Scientia Agraria Paranaensis – Sci. Agrar. Parana.
ISSN: 1983-1471 – Online

EMPIRICAL METHODS FOR REFERENCE EVAPOTRANSPIRATION ESTIMATION

Oswaldo Palma Lopes Sobrinho[1*], Wady Lima Castro Júnior[2], Leonardo Nazário Silva dos Santos[1], Gerlange Soares da Silva[3], Álvaro Itaúna Schalcher Pereira[2], Germanna Gouveia Tavares[1]

SAP 21487 Received: 09/01/2020 Accepted: 11/05/2020
Sci. Agrar. Parana., Marechal Cândido Rondon, v. 19, n. 3, jul./sep., p. 203-210, 2020

ABSTRACT - The reference evapotranspiration (ETo) is a parameter applied in meteorological, climatological and hydrological studies being of great importance for the planning, management and management of water resources. Due to the need for knowledge about the loss of water from vegetated surfaces, researchers have developed a variety of methods for estimating ETo, some of which are well accepted, while others are criticized, such as the Penman-Monteith-FAO (PM-FAO) meteorological data, which is not always available by limiting its use. The PM-FAO method has been used for decades to be considered internationally and most appropriate for ETo estimates. This method represents the physical phenomenon of evapotranspiration that involves almost all meteorological elements analyzed in automatic and conventional meteorological stations. On the other hand, when this method is impossible to apply due to the lack of some input data, alternative methods are justified (Hargreaves-Samani, Blaney-Criddle, Priestley-Taylor, Jensen-Haise, Camargo, Makkink, Kharrufa , Linacre, Class A tank, Thornthwaite and solar radiation) according to soil and climatic conditions.
Keywords: method performance, Penman-Monteith-FAO, water resources.

MÉTODOS EMPÍRICOS PARA ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA

RESUMO - A evapotranspiração de referência (ET_o) é um parâmetro aplicado em estudos meteorológicos, climatológicos e hidrológicos sendo de grande importância para o planejamento, manejo e gerenciamento dos recursos hídricos. Em virtude da necessidade do conhecimento sobre a perda de água de superfícies vegetadas, pesquisadores desenvolveram variados métodos para estimativas da ET_o sendo alguns bem aceitos, enquanto outros bastantes criticados, a exemplo do método de Penman-Monteith-FAO (PM-FAO) por exigir maior número de dados meteorológicos, que nem sempre estão disponíveis limitando a sua utilização. A presente revisão busca apresentar e discutir o(s) método(s) mais apropriado(s) em virtude da realidade de uso. O método de PM-FAO vem sendo utilizado há décadas sendo considerado internacionalmente e o mais apropriado para as estimativas da ET_o. Este método representa o fenômeno físico da evapotranspiração que envolve quase todos os elementos meteorológicos analisados em estações meteorológicas automáticas e convencionais. Em contrapartida, quando este método é impossibilitado de aplicação, devido à falta de algum dado de entrada, justifica-se a utilização de métodos alternativos (Hargreaves-Samani, Blaney-Criddle, Priestley-Taylor, Jensen-Haise, Camargo, Makkink, Kharrufa, Linacre, Tanque Classe A, Thornthwaite e radiação solar), de acordo com as condições edafoclimáticas.
Palavras-chave: desempenho de métodos, Penman-Monteith-FAO, recursos hídricos.

INTRODUCTION

Determining the amount of water needed for crops is one of the main parameters for the correct planning, dimensioning and management of any irrigation system. Its quantification can be performed by making the water balance of the soil layer occupied by the root system of the crop, which has evapotranspiration (ET) and rainfall, its main components. It is controlled by the energy balance, the atmospheric demand and the supply of water from the soil to the plants (BERNARDO et al., 2013).

ETo determination is a common problem in several sciences that study the soil-water-plant-atmosphere system. In view of the need to know the loss of water from vegetated surfaces, researchers have developed various methods of estimating ETo, many of which are almost unanimously accepted, while others are widely criticized and even despised (TURCO et al., 2008).

There are about fifty methods for estimating ETo, which require different meteorological information and, therefore, often produce inconsistent results (GRISMER et al., 2002). The equations are based on meteorological data for the calculation of ETo. Some of the more precise methods are difficult to apply, not only because of the complexity of the calculations, but also because they require a large number of meteorological data, which are

[1]Federal Institute of Education, Science and Technology Goiano, *Campus* Rio Verde (IF Goiano), Rio Verde, Goiás, Brazil. E-mail: oswaldo-palma@hotmail.com. *Corresponding Author.
[2]Federal Institute of Education, Science and Technology of Maranhão, *Campus* Codó (IFMA), Codó, Maranhão, Brazil.
[3]Federal University of Recôncavo da Bahia (UFRB), Cruz das Almas, Bahia, Brazil.

not always available to the farmer (BERNARDO et al., 2013).

