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AVALIAÇÃO DO DESEMPENHO DE MÉTODOS DE ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA PARA O MUNICÍPIO DE MANICORÉ, AMAZONAS (*)

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1 RESUMO

Um dos fenômenos de grande importância na determinação das necessidades hídricas de uma cultura, constatando períodos de excessos ou escassez de água, é a evapotranspiração. Portanto, o objetivo do estudo foi avaliar métodos de evapotranspiração de referência de Blaney-Criddle, Camargo, Hargreaves-Samani, Jensen-Haise, Thornthwaite, Thornthwaite-Camargo, FAO 54 da Radiação e Blaney-Criddle-Frevert ao método de Penman-Monteith, recomendado pela FAO como método padrão, para o município de Manicoré, AM. Os dados meteorológicos utilizados foram obtidos na estação meteorológica convencional de Manicoré do Instituto Nacional de Meteorologia, compreendendo dados mensais de uma normal provisória de 10 anos. Os indicadores estatísticos utilizados foram, o coeficiente de correlação, coeficiente de determinação, índice de exatidão e o coeficiente de segurança ou desempenho. A classificação dos métodos de Jensen-Haise, Hargreaves-Samani e FAO-24 da radiação tiveram desempenho "ótimo" na estimativa da evapotranspiração de referência, sendo recomendado para o município de Manicoré, AM, tendo sua utilização confiável para os agricultores da região caso não se tenha todas as variáveis necessárias para utilização do método Penman-Monteith FAO – 56. Os métodos de Blaney-Criddle-Frevert e Thornthwaite apresentaram bom e muito bom desempenho, respectivamente, podendo ser recomendado mediante ajustes locais.

Palavras-chave: irrigação, necessidade hídrica, Penman-Monteith.

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PERFORMANCE EVALUATION OF REFERENCE EVAPOTRANSPIRATION ESTIMATION METHODS FOR THE CITY OF MANICORÉ, AMAZONAS

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2 ABSTRACT

One of the phenomena of great importance in determining the water needs of a crop, noting periods of excess or shortage of water, is evapotranspiration. Therefore, the objective of the study is to evaluation the reference evapotranspiration methods of Blaney-Criddle, Camargo, Hargreaves-Samani, Jensen-Haise, Thornthwaite, Thornthwaite-Camargo, FAO 54 da Radiação and Blaney-Criddle-Frevert to the Penman-Monteith method, recommended by FAO as a standard method, for the municipality of Manicoré, AM. The meteorological data used were obtained from the conventional meteorological station of Manicoré of the Instituto Nacional de Meteorologia, comprising monthly data from a 10-year provisional normal. The statistical indicators used were the correlation coefficient, determination coefficient, accuracy index and safety or performance coefficient. The classification of the Jensen-Haise, Hargreaves-Samani and FAO-24 methods of radiation had an excellent performance in estimating the reference evapotranspiration, being recommended for the municipality of Manicoré, AM, having its reliable use for farmers in the region if it is not have all the variables needed to use the Penman-Monteith FAO – 56 method. The Blaney-Criddle-Frevert and Thornthwaite methods showed good and very good performance, respectively, and can be recommended through local adjustments, while the other methods did not show a good safety coefficient.

Keywords: irrigation, water requirements, Penman-Monteith.

3 INTRODUCTION

Water is considered the most critical resource for sustainable agricultural development worldwide (CHARTZOULAKIS; BERTAKI, 2015). Irrigated areas will increase in the coming years, and the decision about the appropriate time and the adequate amount of water to be applied are generally based on the farmer's practical concepts, which almost always leads to excess or deficit water for the crop.

Furthermore, irrigation efficiency is very low, as less than 65% of the water applied is actually used by crops (CHARTZOULAKIS; BERTAKI, 2015). Therefore, to ensure the existence of the next generations, rational management of water resources is necessary, especially in agricultural use.

Reference evapotranspiration (ETo) is one of the main variables for irrigation planning and management and for hydrological and climatological studies (ANDRADE *et al*., 2016; ABRISHAMI; SEPASKHAH; SHAHROKHNIA, 2019). ETo refers to the transfer of water to the atmosphere, evaporated from the soil surface and plant transpiration (SILVA JÚNIOR *et al.* , 2017; QUEJ *et al*., 2019). Therefore, knowledge of evapotranspiration is fundamental to determine the real water needs for the crop to preserve this liquid that is so important for terrestrial life (FERNANDES; TURCO, 2003), or better, by determining the crop's evapotranspiration, which is estimated by the reference evapotranspiration and the crop coefficient (ALLEN; PEREIRA; RAES, 1998).

Determining crop water consumption can be carried out through direct measurements in the field or indirectly through empirical equations. Direct measurements require the use of sophisticated and expensive equipment (CAVALCANTE JUNIOR *et al*., 2011). Therefore, empirical equations have been used, as they are more practical and viable to use.

Over the years, several methods have been developed to estimate reference potential evapotranspiration (ETo). This happens due to three important situations: suitability of the method to the region's climatic conditions, simplicity of use and limitation of meteorological or climatic elements that feed these methods (CARVALHO *et al.*, 2011*)*.

