Effect of vents' opening and insect screen on greenhouse ventilation

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ABSTRACT

The objective of this work was to experimentally investigate the influence of vent type and of insect proof screens on ventilation rate of a round arch plastic covered greenhouse. The greenhouse was equipped with side roll-up windows and a flap roof window and is located at the University of Thessaly near Volos in the coastal area of Eastern Greece. Microclimate variables as well as the greenhouse ventilation rate (*G*) were measured. Two measuring methods were used for the determination of *G*: (a) the decay rate tracer gas method, using N_2O as tracer gas, and (b) the greenhouse energy balance method. In order to study the effect of vent type on *G*, in a greenhouse with an insect proof screen in the vent openings, the *G* was determined during periods were the ventilation was performed by (i) roof, (ii) side and (iii) both roof and side vents. Furthermore, in order to study the effect of insect proof screens on *G*, measurements were carried out also during periods were the ventilation was performed by side vents without a screen in the openings. The two measuring methods gave similar results, but the tracer gas method provided a better fit to the experimental data. Concerning the ventilation performance, the results showed that the most effective vent configuration was the combination of roof and side vents, followed by side vents only. As far as the effect of screens on ventilation rate is concerned, it was found that their use in the vent openings caused a greenhouse ventilation rate reduction of about 33%.

1. INTRODUCTION

In the last decade it is true that the protection of crops from insects is regarded in the Mediterranean basin as more important than protecting them from the weather. Therefore many growers have adopted physical means such as screens, to exclude insects from greenhouses. Screens reduce insect migration and the consequent crop damage, thus reduce the need for pesticide application and so they protect the environment. However, at the same time, screens impede ventilation, making the problems of high internal temperatures, occurring in Mediterranean greenhouses, even worse. Thus a good climatization is crucial in Mediterranean greenhouses in order to maintain high quality production over much of the year.

Natural ventilation is the normal practice for cooling the greenhouse atmosphere, as nowadays all greenhouses include some type of ventilation system (Boulard and Baille, 1995; Kittas et al., 1997). Various methods have been applied to measure greenhouse ventilation performance, such as the 'tracer gas' and 'energy balance' methods (e.g. Fernandez and Bailey, 1992; Kittas et al., 1996; Shilo et al., 2004).

The reduction of ventilation caused by the different kinds of screens (anti-thrip, anti-aphid and shade screens) was recently quantified by some authors (Montero et al., 1997; Fatnassi et al., 2002; Kittas et al., 2002), while the resistance of insect screens has been investigated using the Bernoullis' approach (Munoz et al., 1999; Teitel et al., 1999; Kittas et al., 2002; Fatnassi et al., 2003) or based on the flow through porous media, using the Forchheimer equation (e.g. Miguel et al., 1997).

The aim of the present study was to: (i) compare the two, most widely used, methods for greenhouse ventilation rate measurement, namely the ‘tracer gas’ and the ‘energy balance’ methods, (ii) determine the effect of an insect screen on wind driven ventilation; and (iii) examine the influence of vents’ configuration on greenhouse ventilation performance.

2. THEORY

2.1 Greenhouse energy balance

The energy balance equations used in the present study are similar to those described by Demrati et al. (2001). The ventilation flux G ($m^3\ s^{-1}$) was deduced by the following equation:

$$G = \frac{A_g(R_{net} - F_g) - A_g[K\Delta T_{i\text{-}o} + (\frac{A_c}{A_g})C_h\Delta T_{i\text{-}c}]}{\rho_a[c_p\Delta T_{i\text{-}o} + \lambda\Delta H_{i\text{-}o}]} \quad (1)$$

where A_g and A_c (m^2) are the greenhouse soil and cover area, respectively, R_{net} ($W\ m^{-2}$) is the net radiation, F_g ($W\ m^{-2}$) is the thermal flux in the soil, K ($W\ m^{-2}\ K^{-1}$) is the global sensible heat loss coefficient of the greenhouse through the cover, $\Delta T_{i\text{-}o}$ and $\Delta T_{i\text{-}c}$ (ºC) are the temperature differences between inside and outside air and between inside air and plastic cover, respectively, C_h ($W\ m^{-2}\ K^{-1}$) is the convective heat exchange coefficient, ρ_α (kgm^{-3}) and c_p ($J\ kg^{-1}\ K^{-1}$) are the density and specific heat of air respectively, λ ($J\ kg^{-1}$) is the latent heat of water vaporization and $\Delta H_{i\text{-}o}$ ($kg\ kg^{-1}$) is the absolute humidity difference between inside and outside air.

2.2 Ventilation models

Based on the application of Bernoulli’s equation, G can be derived by taking into account the two main driving forces of natural ventilation: the wind and stack effects (Boulard and Baille, 1995; Baptista et al., 1999).