In this context, some equations are based on radiation data and others on temperature data. However, equations can combine the effects of radiation, temperature, air humidity and wind speed, as in the FAO Penman-Monteith method (ALLEN et al., 1998).

Evapotranspiration (ET)

Water availability can affect productivity. The ideal situation for a culture is that the current evapotranspiration is equal to the maximum evapotranspiration (ET_{max}). Since, the current evapotranspiration is lower than ET_{max}, there will be water restriction and its productivity may be compromised (REICHARDT; TIMM, 2004). Thus, to calculate the maximum climatic demand of a crop in irrigation projects, ET_{max} is used.

It was in the early 1940's that the term evapotranspiration (ET) was introduced by Thornthwaite, to express the simultaneous occurrence of the processes of evaporation and transpiration that take place on a vegetated surface (PEREIRA et al., 1997). Before that, ET was called consumptive use, which also considers water retained in the plant (JENSEN, 1973). There are currently four types of ET to be appreciated in climatological studies: potential evapotranspiration (ETP); reference evapotranspiration (ETo), real evapotranspiration (ETR) and culture evapotranspiration (ETc).

Evapotranspiration comprises both evaporation and transpiration, processes controlled by the water supply to plants and the availability of energy resulting from the interaction with meteorological variables that condition atmospheric demand (PEREIRA et al., 2013). Therefore, ETo is a value indicative of the evapotranspirative demand of the atmosphere of a place in a period and a fundamental climatological element, which corresponds to the opposite process of rain, which is also expressed in millimeters (SENTELHAS; ANGELOCCI, 2007).

Both evaporation and transpiration are physical processes responsible for the loss of water from the surface to the atmosphere. Evaporation is the process by which water is lost to the soil in the form of steam, without the participation of biological activities in the culture (REICHARDT, 1990). Transpiration is a process that is related to the loss of water to the atmosphere in the form of steam through stomata (TAIZ et al., 2017).

ET depends on several factors related to meteorological and climatic conditions, such as: air temperature, relative humidity, intensity of solar radiation, wind speed, rain and vapor pressure. Regarding the characteristics of the crop, it depends on factors such as: leaf area, species, stage of development/growth, among others that are associated with the crop coefficient (Kc), in addition to factors of crop and soil management, for example there are: water storage, planting spacing and density (COUTO; SANS, 2002; ALLEN et al., 1998; PEREIRA et al., 2013; AFANDI; ABDRABBO, 2015).

ET is of great importance for plants, as it is associated with the process of decreasing temperature and the absorption of nutrients from the soil (LARCHER, 2000; MAVI; TUPPER, 2004). Thus, Allan et al. (1998) emphasize that ET reflects the evaporating power of the atmosphere and plays a very important role in estimating the water needs of crops (XIE; ZHU, 2013).

ET is controlled by atmospheric demand, the energy balance and water supply from the soil to the plants (BERNARDO et al., 2013). Therefore, it is represented by the total loss of water, in the form of steam, by the surface of any vegetated area (PEREIRA et al., 2013).

Reference evapotranspiration (ETo)

Jensen (1973) defines that ETo would be the maximum evapotranspiration, which occurs in an alfalfa culture (*Medicago sativa* L.) with a height of 0.30 m to 0.50 m, of approximately 100 m of buffer area. Then, the ETo is conceptualized as that which happens in an extensive area of grass presenting height of 0.08 to 0.15 m in active growth, totally covering the soil and without water restriction (DOORENBOS; PRUITT, 1977; DOORENBOS; KASSAM, 1994).

Allen et al. (1998), ETo is designated as which occurs in a hypothetical culture, which has a fixed height of 0.12 m, albedo equal to 0.23 and surface resistance to water vapor transport equal to 70 ms^{-1}. Therefore, it is a climatic element that represents the evaporating power of the atmosphere. Based on this assumption, this concept was originally introduced to investigate the evaporative demand of the atmosphere, regardless of the type of culture, phenology and cultural treatments (ALENCAR et al., 2011).

In irrigated areas, ETo estimates are essential to improve both the planning and efficiency of the use of water resources (ALLEN et al., 2011; FOOLADMAND, 2012; NIAGHI et al., 2013; TABARI et al., 2013). In view of the need for standardization in ETo estimates, the United Nations Food and Agriculture Organization (FAO) recommends the Penman-Monteith equation (PM-FAO 56) as a standard. According to Allen et al. (1998), the results indicated that the PM-FAO 56 method presents safer estimates when compared to lysimeter data.

The PM method requires a large number of input data such as: solar radiation, air temperature, relative humidity and wind speed (TODOROVIC et al., 2013; BERTI et al., 2014). Because of this, its use has been limited, especially in regions that do not have stations that monitor the input variables (THEPADIA; MARTINEZ, 2012; VALIANTZAS, 2013).

