SCIENTIFIC NOTE

Calibration of alternative equations to estimate the reference evapotranspiration in Nova Venécia, Espírito Santo, Brazil

Calibración de ecuaciones alternativas para estimar la evapotranspiración de referencia en Nova Venécia, Espírito Santo, Brasil

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ABSTRACT

The estimation of the reference evapotranspiration is fundamental in defining irrigation projects. However, an estimation using the standard equation requires climate variables that are difficult to measure and are not very accessible. Thus, the objective of this study was to calibrate and validate alternative methods to estimate evapotranspiration that use simple variables and to compare performance with the standard Penman-Monteith method for the municipality of Nova Venécia, Espírito Santo, Brazil. For this, a 12-year time series (2008-2019) of meteorological data from the Instituto Nacional de Meteorología was used. The standard FAO-56 Penman–Monteith method was used to evaluate alternative methods: Hargreaves and Samani, Benevides and Lopes, Linacre, Hamon and Camargo. Method performance was analyzed by correlation coefficient, Willmott index, root mean square of normalized error, and performance index. Calibration improved the statistical indices, increasing the performance of the Hargreaves and Samani, Benevides and Lopes, and Linacre methods to "very good" in the rainy season and to "intermediate" in the dry season. They were superior to the Hamon and Camargo methods, which continued to show "tolerable" to "very poor" performance in both periods.

Key words: alternative methods, agricultural meteorology, FAO-56 Penman–Monteith, irrigation.

RESUMEN

La estimación de la evapotranspiración de referencia es fundamental en la definición de proyectos de riego. Sin embargo, una estimación utilizando la ecuación estándar requiere variables climáticas difíciles de medir y poco accesibles. Por lo tanto, el objetivo de este estudio fue calibrar y validar métodos alternativos para estimar la evapotranspiración que utilizan variables simples y comparar el desempeño con el método estándar de Penman-Monteith para el municipio de Nova Venécia, Espírito Santo, Brasil. Para ello se utilizó una serie temporal de 12 años (2008-2019) de datos meteorológicos del Instituto Nacional de Meteorología. Se utilizó el método estándar FAO-56 Penman-Monteith para evaluar métodos alternativos: Hargreaves y Samani, Benevides y Lopes, Linacre, Hamon y Camargo. El desempeño del método se analizó mediante el coeficiente de correlación, el índice de Willmott, la raíz cuadrática media del error normalizado y el índice de desempeño. La calibración mejoró los índices estadísticos, aumentando el desempeño de los métodos de Hargreaves y Samani, Benevides y Lopes, y Linacre a "muy bueno" en época de lluvias y a "intermedio" en época seca. Estos fueron superiores a los métodos de Hamon y Camargo, que continuaron mostrando un desempeño "tolerable" a "muy pobre" en ambos períodos.

Palabras clave: métodos alternativos, meteorología agrícola, FAO-56 Penman–Monteith, irrigación.

Introduction

Coffee cultivation is of significant importance to the world economy, with Brazil as the largest producer and exporter of coffee (*Coffea* spp.), corresponding to 37% of world production, and as the second largest producer of the species *Coffea canephora* (USDA, 2019; Belan *et al*., 2020). In addition, Brazil is also one of the largest producers of black pepper (*Piper nigrum*) (Carneiro *et al*., 2017). The State of Espírito Santo is currently the second largest coffee producer and the first producer of Conilon coffee, the second producer of papaya, and the largest exporter and second producer of black pepper (Dadalto *et al*., 2016).

The municipality of Nova Venécia is located in the northwest region of the state of Espírito Santo; agriculture is one of the main activities of the region. According to the 2018 Agricultural Census, the municipality was the 9th largest

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producer of Conilon coffee (27,920 t) and the 5th largest producer of black pepper (4,200 t) nationally. One of the main factors contributing to this productive position is the use of irrigation, which according to this census covers approximately 15,000 productive hectares and is present in about 2,500 agricultural establishments (IBGE, 2018).

In irrigated agriculture, the quantification of the water consumption of the crops during development stages allows for the planning, dimensioning, and rational management of the irrigation. One of the techniques that helps to quantify the volume of water needed for irrigation is the determination of crop evapotranspiration (ETc), which reflects the measurement of the total amount of water lost to the atmosphere, resulting from the processes of soil evaporation and plant transpiration.

To determine ETc, it is necessary to estimate the Reference Evapotranspiration (ET_o), which represents a standardized measure of the evapotranspiration rate of a location, considering the local climate variables. Then, ET_o is corrected by the Crop Coefficient (Kc), which is a ratio between ETc and ET_o. The value of Kc varies depending on the crop and its stage of growth.