Bernardo, Soares and Mantovani (2006) mention that there are several equations based on meteorological data to calculate ET. Most of them are difficult to apply, not only because of the complexity of the calculation but also because there are a large number of meteorological elements, only provided by first-class or automatic stations.

Among the various methods mentioned in the literature, the Penman–Monteith – FAO 56 is used as a standard of comparison, which is an improvement on the original Penman method, as several studies carried out in Brazil and around the world prove its accuracy (YODER; ODHIAMBO; WRIGHT, 2005; JABLOUN; SAHLI, 2008; BARROS *et al*., 2009; CARVALHO *et al*., 2011; CAPORUSSO; ROLIM, 2015). However, its use is quite limited due to the requirement for many data that cannot be readily obtained (MARTINEZ; THEPADIA, 2010; QUEJ *et al.*, 2019). As an alternative, particularly in developing countries in the tropics, it uses equations with smaller numbers of variables, which is the case for Blaney-Criddle, Hargreaves-Samani, Camargo and Jensen-Haise (OLIVEIRA *et al*., 2005; AYOADE, 2013).

To apply a method to a given location, it is necessary not only to observe its performance in the region's climatic conditions (ARAÚJO; COSTA; SANTOS, 2007) but also if there are limitations of meteorological or climatic elements that feed these methods, as well as simplicity of use and, when necessary, perform calibrations to minimize estimation errors (CARVALHO *et al.*, 2011).

Scaloppi, Villa Nova and Salati (1978) report that the main purpose of irrigation is to prevent cultivated plants from suffering water deficits, hence the need to find models that can be adjusted to smaller amounts of variables and that meet the region of interest in the study. The availability of water for a crop can be best explained by the interval in which the climate will allow the plant to maintain a transpiration rate equal to the rate of water absorption by the roots. As long as water absorption by the plant is maintained at the same loss rate, there will be no deficit; otherwise, there will be an irreversible reduction in production.

Given the need to seek simpler methods for estimating ETo that better adapt to the climatic conditions of the municipality of Manicoré, AM, the objective of this work was to evaluate the performance of indirect methods for estimating reference evapotranspiration, such as Blaney-Criddle, Camargo, Hargreaves-Samani, Jensen-Haise, Thornthwaite, Thornthwaite-Camargo, FAO 54 Radiation and Blaney-Criddle-Frevert, and compare them with the FAO Penman–Monteith standard method.

4 MATERIALS AND METHODS

The research was developed based on data from the conventional meteorological station of a provisional normal from 2001 to 2010, obtained from the Meteorological Database for Teaching and Research (BDMEP) of the National Institute of Meteorology (INMET, 2023) for the locality of Manicoré, AM (World Meteorological Organization – WMO: 82533), latitude 5.817732° South and longitude 61.290736° West, at 40.1 meters altitude.

According to Köppen and Geiger, the climate classification of Manicoré, AM, is tropical, Af, with significant rainfall throughout the year, approximately 2,941 mm and an average annual temperature of 26°C (CLIMATE DATA, 2023).

The meteorological variables considered in this investigation were: rainfall; dry and wet bulb temperatures; maximum and minimum air temperatures; relative humidity; atmospheric pressure; insolation and wind direction and speed, necessary for estimates of daily ETo by the standard method, FAO - 56 Penman–Monteith, and by the evaluated methods, Blaney-Criddle, Hargreaves, Jensen- Haise and Camargo. The values for these variables were tabulated using Microsoft Excel spreadsheets.

The estimate of daily ETo using the FAO-56 method (Penman–Monteith) is summarized in Equation 1 (ALLEN; PEREIRA; RAES, 1998).

$$\mathrm{ETo} = \frac{0{,}408\Delta(\mathrm{Rn}-\mathrm{G})+\gamma\left(\frac{900}{\mathrm{T}+273}\right)\mathrm{U}_2(\mathrm{e_s}-\mathrm{e_a})}{\Delta+\gamma(1+0{,}34\mathrm{U}_2)} \quad (1)$$

Where ETo is the reference potential evapotranspiration (mm d $^{-1}$); Δis the slope of the saturation vapor pressure curve (kPa °C $^{-1}$); Rn is the daily net radiation (MJ m $^{-2}$ d $^{-1}$); G is the heat flux in the soil (MJ m $^{-2}$ d $^{-1}$); γis the psychrometric constant (kPa °C $^{-1}$); T is the compensated average air temperature (°C) (INMET, 2022); U $_2$ is the wind speed measured at a height of 2 m (ms $^{-1}$); $_s$ is the vapor saturation pressure (kPa); and e e $_a$ is the current vapor pressure of the air (kPa).

The estimate of daily ETo using the Blaney and Criddle (1950) method, known as Blaney-Criddle FAO 24, is summarized in Equation 2 (PEREIRA; VILLA NOVA; SEDIYAMA, 1997).

$$\mathrm{ETo} = (0{,}457 * \mathrm{T} + 8{,}13) * \mathrm{p} * \mathrm{c} \quad (2)$$

Where ETo is the reference potential evapotranspiration (mm month $^{-1}$); T is the compensated average air temperature (°C) (INMET, 2022); “p” is the monthly percentage of annual hours of sunlight; and “c” is the regional adjustment coefficient of the equation (BERNARDO; SOARES; MANTOVANI, 2006).

