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Reference evapotranspiration estimation by different methods for the sucroenergy sector of Colombia[1]

Estimativa da evapotranspiração de referência por diferentes métodos para o setor sucroenergético da Colômbia

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HIGHLIGHTS:
Improving the estimating reference evapotranspiration could potentially enhance the efficiency of sugarcane water use.
Reference evapotranspiration based on method used in CENICAÑA are underestimated compared to Penman-Monteith method.
High variability in the reference evapotranspiration values. It is necessary to use a field reference method, lysimeter.

ABSTRACT: In the Colombian Sugarcane Research Center CENICAÑA, efficient use of water is always performed based on estimating reference evapotranspiration. In this method, class A pans have been used to estimate the reference evapotranspiration, which provides a more precise estimate of this important variable for water resource management. The objective of this study was to evaluate different reference evapotranspiration methods for the region of influence of the climatological station of the CENICAÑA experimental station. The class A pan method traditionally used in CENICAÑA was compared with and the Penman-Monteith FAO 56 standard method. The historical series used was from January 1, 1994, to December 31, 2014. The climatic variables were the maximum, mean, and minimum temperatures, the mean relative air humidity, solar radiation, and wind speed at 10 m. Willmott's coefficients, the confidence index (c), and the root mean squared error were used in the performance evaluation. In the comparison with the Penman-Monteith FAO 56 method, all methods presented performance below the minimum requirement of (c) = 0.400. When all methods were compared with the method used in CENICAÑA (Class A pan), only the Penman-Monteith FAO 56 method showed performance classified as good (c = 0.689).

Key words: irrigation management, Penman-Monteith FAO 56 method, mean absolute error, CENICAÑA

RESUMO: No Centro de Pesquisa de Cana-de-açúcar da Colômbia (CENICAÑA), o uso eficiente da água é praticado sempre com base na estimativa da evapotranspiração de referência. Dessa forma, o Tanque Classe A sempre foi utilizado como forma de estimar a evapotranspiração de referência, sendo, portanto, uma estimativa mais precisa dessa importante variável no processo de gerenciamento dos recursos hídricos. Nesse sentido, o objetivo foi avaliar diferentes métodos de estimativa da evapotranspiração de referência para a região de influência da estação climatológica da estação experimental da CENICAÑA, comparando com o método do Tanque Classe A, tradicionalmente utilizado no CENICAÑA, e Penman-Monteith FAO 56 (padrão). Foi utilizada a série histórica de 01/01/1994 a 31/12/2014 com as variáveis climáticas de temperaturas máxima, média e mínima, umidade relativa média do ar, radiação solar e velocidade do vento a 10 m. Os coeficientes de Willmott, indice de confiança (c) e a raiz quadrada do erro quadrático médio foram utilizados na avaliação do desempenho. Na comparação com o método Penman-Monteith FAO 56, todos os métodos apresentaram desempenho abaixo do mínimo exigido, c = 0,400. Quando todos os métodos foram comparados ao método usado no CENICAÑA (Tanque Classe A), apenas o Penman-Monteith FAO 56 apresentou desempenho classificado como bom, c = 0,689.

Palavras-chave: manejo da irrigação, método de Penman-Monteith FAO 56, erro quadrado médio, CENICAÑA

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Introduction

Water management and efficient water resource use are two challenges in the sustainable management of any crop. The determination of water requirements is capital for achieving high water-use efficiency. Insufficient or excess water application result in losses and damages to the crops, soil, and nutrients, thus decreasing irrigation efficiency (Fietz et al., 2005; Bernardo et al., 2006). Therefore, to know the irrigation volumes to supply the minimum productive conditions, it is necessary to know the atmosphere's capacity to extract water from a surface. In the agricultural context, the reference evapotranspiration (ET_0) is used to determine the atmospheric power to remove water from a crop surface with no soil-water deficit.

In practical terms, ET_0 could be indirectly measured with a class A pan (ECA) or computed using weather data. The evaporation data from a class A pan should be adjusted using the tank coefficient (Kp) (Cruz, 2015) to obtain the ET_0 value. The Penman-Monteith (FAO-PM) method for ET_0 estimation is based on weather data. This method has been parameterized and recommended as standard by the Food Agriculture Organization (FAO). However, a disadvantage of the FAO-PM method is that the technique requires a large amount of measured meteorological data. Therefore, in some conditions, more straightforward approaches are necessary to estimate ET_0 (Landeras et al., 2008; Martí et al., 2015).

The Colombian Sugarcane Research Center CENICAÑA is the research center of the agro-industrial sector of sugarcane in Colombia. CENICAÑA has the most complete and reference-automated meteorological station for sugarcane crops. Therefore, comprehensive and accurate estimation of ET_0 in this locality is highly important. It is necessary to carry out a scientific study based on this locality for the estimation of ET_0. Thus, the objective of this investigation was to evaluate the performance of different calculation methods for estimating the daily ET_0 in CENICAÑA based on comparisons with the standard Penman-Monteith method and the class A pan technique used by CENICAÑA.

