DAILY REFERENCE EVAPOTRANSPIRATION ESTIMATION: COMPARING MODELS WITH DRAINAGE LYSIMETER READINGS

N. L. Ribeiro[1], A. N. de Almeida[1], J. de O. Costa[1], T. H. S. Barros[2], A. M. de Almeida[3], R. D. Coelho[4]

ABSTRACT: One of the alternatives to rationalize water use in irrigation systems projects is to estimate the reference evapotranspiration (ETo) in such a way that, when used together with the crop coefficient (Kc), it correctly represents crop evapotranspiration (ETc). One way to verify the efficiency of ETo estimation methods is to compare them to a standard method. In this work the objective was to compare the ETo values obtained from the estimation methods, models and equation, with the ETo values obtained from a drainage lysimeter. The meteorological data used were collected at the ESALQ/USP meteorological station, located in Piracicaba-SP. The ETo was estimated by Penman-Monteith, Priestley-Taylor, Hargreaves-Samani, Camargo, Jensen-Haise, Makkink and Linacre. The results indicated that, for the daily scale, the evaluated methods presented a good fit when compared to the Penman-Monteith method, with correlation coefficients (r) ranging from 0.85 to 0.93. The concordance coefficient (d) presented values from 0.57 to 0.94. The methods of Hargreaves-Samani and Camargo presented the best performance for Piracicaba-SP. The data obtained with the lysimeter did not present a good correlation with the estimation methods evaluated.

KEY WORDS: irrigation; lysimeter; Penman-Monteith.

COMPARAÇÃO DE MODELOS DE ESTIMATIVA DE EVAPOTRANSPIRAÇÃO DE REFERÊNCIA DIÁRIA COM LISÍMETRO DE DRENAGEM

RESUMO: Uma das alternativas para racionalizar o uso da água em projetos de sistemas de irrigação é estimar a evapotranspiração de referência (ETo) de tal forma, para que quando utilizado juntamente com o coeficiente de cultura (Kc) represente de forma correta a evapotranspiração da cultura (ETc). Uma forma de verificar a eficiência de métodos de

[1]PhD Student, University of São Paulo, College of Agriculture “Luiz de Queiroz” (ESALQ/USP), Biosystems Engineering Dept., Piracicaba, SP.
[2]PhD Student, ESALQ/USP, Biosystems Engineering Dept. Av. Pádua Dias, 11, Postal Code 9, Piracicaba, SP. Phone:(87)999915055.e-mail: timoteo@usp.br
[3]Master Student, Biosystems Engineering Dept., ESALQ/USP, Piracicaba, SP.
[4]PhD, Full Professor, Biosystems Engineering Dept., ESALQ/USP, Piracicaba, SP.

estimativa da ETo é a comparação com um método-padrão. Neste trabalho o objetivo foi comparar os valores de ETo obtidos a partir dos métodos de estimativa com os valores encontrados de ETo a partir de um lisímetro de drenagem. Os dados meteorológicos utilizados foram coletados na estação meteorológica da ESALQ/USP, instalada em Piracicaba-SP. A ETo foi estimada pelos métodos Penman-Monteith, Priestley-Taylor, Hargreaves-Samani, Camargo, Jensen-Haise, Makkink e Linacre. Os resultados indicaram que, para a escala diária, os métodos avaliados apresentaram bom ajuste, quando comparados ao método de Penman-Monteith, com coeficientes de correlação (r) variando entre 0,85 e 0,93. O coeficiente de concordância (d) apresentou valores entre 0,57 e 0,94. Os métodos de Hargreaves-Samani e Camargo apresentaram os melhor desempenho para Piracicaba-SP. Os dados obtidos com o lisímetro não apresentaram boa correlação com os métodos de estimativa avaliados.

PALAVRAS-CHAVE: irrigação; lisimetria; Penman-Monteith.

