in S and SM, approximately) and minimum temperatures (23 °C in OF and 21 °C in S and SM), in both cycles. These higher soil temperatures were due to the absorption of radiation in the whole spectral range by the black mulch and by the conduction of some of the heat from the plastic into the soil, thereby increasing its temperature (SUÁREZ-REY et al. 2008). The mulch in the S and SM systems received less solar radiation because it was under the screen.

Leaf temperature

As far as the comparison of temperatures on the upper and lower sides of the leaves is concerned, there were no significant differences between the eastern and western sectors of our experimental sites during the 2008 and 2009 cycles. Significant differences in leaf temperature between the different cultivation systems were observed in the measurements made at solar midday when the misting system was in operation (Table 3).
If we compare the leaf temperatures for S and OF during the 2008 cycle, it can be observed that the screen reduced the temperature significantly on both, the upper and lower, sides of the leaf (by 6.9 °C and 6.5 °C, respectively). In the 2009 cycle, the difference between the inside and outside radiation was lower than in the 2008 cycle and therefore, in 2009 the difference in leaf temperature was lower. So, one effect of the shade-screen on the crop was the reduction of leaf temperature. CASTILLA (2007) and LÓPEZ-MARÍN et al. (2009b) indicated that the increased energy provided by the high levels of radiation may lead to an increase in the temperature of the leaves, thus increasing water consumption, and, in extreme cases, desiccation of the leaves.

Misting also significantly reduced leaf temperature on both sides in SM compared to S. In the 2008 cycle, temperatures were up to 3.6 °C lower on the upper and 2.8 °C on the lower side and in the 2009 cycle the difference was approximately 1 °C lower (as found by TANNY et al. 2008) on both sides. The significant differences are larger if we compare the two extremes (SM and OF), reaching as much as 10.5 °C (upper) and 9.3 °C (lower) in the 2008 cycle and about 3 °C on both sides of the leaf in the 2009 cycle.

The leaf temperatures values in all treatments are proportional to the mean radiation values recorded at the time of measurement (approximately 568 W m–2 in S, 464 W m–2 in SM and 940 W m–2 in OF, in 2008 and 6201 W m–2 in S, 600 W m–2 in SM and 989 W m–2 in OF, in 2009) as well as proportional to mean air temperatures (34.9 °C in S, 31.4 °C in SM and 36.7 °C in OF, in 2008 and 35.4 °C in S, 34.3 °C in SM and 36.9 °C in OF, in 2009).

In our study, the screenhouse with misting proved to be an effective cooling system since reduced plant canopy temperature. By contrast, GÁZQUEZ et al. (2006) found that misting in a plastic greenhouse cooled the air but not the plants (reducing the transpiration rate), which indicated that ventilation was also required to keep the leaves within an adequate temperature range.

**Final cumulative total and commercial production**

Table 4 shows the final green bean production for the 2008 and 2009 cycles. In 2008 the SM crop system achieved maximum total (commercial plus non commercial beans) and commercial production levels with significant differences compared to S and OF at 109 d.a.s. At 164 d.a.s., significant differences were found in commercial production, which was higher in SM compared to S, but not in total production levels. In 2009 S and SM achieved significantly higher total and commercial production than OF. In 2009 green bean productions were lower than in 2008 because in 2009, weather conditions were more extreme (40 °C approximately during 30 days for 6 hours daily). The environmental conditions were similar in S

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Table 3. Temperature of the upper and lower sides of the leaf at 12:00 solar time inside the screenhouse without a misting system (S), the screenhouse with a misting system (SM) and in the open-field (OF) during the 2008 and 2009 cycles. Numbers followed by different letters in the same line (upper and lower, respectively) indicate significant differences (P < 0.05). (Standard error for comparison = 0.42)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Upper</th>
<th></th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>SM</td>
<td>OF</td>
</tr>
<tr>
<td>2008</td>
<td>31.1 b</td>
<td>27.5 c</td>
<td>38.0 a</td>
</tr>
<tr>
<td>2009</td>
<td>28.6 b</td>
<td>27.7 c</td>
<td>30.4 a</td>
</tr>
</tbody>
</table>

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Table 4. Final cumulative total and commercial production of green beans inside the screenhouse without a misting system (S), the screenhouse with a misting system (SM) and in the open-field (OF) during the 2008 and 2009 cycles. Numbers followed by different letters in the same line indicate significant differences (P < 0.05).

<table>
<thead>
<tr>
<th>Cycle</th>
<th>d.a.s.</th>
<th>Total (kg M–2)</th>
<th>Commercial (kg M–2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>SM</td>
</tr>
<tr>
<td>2008</td>
<td>109</td>
<td>8.00 c</td>
<td>8.59 a</td>
</tr>
<tr>
<td></td>
<td>164</td>
<td>14.14 a</td>
<td>14.85 a</td>
</tr>
<tr>
<td>2009</td>
<td>135</td>
<td>5.40 a</td>
<td>5.80 a</td>
</tr>
</tbody>
</table>

d.a.s. (days after sowing)
and OF (Fig. 3), however, the production was lower in OF (Table 4). This may be explained by higher leaf temperature values reached in OF as a consequence of higher incident radiation (Fig. 2), stressing the plant.