Material and Methods

ET_0 was calculated using the daily data on variables measured in the automated meteorological station of CENICAÑA. The station is located in the municipality of Florida, Valle del Cauca, at a latitude of 03° 21' 37.38 north, longitude of 76° 17' 59.90 west, and altitude of 1020 m above sea level. According to the Köppen classification (Köppen, 1923), the municipality has a tropical savanna climate (Aw) with two dry periods (April-June and September-November). The annual average temperatures are above 23°C, and the rainfall indices vary from 1200 to 1500 mm annually. The data used were related to the following meteorological elements: maximum air temperature (Tmax; °C), mean air temperature (Tm; °C), minimum air temperature (Tmin; °C), global solar radiation (SR, MJ m^{-2} day), average daily wind speed (U2; m s^{-1}), and average daily relative air humidity (RHaver; %).

At CENICAÑA station, Tmax generally occurs at 15:00 local time and 20:00 UTC (Universal Time, Coordinated). Tmin is usually registered at 07:00 local time (12:00 UTC). Tm is collected as the average of 24 hourly mean temperature data, and the wind speed sensor (U10) is 10 m high. RHaver was obtained in the same way as the average air temperature. Global SR was measured with a pyranometer (LICOR, Lincoln, Nebraska). The conversion of the wind speed for a height of 2 m (U2) from the information at 10 m was carried out according to Allen et al. (1998). The data were obtained from January 1, 1994, to December 31, 2014.

Consistency analysis of the daily data was performed for the 20-year series used for the ET_0 calculation with different methods. This analysis consisted of identifying discrepant values, such as Tmin values higher than Tmax; Tm values greater than Tmax; RHaver values greater than 100%; and U2 values greater than 8 m s^{-1}. A set of figures where each variable was depicted as a time series was used for graphical representation to supplement the data consistency verification with a visual analysis of the figures. This series of data was used because it is from a period in which the station began to operate automatically with the same number and type of weather sensors elements, and there were no missing data for more than 10 consecutive days.

Different methods were used for the estimation of ET_0. The Penman-Monteith FAO 56 method (Allen et al., 1998) is considered the reference standard. The other methods were the Blaney-Criddle (Blaney & Criddle, 1950), Camargo (Camargo, 1971), Hargreaves-Samani (Hargreaves & Samani, 1985), and Priestley-Taylor methods (Priestley & Taylor, 1972). The Penman-Monteith FAO 56 method was used to check the ET_0 estimate obtained with the other techniques.

The comparison was also performed with the ET_0 value calculated using the CENICAÑA method based on the class A pan evaporation value. The weather stations installed and operated by the CENICAÑA estimate a class A pan evaporation value (daily scale). The estimation is based on an empirical approach that considers daily SR, air temperature (thermal amplitude), air relative humidity, and wind speed (Peña et al., 2005). When farmers use the water balance performed by CENICAÑA, the class A pan evaporation value is converted to ET_0 by using a generic coefficient (0.75).

The Penman-Monteith FAO 56 method was used for obtaining ET_0 with the equation developed by Allen et al. (1998):

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} U_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34U_2\right)} \tag{1}$$

where:

- ET_0 - reference evapotranspiration, mm per day;
- Rn - net radiation at the crop surface, MJ m^{-2} per day;
- G - soil heat flux density, MJ m^{-2} per day;
- T - mean daily air temperature at 2-m height, °C;
- U_2 - wind speed at 2-m height, m s^{-1};
- e_s - saturation vapor pressure, kPa;
- e_a - actual vapor pressure, kPa;
- (e_s - e_a) - saturation vapor pressure deficit, kPa;
- Δ - slope vapor pressure curve, kPa °C^{-1}; and,
- γ - psychrometric constant, kPa °C^{-1}.

The Blaney-Criddle FAO method was obtained by relating the monthly evapotranspiration values to the product of the monthly average temperature by the monthly percentage of annual hours of sunlight. This was modified by FAO, including local climate adjustments. It is adequately calculated with the following equation:

$$ET_0 = P\left(0.457T_m + 8.13\right) \quad (2)$$

where:

ET_0 - reference evapotranspiration, mm per day;
T_m - mean daily air temperature at 2-m height, °C; and,
P - daily percentage of annual hours of sunlight.

The Camargo method is an empirical method based on the Thornthwaite method. Thus, it presents the same advantages and restrictions as the Thornthwaite approach, but it has one more advantage: it does not need the normal annual average temperature. However, it considers extraterrestrial SR (Qo), which is obtained from tables.

$$ET_0 = 0.01\ Qo\ Tm \quad (3)$$

where:

Qo - extraterrestrial SR, mm per day.