Allen et al. (1998) knowing the difficulty of using the PM method in regions where there is a lack of climatic data, they suggested procedures for estimating missing data, such as radiation, vapor pressure deficit and wind speed. Currently, some empirical methods such as Camargo, Blaney-Criddle, Hargreaves, Thornthwaite, among others are evaluated using the PM equation as a reference (PEREIRA et al., 2013).

Factors affecting evapotranspiration

The factors that affect the ET rates of agricultural crops can be classified into three categories: plant factors, climatic factors and soil management factors (LEMOS FILHO et al., 2010). ET is derived from a combination of many meteorological elements concurrently. Of the elements that characterize the climate, solar radiation, air temperature, UR and wind speed are those that have the greatest effect on ET (TEIXEIRA, 2010).

The biggest source of energy is solar radiation. Therefore, the potential amount of this energy that reaches the surface can be determined by both the location and the time of year, due to the different positions of the sun. When studying the effects of solar radiation on ET, it is considered that not all available energy is used to vaporize water, part of it is used to heat the atmosphere and the soil profile (COUTO; SANS, 2002).

The air temperature directly influences the UR, to the point that indicates how much air, in ambient conditions, is lacking to reach its maximum content and saturate (cooling or increasing the steam). The UR is the ratio between the partial vapor pressure (ea) and the saturation pressure (es), expressed in terms of percentage. When the temperature increases (es) it increases exponentially contributing to the decrease in UR. The amount left before the air reaches saturation (UR = 1 or 100%) is called vapor deficit or deficit of saturation (Δe). Otherwise, as the air temperature decreases, there is an increase in relative humidity and a decrease in ET (MEDEIROS et al., 2003).

In addition to climatic factors, ET can be influenced by plant characteristics such as: species, reflection coefficient (albedo), developmental stage, plant height, depth of the root system and also by crop and soil management factors such as: planting spacing and density , planting orientation, water storage capacity and physical and chemical impediments (PEREIRA et al., 2002).

The knowledge of the relative effects of the variables in the ET process is of fundamental importance within the context of irrigation, since a large part of the national territory has problems with the availability of water, with high levels of water deficit, requiring, therefore, the rational use of the water resource. The greatest vulnerability comes from the climate and the lack of water resources (ANDRADE et al., 2003).

Evapotranspiration measurement methods

The equipment used to measure evapotranspiration is called lysimeters or evapotranspirometers, which are used to determine any type of ET. The determination of ET in the field can be carried out by direct measurement methods, such as the use of a lysimeter, which is an instrument capable of computing the water balance in the soil (JENSEN et al., 1990).

According to Silva et al. (2006), lysimeters can have different configurations depending on the climate, availability of materials and costs involved in their construction. Studies carried out with lysimeters installed in the field have shown to be a sustainable tool for determining the components of the water balance for the Soil-Plant-Atmosphere System (SSPA) (LOOS et al., 2007). The lysimeters most used in ET measurements are: drainage, constant water table and weighing, respectively.

Bossie et al. (2009) using drainage lysimeters to determine the onion Kc, found values different from those proposed in the FAO-56 Bulletin, which reinforces the need to generate these values at the local level. Klosowski and Lunardi (2002) in a study with groundwater lysimeters in order to determine the water consumption and the Kc of the pepper in a protected environment obtained the following results: the total water consumption of the pepper in a 198-day cycle was 293.5 mm with average of 1.5 mm day^{-1}. The Kc varied between 0.4 and 0.7 according to the stage of development of the culture.

Evaporation is measured using evaporimeter tanks and atmometers, where the evaporated water layer from a given area is obtained. The most common in Brazil is the “Class A” tank (TCA). The TCA method for estimating ETo was developed to have a practical way of estimating ETo applied to irrigation management. This method requires the determination of a coefficient called the tank coefficient (Kp), which varies according to the location and climatic conditions (ALLEN et al., 1998). There are also other types of evaporimeters, including the atmometer, specifically the Tar type. This is in the shade, located inside the meteorological shelter, being more practical to manage than the TCA.

Evapotranspiration estimation methods

Several methods have been developed and used by researchers to estimate ETo according to the availability of historical and current meteorological data (Table 1) (BENLI et al., 2010; LUO et al., 2012; KISI, 2014). Therefore, the application of a specific method for estimating ETo will generally depend on the availability of data at the study site (SHIRI et al., 2014). Based on this assumption, it is very important to know its suitability, since it varies from region to region.

The use of one or the other method depends on some factors such as: the availability of meteorological data and the required time scale. Generally, the Thornthwaite and Camargo methods estimate ETo on a monthly scale, while the methods that involve the radiation balance show good estimates on the daily scale (PEREIRA et al., 2002).

Alencar et al. (2011) evaluated ETo estimation methods for three locations in Northern Minas Gerais by comparing the methods of Blaney-Criddle-FAO 24, Hargreaves, Priestley-Taylor and Solar Radiation with the standard method of PM-FAO using different statistical indexes. Among the methods studied, solar radiation showed the worst performance for the period of low evaporative demand, overestimating the PM-FAO method for all periods studied.