The estimate of daily ETo using the Camargo method (1971) was calculated with Equation 3 (PEREIRA; VILLA NOVA; SEDIYAMA, 1997; PEREIRA; ANGELOCCI; SENTELHAS, 2007).

$$\mathrm{ETo} = \mathrm{R_T} * \mathrm{T} * \mathrm{k_f} * \mathrm{ND} \quad (3)$$

Where ETo is the reference evapotranspiration (mm d $^{-1}$); R $_T$ is the extraterrestrial solar radiation (mm d $^{-1}$ of equivalent evapotranspiration); T is the compensated average air temperature (°C) (INMET, 2022); kf is the adjustment factor that varies with the average local annual temperature (kf = 0.01 for T < 23°C; kf = 0.0105, for T = 24°C; kf = 0.011, for T = 25°C; kf = 0.0115, for T = 26°C; and kf = 0.012, for T > 26°C); and ND is the number of days in the analyzed period.

The estimate of daily ETo using the method of Hargreaves and Samani (1985) was obtained by Equation 4.

$$ET_o = 0{,}0135 * KT * (T_m + 17{,}8) * R_a * 0{,}408 * (T_x - T_n)^{1/2} \quad (4)$$

Where ET $_{is}$ the reference potential evapotranspiration (mm month $^{-1}$); KT is the global atmospheric transmissivity coefficient, whose value for an inland region is 0.162 and equal to 0.19 for a coastal region; T $_m$ is the compensated average air temperature (°C) (INMET, 2022); R $_a$ is the radiation at the top of the atmosphere (MJ m $^{-2}$ day $^{-1}$); T $_x$ is the maximum air temperature (°C); and T $_n$ is the minimum air temperature (°C).

The estimate of daily ETo using the Jensen-Haise (1963) method was obtained by Equation 5 (PEREIRA; VILLA NOVA; SEDIYAMA, 1997).

$$\mathrm{ETo} = \mathrm{R_s}(0{,}0252 * \mathrm{T} + 0{,}078) \qquad (5)$$

Where ETo is the reference potential evapotranspiration (mm month $^{-1}$); Rs is global solar radiation (mm d $^{-1}$); and T is the compensated average air temperature (°C) (INMET, 2022).

The estimate of daily ETo using the Thornthwaite method (1948) was obtained by Equation 6 (PEREIRA; ANGELOCCI; SENTELHAS, 2007).

$$\mathrm{ETo} = \mathrm{ET_{Padrão}} * Cor \qquad (6)$$

Where ETo is the reference potential evapotranspiration (mm month $^{-1}$); ET $_{\mathrm{Standard}}$ is the standard evapotranspiration (mm month $^{-1}$); and Color is the factor of.

The estimate of daily ETo using the Thornthwaite method (1948) simplified by Camargo (1962) was obtained by Equation 7 (PEREIRA; ANGELOCCI; SENTELHAS, 2007).

$$\mathrm{ETo} = 30 * \mathrm{ET_T} * Cor \qquad (7)$$

Where ETo is the reference potential evapotranspiration (mm month $^{-1}$); ET $_{\mathrm{T}}$ is the daily potential evapotranspiration (mm d $^{-1}$); and color is the correction factor.

The estimate of daily ETo using the FAO-24 radiation method, an adaptation made by Doorenbos and Pruitt (1977) and Doorenbos and Kassam (1994) for the Makkink method, was obtained by Equation 8.

$$\mathrm{ETo} = \mathrm{c} * \mathrm{W} * \mathrm{R_s} \qquad (8)$$

Where ETo is the reference potential evapotranspiration (mm d $^{-1}$); “c” is the regression angular coefficient; W is a weighting factor, which includes the effects of temperature and altitude on the relationship between ground surface radiation and reference evapotranspiration (DOORENBOS; PRUITT, 1977); and Rs is the global radiation (mm d $^{-1}$).

The estimate of daily ETo using the Blaney and Criddle (1950) method adapted by Frevert, Hill and Braaten (1983) was obtained using Equation 9 (FERNANDES *et al.*, 2010).

$$\mathrm{ETo} = \mathrm{a} + \mathrm{b} * \mathrm{p}(0{,}457 * T + 8{,}13) \qquad (9)$$

Where ETo is the reference potential evapotranspiration (mm d $^{-1}$); “a” and “b” are the coefficients; “p” is the monthly percentage of annual hours of sunlight; and T is the compensated average air temperature (°C) (INMET, 2022).

ETo estimates were analyzed by linear regression (Equation 10), using the Blaney-Criddle, Camargo, Hargreaves-Samani, Jensen-Haise, Thornthwaite, Thornthwaite-Camargo, and FAO-24 radiation methods as the dependent variable (Y). and Blaney-Criddle-Frevert as independent variables (X), the ETo values estimated by the Penman–Monteith-FAO 56 method.

$$\mathrm{Y} = \beta\mathrm{o} + \beta 1\mathrm{X} \qquad (10)$$

Where Y is the estimated value for empirical methods; βo is the angular coefficient; β1 is the linear coefficient; and X is the value estimated by the standard Penman–Monteith-FAO 56 method.

