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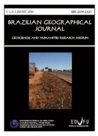

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# Performance of differents methods for estimating reference evapotranspiration on the distinct annual seasons in Minas Gerais State

Master Arthur Ribeiro Ximenes, Master Fernando Mendes Sanches, Master Marco Aurélio de Castro
Majoring in Agronomy, College of Chapadão do Sul, Federal University of Mato Grosso do Sul. Road MS 306, km 105, Zip Code: 79560-000 - Chapadão do Sul, Mato Grosso do Sul, Brazil. E-mail: arthur-ximenes@hotmail.com, fernandomendess92@gmail.com, falecomarco@yahoo.com.br

Doctor Paulo Carteri Coradi
Course of Agronomy and Forestry Engineering, College of Chapadão do Sul, Federal University of Mato Grosso do Sul. Road MS 306, MS 306, km 105, Zip Code: 79560-000 - Chapadão do Sul, Mato Grosso do Sul, Brazil. E-mail: paulo.carteri@ufms.br

Doctor Fernando França da Cunha
Course of Agronomy and Agricultural Engineering, College of Unaí, Federal University of the Vale of Jequitinhonha and Mucuri. Road BR 251, km 12, Zip Code: 38610-000 - Unaí, Minas Gerais, Brazil. E-mail: fernando.cunha@ufvjm.edu.br

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ABSTRACT

Reliable estimates of reference evapotranspiration (ET0) are necessary to address different aspects related to the management of water and environmental resources. There are several models for estimating ET0, each designed for different climatic conditions and which require review before being used in the new region. Given this, we aimed to compare different methodologies for estimating ET0 in different seasons in Minas Gerais State. The methodologies tested were Hargreaves-Samani, Jensen-Haise, Linacre, Makkink and Priestley-Taylor. Estimates of ET0 were held in different annual season (spring, summer, autumn and winter). The meteorological data needed to perform this work were taken from Standard Climatological (1961-1990) of 50 localities of Minas Gerais, provided by the National Institute of Meteorology (Inmet). The method was taken as the standard Penman-Monteith-FAO56 and comparison of results was by the coefficient of determination ($r^2$), the coefficients "a" and "b" of the linear regression equations, standard error of estimate (ESE), Willmott index of agreement (d), the Pearson correlation coefficient (r) and confidence coefficient (c). Independent of the season the Jensen-Haise and Makkink methods should not be use to estimate of ET0 in Minas Gerais State. On the winter, the

Hargreaves-Samani, Priestley-Taylor e Linacre methods can be use to estimate of ET0 in Minas Gerais, however, the Hargreaves-Samani method should be preferred and use when it has only air temperature data. It is recommended, in the summer and autumn seasons, the Priestley-Taylor method and, on the spring, the Hargreaves-Samani method for estimating ET0 in Minas Gerais State.

PALAVRAS-CHAVE:
ET0
Evaporação
Hargreaves-Samani
Penman-Monteith
Sevap

RESUMO: DESEMPENHO DE DIFERENTES MÉTODOS DE ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA NAS DISTINTAS ESTAÇÕES ANUAIS EM MINAS GERAIS. Estimativas confiáveis da evapotranspiração de referência (ET0) são necessárias para enfrentar diferentes aspectos relacionados ao gerenciamento dos recursos hídricos e ambientais. Existem diversos modelos de estimativa da ET0, cada um concebido em condições climáticas diferentes e que necessitam de avaliação antes de serem utilizados em nova região. Diante disso, objetivou-se comparar diferentes metodologias para estimativa da ET0 em distintas estações do ano em Minas Gerais. As metodologias testadas foram Hargreaves-Samani, Jensen-Haise, Linacre, Makkink e Priestley-Taylor. As estimativas de ET0 foram realizadas nas diferentes estações anuais (primavera, verão, outono e inverno). Os dados meteorológicos necessários para execução desse trabalho foram retirados das Normais Climatológicas (1961-1990) de 50 localidades de Minas Gerais, disponibilizadas pelo Instituto Nacional de Meteorologia (Inmet). O método tomado como padrão foi o Penman-Monteith-FAO56 e a comparação dos resultados foi por meio do coeficiente de determinação (r2), dos coeficientes “a” e “b” das equações de regressão linear, erro-padrão da estimativa (ESE), índice de concordância de Willmott (d), coeficiente de correlação de Pearson (r) e do coeficiente de confiança (c). Independente da estação os métodos de Jensen-Haise and Makkink não devem ser utilizados para estimativa da ET0 em Minas Gerais. No inverno, os métodos de Hargreaves-Samani, Priestley-Taylor e Linacre podem ser utilizados para estimativa da ET0 em Minas Gerais, entretanto, o método de Hargreaves-Samani deve ser preferido e, utilizado quando se dispõe apenas de dados de temperatura do ar. Recomenda-se nas estações verão e outono o método de Priestley-Taylor e na primavera o método de Hargreaves-Samani para estimativa da ET0 em Minas Gerais.

RESÚMEN:
ET0
Evaporación
Hargreaves-Samani
Penman-Monteith

RESÚMEN. EL USO DEL SOFTWARE SEVAP PARALA ESTIMATIVA DE REFERENCIA EM LA PROVINCIA DE MINAS GERAIS, BRASIL. Estimativas confiables de la evapotranspiración de referencia (ET0) son necesarias para enfrentar diferentes aspectos relacionados con la gestión de los recursos hídricos y ambientales. Debido a la complejidad de las ecuaciones, hay una demanda del uso de softwares para la obtención de la ET0. Hay diversos modelos para estimar la ET0, cada uno diseñado en distintas condiciones climáticas y requieren evaluación antes de ser utilizados en nueva región. Delante de eso, se objetivó en ese trabajo probar el “software SEVAP” con sus diferentes metodologías para estimativa de la ET0 en la provincia de Minas Gerais. Las metodologías probadas fueron Hargreaves-Samani, Jensen-Haise, Linacre, Makkink y Priestley-Taylor. Los datos meteorológicos necesarios para la ejecución de ese trabajo fueron retirados de las Normales Climatológicas (1961-1990) de 50 localidades de Minas Gerais, proporcionados por el Instituto Nacional de

Meteorología (Inmet). El método tomado como estándar fue el Penman-Monteith-FAO56 y la comparación de los resultados fue por medio del coeficiente de determinación (r2), de los coeficientes "a" y "b" de las ecuaciones de regresión lineal, error-estándar de la estimativa (ESE), índice de concordancia de Willmott (d), coeficiente de correlación de Pearson (r) y del coeficiente de fiabilidad (c). El "software SEVAP" presentó simplicidad en su uso y precisión en la estimativa de la ET0 en Minas Gerais. Las mejores metodologías para la estimación de la ET0 en Minas Gerais fueron Pristley-Taylor, Hargreaves-Samani y Linacre. El método de Hargreaves-Samani debe ser preferido y utilizado sólo cuando se dispone de los datos de temperatura del aire. Las metodologías de Jensen-Haise y Makkink no deben ser utilizadas para estimar la ET0 en Minas Gerais.