The Hargraves-Samani (1985) method incorporates the SR received on a horizontal surface on the outside of the atmosphere, in addition to the minimum, mean, and maximum air temperatures. The radiation factor considered is a function of latitude and the period of the year. Therefore, ET_0 can be obtained by the following equation:

$$ET_0 = \sqrt{0.0023\left(T_m + 17.8\right)\left(T_{max} - T_{min}\right)}\ Ra\ 0.408 \quad (4)$$

where:

Tm, Tmax, and Tmin - the mean, maximum, and minimum temperatures (°C), respectively; and,
Ra - SR on the surface of the atmosphere, MJ m^{-2} per day.

The Priestley-Taylor method is a physical method based on the original Penman method. It considers that most of the evaporative power of the air is conditioned by the energy term. Therefore, according to the Priestley-Taylor approach, advection can be ignored. Thus, even when taking the energy balance into consideration, this method has an empirical component.

$$ET_0 = \frac{1.26\ W\ \left(Rn - G\right)}{\gamma} \quad (5)$$

where:

W - weighting factor dependent on air temperature (Tm); and,
W = 0,407 + 0,0145 T (for 0 °C < Tm < 16 °C) or W = 0,483 + 0,01 T (for Tm > 16 °C).

The performance analysis of the evaluated methods was carried out by comparing the obtained evapotranspiration values with those estimated by the Penman-Monteith-FAO 56 method and the value obtained by the procedure performed at CENICAÑA. The following parameters were considered as indicators for comparing the performance of the methods: mean absolute error (MAE), the root mean squared error (RMSE), the square root of the systematic mean square error (RMSES), the square root of the nonsystematic mean square error (RMSENS), the concordance index (d), the confidence index (c), the correlation coefficient (r), and the coefficient of determination (R^2).

The methodology adopted for the comparison of the results was proposed by Allen et al. (1998) and is based on the estimate of the MAE calculated by Eq. 6. The following expressions were used (Camargo & Sentelhas, 1997, Willmott & Matsuura, 2005):

$$MAE = \frac{\sum_{i=1}^{N}\left|P_i - O_i\right|}{N} \quad (6)$$

$$RMSE = MSE^{0.5} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)^2\right]^{\frac{1}{2}} \quad (7)$$

$$RMSES = MSES^{0.5} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\hat{P}_i - O_i\right)^2\right]^{\frac{1}{2}} \quad (8)$$

$$RMSENS = MSENS^{0.5} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\hat{P}_i - P_i\right)^2\right]^{\frac{1}{2}} \quad (9)$$

$$d = 1 - \frac{\sum_{i=1}^{N}\left(P_i - O_i\right)^2}{\sum_{i=1}^{N}\left(\left|P_i - \bar{O}\right|\right) + \left(O_i - \bar{O}\right)^2} \quad (10)$$

$$c = d\ r \quad (11)$$

where:

Pi - reference evapotranspiration obtained by the method to be evaluated, mm per day;
Oi - reference evapotranspiration obtained by the standard method, mm per day;
MSE - mean squared error;
MSES - systematic mean squared error;
$\hat{P}_i$ - Pi estimation based on the linear regression model, mm per day;
MSENS - nonsystematic mean square error;
$\bar{O}$ - mean of the values obtained by the standard method, mm per day; and,
N - number of observations.

Accuracy is related to the estimated values' approximation of the observed values. The similarity of the ET_0 values determined by the methods studied to the standard results was found by employing a designated index of agreement or adjustment (d) (Willmott et al., 1985). The index varies from zero (for

Table 1. Performance classification according to the confidence index c

Value of c	Performance
≥ 0.85	Optimum
0.76 a 0.85	Very good
0.66 a 0.75	Good
0.61 a 0.65	Moderate
0.51 a 0.60	Regular
0.41 a 0.50	Bad
≤ 0.40	Terrible

Source: Camargo & Sentelhas (1997)

no agreement) to one (for perfect agreement). The results are qualified according to Table 1. The approximation index is calculated with Eq. 5. A confidence index c was used as a statistical comparison tool as proposed by Camargo and Sentelhas (1997). It serves as an indicator of a method's performance using the precision index r and accuracy index d, as expressed in Eq. 10.

Results and Discussion

Table 2 shows the obtained regression parameters. The empirical methods that take into account the estimated SR had the lowest R^2, which is the same result found by Alencar et al. (2015). This occurs because the main factor contributing to evapotranspiration is SR (Allen et al., 1998). Thus, the equations are inadequate to estimate SR in the studied region.