The correlation between the Penman–Monteith-FAO 56 method and the empirical methods was carried out based on statistical indicators to observe the precision given by the correlation coefficient (r), which is associated with the deviation between the estimated and measured values, indicating the degree of dispersion of the data obtained in relation to the average, using Equation 11.

$$r = \sqrt{\frac{[\sum(Y_e - \bar{Y})(Y - \bar{Y})]^2}{\sum(Y_e - \bar{Y})^2 \sum(Y - \bar{Y})^2}} \qquad (11)$$

Where Y_e is the estimated value of the evaluated method; Y is the estimated value from the Penman–Monteith FAO 56 method; and $\bar{Y}$ is the average of the standard method values.

Accuracy in estimating ETo in relation to the standard model was obtained by calculating the index “d” (Equation 12), which varies from 0 to 1 (WILLMOTT; CKLESON; DAVIS, 1985).

$$d = 1 - \left[\frac{\sum(Y_e - \bar{Y})^2}{\sum(|Y_e - \bar{Y}| + |Y - \bar{Y}|)}\right] \qquad (12)$$

The safety coefficient or performance “c” (Table 1) was calculated by the product of red (c = r*d) (CAMARGO; SENTELHAS, 1997).

Table 1. Performance coefficient values according to Camargo and Sentelhas (1997).

Value of “c”	Performance
> 0,85	Excellent
0,76 a 0,85	Very good
0,66 a 0,75	Good
0,61 a 0,65	Median
0,51 a 0,60	Sufferable
0,41 a 0,50	Bad
≤ 0,40	Terrible

The most appropriate methods for estimating ETo were based on the lowest values of the standard error of estimate (EPE) (Equation 13). The quantification of errors provided by the estimates was obtained by EPE and through the relationship of average values (Equation 14), expressed as a percentage (%).

$$EPE = \sqrt{\frac{\sum(Y_e - \bar{Y})^2}{n}} \qquad (13)$$

$$\% = \left(\frac{\bar{Y}_e}{\bar{Y}}\right) * 100 \qquad (14)$$

Where Y_e is the average of the estimated method; $\bar{Y}$ is the mean of the standard method; and en is the number of observations.

5 RESULTS AND DISCUSSION

Analyzing the 10-year provisional normal (Table 2), monetary averages, it was noted that the minimum (Tn) and maximum (Tx) temperatures varied from 21.65°C to 23.16°C and between 32.06°C to 34.53□C, respectively. The lowest amplitude was observed in the lows, with a value of 1.51°C. In a similar research carried out in the municipality of Maués, AM, Barbosa et al. (2022), found that the lowest amplitude in minimum temperatures, with a value of 0.94°C. The low amplitude of minimum temperatures is characteristic of regions of low latitude and altitude, as happens in Boa Vista, RR (ARAÚJO; CONCEição; VENANCIO, 2012). It was also noted that the average relative humidity always remained above 78.57%, even in months with less rainfall.

Table 2. Monthly average minimum temperature (T_n), maximum temperature (T_x) and compensated average temperature (T_{MC}), relative humidity (RH), wind speed (U_2), global solar radiation (Qg) and insolation (n) of the municipality of Manicoré, AM.

Months	**T_n**	**T_x**	**T_{MC}**	**UR**	**U_2**	**Qg**	**n**
		°C		**%**	**m s^{-1}**	**MJ m^{-2}**	**h**
January	22,96	32,23	26,33	86,89	0,44	15,77	3,73
February	22,98	32,06	26,31	87,20	0,49	15,07	3,25
March	22,96	32,17	26,38	87,08	0,47	14,02	2,91
April	22,93	32,28	26,50	86,80	0,44	14,17	3,73
May	22,80	32,08	26,46	87,05	0,43	13,53	4,02
June	21,96	32,44	26,23	84,51	0,45	16,04	6,13
July	21,65	33,54	26,62	80,32	0,44	18,57	7,37
Aug.	21,90	34,53	27,08	78,57	0,44	18,14	6,05
Sept.	22,59	34,31	27,19	79,72	0,49	17,86	5,26
Oct.	22,96	33,77	27,15	82,10	0,48	17,28	4,77
Nov.	23,16	33,28	27,06	83,05	0,46	16,88	4,63
Dec.	23,08	32,26	26,49	85,28	0,47	15,36	3,63

The wind speed (Table 2) did not reach 1.0 ms^{-1} in any month, with its maximum speed recorded in February and September, 0.49 ms^{-1} (1.76 km h^{-1}), and the minimum in May, 0.43 ms^{-1} (1.55 km h^{-1}), remaining practically constant throughout the year. These wind speed values fall into scale 1, with an almost calm category (Beaufort), which can favor agricultural planning activities in the region, as well as decision-making in operations to be carried out in agriculture.