INTRODUCTION

One of the alternatives to rationalize the use of water in agricultural projects is to estimate crop evapotranspiration (ETc) from reference evapotranspiration (ETo) and crop coefficient (Kc). This is one of the most used methods in irrigated production systems (Bernardo, 1995).

Based on physical principles, Penman (1948) combined the energy balance with mass transfer theories and derived an equation to calculate the evaporation of a free water surface from normal climatological records of solar radiation, temperature, humidity, and wind speed.

This methodology, called combined method (estimates the effects of energy balance as well as the evaporating power of air), was developed by several researchers and extended to cultivated surfaces through the introduction of resistance factors (Allen et al., 1998).

These resistance factors were then divided between surface resistance and aerodynamic drag (Monteith, 1965). Surface resistance parameters are most often combined into a single parameter representing total surface resistance, operating in series with the aerodynamic drag.

Based on the principles of mass conservation, also used in the prediction of water balance, several researchers have used lysimetry to quantify the evapotranspiration of either crop or reference surface (lawn) (Allen et al., 1991).

According to Pereira (1997) the lysimeter is an equipment that consists of an impermeable box, containing a volume of soil, and allows to know in detail some terms of the water balance of the sampled volume. In the case of the drainage lysimeter, it is sought to keep the variation of the storage as small as possible through frequent irrigations, however causing some drainage (measured).

In this work the objective was to compare the ETo values obtained from different estimation methods with the ETo values found from a drainage lysimeter.

MATERIALS AND METHODS

The variables used in the evapotranspiration calculations were obtained from the meteorological station of the "Luiz de Queiroz" School of Agriculture (ESALQ), located in Piracicaba-SP, at the geographical coordinates of 22º42'30 " longitude and 47º38'00 " longitude and is 576 meters high, with Cwa climate, according to Köppen classification, with rainy summer and dry winter.

For the estimation of ETo, the following climatic variables were used: radiation balance, maximum, minimum and average air temperature, average relative humidity, average wind speed, precipitation, and atmospheric pressure, for the period of october 2_{nd} to november 24, 2014.

The methods of estimating evapotranspiration used were Penman-Monteith, Priestley-Taylor, Hargreaves-Samani, Camargo, Jensen-Haise, Makkink and Linacre.

The Penman-Monteith method is a method parameterized by the Food and Agriculture Organization (FAO), which recommends it as a standard for the calibration of other estimation methods and is given by Equation 1 (Allen et al., 1998).

$$ETo = \frac{0.408\ \Delta\ (SR - G) + \gamma \frac{900}{T + 273} u_2\ (DPV)}{\Delta + \gamma\ (1 + 0.34\ u_2)} \qquad (1)$$

on what,

SR – Radiation balance, MJ m^{-2} day^{-1};

G – Soil heat flow, MJ m^{-2} day^{-1};

T – Air temperature at 2 m, °C;

u_2 – Wind speed at 2 m, m s^{-1};

e_s – Vapor saturation pressure, KPa;

e_a – Current vapor pressure, KPa;

DPV – Vapor pressure deficit, KPa;

Δ – Slope of the vapor pressure curve, KPa $°C^{-1}$;

γ – Psychrometric constant, KPa $°C^{-1}$.

The method of Priestley & Taylor (1972), constitutes an approximation of the method of Penman. In this equation only the radiation balance corrected by an empirical coefficient known as the Priestley-Taylor parameter remains, which incorporates the additional energy to the evapotranspiration process from the aerodynamic term. It was showed that this coefficient varies from 1.08 to 1.34, with a mean of 1.26 under minimum regional advection conditions. Through this method, the evapotranspiration, in MJ m^{-2} day^{-1}, can be obtained by Equation 2.

$$ETo = \alpha \, W \, (Rn - G) \quad (2)$$

on what,

α –Priestley-Taylor parameter, dimensionless;

Rn – Radiation balance, MJ m^{-2} day^{-1};

W – Weighting factor, dimensionless.

