ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

AVALIAÇÃO DO DESEMPENHO DE MÉTODOS DE ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA PARA O MUNICÍPIO DE MAUÉS, AMAZONAS*

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**Trabalho retirado do trabalho de conclusão de curso "Avaliação do desempenho de métodos de estimativa da evapotranspiração de referência para o município de Maués, Amazonas", Universidade Federal do Amazonas, defendido em 29 de novembro de 2021.*

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1 RESUMO

A estimativa precisa da evapotranspiração de referência (ETo) é essencial para o cálculo das necessidades de água de uma cultura, bem como para a programação dos eventos de irrigação e para a gestão sustentável de recursos hídricos. Neste sentido, o objetivo deste estudo foi correlacionar os métodos de Blaney-Criddle, Hargreaves, Jensen-Haise e Camargo com o método de Penman-Monteith, recomendado pela Organização das Nações Unidas para a Alimentação e Agricultura (FAO) como método padrão para a estimativa da ETo, para o município de Maués, AM, baseando-se em dados obtidos no Instituto Nacional de Meteorologia (INMET), oriundos de uma estação automática, série de dados de 2009 a 2018. Para comparar os métodos de estimativa de ETo, foram utilizados o erro-padrão de estimativa em relação ao método padrão (EPE), os coeficientes de correlação (r), de determinação (r^2) e de desempenho (c) e o índice de concordância (d). Dentre os resultados obtidos, verificou-se que todos os métodos avaliados superestimaram a ETo em comparação com o método padrão, Penman-Monteith, em todos os meses do ano. O método de Blaney-Criddle foi o que melhor atendeu a estimativa da ETo para o munícipio de Maués, AM, seguido pelos métodos de Hargreaves, Jensen-Haise e Camargo.

Palavras-chave: irrigação, Camargo-Sentelhas, Penman-Monteith.

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2 ABSTRACT

The accurate estimation of reference evapotranspiration (ETo) is essential for calculating the water requirements of a crop and for scheduling irrigation events and for a sustainable management of water resources. In this sense, this study aimed to correlate the Blaney-

Recebido em 21/12/2020 e aprovado para publicação em 03/10/2021
DOI: http://dx.doi.org/10.15809/irriga.2022v27n1p79-91

Criddle, Hargreaves, Jensen-Haise, and Camargo methods with the Penman-Monteith method, recommended by the Food and Agriculture Organization of the United Nations (FAO) as the standard method for estimating ETo, for the city of Maués, AM, based on data obtained from the National Institute of Meteorology (INMET), from an automatic station, time series from 2009 to 2018. The standard error of estimate in relation to the standard method (EPE), the coefficients of correlation (r), determination (r^2), and performance (c), and the agreement index (d) were used to compare the ETo estimation methods. Among the results obtained, it was found that all methods evaluated overestimated ETo compared to the standard method, Penman-Monteith, in all months of the year. The Blaney-Criddle method was the best at estimating ETo for the city of Maués, AM, followed by the methods of Hargreaves, Jensen-Haise, and Camargo.

Keywords: irrigation, Camargo-Sentelhas, Penman-Monteith.

3 INTRODUCTION

One of the essential requirements for estimating the amount of water needed for agricultural production is to effectively understand the relationships between climatic conditions and evapotranspiration (ARAÚJO; COSTA; SANTOS, 2007; CARVALHO *et al.*, 2011).

Reference evapotranspiration (ETo) is one of the main variables of the hydrological cycle. ETo refers to the transfer of water to the atmosphere, evaporation from the soil surface, and plant transpiration (SILVA JÚNIOR *et al.*, 2017; QUEJ *et al.*, 2019).

Quantitative information on ETo is highly important for assessing the severity, distribution and frequency of water deficits, project development and management of irrigation systems and drainage (HENRIQUE; DANTAS, 2007).

