Volumen 34, Nº 4. Páginas 55-62
IDESIA (Chile) Agosto, 2016

Analysis of reference evapotranspiration of Janaúba, Minas Gerais

Análisis de la evapotranspiración de referencia de Janaúba, Minas Gerais

Matheus Mendes Reis[1], Flávio Gonçalves Oliveira[1], Érika Manuela Gonçalves Lopes[1], Fúlvio Rodriguez Simão[1]*

ABSTRACT

Knowledge of the reference evapotranspiration (ETo) is essential for the irrigation management of agricultural crops worldwide. The Penman Monteith demand different weather variables, which hinders its application in areas with few weather stations such as the north of Minas Gerais. This work, compare the method of Hargreaves Samani with Penman Monteith and determine the frequency of occurrence of the reference evapotranspiration in the city of Janaúba, MG. To assess the fit of Hargreaves Samani equation with Penman Monteith used the coefficient of determination (r^2), the coefficient of correlation (r), the standard error of estimate (SEE), the index agreement (d) and the index performance (c). Kimball's method was used for determining the frequency of occurrence. The results indicate that the Hargreaves Samani method overestimates the values of Penman Monteith at 8%, but in the monthly analysis, it is observed that between the months April to August Penman values were superior to Hargreaves. All statistical criteria used showed Hargreaves Samani fitted equation with a better assessment when compared with the Penman Monteith. The higher frequency of occurrence was between 4.5 and 4.7 mm day^{-1} (6.62%) and the equation that indicates the probability of being equaled or exceeded evaporation showed an r^2 equal to 0.9676.

Key words: Penman Monteith, Hargreaves Samani, frequency of occurrence, water, agrometeorology.

RESUMEN

El conocimiento acerca de la evapotranspiración de referencia (ETo) es esencial para el manejo del riego en los cultivos agrícolas en todo el mundo. El método de Penman Monteith utiliza diversas variables meteorológicas, dificultando su utilización en regiones con pocas estaciones meteorológicas, como es el caso del norte de Minas Gerais. El objetivo de este trabajo fue realizar una comparación entre los métodos de Hargreaves Samani y Penman Monteith así como determinar la frecuencia de ocurrencia de la evapotranspiración de referencia en el municipio de Janaúba. Para evaluar el ajuste de la ecuación de Hargreaves Samani con el método de Penman Monteith se utilizó el coeficiente de determinación (r^2), desempeño (c), correlación (r), error estándar de estimativa (EPE) y el índice de concordancia (d). Para determinar la frecuencia de ocurrencia se utilizó el método de Kimbal. Los resultados indicaron que el método de Hargreaves Samani sobreestima los valores de Penman Monteith en 8%, por lo que en el análisis mensual se observa que entre los meses de abril y agosto los valores de Penman fueron superiores a los de Hargreaves. En todos los criterios estadísticos utilizados la ecuación ajustada de Hargreaves Samani presentó mejor comportamiento al compararla con el método de Penman Monteith. La mayor frecuencia de ocurrencia estuvo entre 4,5 y 4,7 mm día^{-1} con 6,62% y la ecuación que indicó la probabilidad de igualar o superar la evapotranspiración presentó un r^2 igual a 0,9676.

Palabras clave: *Penman Monteith, Hargreaves Samani, frecuencia de ocurrencia, agua, agrometeorología.*

Introduction

There are several factors related to the development of crops in the soil-plant-atmosphere system, in which, the adequate supply of water throughout the growing season is the most limiting factor in some regions. The semi-arid regions are characterized by long periods without rain, significant moisture stress, low annual rainfall and high availability of solar energy.

Get values from the crop water consumption through evapotranspiration estimates is essential for sizing and management of irrigation systems, mainly because it is growing awareness of the importance of water resources (Lopes *et al.*, 2011; Rodrigues *et al.*, 2011).

The crop evapotranspiration (ETc) is the product of multiplying the reference evapotranspiration (ETo), which is the evapotranspiration of a standard hypothetical culture, and the crop coefficient (Kc)

[1] Instituto de Ciências Agrárias, Universidade Federal de Minas Gerais, Montes Claros, MG, 39404547, Brazil.
* Corresponding author: matheussmendes@hotmail.com, flavioliveira@ica.ufmg.br

Fecha de Recepción: 19 Febrero, 2016.
Fecha de Aceptación: 19 Julio, 2016.