The Hargreaves & Samani method (1985) obtained in California's semi-arid conditions from evapotranspiration of a grass-grown weighing lysimeter for estimating evapotranspiration at Equation 3.

$$ET = 0.0023 \, Q_0 \, (Tmax - Tmin)^{0.5} (Tmed + 17.8) \quad (3)$$

on what,

Q_0 – Irradiância solar global terrestre, MJ m^{-2} day^{-1};

Tmax – Maximum air temperature, °C;

Tmin – Minimum air temperature, °C;

Tmed – Average air temperature, °C.

The Camargo (1971) method proposed a simplification of the Thornthwaite method, proposing the following Equation 4:

$$ET = 0.01 \frac{Q_0}{2.45} \, T \, ND \quad (4)$$

on what,

ND – Number of days in the period considered.

For arid and semi-arid regions, Jensen & Haise (1963) presented Equation 5 for the calculation of reference evapotranspiration:

$$ETo = Rs \, (0.025 \, T + 0.08) \quad (5)$$

on what,

Rs – Global solar radiation converted into units of evaporated water, mm.

The equation for the estimation of reference evapotranspiration, from the measurement of solar radiation, was also proposed by Makkink (1957), according to Equation 6:

$$ETo=0.61\ W\ Rs - 0.12 \quad (6)$$

By the method of Linacre (1977), evapotranspiration, in mm day^{-1}, can be obtained as a function of altitude, latitude and maximum, minimum and dew point daily temperatures, through Equation 7.

$$ET_0=\frac{700\frac{Tm}{100-\varphi}+15\ (T-T_d)}{80-T} \quad (7)$$

on what,

Tm = Ta + 0,006z;

z – Altitude, m;

φ – Latitude, graus;

T_d – Average dew point temperature, ºC.

In addition to the ETo estimation values, measured data from this variable were obtained by means of lysimetry. To obtain the lysimeter data, five drainage lysimeters with drain were used in the lower part and an access tank for the collection and measurement of the drained volume, installed near the meteorological station and cultivated with batatais grass (*Paspalum notatum*). The value of ETo in the period considered was given by Equation 8:

$$ETo=\frac{P+I-D}{A} \quad (8)$$

on what,

P – Precipitation, mm;

I – Irrigation, mm;

D – Drainage, mm;

A – Lysimeter area, m^2.

The methods were compared by linear regression analysis, coefficient of determination, Wilmott coefficient and covariance analysis.

The methodology used to compare the results was based on the regression equation parameters (a and b), the coefficients of determination (R^2), the Wilmott concordance index (d) and the covariance analysis.

RESULTS AND DISCUSSION

The Figure 1 shows the daily ETo estimated by the seven methods chosen for the period considered. The lowest mean was obtained with the Penman-Monteith method, 2.52 mm day^{-1}, and the highest mean with the lysimeter measurement, around 5.35 mm day^{-1}. This behavior for the "standard" methods remained practically throughout the period, with higher values for lisimetry and lower values for Penman-Monteith. There was a large variation in estimated evapotranspiration values for the period. For the Penman-Monteith method, the minimum value observed was 0.27 mm day^{-1} and the maximum of 3.72 mm day^{-1}, however, the values maintained a similar trend among the methods studied, with the exception of the method Of Linacre and of the lysimeter, which consider a longer time interval, being less sensitive to the daily variation of evapotranspiration.

In the comparison of the empirical methods of estimation with the Penman-Monteith method (Figure 2), the best relationships were Hargreaves-Samani and Camargo with R^2 higher than 0.93 and correlation of 0.97 and 0.96, respectively (Table 1). Silva et al. (2014) also concluded that the Hargreaves-Samani and Camargo methods, in the climatic conditions of Piracicaba, presented the best confidence indexes, thus showing results close to those obtained from the FAO standard method and reliability in the estimation of ETo.