Table 3 presents the average reference evapotranspiration (ETo) for the municipality of Manicoré, AM, obtained by the evaluated methods. Such models, with the exception of the Blaney-Criddle method in the period from July to October, overestimated ET$_o$ during all months of the year, with the difference between the average ET$_o$ values varying from 3.14 mm d^{-1} in May (Blaney-Criddle-Frevert method) to 5.68 mm d^{-1} in July (Jensen-Haise method). This fact can be confirmed in FAO bulletin 56, where Allen *et al.* (2006) state that it is also important to highlight that the Hargreaves-Samani model tends to underestimate ETo values under strong wind conditions (U2 > 3 ms^{-1}) and overestimate ETo under conditions of high relative humidity, which in fact was found in the Manicoré region (Table 2). Furthermore, the results obtained corroborate those found by Back (2008), Ferraz (2008), Carvalho and Delgado (2016), Souza and Sousa (2020), and Ferreira *et al.* (2020) and Barbosa *et al.* (2022), who found, during all months of the year, a tendency to overestimate reference evapotranspiration using the methods of Blaney-Criddle, Camargo, Hargreaves-Samani, Jensen-Haise, Thornthwaite, Thornthwaite-Camargo, FAO 54 da Radiação and Blaney-Criddle-Frevert.

Tabela 3. Médias da evapotranspiração de referência (ET_o) estimadas pelos métodos de Penman-Monteith [$ET_{o(P-M)}$], Blaney-Criddle [$ET_{o(B-C)}$], Camargo [$ET_{o(C)}$], Hargreaves-Samani [$ET_{o(H-S)}$], Jensen-Haise [$ET_{o(J-H)}$], Thornthwaite [$ET_{o(T)}$], Thornthwaite-Camargo [$ET_{o(T-C)}$], FAO 54 da Radiação [$ET_{o(R)}$] e Blaney-Criddle-Frevert [$ET_{o(B-C-F)}$] para Manicoré, AM, 2001 a 2010.

Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Média**	**ME-PM***
	mm d^{-1}													
ETo_{PM}	3,3	3,2	3,0	2,9	2,8	3,1	3,5	3,6	3,7	3,6	3,5	3,3	3,3	-
ETo_{BC}	3,6	3,6	3,5	3,5	3,5	3,4	3,5	3,5	3,6	3,6	3,7	3,6	3,6	0,3
ETo_{C}	5,0	5,0	4,8	4,4	4,1	4,0	4,3	4,7	5,0	5,1	5,0	4,9	4,7	1,4
ETo_{HS}	4,6	4,6	4,4	4,1	3,8	3,9	4,5	5,1	5,2	5,1	4,8	4,6	4,6	1,3
ETo_{JH}	4,8	4,6	4,2	4,3	4,1	4,8	5,7	5,6	5,6	5,4	5,2	4,7	4,9	1,6
ETo_{T}	4,6	4,5	4,5	4,5	4,4	4,3	4,5	4,7	4,8	4,8	4,8	4,7	4,6	1,3
ETo_{TC}	4,6	4,0	4,5	4,4	4,5	4,2	4,5	4,7	4,7	4,9	4,7	4,7	4,5	1,2
ETo_{M}	2,8	2,7	2,5	2,5	2,4	2,9	3,3	3,3	3,2	3,1	3,0	2,7	2,9	-0,4
ETo_{R}	3,9	3,7	3,5	3,5	3,4	4,0	4,6	4,5	4,5	4,3	4,2	3,8	4,0	0,7
ETo_{BCF}	3,3	3,2	3,1	3,2	3,3	4,0	4,5	4,2	3,9	3,9	3,7	3,3	3,7	0,3

(*) Difference between the reference evapotranspiration means of the empirical methods and the mean of the FAO-56 standard method.

The evaluated methods (Table 3, Figure 1) overestimated the ET_o in relation to the Penman–Monteith FAO - 56 method, with the Blaney-Criddle [$ET_{o\ (BC)}$] (Figure 1) being the one that least overestimated the ET_{or} every month of the year. The Jensen-Haise [$ET_{o\ (JH)}$] method was the one that most overestimated the ET during the months of June to November, the Amazonian summer period, and in the months of January to May, the Amazonian winter period, it was the method of Camargo [$ET_{o\ (C)}$]. According to Pereira, Villa Nova and Sediyama (1997), the Jensen-Haise method was developed in regions of the American semiarid region, unlike the region of Manicoré, AM, which has a tropical climate. However, among the models investigated, this model showed a greater increase in ET during the months with lower rainfall compared to the months with higher rainfall in the region of Manicoré, AM. The same behavior was observed by Ferreira *et al.* (2020) in the municipality of Parintins, AM and by Barbosa *et al.* (2022) in the municipality of Maués, AM.

The results obtained corroborate those found by Mendonça *et al.* (2003), Fietz, Silva and Urchei (2005), Syperreck *et al.* (2008) and Souza and Sousa (2020), who observed that the models evaluated overestimated ETo, similar to the Camargo and Thornthwaite method.