In estimating the water requirements of a crop in each of its development phases, the method usually used is based on the estimate of crop evapotranspiration (ETc), which can be obtained through the ETo value corrected by the crop coefficient (Kc), a coefficient that depends on the crop used and its development stage (CHAGAS *et al.).* , 2013).

ETo depends on several factors related to the soil, plants, and climate, constituting an agrometeorological parameter. As mentioned, it is essential for quantifying crop water needs and for studies on water resource utilization. Therefore, it is necessary to analyze possible methods to better estimate this variable (FERRAZ, 2008). This important parameter can be estimated, for example, through mathematical models. Some of the available mathematical models are empirical and do not allow for reasonable estimates in areas whose characteristics differ from those for which they were calibrated (AYOADE, 2013).

Several studies testing the accuracy of evapotranspiration estimation methods have been carried out with the aim of determining the most accurate models for each location (MEDEIROS, 1998; CAPORUSSO; ROLIM, 2015; SANTOS *et al.*, 2017; SILVA JÚNIOR *et al.*, 2017; SOUZA; SOUSA, 2020), with the results of these studies showing that these equations can be used to estimate ETo in conditions of data limitations, as long as they are validated and calibrated, taking into account edaphoclimatic conditions.

In the Northeast Region and North Region of Brazil, whose climates range from semiarid (Bs) to tropical (As, Aw, and Af) according to the Köppen classification, the most common methods with the best adjustments have been the Blaney-Criddle

FAO-24, Solar Radiation FAO-24, and Priestley-Taylor methods. The satisfactory adjustments obtained by the Blaney-Criddle method are because this model was developed in a semiarid climate in the western United States of America, with microclimatic characteristics similar to those of Northeast Brazil (MUNHOZ *et al*., 2012).

A frequently used way to verify the efficiency of ETo estimation methods is by comparing them with the Penman–Monteith method (ALLEN *et al*., 1998), parameterized by the Food and Agriculture Organization of the United Nations (FAO) (TURCO; PERECIN; PINTO JÚNIOR, 2008). Among the various existing methods, the FAO decided to use it as the standard method for estimating evapotranspiration. The adoption of this method by the FAO is justified by its efficiency in resulting in ETo under variable atmospheric humidity conditions (CAMARGO; CAMARGO, 2000).

Owing to the difficulty in acquiring the data needed to use the Penman–Monteith equation, as Ayoade (2013) stated, the greatest disadvantage of this method is the requirement for many data that cannot be readily obtained, particularly in developing countries in the tropics, models with smaller quantities of variables are used, as is the case with the Blaney–Criddle, Hargreaves and Priestley–Taylor equations.

Given the above, the objective of this work was to evaluate the performance of the Blaney-Criddle, Hargreaves, Jensen-Haise and Camargo methods in relation to the Penman–Monteith-FAO method for estimating potential reference evapotranspiration in the municipality of Maués, AM.

4 MATERIALS AND METHODS

The data used in this research, which originated from an automatic meteorological station with historical series from 2009--2018, were obtained from the Meteorological Database for Teaching and Research (BDMEP) of the National Institute of Meteorology (COSTA, 2019) for the location of Maués, AM (OMM: 81734), latitude 03° 22' 54” South and longitude 57° 42' 55” West, at an altitude of 35 meters.

According to Köppen and Geiger, the climate classification of Maués, AM, is tropical, Af, with significant rainfall throughout the year, approximately 2,100 mm and an average annual temperature of 27.2°C (CLIMATE-DATA. ORG, 2019).

The meteorological variables considered in this study were rainfall; dry and wet bulb temperatures; maximum and minimum air temperatures; relative humidity; atmospheric pressure; sunshine; and wind direction and speed, which are necessary for estimating daily ETo via the standard FAO-56 Penman–Monteith method and the Blaney–Criddle, Hargreaves, Jensen–Haise, and Camargo methods. The values for these variables were tabulated via Microsoft Excel spreadsheets.