Kittas et al. (1997) proposed calculating G by:

$$G = C_d\sqrt{(\frac{A_R A_S}{\sqrt{A_R^2 + A_S^2}}) * (2g\frac{\Delta T}{T_o}h) + (\frac{A_T}{2}) * C_w u^2} \quad (2)$$

for a greenhouse equipped with side and roof vents; and by:

$$G = \frac{A_T}{2}C_d(2g\frac{\Delta T}{T_o}\frac{h}{4} + C_w u^2)^{0.5} \quad (3)$$

for a greenhouse equipped with roof vents only, where A_R, A_S, A_T (m^2) are the roof, side and total opening areas, respectively, g ($m\ s^{-2}$) is the gravitational constant, u ($m\ s^{-1}$) is the outside wind speed, C_d and C_w are the discharge and the wind effect coefficients, respectively, T_o (K) is the outside air temperature and h (m) is the vertical distance between the midpoint of side and roof openings.

When the contribution of stack effect to ventilation is negligible, G can be expressed by the following relation (Kittas et al., 1996):

$$G = \frac{A_T}{2}C_d\sqrt{C_w}\,u \quad (4)$$

If G_0 represents the airflow rate (or leakage) when the greenhouse is closed ($A_T = 0$), Eqn (4) becomes as follows:

$$G = \frac{A_T}{2}C_d\sqrt{C_w}\,u + G_0 \quad (5)$$

3. MATERIALS AND METHODS

3.1 Site and greenhouse description

The experiments were performed in an arch, plastic covered greenhouse, N-S oriented (36º declination from north 0º), located at the University of Thessaly near Volos, (Latitude 39º44′, Longitude 22º79′, Altitude 85 m) on the coastal area of Eastern Greece, during summer period of 2000. The geometrical characteristics of the greenhouse were as follows: eaves height =2.4 m; ridge height =4.1 m; total width =8 m; total length =20 m; ground area A_g =160 m^2, and volume V =572 m^3. The greenhouse was equipped with two side roll-up vents located at a height of 0.65 m above the ground with a maximum opening area of 13.5 m^2 (15 m length × 0.9 m height) for each one. Furthermore, a flap roof window was located in the roof of the greenhouse. The window was 20 m long and had a maximum opening height of 0.9 m. The prevailing wind of the region has a north-south direction. The greenhouse soil was totally covered by a double-side (black downwards - white upwards) plastic film.

In order to study the effect of vent type on G, three different cases were examined: the greenhouse ventilation was conducted by (i) side vents, (ii) roof vents and (iii) both side and roof vents. Furthermore, in order to study the effect of insect screen on G, two different cases were examined: the greenhouse ventilation was conducted by: (i) side vents with a screen installed in the openings, and (ii) side vents without screen in the openings.

The porosity ε (=fraction of the total area of the screen occupied by air space) of the screen used in the greenhouse opening was 0.5 $m^2 m^{-2}$.

3.2 Crop

The greenhouse was occupied by a tomato crop which, during the period of measurements, had an average height of about 1.8 m. The tomato crop (cv. Condesa) was planted in the soil on January, 2000 and the plant density was 2.4 plants m^{-2}. The plants were laid out 0.33 m apart in four double rows, with an intra-row distance of 0.75 m and an inter-row distance of 0.8 m. Water and fertilizers were supplied by a drip-system, which was automatically controlled by a fertigation computer. The plants were grown following the technique that is usually implemented by the producers. The leaf area index of the crop [m^2 (leaf) m^{-2} (ground)] during the period of measurements was about 2.5.

3.3 Climatic measurements

The following climatic data were recorded: greenhouse air temperature and relative humidity, incoming solar radiation, net radiation above the top of the crop, conductive soil heat flux inside and outside the greenhouse, leaf temperature, greenhouse plastic cover temperature. Additionally, measurements of wind speed and wind direction on a mast 4 m above the ground at a distance of 15 m from the greenhouse were also carried out. All the above measurements were recorded in a data logger with 1 Hz measuring frequency.

3.4. Ventilation rate measurements

The air exchange rate measurements were performed by means of the impulse peak method using N_2O as tracer gas because the natural concentration of this gas in the atmosphere is almost null (≈ 0.3 ppm).

The greenhouse ventilation rate measurements were based on the mass balance of N_2O in the greenhouse air. Detailed description of the method and the equations used for the calculation of G by this method is given by Roy et al. (2002).

