ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.22, n.2, p.83-89, 2018
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v22n2p83-89

Performance of different methods for reference evapotranspiration estimation in Jaíba, Brazil

Gustavo H. da Silva[1], Santos H. B. Dias[1], Lucas B. Ferreira[1],
Jannaylton É. O. Santos[1] & Fernando F. da Cunha[1]

[1] Universidade Federal de Viçosa/Centro de Ciências Agrárias/Departamento Engenharia Agrícola. Viçosa, MG. E-mail: dasilva.h.gustavo@gmail.com (Corresponding author); santosdiasagro@gmail.com; luckasborges2010@hotmail.com; jannaylton@gmail.com; fernando.cunha@ufv.br

Key words:
missing data
modeling
irrigation management
FAO-Penman-Monteith

A B S T R A C T

FAO-Penman-Monteith (FAO-PM) is considered the standard method for the estimation of reference evapotranspiration (ET_0) but requires various meteorological data, which are often not available. The objective of this work was to evaluate the performance of the FAO-PM method with limited meteorological data and other methods as alternatives to estimate ET_0 in Jaíba-MG. The study used daily meteorological data from 2007 to 2016 of the National Institute of Meteorology's station. Daily ET_0 values were randomized, and 70% of these were used to determine the calibration parameters of the ET_0 for the equations of each method under study. The remaining data were used to test the calibration against the standard method. Performance evaluation was based on Willmott's index of agreement, confidence coefficient and root-mean-square error. When one meteorological variable was missing, either solar radiation, relative air humidity or wind speed, or in the simultaneous absence of wind speed and relative air humidity, the FAO-PM method showed the best performances and, therefore, was recommended for Jaíba. The FAO-PM method with two missing variables, one of them being solar radiation, showed intermediate performance. Methods that used only air temperature data are not recommended for the region.

Palavras-chave:
dados faltantes
modelagem
manejo da irrigação
Penman-Monteith-FAO

Desempenho de diferentes métodos de estimativa da evapotranspiração de referência em Jaíba, Brasil

R E S U M O

O método de Penman-Monteith (PM-FAO) é considerado padrão para estimativa da evapotranspiração de referência (ET_0), mas exige vários dados meteorológicos, que muitas vezes não estão disponíveis. O objetivo deste trabalho foi avaliar o desempenho do método de PM-FAO com dados meteorológicos limitados e de outros métodos como alternativas para estimativa da evapotranspiração de referência no município de Jaíba, Brasil. Foram utilizados dados meteorológicos diários de 2007 a 2016 da estação do Instituto Nacional de Meteorologia. Os valores de evapotranspiração de referência diários foram aleatorizados, sendo que, 70% desses foram utilizados para determinar os parâmetros de calibração da evapotranspiração de referência para as equações de cada método sob estudo. Os dados restantes foram utilizados para testar a calibração em relação ao método padrão. Na avaliação de desempenho foram utilizados os coeficientes de Willmott, de confiança e a raiz do erro quadrático médio. Quando houve ausência de um dado meteorológico, seja radiação solar, umidade relativa do ar ou velocidade do vento, ou na ausência simultânea de velocidade do vento e umidade relativa do ar o método de PM-FAO apresentou os melhores desempenhos, sendo assim recomendado para Jaíba. O método de PM-FAO com dois dados faltantes, sendo um deles a radiação solar, apresentou desempenho intermediário. Os métodos que utilizaram apenas dados de temperatura do ar não são recomendados para a região.

Ref. 178182 – Received 6 Apr, 2017 • Accepted 19 Sept, 2017 • Published 22 Dec, 2017

Introduction

On a vegetated surface, evapotranspiration consists in the transfer of water from the soil-plant system to the atmosphere. Adequate estimation of evapotranspiration is fundamental for a project and management of irrigation, hydrological studies, among others (Antonopoulos & Antonopoulos, 2017).

In order to know the evapotranspiration of a crop, particularly to quantify the water to be applied through irrigation, it is necessary to previously know the reference evapotranspiration (ET_0). The Penman-Monteith method (FAO-PM) was parameterized and then recommended as a standard by FAO (Food Agriculture Organization) to estimate ET_0, and has been adopted in various parts of the world due to its accuracy (Allen et al., 1998).

As a disadvantage, the method requires a large amount of measured meteorological data, which are often unavailable or not reliable, especially in non-developed countries, thus demanding a simpler approach and use of other alternative methods to estimate ET_0 (Landeras et al., 2008; Martí et al., 2015).