## Introduction

Reliable estimates of ET0 are necessary to address different aspects related to the management of water and environmental resources, such as public water supply, the irrigation of crops or environmental preservation of waterways. Allen et al. (1998) define the ET0 as the evapotranspiration that occurs in a hypothetical culture, which has a fixed height of 0.12 m, albedo equal to 0.23 and the surface resistance to transport of water vapor equal to 70 s $m^{-1}$.

The development and application of techniques for estimating ET0 are important aspects of hydrological research (BIDLAKE, 2002). According to Liang; Li; Liu (2009), evapotranspiration is primarily responsible for the loss of water in the watershed, and is closely related to the dynamics of soil moisture, recharging of aquifers and surface runoff. Furthermore, the optimization and conservation of water resources are increasingly important, especially for the over-exploitation they are subjected (JENSEN et al., 1997; SANIJ; YAMAMOTO; RASIAH, 2004).

The ET0 can be determined in different ways. According to Burman et al. (1983), this parameter can be obtained from direct methods, including different types of lysimeters and water balance in the soil, or indirect methods involving measurements of climatic elements.

Within the direct methods for determining ET0, the more accurate is the weighing lysimeter, being of high cost and restricted to research institutions for regional calibration of indirect methods. According to Jensen; Burman; Allen (1990), the indirect methods are checked models of Penman, Jensen-Haise, Priestley-Taylor, Hargreaves-Samani, Linacre, Makkink, among others, and also the evaporimeters, as the Class A pan and atmometer modified. The method based on the evaporation tanks, such as Class A, measures the effect integrated of radiation, wind speed, temperature and relative humidity over the evaporation of a surface of free-water.

There are also methods for estimating ET0 by the meteorological elements that feed empirical equations and/or with physical fundamentation. Many of these methods have variants, for issues of local adjustments and local calibrations, further increasing the amount of available methods (CARVALHO et al., 2011).

The method of Penman-Monteith-FAO56 (ALLEN et al., 1998) according to various studies, in Brazil and in the world, is quite accurate (XU; CHEN, 2005; YODER; ODHIAMBO; WRIGHT, 2005; LÓPEZ-URREA et al., 2006; JABLOUN; SAHLI, 2008; BARROS et al., 2009) being thence, widely used as a standard for comparison with other methods. According to Allen et al. (1998), this model provides reliable and consistent estimates of ET0 because it associates the effects of energy balance and aerodynamic terms in estimating evapotranspiration. Doorenbos; Pruitt (1977) modified the equation of Penman (1963), giving greater sensitivity due to the wind, adjusting the correction factor FAO (c), based on local weather conditions and assuming flux density heat the ground (G) equal to zero at times daily. According to Cavalcante Jr. et al. (2011), despite the Penman-Monteith-FAO56 ET0 estimate satisfactorily, often not all meteorological elements required for use of this model are available. In this scenario, other methods that require fewer meteorological elements can be used.

The Linacre method was developed in 1977 and based on correlations founds between the various meteorological factors, simplified the Penman equation estimating the potential evaporation and potential evapotranspiration just based on geographical data (latitude and altitude) and air temperature (DOLAN et al., 1984). The Makkink method is derived from the Penman-Monteith and was developed for climate conditions of Wageningem, the Netherlands, requiring the following input parameters: slope of the pressure curve, psychrometric coefficient and global radiation (BERLATO; MOLION, 1981). The Hargreaves-Samani method is derived from the Hargreaves method that was developed in Davis, California based on a study of grass in lysimeters. This method was developed for regions where the availability of climatological data was limited (JACOBS; SATTI, 2001), requiring measures terrestrial radiation and maximum and minimum temperatures. In 1985, Hargreaves and Samani simplified this formula where only measures temperature maximum and minimum (PEREIRA; VILLA NOVA; SEDIYAMA, 1997). The Priestley-Taylor equation was developed in 1972 and simulates the evaporation surfaces in a saturated atmosphere not saturated, which is the normal condition of nature. The input parameters are slope of the pressure curve, psychrometric coefficient and net radiation (BERLATO; MOLION, 1981). The Jensen-Haise method is simple and based only on daily values of mean temperature and solar radiation.

Minas Gerais is one of the largest states, in area size, and agricultural producer in the country. Therefore, this state has several hydro-agricultural projects that require fast and reliable estimates of ET0. Despite the existence of many estimated ET0, these, however, are used in very different climatic and agronomic conditions from those that were originally designed and therefore is of utmost importance to assess the degree of accuracy of these models, before use them to new condition. Several studies comparing the various methods for estimating ET0 are found in the literature for different regions (ARAÚJO; COSTA; SANTOS, 2007; BACK, 2008; SYPERRECK et al., 2008; BARROS et al., 2009; KISI, 2009; PEREIRA et al., 2009; CAVALCANTE Jr. et al., 2011; KISI; ALI BABA; SHIRI, 2012; MAGALHÃES; CUNHA, 2012; SAHOO et al., 2012; CUNHA; MAGALHÃES; CASTRO, 2013). In addition to the variations among models to estimate ET0, these can also present different behaviors in different annual season.

Given this, the present study aimed to compare different methodologies for estimating ET0 in different annual seasons in Minas Gerais State.

## Material and Methods

Were tested the following methodologies to estimates of reference evapotranspiration (ET0): Hargreaves-Samani, Jensen-Haise, Linacre, Makkink and Priestley-Taylor. The estimate were realized on the different annual season (spring, summer, autumn and winter), using for this the SEVAP software (SILVA et al., 2005). Table 1 shows the input parameters for the five models tested and to the method of Penman-Monteith-FAO56 (ALLEN et al., 1998), which was taken as the standard for estimating ET0, following recommendations from the Food and Agriculture Organization.

Table 1. Input parameters for estimating reference evapotranspiration (ET0) for different models of Penman-Monteith used by SEVAP software

| Methods | Input Parameters Measured | | | | | |
|---|---|---|---|---|---|---|
| | $T_{max}$ (°C) | $T_{min}$ (°C) | n (hours) | RH (%) | $U_2$ (m $s^{-1}$) | $P_{atm}$ (hPa) |
| Penman-Monteith | x | x | x | x | x | x |
| Hargreaves-Samani | x | x | | | | |
| Jensen-Haise | x | x | x | | | |
| Linacre | x | x | | x | | |
| Makkink | x | x | x | | | |
| Priestley-Taylor | x | x | x | | | |

$T_{max}$ - Maximum Temperature (°C); $T_{min}$ - Minimum Temperature (°C); n - Duration Solar Brightness (hours); UR - Relative Humidity (%); $U_2$ - Wind speed (m $s^{-1}$); e $P_{atm}$ - Atmospheric Pressure (hPa).