TABLE 1 - Reference evapotranspiration estimation methods.

Methods	Original reference and/or cited	Input meteorological elements	Variables auxiliary input	Equations
Hargreaves-Samani (HG)	Allen et al. (1998)	T, Tx, Tn	DJ, Lat	$ET_o = 0{,}0023(T_m + 17{,}8)\sqrt{(T_x - T_n)}R_a$
Blaney-Criddle (BC)	Doorenbos; Pruitt (1977), Pereira et al. (1997)	Tm, URmín, n, v	DJ, Lat	$ET_o = a_{BC} + b_{BC} f$
Priestley-Taylor (PT)	Pereira et al. (1997); Sentelhas et al. (2010)	T, P, Rn, G	DJ, Lat	$ET_o = 1{,}26 \frac{\Delta}{\Delta + \gamma}(Rn + G)$
Penman (PEN)	Penman (1948)	Tx, Tn, T, UR, v, n, P, Rs, Rn	DJ, Lat	$ETo = \frac{s}{s+\gamma} 0{,}408(Rn - G) + \frac{\gamma}{s+\gamma} 0{,}26\left(1 + \frac{U_2}{160}\right)(e_s - e)$
Penman-Monteith-FAO (PM-FAO)	Allen et al. (1998)	Tx, Tn, T, UR, v, n, P, Rs, Rn	DJ, Lat	$ETo = \frac{0{,}408\Delta(R_n - G) + \left(\gamma \frac{900}{T+273}\right)U_2(e_s - ea)}{\Delta + [\gamma(1 + 0{,}34U_2)]}$
Penman Modificado (PENMOD)	Doorenbos; Pruitt (1977); Chauhan; Shrivastava (2009)	-	-	ETP = C[W·Rn + (1-W)· f(u)·(ea – ed)]
ASCE-Penman-Monteith (ASCE-PM)	Allen et al. (2006)	-	-	$C_s = \frac{\Delta_{ETo_{PM}}}{\Delta_{VC}}$
Jensen-Haise (JH)	Pereira et al. (1997); Moura et al. (2013)	Rs, T	DJ, Lat	ETc = Rs (0.0252T + 0.078)
Camargo (CAM)	Pereira et al. (1997)	Tm	DJ, La	ETo = 0,01 R_a T_a K
Makkink (MK)	Pereira et al. (1997)	Rs, P, T	DJ, Lat	$ET_o = A \times \left(\frac{\Delta}{\Delta + \gamma}\right) \times \left(\frac{Rg}{2{,}45}\right) - B$
Kharrufa (KF)	Borges and Mendiondo (2007); Pereira et al. (2009)	T	DJ, Lat	$ET_o = 0{,}34 \times p \times T_a$
Linacre (LN)	Pereira et al. (1997)	Tm, Tpo, Tx, Tn	Lat, Alt	$ETc = \frac{\frac{J(T + 0{,}006h)}{100 - \phi} + 15(T - To)}{80 - T}$
Tanque Classe A (TCA)	Doorenbos; Pruitt (1977); Allen et al. (1998)	ECA, v, UR	Extensão da bordadura do tanque	ET0 = Kp × ECA
Radiação Solar (RS)	Doorenbos; Pruitt (1977)	T, v, UR, Rs, P	--	ETo = c × W ×Rs
Thornthwaite (TW)	Thornthwaite (1948)	Tmn, Tm, T	Lat	$ETp = 1{,}6\ (10\ T/I)^a$

For the regions of Cariri and Sertão da Paraíba, in the cities of Boqueirão and Patos, the results showed that the evaporation estimation methods that use the relative humidity of the air, wind speed and solar radiation presented the best performances (LEITÃO et al., 2007). Costa et al. (2017) in order to compare empirical methods of ETo estimation (Solar Radiation, Blaney-Criddle, Hargreaves-Samani and Makkink) in relation to the Penman-Monteith method (FAO 56) for the State of Alagoas found that the best performance was obtained with the Blaney Criddle-FAO method based on all the indicators used and, together with the Hargreaves Samani method, presented a behavior similar to the standard Penman-Monteith method.

Araújo et al. (2007) evaluating ETo estimates by the methods of Thornthwaite, Hargreaves-Samani, Blaney-Criddle, Penman-Monteith-FAO, Tank Class “A” and Makkink, for the municipality of Boa Vista (Rondônia) verified that the Hargreaves-Samani showed a poor performance (c=0.57) for the semi-arid condition. Thus, its performance shows a reduction in the precision of the evapotranspiration estimate in the rainy months (ALENCAR et al., 2011).