The estimate of daily ETo via the FAO-56 method (Penman–Monteith) is summarized in Equation (1) (ALLEN *et al*., 1998).

$$ET_o = \frac{0{,}408\Delta(Rn-G)+\gamma\left(\frac{900}{T+273}\right)U_2(e_s-e_a)}{\Delta+\gamma(1+0{,}34U_2)} \qquad (1)$$

where ETo is the reference potential evapotranspiration (mm d^{-1}); Δ is the slope of the vapor pressure curve (kPa $°C^{-1}$); Rn is the total daily net radiation (MJ m^{-2} d^{-1}); G is the soil heat flux (MJ m^{-2} d^{-1}); γ is the psychrometric constant (kPa $°C^{-1}$); T is the average daily air temperature (°C); u_2 is the average wind speed measured at 2 m height (ms $^{-1}$); $_s$ is the saturation pressure of water vapor (kPa); and ee $_a$ is the partial pressure of water vapor (kPa).

To estimate ETo via the Blaney and Criddle method, described in Pereira; Villa Nova; Sediyama (1997), Equation 2 was considered.

$$ET_o = [(0{,}457 * T + 8{,}13) * p] * c \qquad (2)$$

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

To estimate ETo via the Hargreaves and Samani (1985) method, Equation (3) was used.

$$ET_o = 0{,}0135 * KT * (T_m + 17{,}8) * R_a * 0{,}408 * (T_x - T_n)^{1/2} \qquad (3)$$

Where ETo is the reference potential evapotranspiration (mm d $^{-1}$); T_m is the average daily air temperature (°C); T_x is the daily maximum temperature (°C); T_n is the daily minimum temperature (°C); R_a is the radiation at the top of the atmosphere (MJ m $^{-2}$ day $^{-1}$); and 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.

To estimate ETo via the Jensen–Haise method described by Pereira, Villa Nova, and Sediyama (1997), Equation (4) was used.

$$ETo = R_s(0{,}0252 * T + 0{,}078) \qquad (4)$$

where ETo is the reference potential evapotranspiration (mm month $^{-1}$); Rs is the global solar radiation (mm d $^{-1}$); and T is the average monthly temperature (°C).

The ETo estimated via the Camargo method (PEREIRA; VILLA NOVA; SEDIYAMA, 1997) was calculated via Equation 5.

$$ETo = R_T * T * k_f * ND \qquad (5)$$

where ETo is the reference evapotranspiration (mm d $^{-1}$); RT is the extraterrestrial solar radiation (mm d $^{-1}$ of equivalent evapotranspiration); ND is the number of days in the analyzed period; T is the average air temperature (°C); and Kf is the adjustment factor that varies with the average annual air temperature of the site (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).

The estimated ETo values in an Excel spreadsheet were analyzed via linear regression (Equation 6), with the Blaney-Criddle, Hargreaves, Jensen-Haise and Camargo methods as the dependent variable (Y) and the ETo values estimated via the Penman–Monteith–FAO 56 method as the independent variable (X).

$$Y = \beta o + \beta 1X \qquad (6)$$

where Y is the estimated value for empirical methods; βo is the slope; 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 empirical methods was carried out on the basis of 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, via Equation (7) in the calculation.

$$r = \sqrt{\frac{[\sum(Y_e - \bar{Y})(Y - \bar{Y})]^2}{\sum(Y_e - \bar{Y})^2 \sum(Y - \bar{Y})^2}} \quad (7)$$

where Ye is the ETo value estimated via the evaluation method; Y is the value estimated via the Penman–Monteith–FAO 56 method; and Ȳ is the average of the values of the standard method.

The accuracy in the estimation of ETo in relation to the standard model was obtained by calculating the "d" index (Equation 8), which varies from 0 to 1 (WILLMOTT; CKLESON; DAVIS, 1985).

$$d = 1 - \left[\frac{\sum(Y_e - \bar{Y})^2}{\sum(|Y_e - \bar{Y}| + |Y - \bar{Y}|)}\right] \quad (8)$$

The safety or performance coefficient "c" (Table 1) was calculated as 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 to 0.85	Very good
0.66 to 0.75	Good
0.61 to 0.65	Median
0.51 to 0.60	Terrible
0.41 to 0.50	Bad
≤ 0.40	Terrible

Source: Camargo and Sentelhas (1997).