Figure 1. Average reference evapotranspiration values (ET_o, mm d $^{-1}$) estimated by the methods: Penman–Monteith [$ET_{o\,(PM)}$], Blaney-Criddle [$ET_{o\,(BC)}$], Camargo [$ET_{o\,(C}$], Hargreaves - Samani [$ET_{o\,(HS)}$], Jensen- Haise [$ET_{o\,(JH)}$], Thornthwaite [$ET_{o\,(T)}$], Thornthwaite -Camargo [$ET_{o\,(TC)}$], FAO 54 da Radiação [$ET_{o\,(R\,)}$] and Blaney-Criddle-Frevert [$ET_{o\,(BCF)}$] for the municipality of Manicoré, AM.

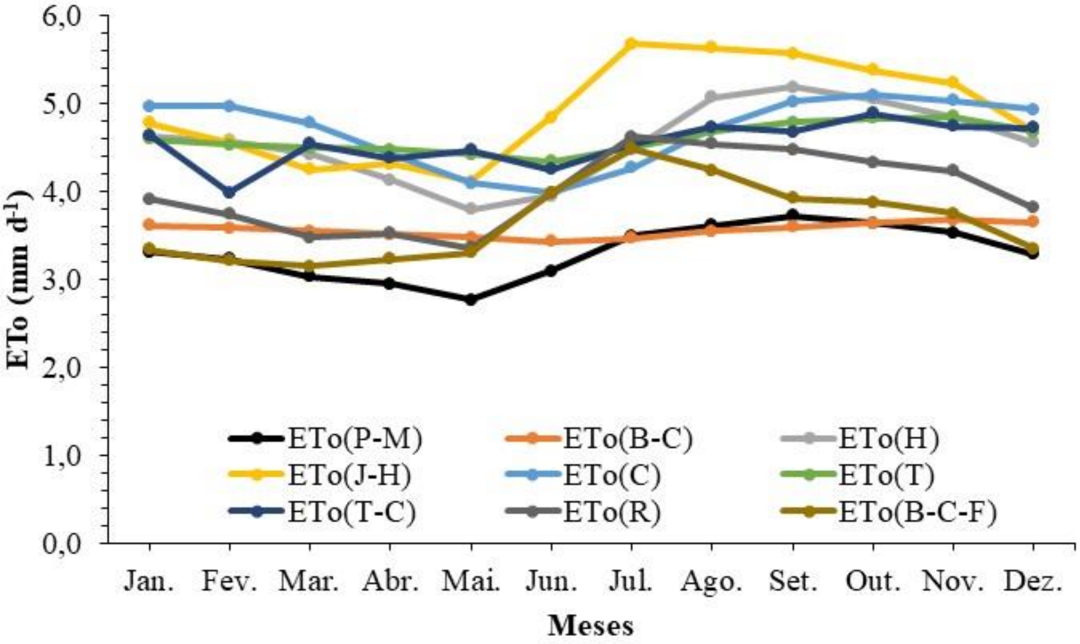


Table 4 contains the average daily values of ET $_{or}$ estimated by each method, the percentages of variation in ET $_o$ in relation to the standard method (%), the standard error of estimation (EPE), the correlation coefficient (r), the coefficient of determination (R^2), the agreement index (d), the performance coefficient (c) and the classification based on the performance coefficient.

Table 4. Percentage in relation to the standard method (%), standard error of estimation (EPE, mm d -1$^)$, correlation coefficient (r), coefficient of determination (R^2), agreement index (d), performance coefficient (c) and classification based on the performance coefficient for the city of Manicoré, AM.

Method	**%**	**EPE (mm d^{-1})**	**d**	**r**	**R^2**	**c**	**Performance Rating**
Blaney-Criddle	107,75	0,07	1,00	0,52	0,27	0,51	Sufferable
Camargo	141,90	0,33	0,97	0,60	0,36	0,58	Sufferable
Hargreaves-Samani	137,82	0,18	0,97	0,92	0,85	0,90	Excellent
Jensen-Haise	148,75	0,22	0,96	0,93	0,86	0,89	Excellent
Thornthwaite	139,11	0,10	0,97	0,80	0,64	0,78	Very good
Thornthwaite-Camargo	137,53	0,22	0,97	0,57	0,32	0,55	Sufferable
FAO-24 da Radiação	121,01	0,18	0,99	0,92	0,84	0,91	Excellent
Blaney-Criddle-Frevert	110,53	0,35	1,00	0,66	0,44	0,66	Good

Analyzing the standard error of estimation (EPE, Table 4), it is possible to state that the Blaney-Criddle method better estimated ETo when compared to the other models tested, despite its "poor" performance. Fernandes *et al.* (2010) mention that the Blaney and Criddle (1950) method was developed for the western region of the United States, a semiarid region in the states of New Mexico and Texas, and added that Doorenbos and Pruitt (1984) inserted a factor correction, enabling its application in various climatic conditions. Still in Table 4, EPE values varied from 0.07 mm d^{-1} to 0.35 mm $d^{-1,\text{ with the lowest value presented by the}}$ Blaney-Criddle method and the highest value by the Blaney-Criddle- method. Frevert, which can be attributed to the modifications made with the Frevert coefficients "a" and "b".