For edaphoclimatic conditions in the region of Dourados, MS, the average daily values of ETo ranged from 3.16 to 5.09 mm day^{-1}. The Penman-Monteith method was the one that estimated the daily ETo most satisfactorily. The Hargreaves-Samani method performed satisfactorily, while the Camargo method performed unsatisfactorily (FIETZ et al., 2005). In the Serra da Mantiqueira region (Minas Gerais), Pereira et al. (2009) found for the Priestley-Taylor method a high reduction in statistical indicators, in the dry period in relation to those obtained for the rainy period. According to the authors, the variability observed in the performance of the Priestley-Taylor equation for the rainy and dry period, can be explained by the effect of the rain seasonality in the place.

Silva (2011) for the Pernambuco region indicated that the Priestley-Taylor method presented one of the best performances for estimating ETo. Silva et al. (2005) working with the methods of Thornthwaite and Camargo and comparing them with that of Penman-Monteith found that these underestimated those obtained by the method of Penman-Monteith. Thus, ET can also be estimated using the method proposed by Penman-Monteith with the parameterization proposed by FAO (ALLEN et al., 1998). This method is more suitable for estimating ETc on the daily scale because it represents the influence of the energy balance component and the aerodynamic component (PEREIRA et al., 2013).

From data obtained in lysimeters, cultivated with grass, in the region of Davis, California (semiarid climate), Hargreaves and Samani in 1985, they proposed an equation to estimate the daily reference evapotranspiration using values of maximum, minimum and average daily temperature in addition to the value of extraterrestrial radiation (PEREIRA et al., 2002). For the region of Jaboticabal (São Paulo), Oliveira; Volpe (2003) compared to different ETo estimation methods, among them: Penman, Penman-Monteith and TCA used data collected daily from a conventional and automatic meteorological station. The values obtained by the Penman method were 17.4 to 21% higher when compared to the Penman-Monteith results. The Penman and Penman-Monteith methods estimated lower ETo values compared to the TCA.

Conception and Mandelli (2005) evaluated the suitability of methods that use air temperature and solar radiation as input variables, comparing them to the daily values estimated by the Standard-FAO method for the Bento Gonçalves region, RS observed that the best results obtained were with methods that employ global incident radiation as a variable.

In a study comparing ETo estimation methods in the municipality of Juazeiro (Bahia), Oliveira et al. (2010) observed that the Hargreaves-Samani method presented the best performance, with “c” = 0.67 and Guedes Filho et al. (2011) studying the correlation of ETo methods in the municipality of Areia (Paraíba) found that the Hargreaves-Samani method showed a coefficient of determination of 95% when correlated with the PM method. Santana et al. (2018) aiming to evaluate the performance of methods for estimating ETo for the location Balsas (Maranhão) in an 18-year continuous historical series found that the Linacre, Benevides-Lopez, Radiação Global, Jensen-Haise, Camargo and Ivanov models presented the worse performances compared to the Penman-Monteith-FAO method.

In studies by Jung et al. (2016) and Cunha et al. (2013) Linacre’s equation overestimated evapotranspiration in relation to Penman-Monteith in all months with an average relative difference of 17.78%. Moura et al. (2013) in a study in the experimental basin of the Gameleira stream, Vitória de Santo Antão (Pernambuco), PE, aimed to determine ETo by indirect methods at various time scales and obtained as results that the Jensen-Haise method and Solar Radiation overestimated ETo in all months, with relative differences between 26.04% (November), 36.18% (May), for the first method, 9.53% (December) and 17.27% (July), for the second method mentioned.

FINAL CONSIDERATIONS

In practical terms of measurement and estimates of reference evapotranspiration, we observe the difficulty and complexity in presenting a method that is satisfactory. In light of the above, researchers have developed several methods for estimating ETo, some of which are well accepted, while others are highly criticized, as is the case with the Penman-Monteith-FAO method for requiring a greater number of meteorological data, which are not always available limiting their use. This method has been used for decades and has been considered internationally as the most appropriate method for estimating ETo. The Penman-Monteith method represents the physical phenomenon of evapotranspiration that involves almost all meteorological elements analyzed in automatic and conventional meteorological stations. In contrast, Hargreaves-Samani, Blaney-Criddle, Priestley-Taylor, Jensen-Haise, Camargo, Makkink, Kharrufa, Linacre, Class A Tank, Thornthwaite, solar radiation) according to edaphoclimatic conditions.

ACKNOWLEDGMENTS

To the research group registered at the National Council for Scientific and Technological Development (CNPq) in Food, Chemistry, Agronomy and Water Resources (AQARH) of the Federal Institute of Education, Science and Technology of Maranhão - *Campus* Codó (IFMA), for their constant support.

REFERENCES

AFANDI, G.E.; ABDRABBO, M. Evaluation of reference evapotranspiration equations under current climate conditions of Egypt. **Turkish Journal of Agriculture - Food Science and Technology**, v.3, n.10, p.819-825, 2015.