The definition of the most appropriate methods for estimating ETo was based on the lowest values of the standard error of estimate (SEE) (Equation 9). The quantification of the errors provided by the estimates was obtained via EPE and through the relationship of the average values (Equation 10), expressed as a percentage (%).

$$EPE = \sqrt{\frac{\sum(Y_e - \bar{Y})^2}{n}} \quad (9)$$

$$\% = \frac{Y_e\,100}{\bar{Y}} \quad (10)$$

where Ye is the mean of the estimated method, Y is the mean of the standard method, and n is the number of observations.

5 RESULTS RESULTS DISCUSSION

Over a 10-year period (2009--2018), the minimum (Tmin), maximum (Tmax), and average air temperatures (Tm) ranged from 22.59°C to 23.53°C, 30.13°C to 34.09°C, and 25.37°C to 27.44°C, respectively (Table 2). The lowest amplitude was observed for the minimums, with a value of 0.94°C. According to Araújo; Conceição; Venancio (2012), this low amplitude of Tmin is characteristic of low latitude and altitude regions, as is the case with Maués, AM. The average relative humidity data always remained above 82.52%, even in the months with less rainfall.

Table 2. Monthly average minimum (Tmin), maximum (Tmax) and average (Tm) temperatures, relative humidity (RH), wind speed (U2), global solar radiation (Qo) and insolation (n) of the municipality of Maués, AM, 2009–2018.

Months	Tmin (°C)	Tmax (°C)	Tm (°C)	RH (%)	U2 (m/s)	Qo (MJ/M ^{2})	n (h)
Jan .	23.05	30,36	25.57	89.46	0.40	13.01	4.75
Feb .	23.10	30.13	25.37	90.75	0.37	12.85	4.06
Sea .	23.31	30.24	25.59	90.84	0.36	12.57	3.68
Apr.	23.53	30.68	25.95	90.53	0.37	12.90	4.41
May .	23.45	31.21	26.08	89.62	0.36	13,12	5.13
Jun .	22.93	31.95	26.19	87.59	0.35	14.80	6.83
Jul .	22.59	32.25	26.23	85.92	0.36	15.25	7.53
Aug.	22.81	33.68	26.95	83.68	0.38	16.61	8.34
Set .	23.14	34.06	27.38	82.52	0.41	17.36	8.13
Out .	23,24	34.09	27.44	82.62	0.43	16.49	7.18
Nov .	23,22	33.02	26.87	85.05	0.39	15.23	5.98
Ten .	23.08	31.30	26.04	88.66	0.36	12.87	5.03

The wind speed data (Table 2) revealed that the speed did not reach 1.0 ms $^{-1}$ in any month, with the maximum speed recorded in October at 0.43 ms $^{-1}$ and the minimum speed recorded in June at 0.35 ms $^{-1}$, remaining practically constant throughout the year.

Table 3 presents the average ETo values for the municipality of Maués, AM, obtained via the evaluated methods. The authors overestimated ETo during all months of the year, with the difference between the average ETo values ranging from 0.72 mm day $^{-1}$ (ETo estimated by the Blaney-Criddle method) to 1.45 mm day $^{-1}$ (ETo estimated by the Camargo method). The results obtained corroborate those reported by Back (2008), Ferraz (2008), Souza and Sousa (2020) and Carvalho and Delgado (2016), who reported a tendency to overestimate the reference evapotranspiration during all months of the year via the Blaney-Criddle, Camargo, Hargreaves and Jensen-Haise methods.