The United Nations Food and Agriculture Organization (FAO) has defined the Penman-Monteith equation as the standard model, recommending it to estimate and calibrate different ET_o methods (Allen *et al*., 1998). Studies have shown the efficiency and representativeness of this model to the factors that govern the process of evapotranspiration; however, its great disadvantage is related to the high number of meteorological variables required for its use, since most of the stations do not have enough sensors to collect all the variables, or the quality of the data collected is poor (Palaretti *et al*., 2014; Carvalho *et al*., 2015; Tanaka *et al*., 2016).

Faced with this problem, the use of simpler methods using few meteorological variables to estimate the ET_o has become a viable solution (Fernandes *et al*., 2012; Sales *et al*., 2018). In this context, Santana *et al*. (2018) recommend that, before choosing the method to be used, an assessment of the climate adaptability to the region be made comparing its performance to the standard Penman-Monteith FAO model 56. This study is necessary because the methods were generally developed under climatic and crop management conditions different from that in which the model will be employed, making it necessary to calibrate the equations for the region in order to minimize the estimation errors (Pereira *et al*., 2009; Rigone *et al*., 2013). Thus, the aim of this study was to calibrate and validate alternative methods for producers in the region that use only simple variables, comparing their performance with that of the standard method recommended by the FAO-56 Penman-Monteith, for the municipality of Nova Venécia, Espírito Santo State, Brazil.

Materials and methods

In this study, hourly data from the automatic meteorological station of the National Institute of Meteorology (INMET), located in the municipality of Nova Venécia, State of Espírito Santo, Brazil, were used. The station is located at latitude 18°41’43” S, longitude 40°24’27” W and has an altitude of 154 m a.s.l. Nova Venécia is located in the northern region of Espírito Santo (Fig. 1), bounded by latitudes 18°17’58” S and 18°56’48” S, and by longitudes 40°45’30” W and 40°17’46” W, covering a total area of 1,439,571 km^2.

The northern region of the state is recognized as the main producer of Conilon coffee, standing out in this activity. In addition, this area also stands out for the production of papaya and black pepper.

The climate of Nova Venécia is classified by Köppen and Geiger (1936) and Peel *et al*. (2007) as tropical with dry season, with a temperature range from 11.8 to 18°C during the colder month and 30.7 to 37°C in the warmer month, reaching an annual average of 24°C. The rainy season is between the months of October to February, and the dry season between the months of March to September.

The data used in this study were collected from a meteorological station installed in the region in 2008, with a historical series of 11 years for producers in the region from 2008 to 2019. It is important to emphasize that, although the historical series is relatively short, local studies of this nature play a crucial role in facilitating the suitability of irrigation projects for the region. However, it is essential to use the results of this study with caution, considering the limitations of the historical series.

The meteorological variables used to estimate the ET_o in mm d^{-1} were: maximum (Tx), minimum (Tn) and average (Tm) air temperature in °C; average dew point temperature (To) in °C; maximum relative humidity (URx), minimum (URn) and average (URm) humidity of the air at 2 m above ground level in %; global solar radiation (Rg) in MJ m^{-2} d^{-1}; and wind speed at 2 m from ground level (U_2) in m s^{-1}, as shown in Table 1.