ALENCAR, L.P.; SEDIYAMA, G.C.; MANTOVANI, E.C.; MARTINEZ, M.A. Tendências recentes nos elementos do clima e suas implicações na evapotranspiração da cultura do milho em Viçosa - MG. **Engenharia Agrícola**, v.31, n.4, p.631-642, 2011.

ALLEN, R.G.; PEREIRA, L.S.; HOWELL, T.A.; JENSEN, M.E. Evapotranspiration information reporting: II. Recommended documentation. **Agricultural Water Management**, v.98, n.6, p.921-929, 2011.

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMITH, M. 1998. **Crop evapotranspiration -** guidelines for computing crop water requirements. Rome: FAO, 1998. 300p.

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMITH, J. **Evapotranspiration del cultivo: guias para la determinación de los requerimientos de agua de los cultivos.** Roma: FAO, 2006. 298p.

ANDRADE, E.M.; SILVEIRA, S.S.; AZEVEDO, B.M. Investigação da estrutura multivariada da evapotranspiração na região centro sul do Ceará pela análise de componentes principais. **Revista Brasileira de Recursos Hídricos**, v.8, n.1, p.3944, 2003.

ARAUJO, G.L.; REIS, E.F.; MARTINS, C.A.S.; BARBOSA, V.S.; RODRIGUES, R.R. Desempenho comparativo de métodos para a estimativa da evapotranspiração de referência (ET_o). **Revista Brasileira de Agricultura Irrigada**, v.5, n.2, p.84-85, 2011.

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

BENLI, B.; BRUGGEMAN, A.; OWEIS, T.; ÜSTÜN, H. Performance of Penman-Monteith FAO56 in a semiarid highland environment. **Journal of Irrigation and Drainage Engineering**, v.136, n.11, p.757-765, 2010.

BERNARDO, S.; SOARES, A.A.; MANTOVANI, E.C. **Manual de Irrigação.** 8a. ed. Viçosa: Editora: UFV, 2013. v.1. 630p.

BERTI, A.; TARDIVO, G.; CHIAUDANI, A.; RECH, F.; BORIN, M. Assessing reference evapotranspiration by the Hargreaves method in north-eastern Italy. **Agricultural Water Management**, v.140, n.10, p.20-25, 2014.

BORGES, A.C.; MENDIONDO, E.M. Comparação entre equações empíricas para estimativa da evapotranspiração de referência na Bacia do Rio Jacupiranga. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.11, n.3, p.293-300, 2007.

BOSSIE, M.; ZELEKE, K.T.; HORDOFA, T. Crop coefficient and evapotranspiration of onion at Awash Melkassa, Central Rift Valley of Ethiopia. **Irrigation and Drainage Systems**, v.23, n.1, p.1-10, 2009.

CHAUHAN, S.; SHRIVASTAVA, R.K. Performance evaluation of reference evapotranspiration estimation using climate-based methods and artificial neural networks. **Water Resource Management**, v.23, n.5, p.825-837, 2009.

CONCEIÇÃO, M.A.F.; MANDELLI, F. Comparação entre métodos de estimativa da evapotranspiração de referência em Bento Gonçalves, RS. **Revista Brasileira de Agrometeorologia**, v.13, n.2, p.303-307, 2005.

COSTA, J.A.; RODRIGUES, G.P.; SILVA, N.D.; LOPES SOBRINHO, O.P.; COSTA, L.D.A. Avaliação de métodos de estimativa da evapotranspiração de referência para Alagoas. **Agrometeoros**, v.25, n.1, p.173-179, 2017.

COUTO, L.; SANS, L.M.A. **Requerimento de água das culturas.** Circular Técnica (INFOTECA-E), EMBRAPA Milho e Sorgo, 2002, 10 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**, v.21, n.2, p.159-172, 2013.

DOORENBOS, J.; KASSAM, A.H. **Efeito da água no rendimento das culturas**. Campina Grande: UFPB, 1994. 306p.

DOORENBOS, J.; PRUITT, W.O. **Necessidades hídricas das culturas.** Campina Grande: UFPB, 1997, p.204.

FIETZ, C.R.; SILVA, F.C.; URCHEI, M.A. Estimativa da evapotranspiração de referência diária para região de Dourados, MS. **Revista Brasileira de Agrometeorologia**, v.13, n.2, p.250-255, 2005.

FOOLADMAND, H.R. Comparing reference evapotranspiration using actual and estimated sunshine hours in south of Iran. **African Journal of Agricultural Research**, v.7, n.7, p.1164-1169, 2012.

GRISMER, M.E.; ORANG, M.; SNYDER, R.; MATYAC, R. Pan evaporation to reference evapotranspiration conversion methods. **Journal of Irrigation Drainage Engineering**, v.128, n.3, p.180-184, 2002.

GUEDES FILHO, D.H.; SANTOS JÚNIOR, J.A.; COSTA FILHO, J.F.; FRANCISCO, P.R.M.; CAMPOS, V.B. Estimativa da evapotranspiração de referência para a cidade de Areia, Paraíba. **Revista Brasileira de Agricultura Irrigada**, v.5, n.1, p.37-47, 2011.