Due to the lower accuracy of these alternative methods to estimate ET_0, many authors calibrated ET_0 through linear regression in relation to the FAO-PM method (Fanaya Júnior et al., 2012; Cunha et al., 2013; Oliveira et al., 2015). On the other hand, only a few calibrated ET_0 values of the FAO-PM method using limited meteorological data (Carvalho et al., 2013; Alencar et al., 2015;).

The municipality of Jaíba is located in the Northern region of Minas Gerais and has the largest public irrigated perimeter in Latin America, with capacity to irrigate an area of 65,879 ha. In 2015, the irrigated area was 11,182 ha and water consumption was 334.6 million m^3 (DIJ, 2016).

Considering the importance of the water resources and the need for good use of water through correct ET_0 estimation, this study aimed to evaluate the performance of the FAO Penman-Monteith method with limited meteorological data and other methods as alternatives to the FAO Penman-Monteith method with all required data for the municipality of Jaíba-MG, Brazil.

Material and Methods

Reference evapotranspiration (ET_0) was estimated using daily meteorological data from an automatic station of the National Institute of Meteorology (INMET), relative to 10 years of the historical series (2007 to 2016), located in the municipality of Jaíba, Northern Minas Gerais, Brazil (15° 05' 09" S; 44° 01' 00" W; 454 m). The climate of the region is Aw according to Köppen's classification.

The following meteorological data were used: mean, maximum and minimum air temperature (°C) and relative humidity, solar radiation (MJ m^{-2} d^{-1}), atmospheric pressure (hPa) and wind speed at 10 m height (m s^{-1}). Wind speed was corrected to height of 2 m by multiplying the value by the coefficient 0.7480, according to Allen et al. (1998).

The standard method used to estimate ET_0 was FAO Penman-Monteith (FAO-PM) with complete meteorological data (Eq.1) (Allen et al., 1998). ET_0 was also estimated by the FAO-PM method with absence of one, two and three meteorological variables per time, generating seven combinations. The only meteorological variable that remained in all combinations was air temperature.

$$ET_0 = \frac{0.408s\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2\left(e_s - e_a\right)}{s + \gamma\left(1 + 0.34u_2\right)} \quad (1)$$

where:

ET_0 - reference evapotranspiration, mm d^{-1};
R_n - net radiation on the surface, MJ m^{-2} d^{-1};
G - heat flux in the soil, MJ m^{-2} d^{-1} (considered as null for daily scale);
T - mean air temperature, °C;
u_2 - wind speed at 2-m height, m s^{-1};
e_s - saturation water vapor pressure, kPa;
e_a - actual water vapor pressure, kPa;
s - slope of the saturation water vapor pressure curve, kPa °C^{-1}; and,
γ - psychrometric constant, kPa °C^{-1}.

The studied combinations were: FAO-PM without solar radiation data (Rs); FAO-PM without relative air humidity (RH); FAO-PM without wind speed (WS); FAO-PM without Rs and RH; FAO-PM without Rs and WS; FAO-PM without WS and RH, and lastly FAO-PM without WS, RH and Rs.

In the absence of solar radiation, this variable was estimated using Eq. 2 and, in the absence of relative air humidity data, the value of e_a (actual water vapor pressure in the atmosphere) was estimated by Eq. 3, according to Allen et al. (1998). In the absence of wind speed, the estimation considered the daily mean value relative to the studied 10-years period, 0.86 m s^{-1}, due to the better performance compared with the value proposed by Allen et al. (1998), equal to 2.0 m s^{-1} (Silva et al., 2010).

$$R_S = 0.16R_a\left(T_{max} - T_{min}\right) \quad (2)$$

$$e_a = 0.6108^{\left[\frac{17.27+T_{min}}{T_{min}+273.3}\right]} \quad (3)$$

where:

R_a - solar radiation at the top of the atmosphere, MJ m^{-2} d^{-1};
T_{max} - maximum air temperature, °C; and,
T_{min} - minimum air temperature, °C.