The methods of Linacre and lisimetry had the lowest R^2, 0,07 and 0,10, respectively. The poor performance of these methods in relation to the standard can be explained by the Linacre monthly scale based on extreme values of air temperature and, in the case of lysimetry, the difficulty of handling and the average response to a larger scale than daily. As the user was located in the same area of the meteorological station, that is, what is the result, the expected result was that there was no difference in ETo values for this cause.

According to Bíscaro (2007), drainage lysimeters work properly only during long periods of observation (7 to 10 days), and periodic irrigations must be conducted to keep the storage variation null, with consequent drainage, thus being difficult to handle. The results of Figure 3 confirm the difficulty in obtaining the data, since there was no coherent relation for any of the methods when using the drainage lysimeter as standard.

Allen et al. (1991) state that when measurements obtained by lysimeters differ from estimatives made by models with a strong physical base, such as the Penman-Monteith method, it is possible that the lysimeter is not representing the actual environmental conditions of the study area. It should be noted that, except for the Penman-Monteith method (FAO 56), considered standard and more complete in its formulations, the others would need a longer period of study to have more consistent estimates, since the analysis of data, tends to dilute the inherent climate variability.

CONCLUSION

- The Hargreaves-Samani and Camargo methods presented the best performance for the municipality of Piracicaba-SP when compared to the Penman-Monteith method;
- The data obtained with the drainage lysimeter did not present a good correlation with the estimation methods evaluated, due to the difficulty in handling it.

REFERENCES

ALLEN, R.G.; HOWELL, T.A.; PRUITT, W.O.; WALTER, I.A.; JENSEN, M.E. Lysimeters for evapotranspiration and environmental measurements. New York: Americam Society of Civil Engineers, 444p. 1991.

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMITH, M. Crop evapotranspiration: guidelines for computing crop water requirements. Rome: FAO, 1998. 300p. (FAO. Irrigation and Drainage Paper, 56).

BERNARDO, S. Manual de irrigação. 6.ed. Viçosa: UFV, 1995.

BÍSCARO, G.A. Meteorologia Agrícola Básica. 1. ed. Cassilânday: UNI-GRAF Gráfica e Editora União Ltda., 2007. 86 p.

CAMARGO, A.P. Balanço hídrico no Estado de São Paulo. 3.ed. Campinas: Instituto Agronômico, 1971. 24p. (Boletim, 116).

HARGREAVES, G.H., SAMANI, Z.A. Reference crop evapotranspiration from temperature. Transaction of ASAE, v.1, n.2, 96-99, 1985.

JENSEN, M.E.; HAISE, H.R. Estimating evapotranspiration from solar radiation. Journal of the Irrigation and Drainage Division, New York, v.89, n.4, p.15-41, 1963.

LINACRE, E.T.A simple formula for estimating evaporation rates in various climates, using temperature data alone. Agricultural Meteorology, v.18, n.6, p.409-424, 1977.

MAKKINK, G.F. Ekzamento de la formulo de Penman. Netherlands Journal of Agricultural Science, v.5, p.290-305, 1957.

MONTEITH, J.L. Evaporation and environment. Symposium of Society of Experimental Biology, v.19, p.205-234. 1965.

PENMAN, H.L. Natural evaporation from open water, bare soil, and grass. Proc. Roy. Soc. London A193:120-146. 1948.

PEREIRA, A.R.; VILLA NOVA, N.A.; SEDIYAMA, G.C. Evapotranspiração. Piracicaba: FEALQ, 1997. 183p.

PRIESTLEY, C.H.B.; TAYLOR, R.J. On the assessment of surface heat flux on evaporation using large scale parameters. Monthly Weather Review, v.100, n.1, p.81-92, 1972.

SILVA, M.V.T.; CARNEIRO, M.A.; FERREIRA, P.P.B.; CONCEIÇÃO, G.C.; OLIVEIRA, F.L.; MARACAJA, P.B. Comparação de métodos evapotranspiração de referência para cidade de Piracicaba-SP. ACSA – Agropecuária Científica no Semi-Árido, v. 10, n. 2, p. 61-65, 2014.