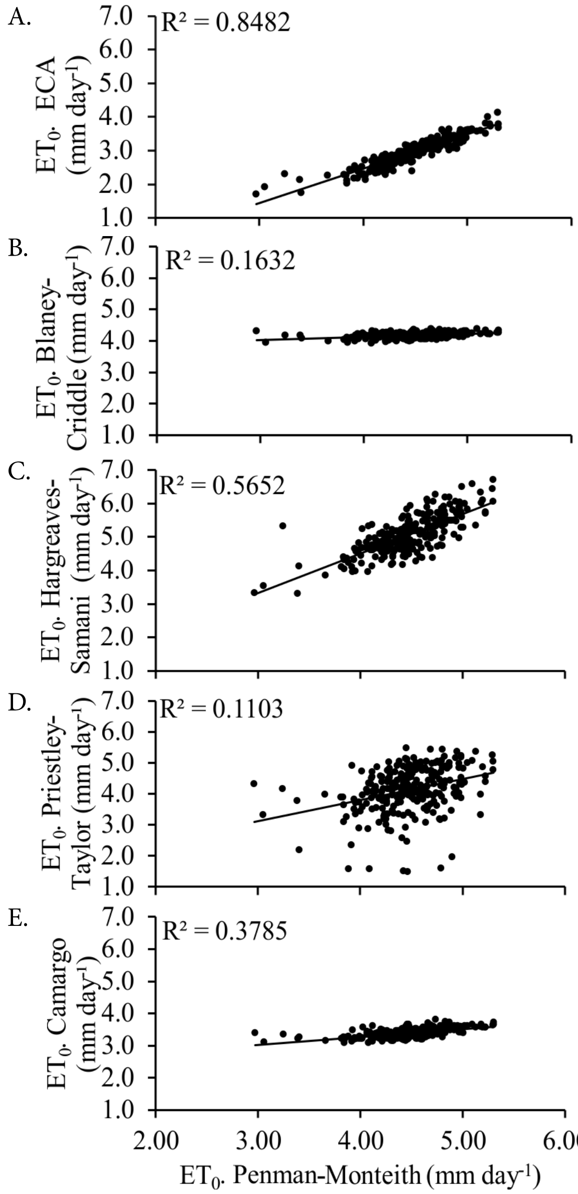
However, regarding the Penman-Monteith approach, the method that considers temperatures and SR for ET_0 calculation has higher R^2 values (0.565) (Table 2). The ET_0 values calculated using the class A pan method are positively associated with the ET_0 values generated using the Penman-Monteith standard method. Thus, R^2 was highest (0.848).

All methods except the Penman-Monteith method presented lower coefficients of determination (Table 2). Therefore, the ET_0 values calculated should not be recommended for the studied region. Although the Penman-Monteith method presented the highest adjustment value (R^2 = 0.8482), the values tended to be underestimated by an average of 1 mm per day compared to the class A pan method (Figure 1A). The estimates made by the Blaney-Criddle and Camargo methods (Figures 1B and E) also tended to underestimate the value of ET_0.

In contrast, the results calculated with the Hargreaves-Samani method (Figure 1C) tended to overestimate the values of ET_0, which is a similar result to that of Mendoza et al. (2016). Likewise, when compared to the Priestley-Taylor method (Figure 1D), the values seemed to remain in a similar range, but the adjustment was the lowest with R^2 = 0.1103. This demonstrates that there is no correlation between the results of the Penman-Monteith method and the evaluated method.

Table 2. Regression parameters (a, b) and coefficient of determination (R^2) for each method evaluated compared to Penman-Monteith and the procedure used in CENICAÑA (Class A pan)

Method evaluated	a	b	R^2
	Comparison to Penman-Monteith		
Class A pan	1.021	-1.614	0.848
Blaney - Criddle	0.099	3.741	0.163
Hargreaves-Samani	1.185	0.242	0.565
Priestley - Taylor	0.677	1.087	0.110
Camargo	0.244	2.295	0.379
	Comparison to class A pan		
Penman-Monteith	0.831	2.020	0.848
Blaney - Criddle	0.083	3.935	0.143
Hargreaves-Samani	0.979	2.168	0.474
Priestley - Taylor	0.666	2.151	0.131
Camargo	0.175	2.873	0.237



ECA - Class A pan method used in CENICAÑA

Figure 1. ET_0 values estimated by ECA (class A pan) (A), Blaney-Criddle (B), Hargreaves-Samani (C), Priestley-Taylor (D), and Camargo (E) methods compared to those estimated by the Penman-Monteith method

Although the Penman-Monteith method presents a high adjustment value (R^2 = 0.828), the values are overestimated (Figure 2A). This also happened with the Hargreaves-Samani method (Figure 2C), but with a much lower coefficient of determination (R^2 = 0.474). The daily ET_0 data calculated by the Priestley-Taylor method are poorly related to the data computed using the CENICAÑA method (R^2 = 0.131) (Figure 2D), and the lowest coefficient of determination was the lowest. In contrast, the Blaney-Criddle and Camargo methods (Figures 2B and E) underestimate the values of ET_0, and the values remain constant. The underestimation of ET_0 values by both