As alternatives, the performance of the methods of Hargreaves-Samani (Hargreaves & Samani, 1985), Jensen-Haise (Jensen & Haise, 1963), Hicks-Hess (Bruin & Keijman, 1979), Priestley-Taylor (Priestley & Taylor, 1972) and Tanner-Pelton (Berlato & Molion, 1981) described in Eqs. 4, 5, 6, 7 and 8, respectively, was also evaluated.

$$ET_0 = R_a 0.0023\left(T + 17.8\right)\left(T_{max} - T_{min}\right)^{0.5} \quad (4)$$

$$ET_0 = R_S\left(0.025T + 0.08\right) \quad (5)$$

$$ET_0 = \frac{R_n}{\lambda}\left(\frac{s}{0.9s + 0.63\gamma}\right) \quad (6)$$

$$ET_0 = 0.5143\frac{s}{s+\gamma}\left(R_n - G\right) \quad (7)$$

$$ET_0 = 0.457R_n - 0.11 \quad (8)$$

where:

R_a - solar radiation at the top of the atmosphere in evaporation equivalent, mm d^{-1};

T_{max} - maximum air temperature, °C;

T_{min} - minimum air temperature, °C;

T - mean air temperature, °C;

R_s - solar radiation on the surface in evaporation equivalent, mm d^{-1};

R_n - net radiation on the surface, MJ m^{-2} d^{-1};

λ - latent heat of evaporation, MJ kg^{-1};

s - slope of the saturation water vapor pressure curve, kPa °C^{-1};

γ - psychrometric constant, kPa °C^{-1}; and,

G - heat flux in the soil, MJ m^{-2} d^{-1}.

To improve the performance of the methods, ET_0 values were subjected to calibration through simple linear regression, according to Eq. 9. The dependent variable was the ET_0 of the evaluated method and the independent variable was the ET_0 of the standard FAO-PM method. In each method evaluated, the values of "a" and "b" were obtained and were subsequently used to calibrate the ET_0 of the respective method, according to Eq. 10.

$$ET_0 = a + bET_{0\ FAO-PM} \quad (9)$$

$$ET_{0cal} = \frac{ET_0}{b} - \frac{a}{b} \quad (10)$$

where:

ET_0 - reference evapotranspiration of the evaluated method, in mm d^{-1};

a and b - calibration parameters obtained through linear regression; and,

$ET_{0\ FAO\text{-}PM}$ - reference evapotranspiration by the FAO-Penman-Monteith method, in mm d^{-1};

$ET_{0\ cal}$ - calibrated reference evapotranspiration, in mm d^{-1}.

In each method evaluated, ET_0 values were previously randomized and then divided into two subsets, calibration and test, as proposed by Shiri et al. (2015). The calibration subset, containing 70% of the ET_0 values, was used to obtain the parameters "a" and "b", whereas the test subset, containing 30% of the ET_0 values, was used to evaluate the performance of the calibrated model.

ET_0 values obtained by the different methods, in relation to the FAO-PM method, were compared using Willmott's index of agreement (Willmott et al., 1985), correlation and confidence coefficients (Camargo & Sentelhas, 1997) and root-mean-square error, according to Eqs. 11, 12, 13 and 14, respectively. Table 1 was used to interpret the confidence coefficient.

$$d = 1 - \left[\frac{\sum_{i=1}^{n}\left(Pi - Oi\right)^2}{\sum_{i=1}^{n}\left(\left|Pi - \bar{O}\right| + \left|Oi - \bar{O}\right|\right)^2}\right] \quad (11)$$

$$r = \frac{\sum_{i=1}^{n}\left(Pi - \bar{P}\right)\left(Oi - \bar{O}\right)}{\sqrt{\left[\sum_{i=1}^{n}\left(Pi - \bar{P}\right)^2\right]\left[\sum_{i=1}^{n}\left(Oi - \bar{O}\right)^2\right]}} \quad (12)$$

$$c = dr \quad (13)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(Oi - Pi\right)^2}{n}} \quad (14)$$

where:

d - Willmott's index of agreement;

c - confidence coefficient;

r - correlation coefficient;

RMSE - root-mean-square error, mm d^{-1};

Oi - values observed with the FAO-Penman-Monteith method, mm d^{-1};

O - mean of observed values, mm d^{-1}

Pi - values predicted by the other methods, mm d^{-1};

P - mean of predicted values, mm d^{-1}; and,

n - number of observations.

Table 1. Criteria to interpret the confidence coefficient "c"

Confidence coefficient "c"	Classification[1]
> 0.85	Excellent
0.76 to 0.85	Very Good
0.66 to 0.75	Good
0.61 to 0.65	Intermediate
0.51 to 0.60	Tolerable
0.41 to 0.50	Poor
< 0.40	Very Poor

[1]Camargo & Sentelhas (1997)

Results and Discussion

ET_0 calibration parameters obtained through linear regression and the coefficient of determination (r^2) for each of the evaluated methods, in relation to the standard FAO Penman-Monteith method (FAO-PM), are described in Table 2.