The Blaney-Criddle, Camargo, Thornthwaite-Camargo and Blaney-Criddle-Frevert methods presented more dispersed values (R^2), while the Hargreaves-Samani, Jensen-Haise, Thornthwaite and FAO-24 radiation methods presented less dispersed values. Sampaio (1998) states that the occurrence of a reduced coefficient of determination (R^2) makes the proposed estimates unreliable, either due to the instability of the studied variable or the fact that the tested model is not suitable for the dispersion of the observed results. To overcome such limitations, in these cases, Bonomo (1999) reports that when models present low $R^{2\text{ values}}$, it indicates the need for regional adjustment. Carvalho *et al.* (2015) recommend carrying out local calibrations of the parameterized coefficients of the evaluated equations. Therefore, to use the models evaluated in the region of Goiânia, GO, as well as in any other region, there is a need for greater adjustments to the more dispersed models to make them reliable. The coefficients of determination (R^2) of the models evaluated in relation to $ET_{o\ (PM)}$ presented values between 0.27 and 0.86 (Figure 2). Souza and Sousa (2020), evaluating the performance of empirical methods for estimating reference evapotranspiration in Rio Branco, Acre, found that with the exception of the Turc-$ETo_{TC\ method}$, the other models exhibited low values for the coefficient of determination (R^2), lower than 0.52, showing that the adjustments to the equations using the standard method - ETo_{PM} - were unsatisfactory, that is, indicating the need for regional adjustment.

The Hargreaves-Samani, Jensen-Haise, Thornthwaite and FAO-24 radiation methods (Table 4) showed good correlation in relation to the standard Penman–Monteith FAO 56 method, with an EPE value of 0.18, 0.22, 0.10 and 0.18 mm day^{-1} and a confidence index "c" of 0.90, 0.89, 0.78 and 0.91, respectively, which according to the classification of Camargo and Sentelhas (1997) is considered " great", " great", "very good" and " excellent", respectively. Contrary to Araújo, Costa and Santos (2007), who state that the Thornthwaite and Hargreaves- Samani methods did not satisfactorily estimate the reference evapotranspiration throughout the year, for the region of Boa Vista, RR. Ribeiro *et al.* (2015), when comparing several methods on a daily scale, for the municipality of Sobral, CE, found a "c" of 0.53 for Hargreaves, justifiable, since this model was developed in arid conditions in the United States.

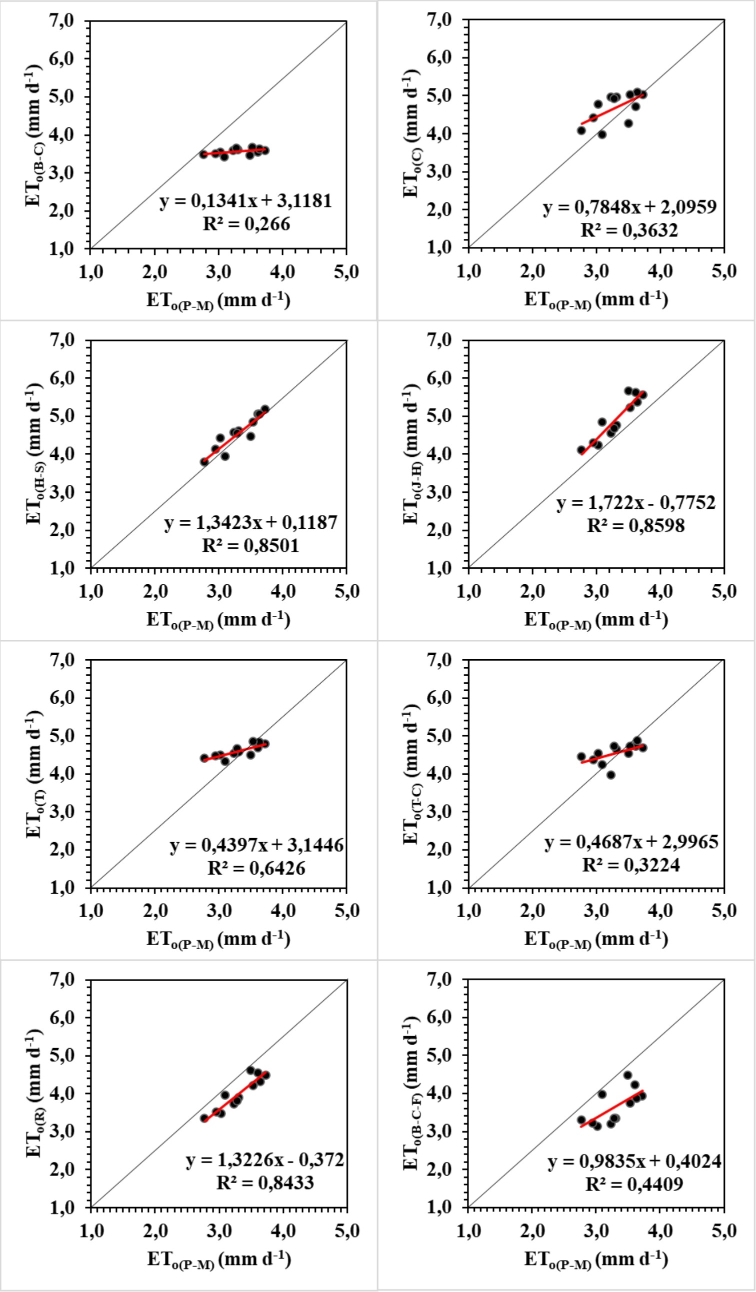
Haise methods as "poor" and "terrible", respectively, in estimating ET_{for} the city of Rio Branco, AC, diverging from the result found in this work, which obtained an "excellent" rating. " for both methods (Table 4). Ferreira *et al.* (2020) found a "bad" classification using Hargreaves' methods in the municipality of Parintins, AM and Barbosa *et al.*. (2022) found an "excellent" classification in the municipality of Maués, AM. Araújo, Conceição and Venancio (2012), working with the Hargreaves method in Boa Vista, RR, obtained a "regular" classification. Gonçalves *et al.* (2009), compared ETo methods with the PM FAO 56 standard for the municipality of Sobral and found for the method of Hargreaves and Samani (1985) a confidence index of 0.76, which according to the classification of Camargo and Sentelhas (1997), is considered "very good".