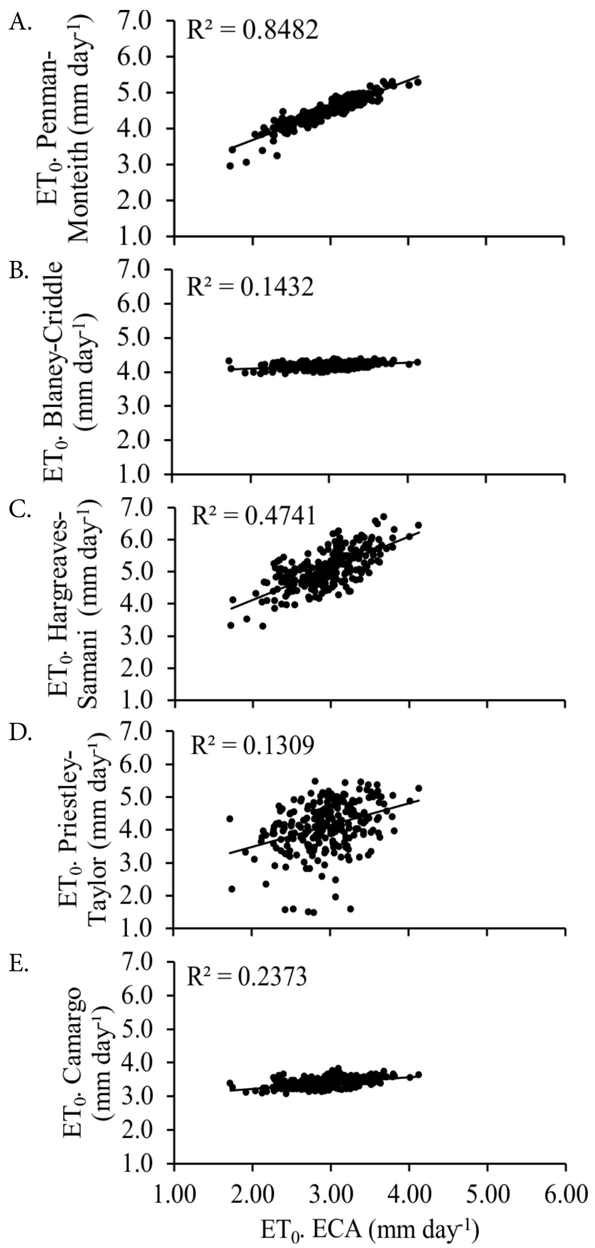


Figure 2. ET_0 values estimated by the Penman-Monteith (A), Blaney-Criddle (B), Hargreaves-Samani (C), Priestley-Taylor (D), and Camargo (E) methods compared to those estimated by the ECA - class A pan method used in CENICAÑA

computing methods is related to the low number of weather variables for ET_0 calculation (only temperature).

Based on the results of the MAE, the methods can be classified in decreasing order in comparison to the Penman-Monteith method: ECA - class A pan, Camargo, Hargreaves-Samani, Priestley-Taylor, and Blaney-Criddle. Similarly, the ECA - class A pan method provided the highest correlation coefficient (0.92) based on the confidence index c (Table 3). However, according to this index, all methods had bad or terrible performance (Table 2).

Between the methods that use only temperature data to estimate the ET_0 value, the Blaney-Criddle method was the one with the lowest MAE (0.29). Similarly, it had the lowest confidence index of 0.19. This is contrary to what was found by Oliveira et al. (2020) for the Mato Grosso do Sul region in Brazil with data on a daily scale. This is possibly due to the differences in the characteristics of the study regions. In evaluating various ET_0 estimation methods, Sousa et al. (2010) concluded that the ones closest to the Penman-Monteith method were the Jensen-Haise, Priestley-Taylor, and Hargreaves, in that order. This is also contrary to what was observed in the present study.

Based on MAE, the different methods can be classified (Table 4) in the following decreasing order: Hargreaves-Samani, Penman-Momteith, Priestley-Taylos, Blaney Criddle, and Camargo. However, when the correlation coefficient was evaluated, the method that had the best adjustment was the Penman-Monteith standard method with r = 0.92 (Table 4). This method was also the only one that had good performance (Table 1).

These results confirmed the findings reported by Montero et al. (2018), who carried out an analysis to compare ET_0 data from a satellite image and data estimated from CENICAÑA's weather data. They determined a high correlation between satellite data and that from the FAO Penman-Monteith standard method (r = 0.915). They also showed that among the methods that use only air temperature data for ET_0 estimation, the data estimated by the Hargraves-Samani method were positively related to data generated with the satellite (r = 0.541). However, the Hargreaves-Samani method overestimated ET_0 at higher proportions (> 80%). This demonstrates that this parameter is not adequate for irrigation management, which is related to the excessive volume of water that the ET_0 value could generate.