The tracer gas was distributed up to 200 ppm while the vents were closed. After gas injection, some time was left to pass before vent opening in order to obtain uniform gas distribution inside the greenhouse. After that, the vent was opened to the desired opening. Air samples were continuously taken at six points in the greenhouse, by means of six equally distributed plastic pipes of the same length, located at a height of approximately 1.8 m from the ground. The air from the six positions was then mixed and pumped to an infrared gas analyzer (model 7000, ADC gas analyzer, Hoddenson, U.K.) and the concentration of N_2O was measured and stored in the data logger system once per second The duration of each experiment varied between 5 and 20 minutes, depending on environmental conditions and on the ventilation opening.

4. RESULTS AND DISCUSSION

The results presented in this study refer to measurements performed during periods with a relatively stable wind direction (north to south, between 0º and 45º, i.e. almost parallel to the greenhouse ridge). The mean values of the outside climate characteristics during the period of measurements are presented in Table 1. It can be seen that climate conditions outside of the greenhouse were very similar during the period of measurements except for the case without insect screens in the openings.

4.1 Methods comparison

The greenhouse ventilation rate was calculated using the 'tracer gas' and the 'energy balance' methods. It has to be noted that during the pe-

Table 1: Average values of outside climate parameters during the period of measurements.

Vent	Screen	T_o °C	RH_o %	SR_o W m^{-2}	WS m s^{-1}	WD deg
S	No	25.2	53.3	284	4.56	35
S	Yes	35.2	26.1	708	1.77	33
R	Yes	32.2	34.4	714	2.94	26
S&R	Yes	37.1	29.5	850	2.20	10

S=side, R=roof, T_o =outside air temperature, RH_o= outside air relative humidity, SR_o= solar radiation, WS= wind speed, WD= wind direction.

riod of the above experiments vents were covered by nets in the openings.

The two ways of estimating G [Eqns (1) and (5)] were in good agreement (data not shown). Shilo et al. (2004) also found a good correlation between the two methods with the average value of ventilation rate obtained from the energy balance method to be slightly higher than with the tracer gas method.

In the following, the tracer gas method was used for the calculation of greenhouse ventilation rate G since it provided a better fit to the experimental data.

4.2 Effect of screen on ventilation rate

Generally, the stack effect can be significant in greenhouses equipped with roof and side openings or when a large inside to outside air temperature difference is observed. For a greenhouse equipped with roof and side openings, Kittas et al. (1997) considered that stack effect is important if the ratio $u/\Delta T^{0.5}$ is <1. Considering the case of the greenhouse with roof and side openings, it was found that the above mentioned ratio $u/\Delta T^{0.5}$ was equal to 1.78, while the inside to outside air temperature difference ΔT_{i-o}, was equal to 1.7ºC. Furthermore, the corresponding values of ΔT_{i-o} for the case of the greenhouse with insect screens and side or roof openings were 5.4ºC and 5.8ºC, respectively, while for the greenhouse without screens in the side openings the ΔT_{i-o}, was very small (mean ΔT_{i-o} 0.7ºC). Accordingly, for all cases studied, stack effect can be neglected and consequently Eqn (5) can be used for the calculation of the air flow rate G.

In Figure 1, the airflow rate measured using the tracer gas method, in a greenhouse without and with screens in the openings, is plotted versus the half product of the effective opening area and wind velocity (0.5 A_s u).

The experimental data were fitted to Eqn (5), using Marquardt's algorithm (Marquardt, 1963), and a regression, which is represented by straight lines in Figure 2, was obtained for each case. The calculated wind-related coefficients, $C_d\sqrt{C_w}$ and the leakage airflow rate G_0 along with their standard errors and the determination coefficients, are shown for each case in Table 2.

From the results shown in Table 2, a t-test was used to determine if the two calculated wind-related coefficients for the above cases (side vents with or without screen) are statistically different. The t value (Mptulsky and Christopoulos, 2003) was found to be 4.44, a value that is higher than 2.38, which is the corresponding t value for 95% of confidence and 26 degrees of freedom (the sum of the degrees of freedom for each fit) and accordingly, the

Table 2: Estimated values and standard error (95% confidence) of the wind-related coefficient $C_d\sqrt{C_w}$, and the leakage ventilation rate G_0, for the cases studied.

C	Vent	Screen	df	$C_d\sqrt{C_w}$	G_0	R^2
(a)	S	No	14	0.078±0.006	0.13±0.15	0.94
(b)	S	Yes	12	0.052±0.002	0.31±0.02	0.99
(c)	R	Yes	24	0.028±0.004	0.22±0.06	0.72
(d)	S&R	Yes	16	0.096±0.009	0.34±0.22	0.88

C= case studied, S=side, R=roof, df=degrees of freedom, R^2=determination coefficient.