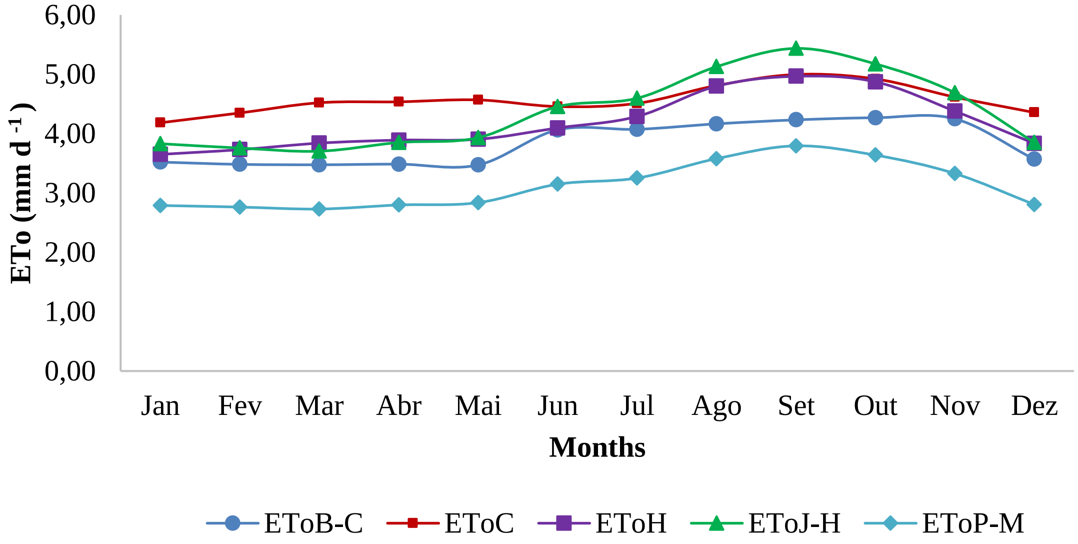
Table 3. Mean reference evapotranspiration (ETo) estimated via the Blaney–Criddle (EToB–C), Camargo (EToC), Hargreaves (EToH), Jensen–Haise (EToJ–H) and Penman–Monteith (EToP–M) methods for Maués, AM.

Months	**EToB-C**	**EToC**	**EToH**	**EToJ-H**	**EToP-M**
			mm d $^{-1}$		
Jan.	3.52	4.18	3.65	3.83	2.79
Feb.	3.48	4.35	3.73	3.76	2.76
Sea.	3.48	4.52	3.84	3.70	2.73
Apr.	3.49	4.54	3.89	3.85	2.80
May.	3.47	4.57	3.91	3.93	2.84
Jun.	4.06	4.46	4.10	4.45	3.15
Jul.	4.07	4.51	4.29	4.60	3.25
Aug.	4.17	4.81	4.80	5.13	3.58
Set.	4.23	5.00	4.97	5.44	3.79
Oct.	4.27	4.92	4.87	5.18	3.64
Nov.	4.25	4.62	4.38	4.69	3.33
Ten.	3.57	4.36	3.84	3.85	2.81
Average	3.84	4.57	4.19	4.37	3.12
ME-PM*	0.72	1.45	1.07	1.25	_

*ME–PM – Difference between the average reference evapotranspiration of the empirical methods and the average of the FAO–56 standard method.

Among the methods evaluated, the Blaney-Criddle method (EToB-C) (Figure 1) overestimated ETo the least during all months of the year. The Camargo method (EToC) overestimated ETo the most during the months of December--June, whereas the Jensen–Haise method (EToJ-H) overestimated ETo the most during the months of July --November. According to Pereira; Villa Nova; Sediyama (1997), the Blaney-Criddle and Jensen-Haise methods were developed in semiarid regions of the United States, which explains why these models present a greater increase in ETo during months with lower rainfall than during months with higher rainfall in the Maués region, Amazonas. The Camargo method is based on the results of the Thornthwaite equation, which, according to Pereira; Villa Nova; Sediyama (1997), is not suitable for oasis regions, resulting in underestimation, which presupposes that for regions with a hot and humid climate such as the municipality of Maués, AM, an overestimation would occur, as observed in the results.