The methods that showed lower coefficients of determination (r^2) were those that incorporated the estimated solar radiation (Rs) (Table 2). The same result was found by Sousa et al. (2010) and Alencar et al. (2015). This is due to the fact that the main factor contributing to the evapotranspiration is solar radiation (Allen et al., 1998). Therefore, the proposed equation is inadequate to estimate Rs for the studied site.

Table 2. Calibration parameters and coefficient of determination for each method evaluated

Methods evaluated	Calibration regression parameters		
	a	b	R^2
FAO-PM without Rs	-1.1441	1.3229	0.8303
FAO-PM without WS	-0.6640	1.1467	0.8525
FAO-PM without RH	0.2150	0.9851	0.9256
FAO-PM without Rs and RH	-1.0474	1.3663	0.7731
FAO-PM without Rs and WS	-2.3025	1.5929	0.7041
FAO-PM without RH and WS	-0.0642	1.0459	0.8295
FAO-PM without Rs, WS and RH	-1.5618	1.4874	0.6734
Hargreaves-Samani	-1.6213	1.2367	0.6539
Jensen-Haise	0.4006	0.8556	0.7934
Hicks-Hess	0.4668	0.9793	0.7956
Priestley-Taylor	0.9833	1.5163	0.8122
Tanner-Pelton	0.3403	0.8305	0.7825

FAO-PM - FAO Penman-Monteith; Rs - Solar radiation; WS - Wind speed; RH - Relative air humidity

The methods FAO-PM without Rs, FAO-PM without RH, FAO-PM without Rs and RH, FAO-PM without Rs and WS, FAO-PM without RH and WS, FAO-PM without Rs, WS and RH, Priestley-Taylor and Hicks-Hess tended to underestimate ET_0 values in comparison to the standard method (Figures 1A, B, D, E, F, G, I and K, respectively).

Similar results for the Priestley-Taylor and Hicks-Hess methods were found by Cunha et al. (2013) and Ferronato et al. (2016). The other methods tended to overestimate ET_0 in comparison to the standard method (Figures 1C, H, J and L), corroborating the results of Fanaya Júnior et al. (2012), Cunha et al. (2013) and Oliveira et al. (2015).

Figure 2 shows the graphical relationship between ET_0 values estimated by the alternative methods after calibration. It is possible to note that calibration avoids under- or overestimation of ET_0, improving the accuracy, but without altering the coefficient of determination (r^2) (Figure 2).

Unlike the present research, Carvalho et al. (2013) used an exponential equation to test ET_0 values, but obtained only a slight increase (0.8%) in the coefficient c. Another alternative to improve the ET_0 estimation method is the calibration of the equation through the addition of coefficients, but such