DOI: 10.4067/S0718-34292016005000017

of interest, this determined through local searches (Allen *et al.*, 1998).

Equipment, methodologies and agrometeorological methods are used to estimate evapotranspiration, but the simplest have inconsistent results (Jensen *et al.*, 1990; Lu *et al.*, 2005; Nandagiri and Kovoor, 2006). The Penman Monteith method recommended by the FAO (Food and Agriculture Organization of the United Nations) to estimate the reference evapotranspiration demand different weather variables (Ortega-Farias *et al.*, 2009) causing difficulties in their use (Conceição, 2010; Alencar *et al.*, 2011; Palaretti *et al.*, 2014), whereas few countries hold enough weather stations throughout its area and with equipment able to provide all the information necessary for implementing this method (Tabari, 2010).

The methods based on the air temperature have frequently been used or recommended (Alencar *et al.*, 2011; Melo *et al.*, 2012; Moura *et al.*, 2013) due to the simplicity of calculations and required data easily obtained. However, simpler methods should be calibrated to specific locations in order to obtain more reliable data (Mohawesh, 2010). One way to define the reliability of the reference evapotranspiration estimated by simplified methods is to determine the degree of approximation to the value estimated by the Penman Monteith method (Vescove and Turco, 2005).

The city of Janaúba, located in the northern state of Minas Gerais, stands out by significant production of fruits, especially bananas. Two irrigated perimeters, Gorutuba and Lagoa Grande, responsible for about 6300 ha of irrigated area are located in the municipality (CODEVASF, 2014).

This study aimed to analyze the reference evapotranspiration of Janaúba, MG, compare Hargreaves Samani method with Penman Monteith and propose adjustments to optimize the Hargreaves Samani method, well as to determine frequency of occurrence of the reference evapotranspiration, this important parameter for determining the water depth of an irrigation project in a region.

Material and Methods

The study was conducted in Janaúba city located in the North of Minas Gerais, whose latitude is 15º 47’ 50” S and longitude is 43º 18’ 31” W. The climate, according to Koppen classification, is Aw, tropical with dry winter.

Were used a historical series of 22 years of daily weather data from the Instituto Nacional de Meteorologia (INMET) installed in the study region, corresponding to the period from 1985 to 2006.

Daily meteorological data available to estimate the reference evapotranspiration (ETo) and to analyze the climatic variables that influence in ETo were: maximum and minimum air temperature, mean air humidity, mean wind speed, insolation and precipitation.

The methods used to estimate ETo values were Penman Monteith-FAO (PM) (Allen *et al.*, 1998) and Hargreaves-Samani (HS) (Hargreaves and Samani, 1985). The daily values of ETo were calculated and presented the mean results for the period of one year.

Description of the methods to estimate ETo

The determination of the evaporation PM method results in the use of Equation 1 (Allen *et al.*, 1998).

$$ETo = \frac{0.408\Delta(Rn\ G) + \gamma \frac{900}{T+273} u_2 (es - ea)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (1)$$

where:
ETo - reference evapotranspiration, mm day^{-1};
Rn - net radiation at the crop surface, MJ m^{-2} day^{-1};
G - soil heat flux density, MJ m^{-2} day^{-1};
T - mean daily air temperature at 2 m height, ºC;
u_2 - wind speed at 2 m height, m s^{-1};
es - saturation vapour pressure, kPa;
ea - actual vapour pressure, kPa;
(es-ea) - saturation vapour pressure deficit, kPa;
Δ - slope vapour pressure curve, kPa ºC^{-1};
γ - psychrometric constant, kPa ºC^{-1}.

The Equation 1 variables were calculated following the methodology proposed in the Technical Report on Irrigation and Drainage nº 56 FAO (Allen *et al.*, 1998), including, where appropriate, the use of recommendations for data poor situations.

The estimation of evapotranspiration by HS method results in the use of the following equation:

$$ETo = kRa(Tmax - Tmin)^{0,5}(T + 17.8) \quad (2)$$

where:
k - adjustment coefficient, whose default value is 0.0023;

Ra - extraterrestrial radiation, MJ m^{-2} day^{-1};
Tmax - maximum air temperature, ºC;
Tmin - minimum air temperature, ºC;
T - mean air temperature, ºC.

