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Research Paper

Effect of roof height on microclimate and plant characteristics in an insect-proof screenhouse with impermeable sidewalls

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An experiment was conducted to study the effect of structure height on air temperature and humidity, on air exchange rate and on transpiration and yield in an insect-proof screenhouse. Two houses with roof heights of 4 and 6 m, and impermeable polyethylene sheets on the sidewalls were examined. Air exchange with the outside environment took place only through the horizontal screened roof and tomato plants were grown in both houses. The results showed that the increase in screenhouse height from 4 to 6 m elicited almost no changes in daily mean air temperature, humidity ratio and consequently, in relative humidity within the canopy. However, it reduced by about 30% the airflow through the screenhouse and consequently the air exchange rate. Moreover, the increase in height did not elicit changes in crop transpiration, yield and plant development. Thus, it is concluded that in insect-proof screenhouses that are ventilated through the roof, there is no benefit in increasing structure height above the current common height of about 4 m.

1. Introduction

1.1. Screenhouse expansion

Screenhouses are modifications of the standard greenhouse with roof and sidewalls usually made of shading or insect-proof porous screens, mounted on metal poles with support cables. The height of such structures is commonly in the 3–6-m range which is usually determined by the crop to be grown in the screenhouse and type of screen used; shading or insect-proof.

In the past, screenhouses were mainly used for shading but, with the growing demand for pesticide-free produce, and

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Nomenclature

A	ventilation opening area, m^2
C_d	discharge coefficient of opening
C_w	wind related coefficient
E	transpiration rate, kg [water] s^{-1}
E'	evaporation from the soil, kg [water] s^{-1}
h	screenhouse height, m
N	air exchange rate, h^{-1}
Q	volume airflow rate through the screenhouse, $m^3\ s^{-1}$
Q_0	volume airflow rate at zero wind speed, $m^3\ s^{-1}$
u	wind speed, m s^{-1}
V_g	screenhouse volume, m^3
ρ	air density, kg m^{-3}
ω	humidity ratio, kg [water] kg^{-1} [air]

the introduction of governmental regulations that restrict pesticide traces in agricultural products, the use of fine-mesh insect-proof screens expanded. Thus, the use of screen materials is nowadays aimed at a number of agricultural objectives and is common practice. These objectives can be divided into several categories: (i) shading from excessive solar radiation (Möller, Cohen, Pirkner, Israeli, & Tanny, 2010); (ii) protection from wind, hail and frost (Teitel, Peiper, & Zvieli, 1996); (iii) exclusion of insects, birds and fruit bats (Tanny, Cohen, & Teitel, 2003); and (iv) changing the solar radiation spectrum to promote light-mediated processes, e.g., use of coloured screens (Shahak, Gussakovsky, Gal, Ganelevin, 2004).

In addition to the benefits provided by screens, these structures have become popular among growers because they cost much less than greenhouses and, therefore, yield adequate returns through use of inexpensive low technology. However, there may be a few drawbacks, especially in the use of fine-mesh screens with low porosity since such screens increase wind resistance and impair light transfer to the canopy (Möller, Tanny, Li, & Cohen, 2004) compared with open-field or low percentage shading screens.

1.2. *Literature survey*

Although fewer than for greenhouses, a number of researchers have analysed the microclimate of screenhouses. A study by Tanny et al. (2003) that addressed the microclimate and air exchange rate inside a flat-roof insect-proof 50-mesh screenhouse planted with pepper was the first to investigate ventilation rates in a full-scale commercial screenhouse. Tanny et al. (2003) also reported a strong interaction between conditions in the upper air layer of the screenhouse and the external environment, but during most hours of the day a temperature inversion inside the screenhouse stabilized the air and reduced mixing. Humidity and temperature profiles showed that within the screenhouse temperature increased and absolute humidity decreased with increasing height. It appeared that when wind speed exceeded 2 m s^{-1} strong mixing between the upper internal region and the external boundary layer above the screen began, which resulted in negligible differences in absolute humidity between the conditions in the upper inner region and external conditions. Also, there was a drop in the internal temperature gradient, due to increased air mixing, as the wind speed reached high values.

Temperature measurements in the same insect-proof, 50-mesh screenhouse in which pepper was grown were reported by Möller, Tanny, Cohen, and Teitel (2003). During daylight hours the inside air was between 1.0 and 2.5 °C warmer than that outside in 33% of all readings, and the temperature difference between inside and outside never exceeded 2.5 °C. For the same screenhouse, essentially similar results were reported by Tanny et al. (2003). Möller et al. (2003) further reported that the air between the upper canopy and the screen was stably stratified throughout the day and that the warming took place most effectively in the upper region of the screenhouse.

Despite the importance of this issue, to the best of our knowledge, only few studies reported on the effect of screenhouse height on microclimate. Its importance emanates from the non-verified belief that taller screenhouses will alleviate heat load from the crop, similar to the observations found with greenhouses (Fatnassi et al., 2015). In the first of these studies, Raya, Parra, and Cid (2006) investigated the effects of changes in screenhouse cover and height on the microclimate in 1–2-ha tomato-growing screenhouses in the Canary Islands, where the growers replaced the traditional 15-mesh screens with denser screens of lower porosity. To compensate for the reduced ventilation rates, they increased structure height from the traditional 2.5–3.0 m to 4–6 m. Raya et al. (2006) measured air temperature and humidity in low (3.2–3.5 m) and high (4.5–5.0 m) screenhouses. Comparatively small differences in air temperature were observed between screenhouses of the two heights, except that the extremes of the maxima (above 26 °C) and minima (below 12 °C) persisted longer in the lower structures. Similar results were found for relative humidity; the difference between the mean values of relative humidity in the screenhouses with different heights was less than 12%.

In the second of these studies Tanny, Teitel, Barak, Esquira, and Amir (2008) studied the effect of height on microclimate in a shading screenhouse. Measurements were conducted in a screenhouse that was divided into two sections of nearly the same floor area – 950 and 790 m^2 – but differing roof heights, of 4 and 2 m, respectively. A black 60% shading screen (that has a lower resistance to airflow than a 50-mesh screen) was deployed on the roof and sidewalls of each of the two houses, in which ornamental *Ruscus*, 0.5 m in height, was grown. The results showed that net radiation was almost identical in the two houses. Air temperature and vapour-pressure deficit near the plants, as well as leaf temperature, were larger in the lower screenhouse than in the higher one. The differences between the two houses in average daily air temperature and leaf temperature were 1.5 and 1.1 °C, respectively. The vertical temperature gradient within the lower screenhouse was about three times larger than that within the higher one, apparently because the air mixing was better in the latter than in the former, and the convective up-flow of warm air was more intense in the higher screenhouse than in the lower one. The diurnal variation of the temperature gradient was well