Between the methods that use only temperature data to estimate the value of ET_0, the Camargo method was the one with the lowest MAE (0.47). Its correlation coefficient was r = 0.50, its concordance index was d = 0.52, and its confidence index

Table 3. Comparison of the methods evaluated with the FAO Penman-Monteith standard method

Methods/Coefficient	Penman-Monteith	Class A pan	Camargo	Hargreaves-Samani	Priestley-Taylor	Blaney-Criddle
Average value (mm per day)	4.47	2.95	3.39	5.06	4.12	4.18
SD (mm per day)	0.37	0.41	0.15	0.58	0.75	0.09
Coefficient of variation (%)	8.17	13.72	4.29	11.38	18.10	2.12
Maximum value (mm per day)	5.30	4.13	3.82	6.71	5.47	4.39
Minimum value (mm per day)	2.97	1.72	3.07	3.31	1.49	3.94
r		0.92	0.62	0.75	0.33	0.40
MAE (mm)		1.52	1.08	0.59	0.36	0.29
RMSE (mm)		1.53	1.12	0.70	0.80	0.45
RMSES (mm)		3.08	1.06	1.83	0.79	0.48
RMSENS (mm)		1.55	2.10	1.18	0.34	0.08
d		0.32	0.61	0.55	0.70	0.48
c		0.30	0.38	0.41	0.23	0.19

SD - Standard deviation; r - Correlation coefficient; MAE - Mean absolute error; RMSE - Square root of the mean square error; RMSES - Square root of the systematic mean square error; RMSENS - Square root of the nonsystematic mean square error; d - Concordance index, the; c - Confidence index

Table 4. Comparison of the evaluated methods with the class A pan method used in CENICAÑA

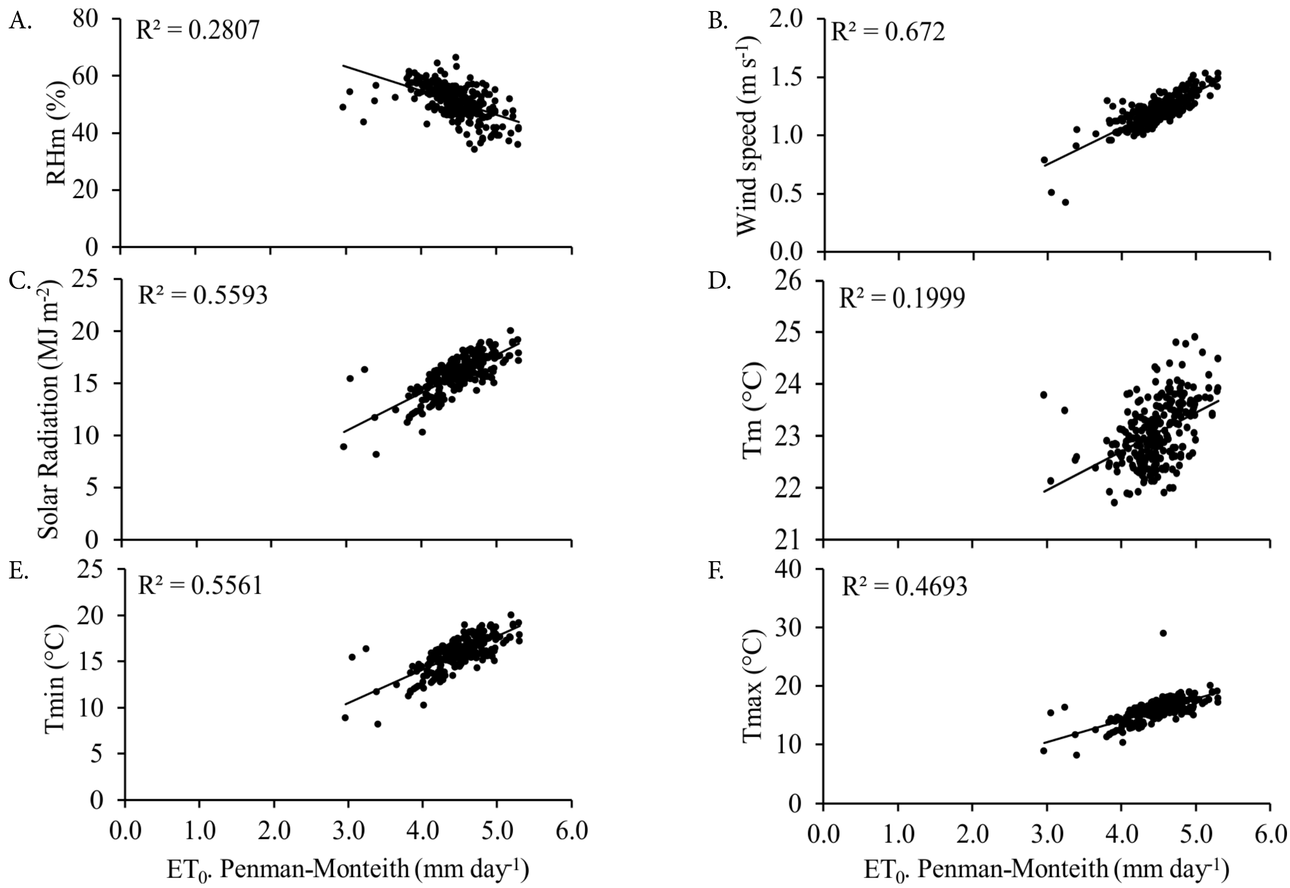
Methods/Coefficients	Class A pan	Hargreaves-Samani	Penman-Monteith	Priestley-Taylor	Blaney- Criddle	Camargo
Average value (mm per day)	2.95	5.06	4.47	4.12	4.18	3.39
SD (mm per day)	0.41	0.58	0.37	0.75	0.09	0.15
Coefficient of variation (%)	13.72	11.38	8.17	18.10	2.12	4.29
Maximum value (mm per day)	4.13	6.71	5.30	5.47	4.39	3.82
Minimum value (mm per day)	1.72	3.31	2.97	1.49	3.94	3.07
r		0.69	0.92	0.36	0.38	0.50
MAE (mm)		2.11	1.52	1.24	1.23	0.47
RMSE (mm)		2.15	1.53	1.36	1.29	0.57
RMSES (mm)		2.67	1.52	2.01	1.41	0.65
RMSENS (mm)		2.06	0.14	0.82	0.15	0.14
d		0.66	0.75	0.35	0.50	0.52
c		0.46	0.69	0.13	0.19	0.25