Comparison of methods for estimating ETo

The accuracy of ETo estimation methods was assessed based on the correlation coefficient (r) (Equation 3), the agreement index (d) (Equation 4) and the confidence index (c) (Equation 5). Methodology similar to that used by Chagas *et al.* (2013), Sousa *et al.*, (2010) and Borges and Mendiondo (2007) to compare methods of estimating ETo with the PM standard method.

$$r = \sqrt{r^2} \quad (3)$$

where:
r^2 – determination coefficient.

$$d = 1 - \left[\frac{\sum_{i-1}^{N} (Pi - Oi)^2}{\sum_{i-1}^{N} \left(|Pi - Omed| - |Oi - Omed| \right)^2} \right], 0 \leq d \leq 1 \quad (4)$$

where:
Pi - evapotranspiration estimated by the HS method;
Oi - evapotranspiration estimated by the PM method;
Omed - mean evapotranspiration values estimated by the PM method;
N - total number of observations.

$$c = rd \quad (5)$$

The index “d” is described in Willmott *et al.* (1982) and its values range from zero (no agreement) and 1 (perfect agreement). Performance and correlation coefficients were classified according to Table 1 and Table 2, respectively.

Table 1. Classification of confidence index (c).

c	Performance
> 0.85	Excellent
0.76 a 0.85	Very good
0.66 a 0.75	Good
0.61 a 0.65	Medium
0.51 a 0.60	Tolerable
0.41 a 0.50	Bad
≤ 0.40	Terrible

Source: Camargo and Sentelhas (1997).

Table 2. Classification of correlation coefficient (r).

r	Classification
0.0 a 0.1	Very small
0.1 a 0.3	Small
0.3 a 0.5	Moderate
0.5 a 0.7	High
0.7 a 0.9	Very high
0.9 a 1.0	Almost perfect

Source: Hopkins (2007).

The estimated standard error (ESE) was also evaluated (Equation 6).

$$ESE = \sqrt{\frac{\sum_{i-1}^{N} (Oi - Pi)^2}{N - 1}} \quad (6)$$

ETo frequency of occurrence

The Kimball method was adopted to determine the occurrence frequency (Equation 7).

$$F = \frac{m}{n + 1} \quad (7)$$

where:
F - frequency of occurrence of the reference evapotranspiration;
m - order event, in other words, number of times a same value reference evapotranspiration occurred or was exceeded in a given period of time;
n - number of analyzed data.

The analysis of frequency was done in two ways: first, the evaporation reference data were grouped into 0.2 mm intervals and then the frequency of each group was determined, aiming to verify which have the highest occurrence; second, all the daily evapotranspiration over the 22 years were ordered decreasingly, to then be calculated cumulative frequency and, finally, the regression of these data was done, aiming to determine the likelihood of evapotranspiration be equaled or exceeded.

Results and Discussion

The average monthly air temperature, air humidity, wind speed and insolation throughout the year for the region under study are shown in Table 3. July was the coldest month and February the warmest with an average temperature of 22.73 and 26.58 ºC respectively. December had the lowest wind speed and insolation values, 5.80 h and 0.87 m s^{-1}, respectively, and higher air humidity, 73.12%. In contrast, August had the highest average sunshine and wind speed, 9.09 h and 2.13 m s^{-1}, respectively, and lower relative humidity, 53.15%.

Precipitation was another weather information analyzed by the time series. Despite this variable is not part of the PM and HS equations, this weather phenomenon influences the other mentioned variables. The monthly average values are presented in Figure 1.

The daily average values of the reference evapotranspiration (ETo), estimated by the PM and HS methods to the study location are shown in Figure 2.

The mean reference evapotranspiration estimated by the HS and PM method, for the series of 22, were 4.75 and 4.40 mm day^{-1}, respectively. In addition, in that same period, the values obtained by the HS method showed an average 8% higher compared to PM.

Sousa *et al.* (2010) observed similar results in the California and Piaui irrigation district, where the average HS values overestimated by 8.33% the PM values. On the other hand, the mean PM and HS values were equal in the Jabiberi irrigation district and HS values underestimated by 2.44% the PM values in the Jacarecica irrigation district.

Table 3. Monthly averages* of maximum (Tmax), minimum (Tmn) and mean (Tmed) air temperature; air humidity (AH); insolation and wind speed (WS) of Janaúba, MG.