There are no published studies of green bean production in screenhouses, but research has been done on this crop in plastic greenhouses. In a winter cycle growing bush beans, a total production of 2.36 kg m\(^{-2}\) was achieved in a symmetrical greenhouse with sand-mulched soil (ESCOBAR 2004). For bush-bean varieties grown in plastic greenhouses, commercial production can range from as low as 1.50 kg m\(^{-2}\) under unfavourable conditions (short, cold days) to as high as 6 kg m\(^{-2}\) with long days, favourable temperatures and 90-day harvesting cycles (ESCOBAR 2004).

In plastic greenhouses during the spring, the figures for the total and the commercial production of green bean ('Festival') were 4.95 kg m\(^{-2}\) and 4.19 kg m\(^{-2}\) respectively (MECA and GÁZQUEZ 2005) and the maximum total and commercial productions reached with bush beans under the same conditions were less than 1.58 kg m\(^{-2}\) and 1.46 kg m\(^{-2}\) respectively (MECA et al. 2007). Other studies with trained green bean in plastic greenhouses in the spring, achieved commercial production levels of 4.00 to 4.50 kg m\(^{-2}\) (HOYOS et al. 2007) and total and commercial production levels of 3.38 kg m\(^{-2}\) to 2.90 kg m\(^{-2}\) respectively (MECA and GÁZQUEZ 2005). These production levels were also lower than those obtained in the screenhouse under our conditions.

Other studies have shown the effectiveness of shading with different crops. In a plastic greenhouse with mobile outside shading, LORENZO et al. (2006) obtained a commercial cucumber production of 18.6 kg m\(^{-2}\) compared to 16.3 kg m\(^{-2}\) in the control greenhouse and SÁNCHEZ-GUERRERO et al. (2008) obtained similar results with early peppers. In our study, the mulch may have improved the WUE. When comparing the S and SM systems, it is clear that WUE in S was greater than in SM for both cycles and was up to 35 % higher in 2009, a year in which the external conditions were less favourable. A more efficient use of water was also achieved in a tomato crop grown under outdoor mobile shading (GARCÍA 2007) and fixed shade in peppers (GÁZQUEZ et al. 2006) compared to crops grown with the misting system. MONTERO et al. (2003) found that misting enabled savings in crop irrigation, but these did not offset the misting system’s increased water costs.

### Water use efficiency

Table 5 shows the water use efficiency (WUE) of the SM, S and OF systems for the 2008 and 2009 cycles. WUE in OF was less than in SM and S, as 119 L of water were required to produce one kilogram of beans in 2008 compared to 62 L in S and 68 L in SM, and 384.6 L in 2009 compared to 90 L in S and 139 L in SM. Lower values of WUE were obtained in 2008 because of the higher productions achieved in 2008. STANSELL and SMITTE (1980) recorded a water consumption of 177 litres per kilogram of produce in an open-field spring green bean crop and REINA-SÁNCHEZ et al. (2005), 76.9 litres per Kilogram in a plastic greenhouse spring tomato crop. It is important to reduce water consumption without reducing production, which is reflected in a greater WUE. According to BARROS and HANKS (1993), soil-mulching increases water use efficiency as it keeps the soil moist and avoids evaporation. In our case the mulch may have improved the WUE.

In our study, WUE was 1.92 times and 4.26 times higher in S respect to OF in 2008 and 2009, respectively. The WUE difference between cycles is explained by the lower commercial production obtained in OF due to the adverse weather conditions that year, as mentioned before. This result matches those obtained in experiments with cucumber crops in shaded plastic greenhouses compared to control greenhouses (LORENZO et al. 2006, SÁNCHEZ-GUERRERO et al. 2008).

When comparing the S and SM systems, it is clear that WUE in S was greater than in SM for both cycles and was up to 35 % higher in 2009, a year in which the external conditions were less favourable. A more efficient use of water was also achieved in a tomato crop grown under outdoor mobile shading (GARCÍA 2007) and fixed shade in peppers (GÁZQUEZ et al. 2006) compared to crops grown with the misting system. MONTERO et al. (2003) found that misting enabled savings in crop irrigation, but these did not offset the misting system’s increased water costs.

### Conclusions

This study shows that the use of inland screenhouses for production of green beans during the May-October period is a viable complementary production system to coastal plastic greenhouse production (during the October-June period) in Mediterranean areas.

Our results indicate that a black-and-white screen of 9 × 6 strands cm\(^{-2}\) generates a important reduction in the global radiation incident on the crop (global value of 1603.4 MJ m\(^{-2}\)) and a reduction in leaf temperature (up to 6.9 °C), compared to the OF system.

In 2008, the use of a low-pressure misting system reduced VPD up to 2 kPa and air temperature up to 4 °C, with respect to the open air midday conditions. This results in a significant increase in total and commercial production. However, in 2009, SM did not show a clear significant increase in total and commercial production with respect to S, which may explained by the extreme adverse climatic conditions reached during the summer. Under those conditions, part of the misted water seeped...
through the permeable screen to the outside, where it was extremely hot and dry, and it was difficult to maintain the preset VPD target value of 2.5 kPa during the midday hours inside the screenhouse. That year, no commercial production was reached in open air conditions, and was similar between S and SM.

It is recommended that future studies address the investigation of additional equipments complementary to the misting system that would improve water consumption by the misting system and maintain the microclimate created by the screen.

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Addresses of authors: Mercedes Romero-Gámez (corresponding author), Elisa M. Suárez-Rey and Teresa Soriano. IFAPA-Centro Camino de Purchil. Apartado 2027. 18080 Granada, Spain, e-mail: mercedes.romero.gamez@juntadeandalucia.es.