SD - Standard deviation; r - Correlation coefficient; MAE - Mean absolute error; RMSE - Square root of the mean square error; RMSES - Square root of the systematic mean square error; RMSENS - Square root of the nonsystematic mean square error; d - Concordance index; c - Confidence index

was c = 0.25. Thus, this method was classified as "terrible" (Table 1). Likewise, the Hargreaves-Samani method presented the highest value of MAE = 2.11, with coefficient values of r = 0.69, d = 0.66, and c = 0.46, "indicating bad" performance (Table 1). The Priestley-Taylor method was the one that showed the worst performance, and the obtained values did not present a good fit concerning the class A pan method used in CENICAÑA The values were of r = 0.36, d = 0.35, and c = 0.13, indicating "terrible" performance. In the same way, Vallory et al. (2016) concluded that the Camargo method for the estimation of ET_0 on a daily basis cannot be recommended in summer climatic conditions, which are the conditions usually found in the study area.

According to the results, it is not possible to determine which method has a more stable ET_0 value. This is clear after comparing results in Tables 3 and 4, which show there is high uncertainty associated with the ET_0 estimation in the studied region. Similarly, from an economic point of view, irrigation can represent 25% of production costs in the cultivation of sugarcane in Colombia (Reyes, 2016), which means that performing more efficient irrigation from the point of view of estimating ET_0 with greater precision will contribute to cost reduction or higher productivity.

It is possible compare the different climatic variables that interfere with the ET_0 methods to find which of them is more relevant to the calculation. Thus, Figures 3 and 4 show the



RHm - relative air humidity, Tm - mean temperature, Tmin - minimum temperature, Tmax - maximum temperature

Figure 3. Relationships between the daily values of ET_0 calculated by the FAO Penman-Monteith standard method with the different available climatic elements