Analyzing the performance classification, Camargo's method presented a "Poor" classification and agreement index (d) of 0.97 and a performance coefficient (c) of 0.58, corroborating Araújo, Conceição and Venancio (2012), who classified the ET $_{\text{estimated}}$ by the Camargo method as "bad" for Rio Branco, AC, highlighting, however, that better performance of this method is possible in conditions of greater cloudiness.

Blaney-Criddle, Camargo, Thornthwaite-Camargo methods presented a "Poor" classification and performance coefficient (c) of 0.51, 0.58 and 0.55, respectively, contradicting the result obtained by Araújo, Costa and Santos (2007) with the Blaney-Criddle method in Boa Vista, RR, which obtained an "excellent" classification and contradicting Ferreira *et al.*. (2020), who found "very good" and "excellent" classifications in the municipality of Parintins, AM, respectively, using the Blaney-Criddle and Jensen-Haise methods, Barbosa *et al*. (2022) found an "excellent" classification for the Blaney-Criddle and Jensen-Haise methods in the municipality of Maués, AM. Back (2008) obtained "terrible" performance in the Blaney-Criddle method in a study carried out in Urussanga, SC, and attributed the poor performance to the fact that the method was developed for semiarid conditions, differing from the conditions of the studied region, with a tropical climate. .

results of the correlation between the ET estimation methods in relation to the standard method, Penman–Monteith, are presented. The Blaney-Criddle-Frevert method obtained the angular coefficient (+ 0.9835), being the closest to 1, followed by Thornthwaite (+ 0.4397), Thornthwaite-Camargo (+ 0.4687), Camargo (+ 0.7848), FAO 54 Radiation (+ 1.3226), Hargreaves-Samani (+ 1.3423) and Jensen-Haise (+ 1.7220). This shows that the reference potential evapotranspiration of the empirical methods evaluated increased with the increases in the reference evapotranspiration of the Penman–Monteith-FAO 56 standard method. On the other hand, these coefficients show that for every 1 mm d $^{-1}$ of evapotranspired water, in the interval of the historical series considered, ET $_{\text{increases}}$ from 0.4397 mm d $^{-1}$ to 1.7220 mm d $^{-1}$, on average. The Hargreaves-Samani method achieved a linear coefficient of 0.1187, being the closest to 0, followed by the FAO 54 Radiation method of -0.3720 and Blaney-Criddle-Frevert of 0.4024.

Figure 2. Linear regression between reference evapotranspiration values (ET_o, mm $d^{-1)}$ estimated by the Blaney-Criddle [$ET_{o\ (BC)}$], Camargo [$ET_{o\ (C}$], Hargreaves- Samani [$ET_{o\ (HS)]}$ methods], Jensen- Haise [$ET_{o\ (JH)}$], Thornthwaite [$ET_{o\ (T)}$], Thornthwaite- Camargo [$ET_{o\ (TC)}$], FAO 54 da Radiação [$ET_{o\ (R)}$] and Blaney-Criddle-Frevert [$ET_{o\ (BCF)}$], with the standard method, Penman–Monteith [$ET_{o\ (PM)}$], Manicoré, AM.



6 CONCLUSIONS

The classification of the Jensen-Haise, Hargreaves-Samani and FAO-24 radiation methods performed "optimally" in estimating reference evapotranspiration, being recommended for the municipality of Manicoré, AM. Therefore, the use of these models is considered reliable for farmers in the region if all the variables necessary to use the Penman–Monteith FAO-56 method are not available.

Blaney-Criddle-Frevert and Thornthwaite methods presented “good” and “very good” performance, respectively, and can be recommended through local adjustments.

Blaney-Criddle, Camargo and Thornthwaite-Camargo methods presented “poor” performance and are not recommended due to their low accuracy and precision.

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