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Evaluation of evaporation-measuring equipments for estimating evapotranspiration within a greenhouse

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Abstract: With the objective of evaluating the performance of simple evaporation measuring equipments in estimating the evapotranspiration in greenhouse, an experiment was conducted in Piracicaba, SP, during a tomato-growing season. Daily water evaporation rate from Piche atmometer, modified atmometer and a reduced evaporation pan installed inside the greenhouse and a Class A pan installed outside were compared to the evapotranspiration rates calculated with Penman-Monteith equation. Results showed that atmometers had the best performance in estimating the crop evapotranspiration in greenhouse and could be used advantageously in relation to the evaporation pans.

Key words: Piche atmometer, evaporation pan, tomato, Penman-Monteith

Avaliação de equipamentos de medida da evaporação para estimativa da evapotranspiração dentro de um ambiente protegido

Resumo: Conduziu-se um experimento em Piracicaba, SP, durante um cultivo de tomateiro, com o propósito de se avaliar a performance de equipamentos simples baseados na evaporação na estimativa da evapotranspiração em ambiente protegido. As taxas diárias de evaporação de um atmômetro de Piche, um atmômetro modificado e de um tanque de evaporação reduzido instalados dentro do ambiente protegido, e de um tanque Classe A instalado no ambiente externo, foram comparadas à evapotranspiração calculada com a equação de Penman-Monteith. Os resultados mostraram que os atmômetros tiveram o melhor desempenho na estimativa da evapotranspiração da cultura e podem ser utilizados com vantagens em relação aos tanques de evaporação.

Palavras-chave: atmômetro de Piche, tanque de evaporação, tomate, Penman-Monteith

INTRODUCTION

Nowadays, greenhouse cultivation plays a significant role on fresh vegetable production in Brazil. However, research is needed on irrigation management to establish the appropriate method to be used to estimate crop evapotranspiration (ET), to avoid the excess or deficit water application, with consequent impacts on nutrient availability for plants, soil salinity and groundwater contamination.

Methods available to estimate crop water requirement either require expensive instrumentation or they are too complicated and not easy to use routinely by growers (Kirda et al., 1994). These authors proposed that the water evaporation from glass beakers placed in five different sites of the greenhouse allow good estimation of the irrigation requirements for greenhouse tomato.

It is assumed that the conditions which affect crop water loss will also affect evaporation from a free water surface in a similar manner (FAO, 1973). Pans of many shapes and sizes have been used to measure free water evaporation, which are inexpensive, relatively easy to maintain and simple to operate (Rosenberg et al., 1983). In Brazil, the Class A pan is most common (Pereira et al., 1997), mainly to estimate the potential evapotranspiration (ET_0), which is converted into ET by multiplying ET_0 with the crop coefficient (Kc). However, due to the large size of Class A pan, for greenhouses, where planting density is high, small pans have been developed and evaporation from smaller pans are, generally, highly correlated with Class A pan (Farias et al., 1986; Medeiros et al., 1997).

Atmometers are relatively inexpensive instruments for obtaining estimates of ET_0 and are, essentially, porous ceramic or paper evaporating surfaces, which are continuously supplied with water (Rosenberg et al., 1983). Bellani and Piche are the most common atmometers and are in wide use. According to FAO (1973) measurements of evaporation with Piche atmometer are usually poorly correlated with evapotranspiration and evaporation from other pans. However, Ferreira (1972) verified that ET_0 estimated by Penman equation was well correlated with ET_0 estimated from Piche evaporation.

Altenhofen (1985) used the Bellani atmometer with some modifications, which was later called as modified atmometer. The ceramic cup was covered with a non-fading green canvas material in order to simulate the albedo of alfalfa and also to introduce a diffusion resistance similar to the stomatal resistance of leaves. Pereira & Coelho (1992) estimated ET_0 by Penman equation and the ratio between ET_0 and the evaporation of the modified atmometer was 1.04. Good correlations between ET_0 and atmometer evaporation were also found by Blume et al. (1988), Law & Israeli (1988) and Broner (1988).