	Tmax (ºC)	Tmin (ºC)	Tmed (ºC)	AH (%)	Insolation (h)	WS (m s^{-1})
January	31.45	20.42	25.94	70.77	7.12	0.88
February	32.76	20.40	26.58	65.86	8.40	1.08
March	32.20	20.52	26.36	67.67	7.72	1.11
April	31.99	19.98	25.98	63.31	8.55	1.55
May	31.15	18.31	24.73	61.31	8.63	1.58
June	29.59	16.51	23.05	59.18	8.71	1.75
July	29.16	16.30	22.73	56.89	9.00	1.97
August	30.48	16.86	23.67	53.15	9.09	2.13
September	32.29	18.54	25.41	53.71	8.31	1.82
October	33.04	20.11	26.57	55.38	7.77	1.51
November	31.10	20.37	25.73	65.38	6.25	1.16
December	30.27	20.53	25.40	73.12	5.80	0.87

* Monthly averages determined by the time series of 22 years.

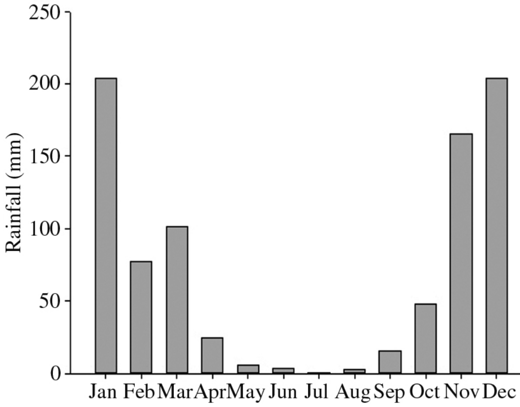

Figure 1. Monthly average precipitation in Janaúba. MG.

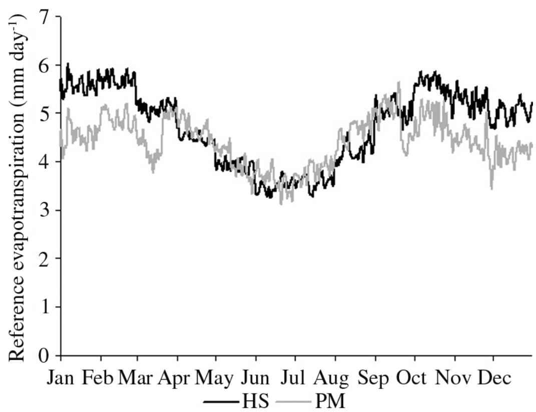

Figure 2. Daily average values of ETo estimated by the PM and HS methods.

Conceição (2013) conducted a similar study and he noted that the HS method overestimates the ETo values determined by the PM standard method in the climatic conditions of São Paulo Northwest.

It is observed, in Table 4, the monthly average and the percentage ratio of ETo of each month. During the rainy season of the year, from October to March, the HS values overestimated by 15% the PM method, but in the dry season, from April to September, the HS method underestimated by 3% the PM values.

Chagas *et al.* (2013) found that, in the rainy season, the HS method overestimated on average 18.88% the PM method, a result that is consistent with this study. However, in the dry season, the ETo values obtained by the HS method also had a higher average, 20.55%, compared to PM.

The PM method presented, in mean, higher values than those determined by HS in the months

Table 4. Average monthly ETo values obtained by PM and HS methods and the percentage ratio between these values.

	Jan	Feb	Mar	Abr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HS	5.58	5.69	5.02	4.48	3.95	3.55	3.62	4.29	5.08	5.60	5.29	5.08
PM	4.54	4.89	4.48	4.68	3.98	3.59	3.81	4.63	4.89	4.85	4.38	4.18
1-(PM/HS)	19%	14%	11%	–4%	–1%	–1%	–5%	–8%	4%	13%	17%	18%

from April to August (Table 4). When compared this information with the climate behavior of this period, it is observed, that the values of rainfall, mean air temperature and air humidity were low, on the other hand, wind speed and insolation were higher than the rest of the year.

Through this information, it is observed that, in the HS equation, the average air temperature and radiation are the only meteorological variables used to determine ETo. However, beyond these two variables, the wind speed and air humidity values are used in the PM equation, which may explain the fact that in the period from April to August the ETo values estimated by PM were higher.

The representative plot of the linear regression analysis between the PM and HS methods is shown in Figure 3. When comparing different methods of estimating evapotranspiration, Gonçalves *et al.* (2009) found that the HS method had the highest coefficient of determination (r²), 0.66.