Table 1. Wilmott coefficient (d), covariance and correlation for the seven methods evaluated when related to the Penman-Monteith method.

Method	d	Covariance	Correlation
Pristley	0.74	0.86	0.93
Hargreaves	0.59	1.07	0.97
Camargo	0.92	0.73	0.96
Jesen-Haise	0.94	0.70	0.94
Makkink	0.57	0.87	0.94
Linacre	0.47	0.10	0.26
Lisímetros	0.28	-0.44	-0.33

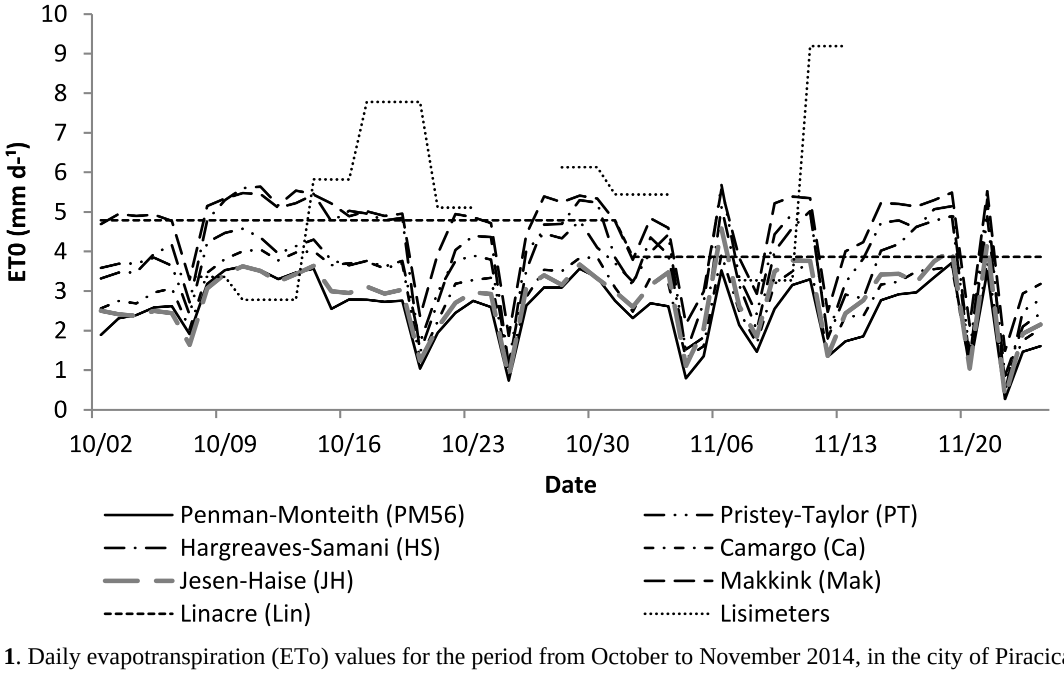

Figure 1. Daily evapotranspiration (ETo) values for the period from October to November 2014, in the city of Piracicaba-SP.