The Penman-Monteith equation is generally used to estimate ET in its original form (Monteith, 1965) or in that proposed by FAO (Allen et al., 1998) and estimating ET with this equation frequently results in good agreement with observed data from lysimeters (Jensen et al., 1990; Steiner et al., 1991; Camargo & Sentelhas, 1997; Santiago, 2001). This model was first developed to estimate ET_0, although, as stated by Camargo & Camargo (2000), it is not restricted to estimation of ET_0, being suitable to estimate the evapotranspiration of any crop. Therefore, if the meteorological variables are measured directly over the crop, no Kc is required because the appropriate values of crop surface and aerodynamic resistance eliminate the concept of Kc and ET_0 as these resistances are crop specific (Smith, 1991; Allen et al., 1998).

Evaluation of the performance of the above described equipments to estimate the ET inside greenhouse during a tomato-growing season was the objective of the present study.

MATERIAL AND METHODS

Reduced evaporation pan, Piche atmometer and modified atmometer were installed inside a 6.4 m wide and 22.5 m long greenhouse, with lateral height of 3.0 m and covered with a polyethylene film of 0.15 mm thickness. All sides of the greenhouse had white anti-aphides screen and without curtains.

The reduced evaporation pan, 0.25 m in height and 0.60 m in diameter, constructed of galvanized iron, was mounted on a 0.15 m height levelled wooden platform. The water depth was maintained between 0.18-0.22 m; the water surface was thus 0.07-0.03 m below the rim in order to avoid great variations in water volume. Water level was observed daily using a hook gauge capable of measuring to 0.01 mm, which was placed on a still well.

Piche atmometer was a cylindrical glass tube graduated from zero to 300 mm, capable of measuring to 1 mm, with a paper disc of 32 mm diameter. Piche was fixed in a stem with the evaporative surface (paper disc) at 1.60 m from the soil surface and evaporation readings were made directly from the equipment's scale. Paper disc was changed every 30 days and water replenishment occurred whenever the water level was above 200mm.

The modified atmometer was also attached to a support, with the evaporative surface at 1.60 m from the soil surface. It consisted of a PVC tube of 75 and 65 mm of external and internal diameters, respectively, and with a porous-porcelain plate (Bellani plate) of 65 mm diameter on the top, which was covered with a non-fading green canvas material. A slight glass of plastic tubing mounted on the side of the reservoir allowed direct readings of the water level inside the PVC tube. A dispositive was used to enlarge the scale to allow higher precision in the evaporation readings, which consisted of a PVC tube of 60 mm external diameter that was placed inside the reservoir. This dispositive was the same as the one used by Pereira (1996) and allowed a precision of 0.16 mm in the evaporation readings, against 1 mm precision of the atmometer in its conventional scale.

A Class A pan was also installed outside the greenhouse, in an adjacent area with bare soil, with the objective to verify if a pan installed outside the greenhouse would result in a better estimate of ET of a crop cultivated inside the greenhouse.

Equipments were installed on December 19, 2001. Tomato seedlings, hybrid Facundo, were transplanted on October 23 in pots, spaced at 0.5 x 1.0 m, giving a plant density of 2 plants m^{-2}. Evaporation readings of reduced pan (E_{red}), Piche atmometer (E_{PI}), modified atmometer (E_{AT}) and Class A pan (E_{CA}) were taken everyday between 7:00 and 8:00 a.m. Readings of the equipments installed inside the greenhouse were not influenced by rain directly, since plastic cover protected the equipments from rain. Measurement of rain depth was needed only for E_{CA} calculation; thus a rain gauge placed close to the Class A pan was used and the precipitation observed was subtracted from the evaporation for the rainy days.

Crop evapotranspiration was calculated using the Penman-Monteith model (ET_{PM}). Net radiation was measured with a net radiometer model Q7-REBS and temperature and relative humidity by a ventilated psychrometer. Sensors were installed at 2 m height from soil surface and connected to a Campbell CR-10 data logger, which was set to make readings every 1 s and to store means at 20 min intervals. Wind speed was set at 5% of that observed outside in a conventional weather station (Prados, 1986). The value of r_a of the Penman-Monteith model was estimated by the equation developed by Brutsaert (1988), and the r_c/r_a ratio was neglected due to the low values of wind speed (less than 0.1 m s^{-1}), that makes this ratio constant and close to zero (Pereira et al., 1995).