The meteorological data needed to perform this work were taken from Normal Climatological (1961-1990) of 50 locations in the Minas Gerais State, provided by the National Institute of Meteorology (Inmet). The codes of meteorological stations and information on latitude, longitude and altitude are shown in Table 2.

Table 2. Information of the Minas Gerais State weather stations used to estimate reference evapotranspiration (ET0) by SEVAP software

| Locality | Code | Latitude (degrees: minutes) | Longitude (degrees: minutes) | Altitude (meters) |
|---|---|---|---|---|
| Aimorés | 83595 | 19°29'S | 41°04'W | 82.7 |
| Araçuaí | 83442 | 16°50'S | 42°03'W | 289.0 |
| Araxá | 83579 | 19°36'S | 46°56'W | 1023.6 |
| Belo Horizonte | 83587 | 19°56'S | 43°56'W | 915.0 |
| Poços de Caldas | 83681 | 21°55'S | 46°23'W | 1150.0 |
| Cambuquira | 83685 | 21°51'S | 45°18'W | 950.1 |
| Capinópolis | 83514 | 18°43'S | 49°33'W | 620.6 |
| Caratinga | 83592 | 19°48'S | 42°09'W | 609.7 |
| Cataguases | 83027 | 21°23'S | 42°41'W | 168.0 |
| Caxambu | 83686 | 21°58'S | 44°56'W | 958.5 |
| Conceição do Mato Dentro | 83589 | 19°01'S | 43°26'W | 652.0 |
| Coronel Pacheco | 83037 | 21°34'S | 43°15'W | 435.0 |
| Curvelo | 83536 | 18°45'S | 44°27'W | 672.0 |
| Diamantina | 83538 | 18°15'S | 43°36'W | 1296.1 |
| Espinosa | 83338 | 14°55'S | 42°51'W | 569.6 |
| Florestal | 83581 | 19°53'S | 44°25'W | 753.0 |
| Formoso | 83334 | 14°56'S | 46°15'W | 840.0 |
| Frutal | 83574 | 20°02'S | 48°56'W | 543.7 |
| Governador Valadares | 83543 | 18°51'S | 41°56'W | 148.0 |
| Ibirité | 83632 | 20°01'S | 44°03'W | 814.5 |
| Itamarandiba | 83488 | 17°51'S | 42°51'W | 1097.0 |
| Itambacuri | 83490 | 18°01'S | 41°01'W | 285.4 |
| Januária | 83386 | 15°27'S | 44°22'W | 473.7 |
| João Monlevade | 83591 | 19°50'S | 43°07'W | 859.8 |
| João Pinheiro | 83481 | 17°42'S | 46°10'W | 760.4 |
| Juiz de Fora | 83692 | 21°46'S | 43°21'W | 940.0 |
| Lavras | 83687 | 21°45'S | 45°00'W | 918.8 |
| Machado | 83683 | 21°39'S | 45°54'W | 873.4 |
| Minas Novas | 83440 | 17°14'S | 42°35'W | 920.8 |
| Monte Azul | 83388 | 15°05'S | 42°45'W | 603.6 |
| Montes Claros | 83437 | 16°41'S | 43°50'W | 646.3 |
| Oliveira | 83637 | 20°41'S | 44°49'W | 966.5 |
| Ouro Fino | 83732 | 22°17'S | 46°22'W | 925.7 |
| Paracatu | 83479 | 17°14'S | 46°53'W | 712.0 |
| Passa Quatro | 83737 | 22°23'S | 44°58'W | 920.0 |
| Patos de Minas | 83531 | 18°31'S | 46°26'W | 940.3 |
| Patrocínio | 83539 | 18°57'S | 47°00'W | 934.0 |
| Pedra Azul | 83393 | 16°00'S | 41°17'W | 648.9 |
| Pirapora | 83483 | 17°21'S | 44°55'W | 505.2 |
| Pompeu | 83570 | 19°13'S | 45°00'W | 690.9 |
| Salinas | 83441 | 16°10'S | 42°18'W | 471.3 |
| São Francisco | 83385 | 15°57'S | 44°52'W | 446.5 |

| | | | | |
|---|---|---|---|---|
| São João del-Rei | 83688 | 21°18'S | 44°16'W | 991.0 |
| São Lourenço | 83736 | 22°06'S | 45°01'W | 953.2 |
| São Sebastião do Paraíso | 83631 | 20°55'S | 47°07'W | 820.0 |
| Sete Lagoas | 83586 | 19°28'S | 44°15'W | 732.0 |
| Teófilo Otoni | 83492 | 17°51'S | 41°30'W | 356.4 |
| Uberaba | 83577 | 19°44'S | 47°57'W | 737.0 |
| Usiminas | 83594 | 19°29'S | 42°32'W | 298.6 |
| Viçosa | 83642 | 20°45'S | 42°51'W | 689.7 |

The ET0 obtained by the proposed method by Penman-Monteith-FAO56 (ALLEN et al., 1998) method was calculated according to the following equations:

$$ET0 = \frac{0.408\ \Delta\ (R_N - G) + \gamma\ \frac{900}{t+273}\ U_2\ \frac{(e_S - e)}{10}}{\Delta + \gamma\ (1 + 0.34\ U_2)} \quad (1)$$

$$R_N = Rns + Rnl \quad (2)$$

$$Rns = R_S\ (1 - \alpha) \quad (3)$$

$$Rnl = 4.8989\ 10^{-9}\ T^4\ \left(0.09\ \sqrt{0.75\ e} - 0.56\right)\left(0.1 + 0.9\frac{n}{N}\right) \quad (4)$$

$$R_S = R_a\ \left(a + b\ \frac{n}{N}\right) \quad (5)$$

$$R_a = 37.6\ d_r\ \left[\frac{\pi}{180}\ w_s\ \text{sen}\,\varphi\ \text{sen}\,\delta + \cos\varphi\ \cos\delta\ \text{sen}\,w_s\right] \quad (6)$$

$$a = 0.29\ \cos\varphi \quad (7)$$

$$b = 0.52 \quad (8)$$

$$N = \frac{2\ w_s}{15} \quad (9)$$

$$d_r = 1 + 0.033\ \cos\left(\frac{360\ \ j}{365}\right) \quad (10)$$

$$w_s = \text{arc}\ \cos[-\ \text{tag}\,\varphi\ \text{tag}\,\delta] \quad (11)$$

$$\delta = 23.45\ \ \text{sen}\ \left[\frac{360}{365}(284 + j)\right] \quad (12)$$

$$e = \frac{RH}{100}\ e_S \quad (13)$$

$$e_S = 6.1078\ 10^{\left(\frac{7.5\ t}{237.3\ +\ t}\right)} \quad (14)$$

$$\Delta = \frac{409.8\ e_S}{(237.3 + t)^2} \quad (15)$$

$$G = 0.05\ R_N \quad (16)$$

$$\gamma = 162.86\ \frac{P}{\lambda} \quad (17)$$

$$\lambda = 2.5\ 10^6 - 2.370\ t \quad (18)$$

$$U_2 = \frac{4.868}{\ln\ (67.75\ z - 5.42)}\ U_z \quad (19)$$

where:

ET0 = reference evapotranspiration of the Penman-Monteith, mm day$^{-1}$;

$\Delta$ = slope vapour pressure curve, kPa °C$^{-1}$;

$R_N$ = net radiation at the crop surface, MJ $m^{-2}$ $day^{-1}$;
$\gamma$ = psychrometric constant, kPa $°C^{-1}$;
t = mean daily air temperature at 2 m height, ºC;
$U_2$ = wind speed at 2 m height, m $s^{-1}$;
$e_S$ = saturation vapour pressure, hPa;
e = actual vapour pressure, hPa;
Rns = net solar or shortwave radiation, MJ $m^{-2}$ $day^{-1}$;
Rnl = net longwave radiation, MJ $m^{-2}$ $day^{-1}$;
$R_S$ = solar or shortwave radiation, MJ $m^{-2}$ $day^{-1}$;
$\alpha$ = albedo or canopy reflection coefficient, dimensionless;
T = average daily temperature of the air, K [K = °C + 273.16];
n = actual duration of sunshine, hour;
N = maximum possible duration of sunshine or daylight hours, hour;
$R_0$= extraterrestrial radiation, MJ $m^{-2}$ $day^{-1}$;
a e b = fraction of extraterrestrial radiation reaching the earth on clear-sky days, dimensionless;
$d_r$ = inverse relative distance Earth-Sun, dimensionless;
$w_s$ = sunset hour angle, degrees;
$\varphi$ = latitude, degrees;
$\delta$ = solar declination, degrees;
j = number of the day in the year between 1 (1 January) and 365 or 366 (31 December);
RH = relative humidity, %;
G = soil heat flux, MJ $m^{-2}$ $day^{-1}$;
P = atmospheric pressure, hPa;
$\lambda$ = latent heat of vaporization, J $kg^{-1}$;
$U_z$ = wind speed at “z” m above ground surface, m $s^{-1}$; and
z = height of wind measurements, m.

After obtaining the daily ET0 through different methodologies, within each annual season, it was conducted a regression analysis that correlated the ET0 values estimated by empirical equations of the SEVAP software with the Penman-Monteith-FAO56 method (ALLEN et al., 1998). It was considered the coefficients “a” and “b” of the respective linear regressions and the coefficient of determination ($r^2$). The best alternative was the one that showed regression coefficient “a” near to zero, coefficient “b” near the unity and higher coefficient of determination, more than 0.60. The precision was measured through the coefficient of determination, which indicates the degree to which the regression explains the sum of the total squared.

The models performance analysis was performed by comparing the daily ET0 values obtained by empirical methods such as the Penman-Monteith-FAO56 (ALLEN et al., 1998). The methodology adopted for comparison of results was proposed by Allen et al. (1989), and is based on the standard error of the estimate (ESE), calculated by Equation 20. The best method to estimate ET0 was the one that presented the lowest ESE.

$$ESE = \left[ \frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{n} \right]^{1/2} \qquad (20)$$

where:

ESE = standard error of estimate, mm day$^{-1}$;
$X_i$ = reference evapotranspiration estimated by the standard method, mm day$^{-1}$;
$Y_i$ = reference evapotranspiration obtained through the tested method, mm day$^{-1}$; and
n = number of observations.

The approximation of ET0 values estimated by the method studied, in relation to the values obtained using the standard method, was obtained by an index called concordance, represented by the letter "d" (WILLMOTT et al., 1985), where its values range from zero, where there is no concordance, to 1, for the perfect concordance. The concordance index (d) was calculated using the Equation 21. To validate the model, it was also obtained the Pearson's correlation coefficient (r) through Equation 22 and the reliable coefficient or performance (c) through Equation 23.

$$d = 1 - \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=1}^{n}\left[\left(\left|X_i - \overline{Y}\right|\right) + \left(\left|Y_i - \overline{Y}\right|\right)\right]^2} \qquad (21)$$

$$r = \frac{\sum_{i=1}^{n}\left(\left|Y_i - \overline{Y}\right|\right)\left(\left|X_i - \overline{X}\right|\right)}{\sqrt{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}\sqrt{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}} \qquad (22)$$

$$c = r\ d \qquad (23)$$

where:
d = Willmott's concordance index;
$X_i$ = reference evapotranspiration estimated through the standard method, mm day$^{-1}$;
$Y_i$ = reference evapotranspiration obtained through the method tested, mm day$^{-1}$;
$\overline{Y}$ = average values of reference evapotranspiration obtained through the method tested, mm day$^{-1}$;
$\overline{X}$ = average values of reference evapotranspiration obtained through standard method, mm day$^{-1}$;
n = number of observations;
r = Pearson's correlation coefficient; and
c = reliable coefficient or performance.

According to Cohen (1988), the correlation coefficient (r) can be classified as: "very low" ($r < 0.1$), "low" ($0.1 < r < 0.3$), "moderate" ($0.3 < r < 0.5$); "high" ($0.5 < r < 0.7$); "very high" ($0.7 < r < 0.9$); and "almost perfect" ($r > 0.9$).

The coefficient "c", proposed by Camargo; Sentelhas (1997), is interpreted in accordance with authors such as: "great" ($c > 0.85$); "very good" ($0.76 < c < 0.85$); "good" ($0.66 < c < 0.75$), "average" ($0.61 < c < 0.65$), "badly" ($0.51 < c < 0.60$), "not good" ($0.41 < c < 0.50$) and "terrible" ($c < 0.40$).

## Results and Discussion

In Figure 1, for each annual season, are shown in the graphs and the models resulting of the linear regression being considering the methods for estimating reference evapotranspiration (ET0) used in the analysis with the Penman-Monteith standardized by FAO as standard. It is observed, on the basis of the regression lines, the method of Jensen-Haise underestimated and the method of Makkink overestimated

ET0 values. These results agree with some studies in the literature. Mendonça et al. (2003) found underestimation of ET0 with the method of Jensen-Haise in the Northern Fluminense on the State of Rio de Janeiro. Magalhães; Cunha (2012) found overestimation of ET0 by Makkink method in Mato Grosso do Sul State. The Linacre method, on the spring and autumn seasons, presented high coefficients “a” and “b”, in the other words, this method overestimated the values of ET0 in relation to the standard method. In general, is observed also in Figure 1 that the Hargreaves-Samani, Linacre and Priestley-Taylor underestimated the ET0 values only when the Penman-Monteith-FAO56 accused estimates above 4.5 mm day$^{-1}$. Cunha; Magalhães; Castro (2013) evaluating the performance of these methods on Chapadão do Sul-MS, observed that the Hargreaves-Samani and Priestley-Taylor methods underestimated the ET0 values only when the standard method accused estimates exceeding 5.5 and 3.0 mm day$^{-1}$, respectively.