Proposal of change of HS equation for Janaúba, MG

Daily ETo estimated by the HS and PM equations were correlated, obtaining daily values of the coefficient K (Equation 2) to Janaúba, MG.

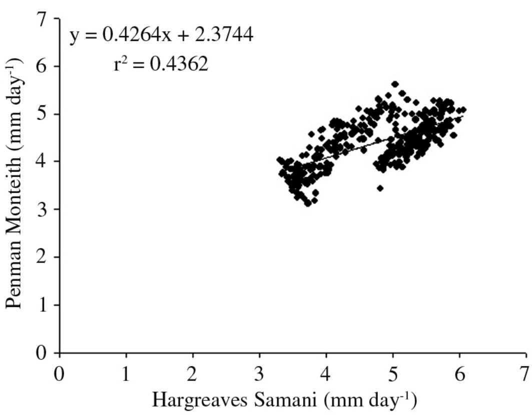

Figure 3. Linear regression between the ETo values estimated by PM and HS.

The values of the coefficient K (Table 5) were determined by the mean daily values.

The comparison between ETo obtained before and after adjusting the HS equation, for the city of Janaúba, MG is shown in Table 6. In the Figure 4, it is observed the representative graph of the linear regression analysis between the HS equation proposal and PM method.

The use of K coefficient proposed for the period from October to March provided an increase in the agreement (d) and confidence (c) index and correlation (r) and determination (r^2) coefficient, matched against, the estimated standard error decreased. It is observed that, with the use of the HS equation proposed to Janaúba, MG, the performance went from bad to good and the correlation classification (Hopkins, 2007) went from high to very high.

The analysis of ETo data from Janaúba, MG (Figures 3 and 4 and Table 6) indicates that the use of the proposed HS equation enables a better estimate of the ETo in the region, when compared to the original equation. This observation is important because in the region of Janaúba, which

Table 5. Values of the original and proposed K coefficients for HS equation.

	K original	K proposed
Oct - Mar	0,0023	0,0020
Abr - Sep	0,0023	0,0023

Table 6. Comparison of the HS equation with original and proposed k coefficient for the Janaúba, MG.

	EPE(%)	r^2	r	d	c	Performance
HSorg	8.733	0.436	0.660	0.721	0.470	Bad
HScor	1.830	0.637	0.798	0.881	0.703	Good

HSorg - HS equation with original coefficient (0.0023); HScor - HS equation with proposed coefficient (Table 5).

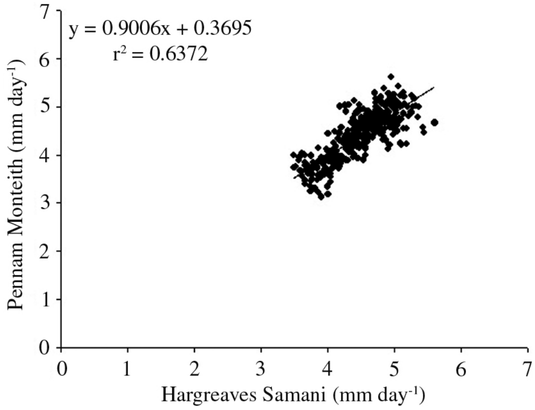

Figure 4. Linear regression between the ETo values estimated by PM and HS equation proposed for the Janaúba, MG.

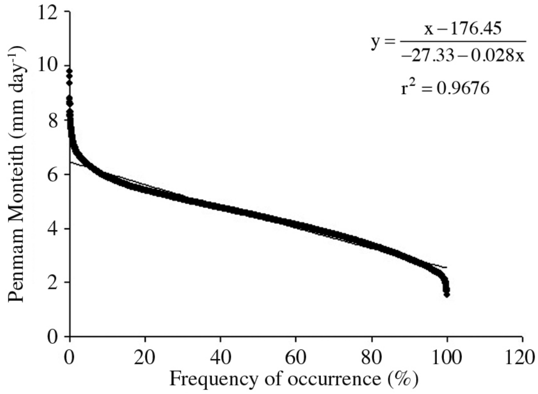

Figure 6. Regression between ETo calculated by PM, and their frequency of occurrence.

has an extensive irrigated area, the weather stations are scarce and direct methods of determining evapotranspiration are few.