As the values of the coefficient of determination (r^2) analysed alone may carry inadequate interpretation about the performance of the equipments in estimating ET (Villa Nova et al., 1997), the agreement index d proposed by Willmott (1981), that expresses the exactness of the regression model, and the coefficient of confidence c (Camargo & Sentelhas, 1997), which includes the coefficients r^2 and d, were also determined and analysed. Differences between the estimated ET by equipments and ET_{PM} were analysed by the paired-t test (Sokal & Rohlf, 1969).

RESULTS AND DISCUSSION

The regression equations and the statistical coefficients obtained for each equipment are shown in Table 1. Modified atmometer provided best estimates of ET and resulted in the higher value of c, followed by Piche atmometer, reduced pan and Class A pan. Modified and Piche atmometers showed very good performance, with values of c equal to 0.78 and 0.77, respectively. Performance of reduced pan was also good, with c equal to 0.62, while Class A pan installed outside the greenhouse did not provide good estimates of ET inside, with c equal to 0.55 which corresponds to a reasonable performance according to the criteria used by Camargo & Sentelhas (1997).

From the regression equations shown in Table 1, the evaporation values of the reduced pan, Class A pan and Piche atmometer were higher than the ET, where the ratios ET_{PM}/E_{red}, ET_{PM}/E_{PI} and ET_{PM}/E_{CA} were 0.95, 0.95 and 0.65, respectively. Only modified atmometer underestimated ET_{PM}, but it was only by 4%, that is, average E_{AT} was very close to the average ET_{PM}. Overestimation of ET_{PM} by pans was probably due to the high evaporation rates during the night resulting from the heat supplied through the walls of the pans in daytime, as demonstrated by Riley (1966). The crop transpiration during the night is very low (van Bavel et al., 1962). In addition, in greenhouses the radiation balance is always positive during the night which induces continuous sensible heat influencing evaporation (Abou-Hadid & El-Beltagy, 1990). ET_{PM}/E_{PI} ratio was probably more influenced by the vapour pressure deficit of the air (Δe) during the day. During the measurement period, average daily temperature was always above 21ºC with some days when maximum temperature exceeded 40ºC. In addition, the relative humidity of the air promoted by the high temperatures reached as low as 43%, which promoted high Δe of about 4.5 kPa during some hours of the day. As E_{PI} is governed mainly by solar radiation and Δe, high evaporation rates were obtained under these conditions. Although transpiration rate is also governed by these factors, under extreme conditions of high temperature and Δe, transpiration is reduced due to the decrease of stomatal conductance, which allow the plant to re-establish the leaf water potential (Rudich & Luchinsky, 1986).

The regression equations were used to estimate ET for each equipment (Figure 1). Estimated values of ET by equipments were very close to that estimated by Penman-Monteith equation, with small differences. Mean values of ET_{PM}, ET_{red}, ET_{AT}, ET_{PI} and ET_{CA} were 2.94, 2.93, 2.92, 2.93 and 2.84 mm d^{-1}, respectively, with no difference between the ET estimated by equipments with ET_{PM} by the paired-t test.

Results showed that the atmometers could be used to estimate ET of greenhouse crops with several advantages in relation to the pans: (i) atmometers are installed on sticks and

Table 1. Regression equation, standard error of mean (SE), coefficient of determination (r^2), agreement index (d), coefficient of confidence (c) and performance of different equipments in estimating evapotranspiration (ET) in greenhouse, compared to ET of Penman-Monteith model (ET_{PM})

Equipment	Equation§	SE	r^2	d	c	Performance
Reduced pan	ET_{PM} - $0.95E_{red}$	0.58	0.76	0.82	0.62	Medium
Modified atmometer	ET_{PM} - $1.04E_{AT}$	0.38	0.86	0.91	0.78	Very good
Piche atmometer	ET_{PM} - $0.95E_{PI}$	0.44	0.86	0.90	0.77	Very good
Class A pan#	ET_{PM} - $0.65E_{CA}$	0.65	0.73	0.76	0.55	Reasonable

Installed outside the greenhouse

§ E_{red}, E_{AT}, E_{PI} and E_{CA} are the evaporation values obtained from the reduced pan inside the greenhouse, modified atmometer, Piche atmometer and Class A pan, respectively, in mm d^{-1}