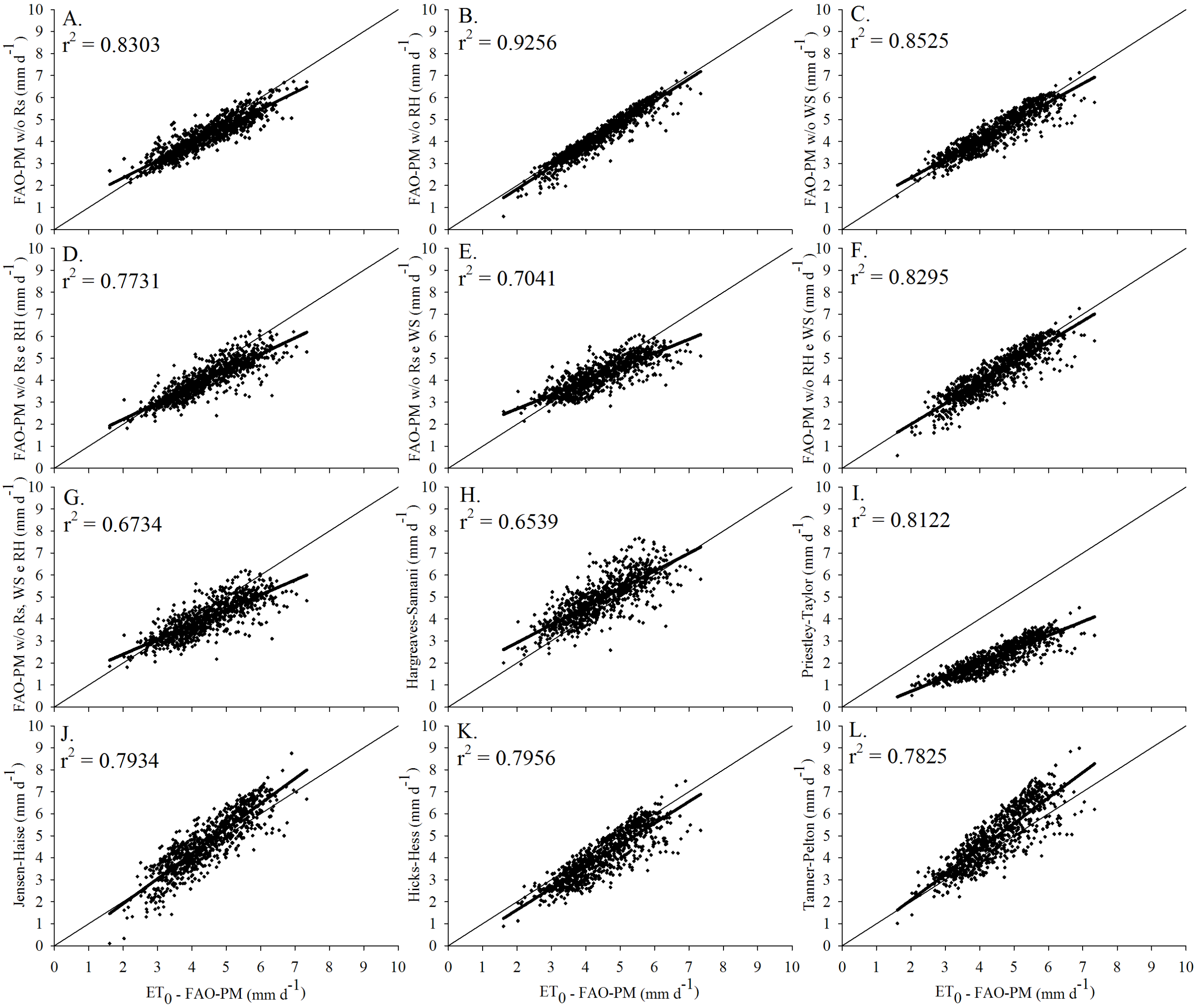

Figure 1. ET_0 values estimated by the methods FAO-PM without Rs (A); FAO-PM without RH (B); FAO-PM without WS (C); FAO-PM without Rs and RH (D); FAO-PM without Rs and WS (E); FAO-PM without RH and WS (F); FAO-PM without Rs, WS and RH (G); Hargreaves-Samani (H); Priestley-Taylor (I); Jensen-Haise (J); Hicks-Hess (K) and Tanner-Pelton (L), in comparison to those estimated by FAO-PM before calibration