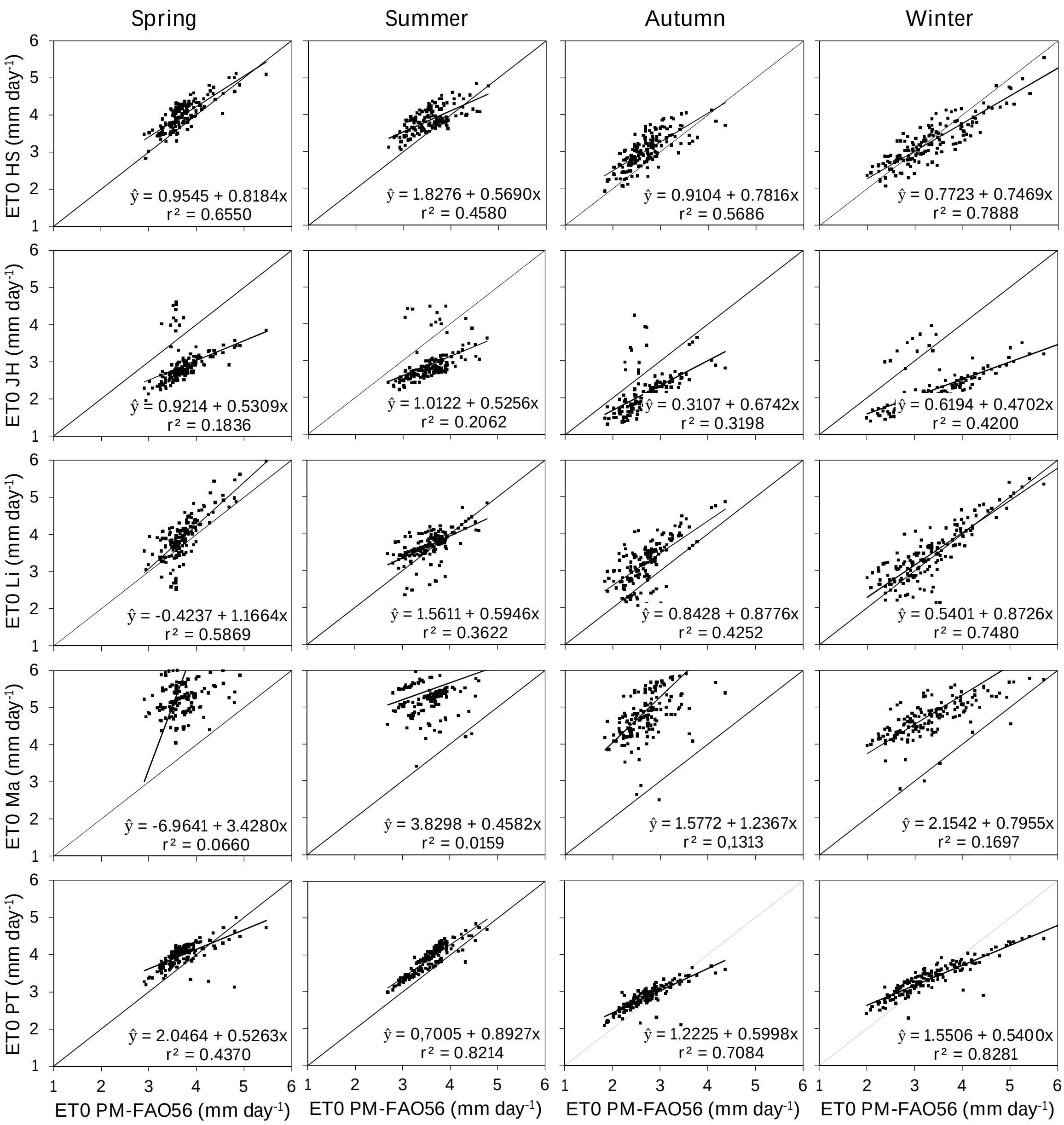


Figure 1. Values of reference evapotranspiration (ET0) obtained by the Penman-Monteith-FAO56 compared with ET0 values obtained by SEVAP through the equations

of Hargreaves-Samani (HS), Jensen-Haise (JH), Linacre (Li), Makkink (Ma) and Priestley-Taylor (PT) in different annual season.

Independent of annual season, the worst fit of the regression equations to determine ET0, according to the coefficient of determination ($r^2$) was observed in Makkink method. Moreover, this method did not match good regression coefficients "a" and "b" corroborating Magalhães; Cunha (2012) evaluated this method in the Mato Grosso do Sul State. Then, the second worst fit was found on the Jensen-Haise method.

In general, the best fit was found using the method of Priestley-Taylor. This method was also presented the best combination of regression coefficients "a" and "b", so that the "a" coefficient approached zero and the coefficient "b" unit. The Priestley-Taylor method, according Berlato; Molion (1981) simulates the evaporation of surfaces saturated on the atmosphere not saturated, which is the normal condition of nature. Marcuzzo; Arantes; Wendland (2008) in the São Paulo State and Magalhães; Cunha (2012) in Mato Grosso do Sul State, also found good fits of the regression equations relating the estimates of ET0 with the methods of Penman-Monteith-FAO56 and Priestley-Taylor.

On the Table 3 are presents the standard error estimate (ESE), Willmott concordance (d), the Pearson's correlation (r), reliability coefficient (c) and performance of Camargo; Sentelhas (1997) obtained by correlations between the ET0 values by Penman-Monteith-FAO56 with the methodologies tested, in each annual season. It is observed in the spring, that Hargreaves-Samani was the better method to estimate of ET0. This method it's highlighted by the low value of ESE, presented the correlation coefficient with classification "very high" according with Cohen (1988) and performance rated as "Good" according Camargo; Sentelhas (1997). Given this, on the spring season, this method should be preferred to estimate reliable of ET0 on the Minas Gerais State. Hargreaves-Samani not estimated accurately the ET0 in some brazilian regions and Oliveira et al. (2008) in Viçosa-MG, Reis; Bragança; Garcia (2007) on Venda Nova do Imigrantes-ES, Bragança et al. (2010) in Cachoeiro do Itapemerim, Sooretama and Venda Nova-ES, Tagliaferre et al. (2010) in Eunápolis-BA, Alencar et al. (2011) in Uberaba-MG. Barros et al. (2009) evaluating Hargreaves-Samani method on the region of Seropédica-RJ found no good estimates of daily ET0. The authors recommend this method only for average estimates from 3 days. Back (2008) observed poor performance of Hargreaves-Samani in estimated ET0 in Urussanga-SC and justified by the fact that the method has been developed for the semi-arid conditions.