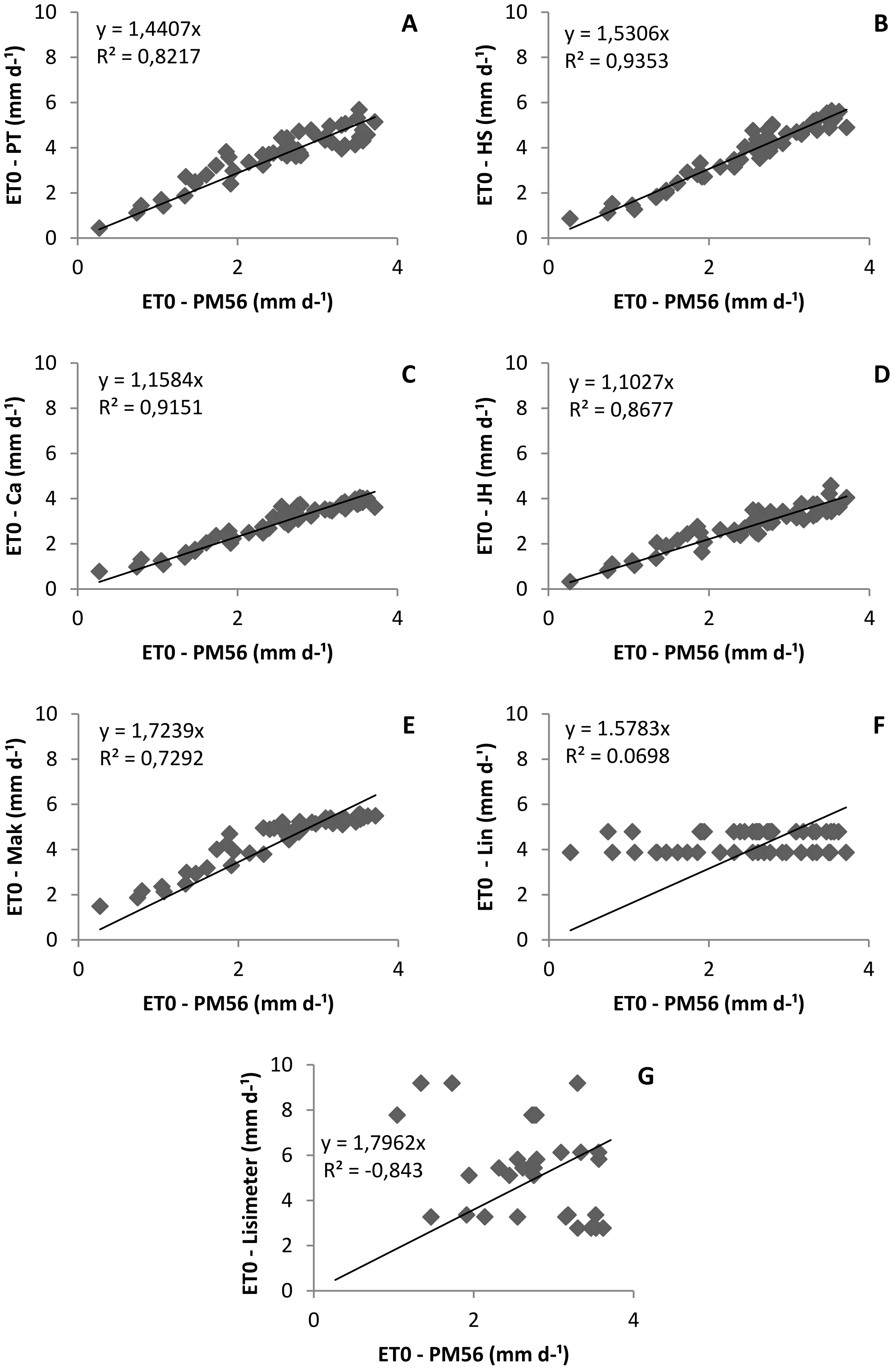

Figura 2. Comparison of the daily reference evapotranspiration (ETo) estimated by the Penman-Monteith method. parameterized in FAO Bulletin 56 and the methods of Priestley-Taylor (A), Hargreaves-Samani (B), Camargo (C), Jensen-Haise (D), Makkink (E), Linacre (F) and Lisimetry (G) for the region of Piracicaba-SP.