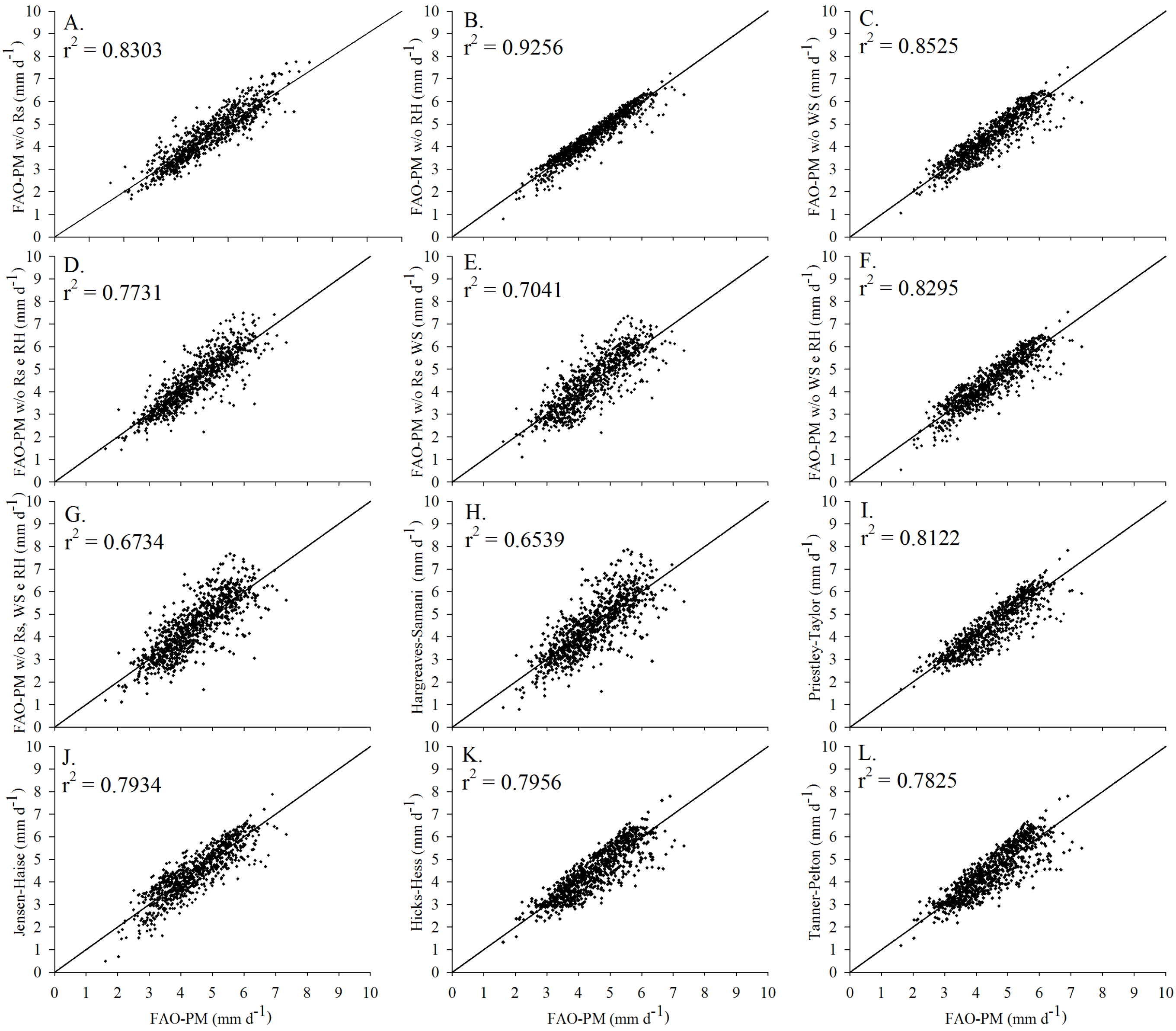

Figure 2. ET_0 values estimated by the methods FAO-PM without Rs (A); FAO-PM without RH (B); FAO-PM without WS (C); FAO-PM without Rs and RH (D); FAO-PM without Rs and WS (E); FAO-PM without WS and RH (F); FAO-PM without Rs, WS and RH (G); Hargreaves-Samani (H); Priestley-Taylor (I); Jensen-Haise (J); Hicks-Hess (K) and Tanner-Pelton (L), in comparison to those estimated by FAO-PM after calibration

procedure does not avoid under- or overestimation of ET_0, decreasing the accuracy (Fernandes et al., 2012).

The most recommended methods for Jaíba or with best performances ("excellent" classification) were FAO-PM with one missing meteorological variable and with simultaneous absence of WS and RH data (Table 3). In the absence of Rs and more one or two meteorological variables, the performance of the FAO-PM method was compromised (Table 3), corroborating the results of Alencar et al. (2015).

The methods Jensen-Haise, Hicks-Hess, Priestley-Taylor and Tanner-Pelton were classified as "Very good", and can still be used. On the other hand, Cunha et al. (2013) found "tolerable" and "intermediate" performance for these methods for Chapadão do Sul-MS. Probably, the tropical megathermal climate in Jaíba favors the use of these methods with greater success, compared with the humid tropical climate of Chapadão do Sul.

Relatively, in the present study, the worst performances ("Good") occurred for methods that used only air temperature

Table 3. Root-mean-square error (RMSE), Willmott's index of agreement (d) and confidence coefficient (c) with the respective classification for the alternative methods with calibrated ET_0 values

Methods	Comparison coefficients			
	RMSE (mm d^{-1})	d	c	Classification of c
FAO-PM without Rs	0.46	0.96	0.87	Excellent
FAO-PM without WS	0.43	0.96	0.88	Excellent
FAO-PM without RH	0.30	0.98	0.94	Excellent
FAO-PM without Rs and RH	0.56	0.94	0.82	Very good
FAO-PM without Rs and WS	0.66	0.92	0.77	Very good
FAO-PM without WS and RH	0.47	0.95	0.86	Excellent
FAO-PM without WS, RH and Rs	0.72	0.91	0.74	Good
Hargreaves-Samani	0.76	0.91	0.72	Good
Jensen-Haise	0.53	0.94	0.82	Very good
Hicks-Hess	0.53	0.94	0.84	Very good
Priestley-Taylor	0.50	0.95	0.85	Very good
Tanner-Pelton	0.55	0.94	0.81	Very good

FAO-PM - FAO-Penman-Monteith method; Rs - Solar radiation; WS - Wind speed; RH - Relative air humidity data (FAO-PM without WS, RH and Rs, and Hargreaves-Samani). These methods also exhibited the highest values of RMSE (0.72 and 0.76 mm d^{-1}) and, therefore, are not recommended (Table 3).