Figure 1. Average values of reference evapotranspiration-ETo (mm d $^{-1}$) estimated by the methods Blaney-Criddle (EToB-C), Camargo (EToC), Hargreaves (EToH), Jensen-Haise (EToJ-H) and Penman–Monteith (EToP-M) for the municipality of Maués, AM.



With respect to the results obtained via the Hargreaves method (EToH), which overestimated ETo (Table 3 and Figure 1), Oliveira (2016) stated that despite its ease of use, this method tends to overestimate the ETo value in humid climates, requiring regional calibration to adjust its accuracy.

Table 4 presents the average daily values of ETo estimated by each method, the percentages of variation of ETo in relation to the standard method (%), the standard error of estimate (SEE), the correlation coefficient (r), the coefficient of determination (r^2), the concordance index (d), the coefficient of performance (c) and the classification based on the coefficient of performance.

Table 4. Percentage in relation to the standard method (%); standard error of estimate (SEE), mm d $^{-1}$; correlation coefficient (r), coefficient of determination (r^2), concordance index (d), coefficient of performance (c) and classification based on the coefficient of performance for the city of Maués, AM.

Method	%	EPE (mm d $^{-1}$)	r	r²	d	w	Performance Rating
Blaney-Criddle	22.94	0.22	0.94	0.88	0.99	0.92	Excellent
Camargo	46.35	0.44	0.86	0.74	0.96	0.83	Very good
Hargreaves	34.15	0.32	0.98	0.97	0.98	0.96	Excellent
Jensen-Haise	39.89	0.38	1.00	1.00	0.97	0.97	Excellent

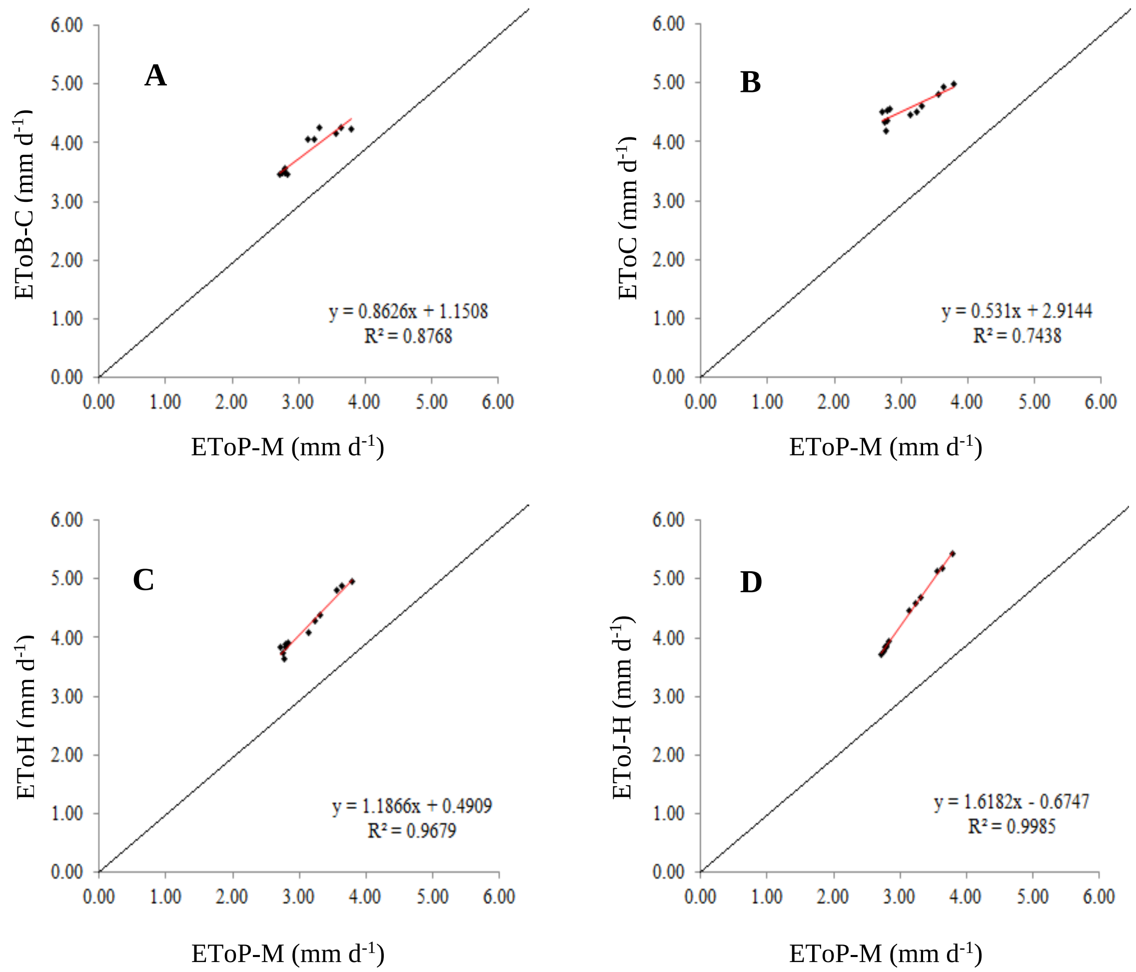
The standard error of estimation (SEE) indicates that the Blaney–Criddle method estimates ETo better than the other methods do. The SEE values ranged from 0.22 mm d $^{-1}$ to 0.44 mm d $^{-1}$, with the lowest value obtained via the Blaney–Criddle method and the highest value via the Camargo method. Notably, the Camargo method presented more dispersed data (r^2), whereas the Jensen–Haise method presented less dispersed data. Araújo; Conceição; Venancio (2012) also reported lower r² values for the conditions of Rio Branco, AC, for the Camargo method.