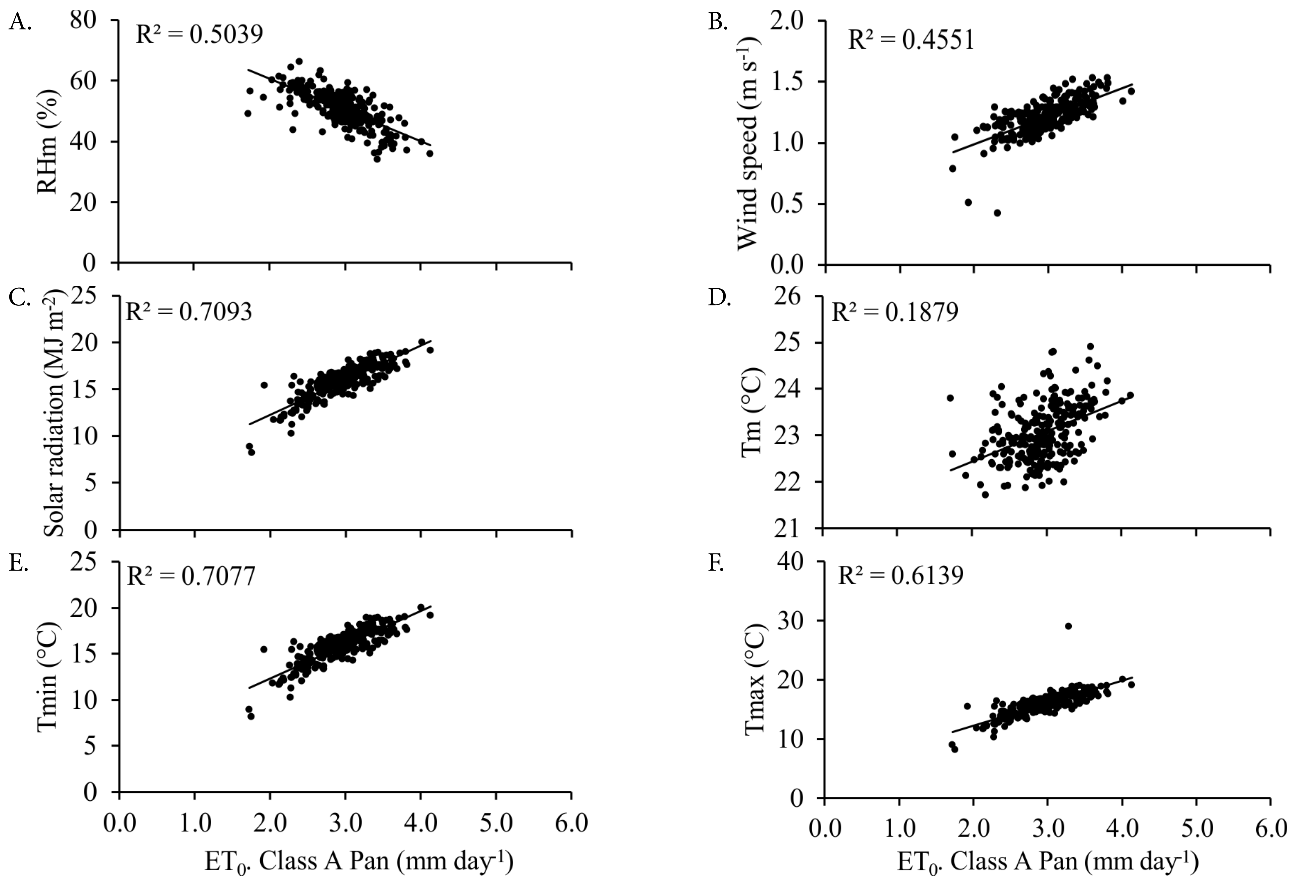


Figure 4. Relationships between the daily ET_0 values calculated by the class A pan method with the different climatic elements available

relationships between climatic variables and the methods evaluated. The variable with the highest coefficients of was the wind speed with $R^2 = 0.672$ (Figure 3B). This is contrary to what was found with the class A pan method used in CENICAÑA.

In this case, the variables that have the highest coefficients of determination are the SR with $R^2 = 0.709$ (Figure 4B), similar to the findings of Montero et al. (2018), and the minimum temperature with $R^2 = 0.708$. The latter result is contrary to those of Amorim et al. (2007), who aimed to determine the direct and indirect effects of meteorological elements on ET_0 by the Penman-Monteith (FAO) and ECA methods in Mossoró, RN, Brazil. In that case, SR was the climate variable with the most significant contribution to ET_0. The order of adjustment of the climatic variables with the class A pan method after wind speed was SR (Figure 3C), minimum air temperature (Figure 3E), maximum air temperature (Figure 3F), relative humidity (Figure 3A), and average air temperature (Figure 3D), with R^2 values of 0.5593, 0.5561, 0.4693, 0.2807, and 0.1999, respectively.

When comparing the climate element for the Penman-Monteith and the class A pan methods, the wind speed does not present the same coefficients of determination (Figures 3B and 4B). The values were R^2 of 0.672 and 0.455, respectively, which shows the variation in the weight that each element has in the result. Figure 4 shows the correlation of relative air humidity (Figure 4A), wind speed (Figure 4B), SR (Figure 4C), and the average (Figure 4D), minimum (Figure 4E), and maximum (Figure 4F) air temperatures with ET_0 in the class A pan method. SR and the minimum and maximum air temperatures were positively and highly correlated with ET_0. However, wind speed and mean air temperature were positively but weakly correlated, while relative air humidity was negatively correlated. From Figure 4, it can be seen that the coefficients of determination of relative air humidity, wind speed, SR, and the average, minimum, and maximum air temperatures were 0.710, 0.675, 0.842, 0.433, 0.841, and 0.784 for ET_0 from the class A pan method, respectively.

It is interesting to note that in the class A pan method, SR, wind speed, average, and the minimum and maximum air temperatures were positively correlated with ET_0. This implies that the ET_0 rate depends directly on these variables. On the other hand, relative humidity was negatively correlated with ET_0, which means that they are inversely related to ET_0 in the class A pan and Penman-Monteith methods. This occurs because the ET_0 rate is low when it is cloudy and humid, while high ET_0 is obtained when it is hot, sunny, and dry. It is interesting to note that the correlation of each variable with ET_0 depends on the influence of the humid, tropical-continental air mass and the warm, tropical-maritime air mass (originating in the Pacific Ocean) prevailing in the study area.

Conclusions

1. The daily ET_0 data obtained with the class A pan method used in CENICAÑA had the best performance based on the MAE values. However, the daily ET_0 data values computed using the class A pan method were underestimated, and the confidence coefficient was classified as terrible.

2. The closest method was the standard method when comparing the different methods of estimating ET_0 with the value obtained by the class A pan method used in CENICAÑA. However, the performance classification did not reach the highest value.

3. Methods that use only average air-temperature data are not recommended for use in the CENICAÑA region, even if they consider other elements such as SR and wind speed. They must be parameterized with ET_0 values obtained with locally installed devices such as lysimeters.

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