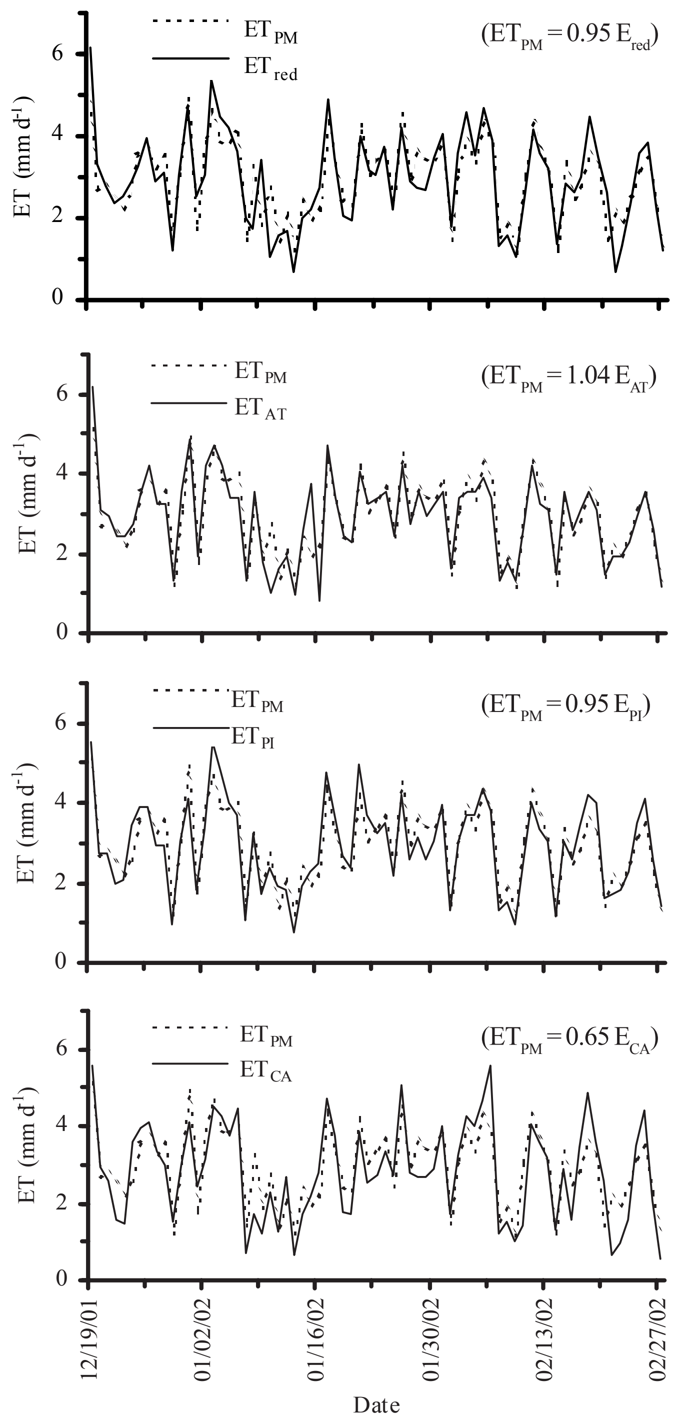

Figure 1. Evapotranspiration in the greenhouse during the tomato-growing season estimated by Penman-Monteith equation (ET_{PM}) and by the regression equations for (A) reduced pan (ET_{red}), (B) modified atmometer (ET_{AT}), (C) Piche atmometer (E_{PI}) and (D) Class A pan (ET_{CA})

do not occupy any space nor interfere with the cultural practices, whereas pans installed between beds hinder the locomotion inside the greenhouse; (ii) maintenance of atmometers is restricted to water replenishment in reservoirs, while pans must be washed periodically; (iii) water volume inside the reservoir is 0.03, 0.14, 60 and 230 L for Piche, modified atmometer, reduced pan and Class A pan, respectively, which makes the maintenance even easier for atmometers than for pans; (iv) evaporation is read directly on a graduated scale, unlike pan which needs a hook gauge that may induce errors.

CONCLUSIONS

1. Evaporation from Piche atmometer, reduced pan and Class A pan, which are equipments based on evaporation of a free water surface, overestimated the crop evapotranspiration, once there is no resistance to water evaporation.

2. Daily evaporation depth value from the modified atmometer was almost equal to the evapotranspiration, due to the resistance promoted by the canvas cover.

3. Piche and modified atmometers could be used to estimate the crop evapotranspiration in greenhouse, providing a more exact estimation in relation to the reduced and Class A pans.

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