JENSEN, M.E. **Consumptive use of water and irrigation water requeriments.** New York: American Society of Civil Engineers, 1973. 215p.

JENSEN, M.E.; BURMAN, R.D.; ALLEN, R.G. **Evapotranspiration and irrigation water requirements.** New York: American Society of Civil Engineers, 1990, 332p.

JUNG, L.H.; BISCARO, G.A.; OLIVEIRA, G.Q.; ALVES, M.A.; GIACON, G.M. Estimativa da evapotranspiração de referência em uma região do Alto Pantanal. **Magistra**, v.28, n.2, p.168-177, 2016.

KISI, O. Comparison of different empirical methods for estimating daily reference evapotranspiration in Mediterranean climate. **Journal of Irrigation and Drainage Engineering**, v.140, n.1, p.1-7, 2014.

KLOSOWSKI, E.S.; LUNARDI, D.M.C. Determinação do coeficiente de cultura de pimentão (*Capsicum annuum* L.) cultivado em ambiente protegido. **Revista Energia na Agricultura**, v.17, n.4, p.33-42, 2002.

LARCHER, W. **Ecofisiologia Vegetal.** São Carlos, SP: RIMA, 2000, 531p.

LEMOS FILHO, L.C.A.; CARVALHO, L.G.; EVANGELISTA, A.W.P.; ALVES JÚNIOR, J. Análise espacial da influência dos elementos meteorológicos sobre a evapotranspiração de referência em Minas Gerais. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.14, n.12, p.1294-1303, 2010.

LEITÃO, M.M.V.B.R.; OLIVEIRA, G.M.; LEITÃO, T.J.V. Avaliação do desempenho de diferentes métodos de estimativa da evaporação para duas regiões da Paraíba. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.11, n.6, p.585-593, 2007.

LOOS, C.; GAYLER, S.; PRIESACK, E. Assessment of water balance simulations for large-scale weighing lysimeters. **Journal of Hydrology**, v.335, n.1, p.259-270, 2007.

LUO, Y.; JIANG, Y.; PENG, S.; KHAN, S.; CAI, X.; WANG, W.; JIAO, X. Urban weather data to estimate reference evapotranspiration for rural irrigation management. **Journal of Irrigation and Drainage Engineering**, v.138, n.9, p.837-842, 2012.

MAVI, H.S.; TUPPER, G.J. **Agrometeorology principles and applications of climate studies in agriculture.** New York, The Haworth Press. 2004, 364p.

MEDEIROS, A.T.; SENTELHAS, P.C.; LIMA, R.N. Estimativa da evapotranspiração de referência a partir da equação de Penman-Monteith, de medidas lisimétricas e de equações empíricas, em Paraipaba, CE. **Engenharia Agrícola**, v.23, n.1, p.31-40, 2003.

MOURA, A.R.C.; MONTENEGRO, S.M.G.L.; ANTONINO, A.C.D.; AZEVEDO, J.R.G.; SILVA, B.B.; OLIVEIRA, L.M. Evapotranspiração de referência baseado em métodos empíricos em bacia experimental do estado de Pernambuco - Brasil. **Revista Brasileira de Meteorologia**, v.28, n2, p.307-314, 2013.

NIAGHI, A.R.; MAJNOONI-HERIS, A.; HAGHI, D.Z.; MAHTABI, G. Evaluate several potential evapotranspiration methods for regional use in Tabriz, Iran. **Journal of Applied Environmental and Biological Sciences**, v.3, n.6, p.31-41, 2013.

OLIVEIRA, A.D.; VOLPE, C.A. Comparação de métodos de estimativa da evapotranspiração de referência, utilizando dados de estações meteorológicas convencional e automática. **Revista Brasileira de Agrometeorologia**, v.11, n.2, p.253-260, 2003.

OLIVEIRA, G.M.; LEITÃO, M.M.V.B.R.; BISPO, R.C.; SANTOS, I.M.S.; ALMEIDA, A.C. Comparação entre métodos de estimativa da evapotranspiração de referência na região Norte da Bahia. **Revista Brasileira de Agricultura Irrigada**, v.4, n.2, p.104-109, 2010.

PEREIRA, A.R.; ANGELOCCI, L.R.; SENTELHAS, P.C. **Agrometeorologia:** fundamentos e aplicações práticas. Porto Alegre: Guaíba Agropecuária, 2002, 478p.

PEREIRA, A.R.; SEDYAMA, G.C.; VILLA NOVA, N.A. **Evapotranspiração.** Campinas: FUNDAG, 2013. 323p.

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

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**, v.39, n.9, p.2488-2493, 2009.

PENMAN, H.L. Natural evaporation from open water, bare soil, and grass. **Proceedings of the Royal Society**, v.193, n.1, p.120-146, 1948.