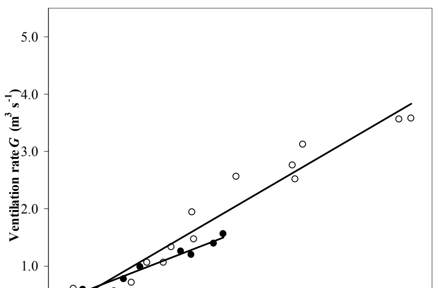

Figure 1. Measured ventilation rate (G) versus the half product of opening surface area and wind velocity (0.5 A_T u), in a greenhouse with side vents (○) without a screen in the openings and (●) with a screen in the openings.

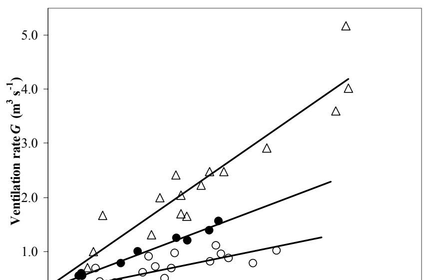

Figure 2. Measured ventilation rate (G) versus the half product of opening surface area and wind velocity (0.5 A_T u), for a screened greenhouse ventilated by (○) roof, (●) side or (Δ) roof and side vents.

two $C_d\sqrt{C_w}$ coefficients calculated are statistically different.

It has to be noted that the values of $C_d\sqrt{C_w}$ found for the greenhouse with side vents without and with screens in the openings (Table 2) are relatively low. This could be partly attributed to the fact that a mature tomato crop, with the plants having a height of about 1.8 m during the period of measurements, occupied the experimental greenhouse and created a barrier between the to side vents of the greenhouse; and accordingly, significantly reduced in that way for both cases the greenhouse ventilation rate. One other thing that might also result in low $C_d\sqrt{C_w}$ values is the fact that the greenhouse was abutted by similar greenhouses in a distance of 4.5 m in its east side; and in a distance of 10 m in its north, front side. However, similarly low values of $C_d\sqrt{C_w}$ have been also referred in the literature e.g. by: Boulard et al. (1997), Fatnassi et al. (2003) and Perez Parra et al. (2004). Using the relation: N=3600 G/V, where N is the greenhouse air exchange rate per hour, the corresponding N_0 values for leakage ventilation were about 0.85 and 1.97 for the greenhouse without and with screen, respectively, values that are relatively similar.

According to the results presented in Table 2, the use of insect screens in the vent openings caused a 33% reduction in the value of the wind-related coefficient $C_d\sqrt{C_w}$ and therefore, according to Eqn (5), in order to obtain the same G, as for the case without screen, a 50% increase of vents' opening area is needed. Consequently, a careful consideration of the greenhouse vent opening area is needed when using screens, in order to prevent greenhouse overheating.

4.3 Effect of vent type on ventilation rate

In Figure 2, the G values measured for the screened greenhouse with roof and both roof and side vents, along with the values of G obtained for the screened greenhouse and side vents (presented also in Fig 1 above), are plotted versus the half product of the effective opening area and wind velocity (0.5 A_T u). The experimental data were fitted to Eqn (5), and the results of the calibration are shown for each case in Table 2.

Following the same statistical analysis presented above and using the $C_d\sqrt{C_w}$ values calculated for the cases (b), (c) and (d) (Table 2), it was found that the calculated wind-related coefficients are statistically different for all cases (Probability values lower than 0.05 for all cases).

It can be seen that from the ventilation performance point of view, the results presented in Figure 2 show that the most effective vent configuration was the combination of roof and side vents, followed by side vents only, while the less effective was the roof vent. According to the results presented in Table 2, and in comparison with the most effective vent configuration (side and roof vents), the ventilation rate obtained by side vents only was 46% lower, while that obtained by roof vents only was 71% lower.

However, Boulard et al. (1997), that examined the ventilation performance of some tunnel greenhouses equipped with side and roof openings, found that side vents only were more efficient than the combination of roof and side vents.

5. CONCLUSION

In this study, two measuring methods were used for the determination of greenhouse ventilation rate G: the decay rate tracer gas method; and the greenhouse energy balance method. The two ways of estimating G were in good agreement but the tracer gas method provided a better fit to the experimental data.

When the greenhouse ventilation performed by side vents only, the use of insect screens in the vent openings caused a 33% reduction in the value of the wind-related coefficient $C_d\sqrt{C_w}$ and accordingly in the greenhouse ventilation rate. However, in a greenhouse with side vents only, the reduction in ventilation rate caused by the installation of an anti-aphid insect screen can be surpassed by the installation of a roof vent, since the ventilation performance of the greenhouse with side and roof vents and screens in the openings was found to be better than that of the greenhouse with side vents only without screens in the openings.

From the greenhouse ventilation performance point of view, it was found that the most effective vent configuration was the combination of roof and side vents, followed by side vents only (46% less ventilation), while the less effective was the roof vent (71% less ventilation).

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