Analysis of ETo frequency of occurrence in Janaúba, MG

The frequency of occurrence of ETo estimated by the PM method was analyzed in 0.2 mm dia^{-1} (Figure 5). It was found that, the major frequency of occurrence was between 4.5 and 4.7 mm dia^{-1} with 6.62%. The interval between 2.7 and 5.9 mm dia^{-1} showed an 82.98% probability of occurrence.

The Figure 6 shows the probability of an ETo be equaled or exceeded in Janaúba MG.

Through rational equation proposed in Figure 6, it is possible to estimate the probability of an ETo be equaled or exceeded. In the case of Janaúba, MG, the probabilities of occurring an ETo to 4.72; 5.40; 6.02 and 6.47 mm day^{-1}, are respectively, 50, 80, 90 and 95%. The knowledge of this information allows irrigation projects are determined with more accuracy and greater safety.

Conclusions

Based on the results of analyzes for implementation of this work, it can be concluded that:

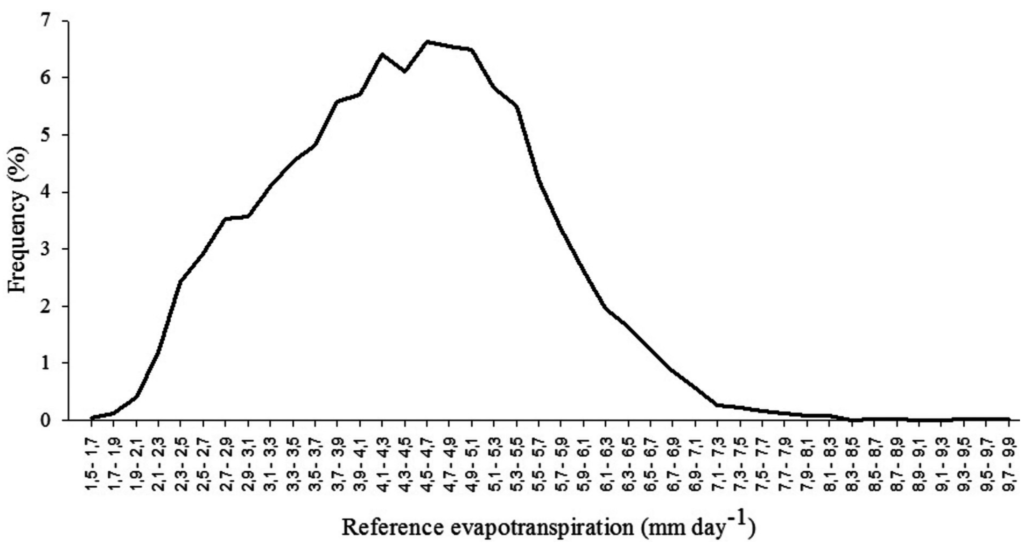

Figure 5. Frequency of occurrence of daily ETo calculated by the PM method in Janaúba, MG.

– There is a tendency of ETo values estimated by the PM method are higher than the HS in the dry season, however, in the rainy period, this situation is opposite;
– The local adjustment of HS method provided significant improvement of the estimated ETo;
– Large proportion of ETo occurring in Janaúba, MG is concentrated in the interval between 2.7 and 5.9 mm day^{-1};
– Through rational equation is possible to determine a safety level on projects that use ETo.

Acknowledgments

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for financial support and fellowships.

Literature Cited

Alencar, L.P.; Delgado, R.C.; Almeida, T.S.; Wanderley, H.S. 2011. Comparação de diferentes métodos de estimativa diária da evapotranspiração de referênci a para a região de Uberaba. *Revista Brasileira de Ciências Agrárias*, 6: 337-343.

Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. 1998. Crop evapotranspiration: guidelines for computing crop water requeriments. FAO. Irrigation and drainage paper 56. Rome, Italia. 333 p.

Borges, A.C. and Mendiondo, E.M. 2007. Comparação entre equações empíricas para estimativa da evapotranspiração de referência na Bacia do Rio Jacupiranga. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 11: 293-300.

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

Chagas, R.M.; Faccioli, G.G.; Netto, A.O.A.; Souza, I.F.; Vasco, A.N.; Silva, M.G. 2013. Comparação entre métodos de estimativa da evapotranspiração de referencia (ETo) no município de Rio Real - BA. *Irriga*, 18: 351-363.

Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba. 2014. Apresenta produtos e serviços referente ao Vale do São Francisco e Parnaíba. Disponível: http://www.codevasf.gov.br. Consulted: 10/nov/ 2014.