It is worth pointing out that a certain method should be selected in such a way to adapt to the available meteorological data and, at the same time, exhibit good performance in ET_0 estimation. Lastly, special attention should be paid to the confidence coefficient.

The methods classified as "excellent" showed the highest and lowest values of c and RMSE, respectively. The method FAO-PM without RH showed the lowest RMSE (0.30 mm d^{-1}), whereas the highest RMSE (0.76 mm d^{-1}) was obtained by the Hargreaves-Samani method (Table 3).

Evaluating various methods of ET_0 estimation, Sousa et al. (2010) concluded that those closest to the Penman-Monteith method were, in sequence, Jensen-Haise, Priestley-Taylor and Hargreaves, as observed in the present study.

Alencar et al. (2015) concluded, for various cities of Minas Gerais, that when only air temperature data are available, the performance of the FAO Penman-Monteith method was superior to that of Hargreaves-Samani. However, in the present study, these two methods showed very similar confidence coefficient and were thus considered as with the same performance ("Good").

The Hargreaves-Samani method was recommended by Allen et al. (1998) in situations with availability of only air temperature data. However, its performance for Jaíba-MG was not satisfactory (Cunha et al., 2013; Alencar et al., 2015).

Conclusions

1. In the absence of only solar radiation, relative humidity or wind speed data, or even simultaneous absence of relative humidity and wind speed data, the FAO Penman-Monteith method showed the best performances.

2. The FAO Penman-Monteith method in the absence of measured solar radiation data and more one meteorological variable showed intermediate performance in ET_0 estimation.

3. With lower performance, the methods Jensen-Haise, Hicks-Hess, Priestley-Taylor and Tanner-Pelton can be used in Jaíba-MG, Brazil.

4. The methods that used only measured air temperature data are not recommended for Jaíba-MG, Brazil, even after calibration of ET_0 values.

Acknowledgments

To the National Institute of Meteorology for providing the meteorological data and to the Minas Gerais Research Support Foundation (FAPEMIG) for the financial support.

Literature Cited

Alencar, L. P. de; Sediyama, G. C.; Mantovani, E. C. Estimativa da evapotranspiração de referência (ET_0 padrão FAO), para Minas Gerais, na ausência de alguns dados climáticos. Engenharia Agrícola, v.35, p.39-50, 2015. https://doi.org/10.1590/1809-4430-Eng.Agric.v35n1p39-50/2015

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO, 1998. 333p.

Antonopoulos, V. Z.; Antonopoulos, A. V. Daily reference evapotranspiration estimates by artificial neural networks technique and empirical equations using limited input climate variables. Computers and Electronics in Agriculture, v.132, p.86-96, 2017. https://doi.org/10.1016/j.compag.2016.11.011

Berlato, M. A.; Molion, L. C. B. Evaporação e evapotranspiração. Porto Alegre: IPAGRO/Secretaria de Agricultura, 1981. 95p.

Bruin, H. A. R. de; Keijman, J. Q. The priestley-taylor evaporation model applied to large, shallow lake in the Netherlands. Journal of Applied Meteorology, v.18, p.898-903, 1979. https://doi.org/10.1175/1520-0450(1979)018%3C0898:TPTEMA%3E2.0.CO;2

Camargo, A. P. de; Sentelhas, P. C. Avaliação do desempenho de diferentes métodos de estimativa da evapotranspiração potencial no estado de São Paulo, Brasil. Revista Brasileira de Agrometeorologia, v.5, p.89-97, 1997.