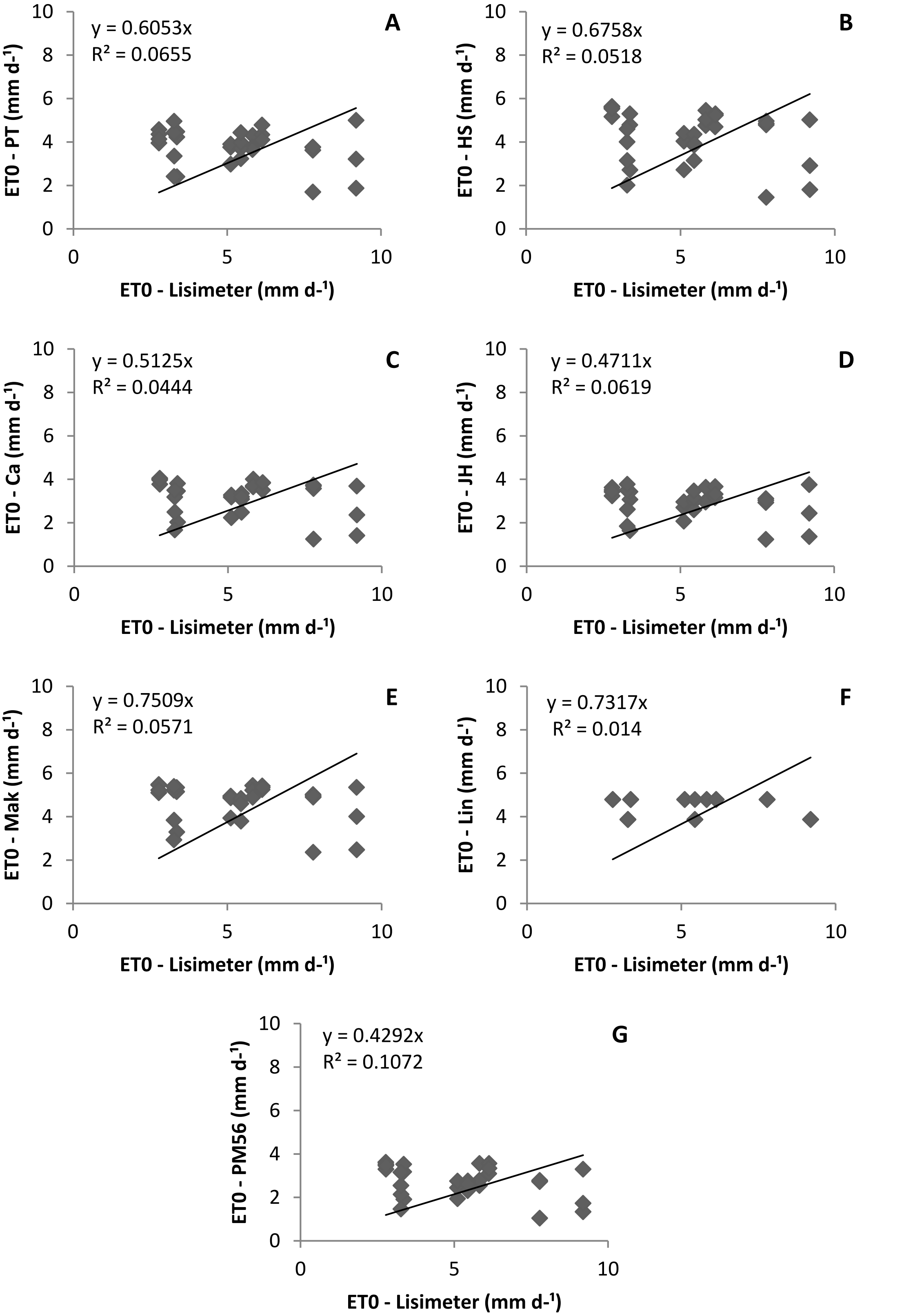

Figura 3. Comparison of the daily reference evapotranspiration (ETo) measured by the lysimeter and the methods of Priestley-Taylor (A), Hargreaves-Samani (B), Camargo (C), Jensen-Haise (D), Makkink (E), Linacre (F) and Penman-Monteith. parameterized in FAO Bulletin 56 (G) for the region of Piracicaba-SP.