In the performance classification, the Camargo method has a “very good” rating and a performance coefficient (c) of 0.83. In contrast, Araújo; Conceição; Venancio (2012) classified the ETo estimated by the Camargo method as “poor” for Rio Branco, AC; however, a better performance of this method is possible under conditions of greater cloudiness.

The Blaney-Criddle, Hargreaves and Jensen-Haise methods presented an “Excellent” classification and performance coefficient (c) of 0.92, 0.96 and 0.97, respectively, corroborating the results obtained by Araújo; Costa; Santos (2007) with the Blaney-Criddle method in Boa Vista, RR. In contrast, Ferraz (2008) classified the Hargreaves and Jensen-Haise methods as “poor” and “terrible”, respectively, in the estimation of ETo for the city of Rio Branco, AC, diverging from the results obtained in this work (Table 4).

Figure 2 presents the results of the correlation between the ETo estimation methods in relation to the standard Penman–Monteith method. The Blaney–Criddle method yields a linear coefficient of 0.8626, which is the closest to 1, followed by the Camargo (0.531), Hargreaves (1.1866) and Jensen–Haise (1.6182) methods. The Hargreaves method achieves a slope of 0.4909, which is the closest to 0, followed by the Jensen–Haise (0.6747), Blaney–Criddle (1.1508) and Camargo (2.9144) methods.

Figure 2. Linear regression between reference evapotranspiration (ETo) values estimated by the Blaney-Criddle-EToB-C (A), Camargo-EToC (B), Hargreaves-EToH (C) and Jensen-Haise-EToJ-H (D) methods with the standard method Penman–Monteith-EToP-M, Maués, AM.



6 CONCLUSIONS

The Blaney-Criddle, Hargreaves and Jensen-Haise methods satisfactorily met the ETo estimation requirements for Maués, AM, both with excellent performance.

Camargo's method also satisfactorily met the ETo estimation for the municipality of Maués, AM, with “very good” performance despite its results falling short of the other methods evaluated.

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