Table 3. Estimate of standard error (ESE), Willmott's concordance (d), the Pearson's correlation (r), reliability coefficient (c) and performance of Camargo and Sentelhas obtained correlations between the values of reference evapotranspiration (ET0) by the method Penman-Monteith-FAO56 with those obtained by SEVAP software with equations of Hargreaves-Samani, Jensen-Haise, Linacre, Makkink and Priestley-Taylor in different annual season

| | Method | ET0 | ESE | d | r | c | Performance |
|---|---|---|---|---|---|---|---|
| Spring | Penman-Monteith | 3,7111 | - | - | - | - | - |
| | Hargreaves-Samani | 3,9917 | 0,3677 | 0,7962 | 0,8666 | 0,6900 | Good |
| | Jensen-Haise | 2,8915 | 0,9420 | 0,4045 | 0,6316 | 0,2555 | Terrible |
| | Linacre | 3,9049 | 0,4264 | 0,7996 | 0,8028 | 0,6419 | Average |
| | Makkink | 5,7576 | 5,4207 | 0,0873 | 0,3044 | 0,0266 | Terrible |
| | Priestley-Taylor | 3,9994 | 0,4101 | 0,6993 | 0,8753 | 0,6121 | Average |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Summer | Penman-Monteith | 3,5701 | - | - | - | - | - |
| | Hargreaves-Samani | 3,8591 | 0,4134 | 0,7081 | 0,7720 | 0,5466 | Badly |
| | Jensen-Haise | 2,8886 | 0,8139 | 0,4880 | 0,6624 | 0,3232 | Terrible |
| | Linacre | 3,6838 | 0,3658 | 0,7567 | 0,7426 | 0,5619 | Badly |
| | Makkink | 5,4657 | 2,3730 | 0,1878 | 0,2909 | 0,0546 | Terrible |
| | Priestley-Taylor | 3,8874 | 0,3593 | 0,8162 | 0,9278 | 0,7573 | Good |
| Autumn | Penman-Monteith | 2,6991 | - | - | - | - | - |
| | Hargreaves-Samani | 3,0201 | 0,4525 | 0,7693 | 0,8016 | 0,6167 | Average |
| | Jensen-Haise | 2,1305 | 0,7326 | 0,5719 | 0,7148 | 0,4088 | Terrible |
| | Linacre | 3,2115 | 0,6875 | 0,6542 | 0,7921 | 0,5182 | Badly |
| | Makkink | 4,9151 | 2,6335 | 0,2380 | 0,4570 | 0,1088 | Terrible |
| | Priestley-Taylor | 2,8415 | 0,2857 | 0,8619 | 0,9255 | 0,7977 | Very Good |
| Winter | Penman-Monteith | 3,3465 | - | - | - | - | - |
| | Hargreaves-Samani | 3,2719 | 0,3623 | 0,9315 | 0,9099 | 0,8476 | Very Good |
| | Jensen-Haise | 2,1930 | 1,2945 | 0,5236 | 0,7903 | 0,4138 | Not Good |
| | Linacre | 3,4604 | 0,4168 | 0,9235 | 0,8938 | 0,8254 | Very Good |
| | Makkink | 4,8164 | 2,0021 | 0,4331 | 0,4474 | 0,1937 | Terrible |
| | Priestley-Taylor | 3,3578 | 0,4005 | 0,8900 | 0,9465 | 0,8424 | Very Good |

On the summer and autumn seasons, it is observed that the Priestley-Taylor was the method that presented better performance, according Camargo; Sentelhas (1997), to the ET0 estimate in Minas Gerais State. This method presented a correlation coefficient (r) with the classification “almost perfect” and, given this, must be preferred to ET0 estimate on this annual seasons. Also, was the model that had the lowest ESE and higher concordance Willmott, confirming its best performance compared to other methods. Bragança et al. (2010) in the Espírito Santo State, Tagliaferre et al. (2010) in Eunápolis-BA, Silva et al. (2011) in Uberlândia-MG and Magalhães; Cunha (2012) in Mato Grosso do Sul State also observed good performance of the Priestley-Taylor method to estimate the daily ET0. Xu; Chen (2005) evaluated in Germany seven methods for the estimation of ET0, among them, Priestley-Taylor, comparing them with data from a weighing lysimeter. The authors concluded that this method has achieved good results, with error below 10%. This methodology is based on net radiation and has been used in many studies because of its simplicity compared to the combined methods, does not require data of wind speed and air relative humidity.

In winter, the Hargreaves-Samani, Linacre and Prietley-Taylor methods overcame the others and had a performance rated "very good", according to Camargo; Sentelhas (1997). The Hargreaves-Samani method stands out for being very simple and easy to apply, requiring only temperature data and latitude of the location. Thus, by requiring only a thermometer maximum and minimum, should be preferred for reliable estimation of ET0 in Minas Gerais, in the winter season. It is worth mentioning that the Priestley-Taylor method despite its better performance of Camargo; Sentelhas (1997) presented coefficient of confidence very close to the Hargreaves-Samani method. Added to this, requires complex data, such as terrestrial radiation and duration dolar brightness for entry on the SEVAP software. It is worth mentioning that the Priestley-Taylor method despite its better performance on this study.

The methodology of Linacre received performance rated as "very good" and can also be used in winter season of Minas Gerais. However, this method has the disadvantage, compared to the method of Hargreaves-Samani, of requiring the calculation of dew point temperature by the relative humidity, which can be obtained by means of a term-higrógrafo. This method is derived from the Penman method and also requires geographic data (latitude and altitude) and mean air temperature. Pereira et al. (2009) in the Serra da Mantiqueira-MG and Mendonça; Dantas (2010) in Capim-PB found no good estimates of ET0 by this method in these regions, and blamed this performance by disregarding radiation and wind speed.

The methodologies of Jensen-Haise and Makkink obtained low correlation coefficients and received, according to Camargo; Sentelhas (1997), performances “not good” and “terrible” in differents annual seasons (Table 3). Besides the low performance, this methodology requires radiation data, which hinders its use. According to Cavalcante Jr. et al. (2011), the equation of Jensen-Haise, the same way that the Hargreaves-Samani equation was developed for arid and semi-arid, and with this, has good adaptability to the dry period. Silva et al. (2005) also confirms that the methodology of Jensen-Haise is suitable for arid and semi-arid, and with this, it should fit well to the north of Minas Gerais, specifically. Souza et al. (2011) evaluating the method of Jensen-Haise in Seropédica-RJ also did not found a perform well in the estimation of ET0. The authors have shown through their results, that the confidence in the use of this method must be reduced as increase the cloudiness on the day of the estimate, ie, when the atmospheric transmissivity decrease. Magalhães; Cunha (2012) using the software SEVAP also found poor performance of Jensen-Haise methodology for estimation of ET0 in Mato Grosso do Sul.