Carvalho, L. C. de; Evangelista, A. W. P.; Oliveira, K. M. G.; Silva, B. M.; Alves, M. de C.; Sá Júnior, A. de; Miranda, W. L. FAO Penman-Monteith equation for reference evapotranspiration from missing data. Idesia, v.31, p.39-47, 2013. https://doi.org/10.4067/S0718-34292013000300006

Cunha, F. F. da; Magalhães, F. F.; Castro, M. A. de. Métodos para estimativa da evapotranspiração de referência para Chapadão do Sul-MS. Engenharia na Agricultura, v.21, p.159-172, 2013. https://doi.org/10.13083/1414-3984.v21n02a06

DIJ - Distrito de Irrigação de Jaíba. Informativo do Distrito de Irrigação de Jaíba. 2016. 8p. Disponível em: <http://www.projetojaiba.com.br/arquivos_upload/informativos/25.pdf>. Acesso em: 22 Fev. 2017.

Fanaya Júnior, E. D.; Lopes, A. da S.; Oliveira, G. Q. de; Jung, L. H. Métodos empíricos para estimativa da evapotranspiração de referência para Aquidauana-MS. Irriga, v.17, p.418-434, 2012. https://doi.org/10.15809/irriga.2012v17n4p418

Fernandes, D. S.; Heinemann, A. B.; Paz, L. R. F.; Amorim, A. de O. Calibração regional e local da equação de Hargreaves para estimativa da evapotranspiração de referência. Revista Ciência Agronômica, v.43, p.246-255, 2012. https://doi.org/10.1590/S1806-66902012000200006

Ferronato, A.; Chig, L. A.; Goulart, D. de B.; Campelo Júnio, J. H. ; Pereira, L. C.; Biudes, M. S. Métodos de estimativa da evapotranspiração de referência para Santo Antônio do Leverger-MT. Revista de Ciências Agroambientais, v.14, p.110-118, 2016.

Hargreaves, G. H.; Samani, Z. A. Reference crop evapotranspiration from temperature. Journal of Applied Engineering in Agriculture, v.1, p.96-99, 1985. https://doi.org/10.13031/2013.26773

Jensen, M. E.; Haise, H. R. Estimating evapotranspiration from solar radiation. Journal of the Irrigation and Drainage, v.4, p.15-41, 1963.

Landeras, G.; Ortiz-Barredo, A.; López, J. J. Comparison of artificial neural network models and empirical and semi-empirical equations for daily reference evapotranspiration estimation in the Basque Country (Northern Spain). Agricultural Water Management, v.95, p.553-565, 2008. https://doi.org/10.1016/j.agwat.2007.12.011

Martí, P.; González-Altozano, P.; López-Urrea, R.; Mancha, L. A.; Shiri, J. Modeling reference evapotranspiration with calculated targets. Assessment and implications. Agricultural Water Management, v.149, p.81-90, 2015. https://doi.org/10.1016/j.agwat.2014.10.028

Oliveira, V. M. R. de; Dantas, G. de F.; Palaretti, L. F.; Dalri, A. B.; Santos, M. G. dos; Fischer Filho, J. A. Estimativa de evapotranspiração de referência na região de Rio Paranaíba-MG. Irriga, v.20, p.790-798, 2015. https://doi.org/10.15809/irriga.2015v20n4p790

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, p.81-92, 1972. https://doi.org/10.1175/1520-0493(1972)100%3C0081:OTAOSH%3E2.3.CO;2

Shiri, J.; Sadraddini, A. A.; Nazemi, A. H.; Martí, P.; Fard, A. F.; Kisi, O.; Landeras, G. Independent testing for assessing the calibration of the Hargreaves-Samani equation: New heuristic alternatives for Iran. Computers and Electronics in Agriculture, v.117, p.70-80, 2015. https://doi.org/10.1016/j.compag.2015.07.010

Silva, Í. N.; Oliveira, J. B. de; Fontes, L. de O.; Brasil, P. P.; Silva, M. G. da. Estimativa da evapotranspiração de referência com dados mínimos para o cariri oeste cearense. Agropecuária Científica no Semiárido, v.6, p.42-48, 2010.

Sousa, I. F. de; Silva, V. de P. R. da; Sabino, F. G.; Aguiar Netto, A. de O.; Silva, B. K. N.; Azevedo, P. V. de. Evapotranspiração de referência nos perímetros irrigados do estado de Sergipe. Revista Brasileira de Engenharia Agrícola e Ambiental, v.14, p.633-644, 2010. https://doi.org/10.1590/S1415-43662010000600010

Willmot, C. J.; Ackleson, S. G.; Davis, R. E.; Feddema, J. J.; Klink, K. M.; Legates, D. R.; O'Donnell, J.; Rowe, C. M. Statistics for the evaluation and comparison of models. Journal of Geophysical Research, v.90, p.8995-9005, 1985. https://doi.org/10.1029/JC090iC05p08995