Conceição, M.A.F. 2013. Ajuste do modelo de Hargreaves para estimativa da evapotranspiração de referência no noroeste paulista. *Revista Brasileira de Agricultura Irrigada*, 7: 306-316.

Conceição, M.A.F. 2010. Evapotranspiração de referência com base na radiação solar global estimada pelo método de Bristow-Campbell. *Engenharia Agrícola*, 30: 619-626.

Gonçalves, F.M.; Feitosa, H.O.; Carvalho, C.M.; Gomes Filho, R.R.; Valmir Júnior, M. 2009. Comparação de métodos da estimativa da evapotranspiração de referência para o município de Sobral - CE. *Revista Brasileira de Engenharia Agricultura Irrigada*, 3: 71-77.

Hargreaves, G.H.; Samani, Z.A. 1985. Reference crop evapotranspiration from temperature. *Applied Engineering Agriculture*, 1: 96-99.

Hopkins, W.G. 2007. Correlation coefficient. Sportscience. Disponível em: http://www.sportsci.org/resource/stats/correl.htm. Consulted: 02 /jun/2014.

Jensen, M.E.; Burman, R.D.; Allen, R.G. 1990. Evapotranspiration and irrigation water requeriments. *Am. Soc. Civ. Engr. Manual* Nº 70. New York, USA. 332 p.

Lopes, F.B.; Souza, F.; Andrade, E.M.; Meireles, A.C.M.; Caitano, R.F. 2011. Determinação do padrão do manejo da irrigação praticada no perímetro irrigado Baixo Acaraú, Ceará, via análise multivariada. *Irriga*, 16: 301-316.

Lu, J.; Sun, G.; McNulty, S.G.; Amatya, D.M. 2005. A comparasion of six potential evapotranspiration methods for regional use in the Southeastern United States. *Journal of American Water Resources Association*, 41: 621-633.

Melo, G.L. and Fernandes, A.L.T. 2012. Evaluation of empirical methods to estimate reference evapotranspiration in Uberaba, State of Minas Gerais, Brazil. *Engenharia Agrícola*, 32: 875-888.

Mohawesh, O.E. 2010. Spatio-temporal calibration of Blaney-Criddle Equation in Arid and Semiarid environment. *Water Resources Management*, 24: 2187-2201.

Moura, A.R.C.; Montenegro, S.M.G.L.; Antonino, A.C.D.; Azevedo, J.R.G.; Silva, B.B.; Oliveira, L.M.M. 2013. Evapotranspiração de referência baseada em métodos empíricos em bacia experimental no estado de Pernambuco - Brasil. *Revista Brasileira de Meteorologia*, 28: 181-191.

Nandagiri, L. and Kovoor, G.M. 2006. Performance evaluation of reference evapotranspiration equations across a range of Indian climates. *Journal of Irrigation and Drainage Engineering*, 132: 238-249.

Ortega-Farias, S.; Irmak, S.; Cuenca, R.H. 2009. Special issue on evapotranspiration measurement and modeling. *Irrigation Science*, 28: 1-3.

Palaretti, L.F.; Mantovani, E.C.; Sediyama, G.C. 2014. Comparação entre métodos de estimativa da evapotranspiração de referência (ETo) em regiões citrícolas paulistas. *Engenharia Agrícola*, 34: 38-47.

Rodrigues, S.B.S.; Mantovani, E.C.; Oliveira, R.A.; Paiva, H.N.; Alves, M.E.B. 2011. Necessidades hídricas de mudas de eucalipto na região centro oeste de Minas Gerais. *Irriga*, 16: 212-223.

Sousa, I.F.; Silva, V.P.R.; Sabino, F.G.; Netto, A.O.A.; Silva, B.K.N.; Azevedo, P.V.
2010. Evapotranspiração de referência nos perímetros irrigados do Estado de Sergipe. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 14: 633-644.
Tabari, H.
2010. Evaluation of reference crop evapotranspiration equationsin various climates. *Water Resources Management*, 24: 2311-2337.
Vescove, H.V. and Turco, J.E.P.
2005. Comparação de três métodos de estimativa da evapotranspiração de referência para a região de Araraquara, SP. *Engenharia Agrícola*, 25: 713-721.
Willmott, C.J.
1982. Some comments on the evaluation of model performance. *Bulletin of the American Meteorological Society*, 63: 1309-1313.