The method Makkink, among all tested methods, showed the largest ESE (Table 3). We expected better performance Makkink method, since it is derived from the Penman-Monteith, but possibly the effect of wind speed of Minas Gerais, which does not include the method, has been the factor responsible for wretched estimated ET0, similar to observations made by Magalhães; Cunha (2012), evaluating this method in the State of Mato Grosso do Sul in the literature, Turco; Perecin; Pinto Jr. (2008 ) in the São Paulo State and Araújo; Costa; Santos (2007) also found in Roraima underperforming the Makkink method, however, the States of Paraíba (SILVA et al., 2005), Rio de Janeiro (MENDONÇA et al., 2003) and Pará (SILVA; COSTA, 2000), this method showed excellent accuracy in the estimation of ET0, when compared to the standard method. In turn, Tabari (2010) evaluated this method on four different climatic types, in Iran. The results showed that the method of Makkink had the worst performance among the methods studied. The author reports that this method has good performance in regions of cold, damp weather, and with this, justified his low performance for estimation of ET0 in the Minas Gerais State.

## Conclusion

It is recommended, in the summer and autumn seasons, the Priestley-Taylor method and, on the spring season, the method of Hargreaves-Samani for estimating ET0 in Minas Gerais State. In winter, the Hargreaves-Samani, Priestley-Taylor and Linacre methods can be used to estimate ET0 in Minas Gerais State, however, the Hargreaves-Samani method should be preferred and used only when it has air temperature data. Independent of the seasons, the Jensen-Haise and Makkink methods should not be used to estimate ET0 in Minas Gerais State.

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### References

ALENCAR, L. P.; DELGADO, R. C.; ALMEIDA, T. S.; WANDERLEY, H. S. Comparação de diferentes métodos de estimativa diária da evapotranspiração de referência para a região de Uberaba. **Revista Brasileira de Ciências Agrárias**, Recife, v. 6, n. 2, p. 337-343, 2011.

ALLEN, R. G.; JENSEN, M. E.; WRIGHT, J.; BURMAN, R. D. Operational estimates of reference evapotranspiration. **Agronomy Journal**, Madison, v. 81, n. 4, p. 650-662, 1989.

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

ARAÚJO, W. F.; COSTA, S. A. A.; SANTOS, A. E. Comparação entre métodos de estimativa da evapotranspiração de referência (ET0) para Boa Vista, RR. **Caatinga**, Mossoró, v. 20, n. 4, p. 84-88, 2007.

BACK, A. J. Desempenho de métodos empíricos baseados na temperatura do ar para a estimativa da evapotranspiração de referência em Urussanga, SC. **Irriga**, Botucatu, v. 13, n. 4, p. 449-466, 2008.
BARROS, V. R.; SOUZA, A. P.; FONSECA, D. C.; SILVA, L. B. D. Avaliação da evapotranspiração de referência na região de Seropédica, Rio de Janeiro, utilizando lisímetro de pesagem e modelos matemáticos. **Revista Brasileira de Ciências Agrárias**, Recife, v. 4, n. 2, p. 198-203, 2009.
BERLATO, M. A.; MOLION, L. C. B. **Evaporação e evapotranspiração**. Porto Alegre: IPAGRO/Secretaria de Agricultura, 1981. 95 p. (Boletim Técnico, 7).
BIDLAKE, E. R. Evapotranspiration and canopy resistance at an undeveloped prairie in a humid subtropical climate. **Journal of the American Water Resources Association**, Washington, v. 38, n. 1, p. 197-211, 2002.
BRAGANÇA, R.; REIS, E. F.; GARCIA, G. O.; PEZZOPANE, J. E. M. Estudo comparativo da estimativa da evapotranspiração de referência no período chuvoso para três localidades no Estado do Espírito Santo. **Idesia**, Arica, v. 28, n. 2, p. 21-29, 2010.
BURMAN, R. D.; NIXON, P. R.; WRIGHT, T. L.; PRUITT, W. O. **Water requeriments**. In: JENSEN, M. E. Design operation of farm irrigation system. Saint Joseph: ASAE, 1983. p. 189-232.
CAMARGO, A. P.; SENTELHAS, P. C. Avaliação do desempenho de diferentes métodos de estimativa da evapotranspiração potencial no estado de São Paulo. **Revista Brasileira de Agrometeorologia**, Santa Maria, v. 5, n. 1, p. 89-97, 1997.
CARVALHO, L. G.; RIOS, G. F. A.; MIRANDA, W. L.; CASTRO NETO, P. Evapotranspiração de referência: Uma abordagem atual de diferentes métodos de estimativa. **Pesquisa Agropecuária Tropical**, Goiânia, v. 41, n. 3, p. 456-465, 2011.
CAVALCANTE Jr., E. G.; OLIVEIRA, A. D.; ALMEIDA, B. M.; ESPÍNOLA SOBRINHO, J. Métodos de estimativa da evapotranspiração de referência para as condições do semiárido Nordestino. **Semina**, Londrina, v. 32, n. suplemento, p. 1699-1708, 2011.
COHEN, J. **Statistical power analysis for the behavioral sciences**. New Jersey: Lawrence Erlbaum, 1988. 569 p.
CUNHA, F. F.; MAGALHÃES, F. F.; CASTRO, M. A. Métodos para estimativa da evapotranspiração de referência para Chapadão do Sul - MS. **Engenharia na Agricultura**, Viçosa, v. 21, n. 2, p. 159-172, 2013.
DOLAN, T. J.; HERMANN, A. J.; BAYLEY, S. E.; ZOLTEK Jr., J. Evapotranspiration of a Flórida, USA, freshwater wetland. **Journal of Hydrology**, Amsterdam, v. 74, n. 1, p. 355-371, 1984.
DOORENBOS, J.; PRUITT, W. O. **Crop water requirements**. Rome: FAO, 1977. 143 p. (Irrigation and Drainage paper, 24).
JABLOUN, M.; SAHLI, A. Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data application to Tunisia. **Agricultural Water Management**, Amsterdam, v. 95, n. 6, p. 707-715, 2008.
JACOBS, J. M.; SATTI, S. R. **Evaluation of reference evapotranspiration methodologies and AFSIRS crop water use simulation model**. Gainesville: Department of Civil and Coastal Engineering, University of Florida, 2001. 114 p.
JENSEN, D. T.; HARGREAVES, G. H.; TEMESGEN, B.; ALLEN, R. G. Computation of ET0 under nonideal conditions. **Journal of Irrigation and Drainage Engineering**, New York, v. 123, n. 5, p. 394-400, 1997.
JENSEN, M. E.; BURMAN, R. D.; ALLEN, R. G. **Evapotranspiration and irrigation water requeriments**. New York: ASCE, 1990. 332 p.
KISI, O. Modeling monthly evaporation using two different neural computing techniques. **Irrigation Science**, New York, v. 29, n. 2, p. 417-430, 2009.
KISI, O.; ALI BABA, A. P.; SHIRI, J. Generalized neurofuzzy models for estimating daily pan evaporation values from weather data. **Journal of Irrigation and Drainage Engineering**, New York, v. 138, n. 4, p. 349-362, 2012.
LIANG, L.; LI, L.; LIU, Q. Temporal variation of reference evapotranspiration during 1961-2005 in the Taoer River basin of Northeast China. **Agricultural and Forest Meteorology**, Amsterdam, v. 150, n. 2, p. 298-306, 2009.
LÓPEZ-URREA, R.; OLALLA, F. M. S.; FABEIRO, C.; MORATALLA, A. Testing evapotranspiration equations using lysimeter observations in a semiarid climate. **Agricultural Water Management**, Amsterdam, v. 85, n. 1, p. 15-26, 2006.
MAGALHÃES, F. F.; CUNHA, F. F. Desempenho do software SEVAP na estimativa da evapotranspiração no Estado de Mato Grosso do Sul. **Revista Agrarian**, Dourados, v. 5, n. 16, p. 151-160, 2012.
MARCUZZO, F. F. N.; ARANTES, E. J.; WENDLAND, E. Avaliação de métodos de estimativa de evapotranspiração potencial e direta para a região de São Carlos-SP. **Irriga**, Botucatu, v. 13, n. 3, p. 323-338, 2008.
MENDONÇA, E. A.; DANTAS, R. T. Estimativa da evapotranspiração de referência no município de Capim, PB. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 14, n. 2, p. 196-202, 2010.
MENDONÇA, J. C.; SOUSA, E. F.; BERNARDO, S.; DIAS, G. P.; GRIPPA, S. Comparação entre métodos de estimativa da evapotranspiração de referência (ET0) na região Norte Fluminense, RJ. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 7, n. 2, p. 275-279, 2003.