REICHARDT, K. **A água em sistemas agrícolas.** São Paulo: Manole, 1990. 188p.

REICHARDT, K.; TIMM, L.C. **Solo, planta e atmosfera:** conceitos, processos e aplicações. São Paulo: Editora Manole Ltda, 2004. 478p.

SANTANA, J.S.; LIMA, E.F.; SILVA, W.A.; FERNANDES, M.C.; RIBEIRO, M.I.D. Equações de estimativa da evapotranspiração de referência (ET_o) para a região de Balsas-MA. **Enciclopédia Biosfera**, v.15, n.27, p.1-14, 2018.

SENTELHAS, P.C.; ANGELOCCI, L.R. **LCE 3006 Meteorologia Agrícola.** Ampliada. 3a. ed. Universidade de São Paulo Escola Superior de Agricultura "Luiz de Queiroz". 2007, 202p.

SENTELHAS, P.C.; GILLESPIE, T.J.; SANTOS, E.A. Evaluation of FAO Penman-Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. **Agricultural Water Management**, v.97, n.5, p.635-644, 2010.

SHIRI, J.; NAZEMI, A.H.; SADRADDINI, A.A.; LANDERAS, G.; KISI, O.; FARD, A.F.F.; MARTI, P. Comparison of heuristic and empirical approaches for estimating reference evapotranspiration from limited inputs in Iran. **Computers and Electronics in Agriculture**, v.108, n.9, p.230-241, 2014.

SILVA, A.O.; MOURA, G.B.A.; SILVA, E.F.F.; LOPES, P.M.O.; SILVA, A.P.N. Análise espaço-temporal da evapotranspiração de referência sob três regimes de precipitação em Pernambuco. **Revista Caatinga**, v.24, n.2, p.135-142, 2011.

SILVA, K.O.; MIRANDA, J.H.; DUARTE, S.N.; FOLEGATTI, M.V. Análise de métodos de estimativa de evapotranspiração na otimização de sistemas de drenagem. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.9, n.2, p.161-165, 2005.

SILVA, C.R.; ALVES JUNIOR, J.; SILVA, T.J.A.; FOLEGATTI, M.V.; CAMPECHE, L.F.S.M. Variação sazonal na evapotranspiração de plantas jovens de lima ácida 'Tahiti'. **Irriga**, v.11, n.1, p.26-35, 2006.

SOUSA, I.F.; SILVA, V.P.R.; SABINO, F.G.; AGUIAR NETTO, A.O.; SILVA, B.K.N.; AZEVEDO, P.V. Evapotranspiração de referência nos perímetros irrigados do Estado de Sergipe. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.14, n.1, p.633-644, 2010.

TABARI, H.; GRISMER, M.E.; TRAJKOVIC, S. Comparative analysis of 31 reference evapotranspiration methods under humid conditions. **Irrigation Science**, v.31, n.2, p.107-117, 2013.

TAIZ, L.; ZEIGER, E.; MOLLER, I.; MURPHY, A. **Fisiologia e desenvolvimento vegetal.** Porto Alegre: Artmed, 2017. 888p.

TEIXEIRA, A.H.C. **Informações agrometeorológicas do polo Petrolina, PE/Juazeiro, BA - 1963 a 2009.** Petrolina, PE: Embrapa Semiárido, 2010, 233p.

THEPADIA, M.; MARTINEZ, C.J. Regional calibration of solar radiation and reference evapotranspiration estimates with minimal data in Florida. **Journal of Irrigation and Drainage Engineering**, v.138, n.2, p.111-119, 2012.

THORNTHWAITE, C.W. An approach towards a rational classification of climate. **Geographycal Review**, v.38, n.1, p.55-94, 1948.

TODOROVIC, M.; KARIC, B.; PEREIRA, L. S. Reference evapotranspiration estimate with limited weather data across a range of Mediterranean climates. **Journal of Hydrology**, v.481, n.1, p.166-176, 2013.

TURCO, J.E.P.; PERECIN, D.; PINTO JUNIOR, D. L. Influência da acurácia de instrumentos de medidas na comparação de métodos de estimativa da evapotranspiração de referência. **Irriga**, v.13, n.1, p.63-80, 2008.

VALIANTZAS, J.D. Simple ET_o forms of Penman's equation without wind and/or humidity data. II: comparisons with reduced set-FAO and other methodologies. **Journal of Irrigation and Drainage Engineering**, v.139, n.1, p.9-19, 2013.

VEGA, E.C.; JARA, J.C. Estimación de la evapotranspiración de referência para das zonas (costa y región andina) del Ecuador. **Engenharia Agrícola**, v.29, n.3, p.390-403, 2009.

XIE, H.; ZHU, X. Reference evapotranspiration trends and their sensitivity to climatic change on the Tibetan Plateau (1970-2009). **Hydrology Process**, v.27, n.25, p.3685-3693, 2013.