OLIVEIRA, R. A.; TAGLIAFERRE, C.; SEDIYAMA, G. C.; MATERAM, F. J. V.; CECON, P. R. Desempenho do Irrigâmetro na estimativa da evapotranspiração de referência. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, v. 12, n. 2, p. 166-173, 2008.
PENMAN, H. L. Vegetation and hydrology. Harpenden: Commonwealth Bureau of Soils, 1963. 125 p. (Technical Communication, 53).
PEREIRA, A. R.; VILLA NOVA, N. A.; SEDIYAMA, G. C. Evapo(transpi)ração. 1.ed. Piracicaba: FEALQ, 1997. 183 p.
PEREIRA, D. R.; YANAGI, S. N. M.; MELLO, C. R.; SILVA, A. M.; SILVA, L. A. Desempenho de métodos de estimativa da evapotranspiração de referência para a região da Serra da Mantiqueira, MG. Ciência Rural, Santa Maria, v. 39, n. 9, p. 2488-2493, 2009.
REIS, E. F.; BRAGANÇA, R.; GARCIA, G. O. Estudo comparativo da estimativa da evapotranspiração de referência para três localidades do Estado do Espírito Santo no período seco. Idesia, Arica, v. 25, n. 3, p. 75-7854, 2007.
SAHOO, B.; WALLING, I.; DEKA, B. C.; BHATT, B. P. Standardization of reference evapotranspiration models for a sub-humid Valley Rangeland of Eastern Himalayas. Journal of Irrigation and Drainage Engineering, New York, v. 138, n. 10, p. 880-895, 2012.
SANIJ, H. D.; YAMAMOTO, T.; RASIAH, V. Assessment of evapotranspiration estimation models for use in semi-arid environments. Agricultural Water Management, Amsterdam, v. 64, n. 1, p. 91-106, 2004.
SILVA, M. M.; COSTA, A. C. L. Estudo comparativo da evapotranspiração em área de floresta de manguezal na região Bragantina-PA. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 11, 2000, Rio de Janeiro. Anais... Rio de Janeiro: CBM, 2000. p. 418-421.
SILVA, V. P. R.; BELO FILHO, A. F. B.; SILVA, B. B.; CAMPOS, J. H. B. C. Desenvolvimento de um sistema de estimativa da evapotranspiração de referência. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, v. 9, n. 4, p. 547-553, 2005.
SILVA, V. J.; CARVALHO, H. P.; SILVA, C. R.; CAMARGO, R.; TEODORO, R. E. F. Desempenho de diferentes métodos de estimativa da evapotranspiração de referência diária em Uberlândia, MG. Bioscience Journal, Uberlândia, v. 27, n. 1, p. 95-101, 2011.
SOUZA, A. P.; CARVALHO, D. F.; SILVA, L. B. D.; ALMEIDA, F. T.; ROCHA, H. S. Estimativas da evapotranspiração de referência em diferentes condições de nebulosidade. Pesquisa Agropecuária Brasileira, Brasília, v. 46, n. 3, p. 219-228, 2011.
SYPERRECK, V. L. G.; KLOSOWSKI, E. S.; GRECO, M.; FURLANETTO, C. Avaliação de desempenho de métodos para estimativas de evapotranspiração de referência para a região de Palotina, Estado do Paraná. Acta Scientiarum Agronomy, Maringá, v. 30, n. 5, p. 603-609, 2008.
TABARI, H. Evaluation of reference crop evapotranspiration equations in various climates. Water Resource Management, Amsterdam, v. 24, n. 10, p. 2311-2337, 2010.
TAGLIAFERRE, C.; SILVA, R. A. J.; ROCHA, F. A.; SANTOS, L. C.; SILVA, C. S. Estudo comparativo de diferentes metodologias para determinação da evapotranspiração de referência em Eunápolis-BA. Caatinga, Mossoró, v. 23, n. 1, p. 103-111, 2010.
TURCO, J. E.; PERECIN, D.; PINTO Jr., D. L. Influência da acurácia de instrumentos de medidas na comparação de métodos de estimativa da evapotranspiração de referência. Irriga, Botucatu, v. 13, n. 1, p. 63-80, 2008.
WILLMOTT, C. J.; ACKLESON, S. G.; DAVIS, J. J.; FEDDEMA, K.; KLINK, D. R. Statistics for the evaluation and comparison of models. Journal of Geophysical Research, Ottawa, v. 90, n. 5, p. 8995-9005, 1985.
XU, C-Y.; CHEN, D. Comparison of seven models for estimation of evapotranspiration and groundwater recharge using lysimeter measurement data in Germany. Hydrological Processes, Chichester, v. 19, n. 18, p. 3717-3734, 2005.
YODER, R. E.; ODHIAMBO, L. O.; WRIGHT, W. C. Evaluation of methods for estimating daily reference crop evapotranspiration at a site in the humid Southeast United States. Applied Engineering in Agriculture, Saint Joseph, v. 21, n. 2, p. 197-202, 2005.