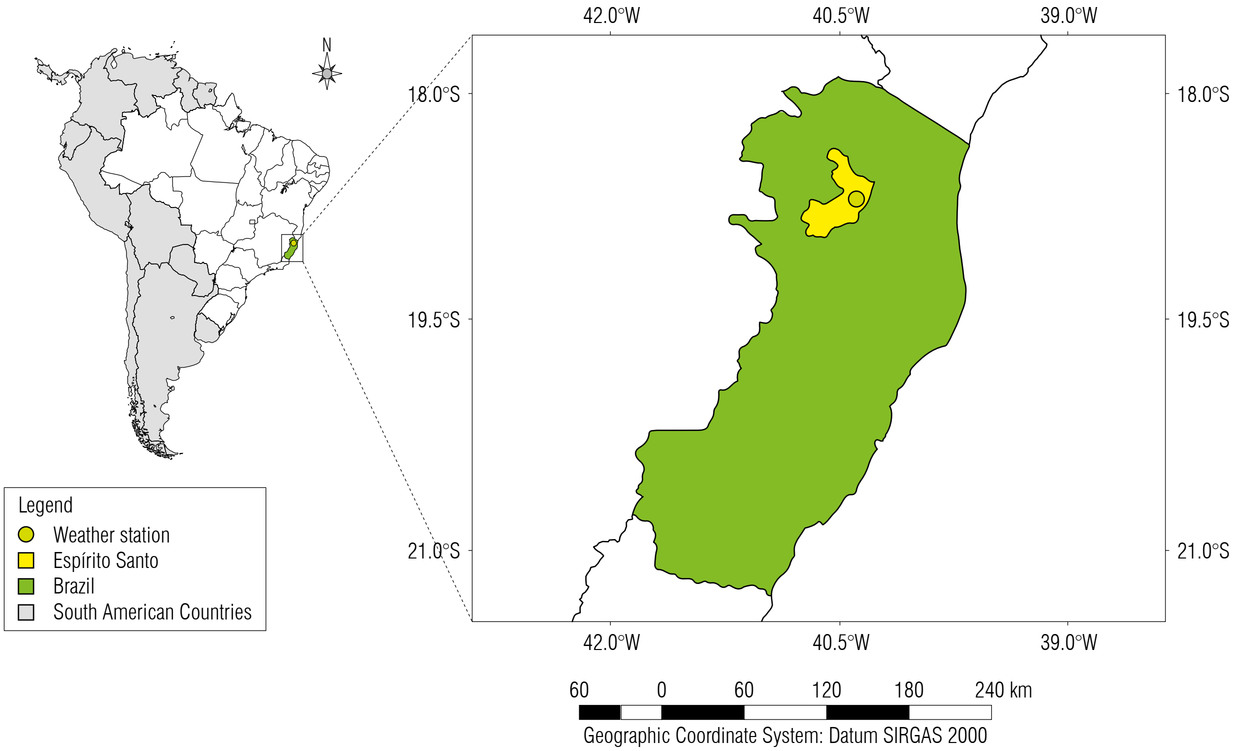

FIGURE 1. Geographical location of the municipality of Nova Venécia in the state of Espírito Santo, Brazil.

TABLE 1. Monthly averages of the climatic data collected by the meteorological station and used by alternative methods to estimate ET_o in Nova Venécia, Espírito Santo, Brazil, between 2008 and 2019.

Month	Rg	Tx	Tn	Tm	To	URx	URn	URm	U_2
January	21.3	32.9	21.3	27.1	17.0	94.1	43.9	69.0	2.1
February	21.8	33.6	21.5	27.6	16.9	94.1	40.4	67.2	1.9
March	18.8	33.2	21.6	27.4	17.2	93.7	43.3	68.5	1.9
April	16.4	31.4	20.4	25.9	17.1	93.7	47.3	70.5	1.8
May	13.7	29.7	18.5	24.1	16.3	93.1	47.6	70.3	1.8
June	11.9	28.4	17.6	23.0	15.8	93.6	48.3	70.9	1.8
July	14.8	27.8	16.7	22.2	15.1	94.0	46.4	70.2	1.9
August	15.8	28.2	16.8	22.5	14.9	93.3	44.4	68.9	2.1
September	17.4	30.0	18.2	24.1	15.2	92.1	41.0	66.6	2.4
October	17.4	30.6	19.7	25.2	16.0	91.75	44.4	68.0	2.5
November	18.1	30.5	20.5	25.5	17.1	93.1	50.4	71.8	2.3
December	20.1	31.8	21.2	26.5	17.5	93.7	48.7	71.2	2.1

Rg - global solar radiation; Tx - maximum air temperature; Tn - minimum air temperature; Tm - average air temperature; To - average dew point temperature; URx - maximum relative humidity; URn - minimum relative humidity; URm - average relative humidity; U_2 - wind speed at 2 m above ground level.

Prior to the estimates, the quality of the data was analyzed in order to eliminate measurement errors, based on the criteria proposed by Sales *et al.* (2018): Tx above 50°C; Tn below 0°C; Tx below Tn for the same day; Rg equal to zero and Rg greater than the extraterrestrial solar radiation. After the analysis, 3865 d remained with consistent data, corresponding to 92% of the data collected by the weather station.

Daily values of ET_o were estimated for the dry and rainy periods, using the alternative methods of (HS) Hargreaves and Samani (1985) (Eq. 1); (BL) García Benevides and López (1970) (Eq. 2); (Li) Linacre (1977) (Eq. 3); (Ho) Hamon (1961) (Eq. 4); (Ca) Camargo (1978) (Eq. 5) and (FAO-56 PM) standard method 56 from FAO Penman-Monteith (Allen *et al.*, 1998) (Eq. 6).

$$ET_o = A\frac{Ra}{2.45}(Tx - Tn)^{0.5}(Tm + B) \tag{1}$$

$$ET_o = A\ 10^{(\frac{7.5\ Tm}{237.5+Tm})}(1 - 0.01\ UR) + B\ Tm - C \tag{2}$$

$$ET_o = \frac{A\frac{Tm+0.006\ alt}{100-lat} + B(Tm - To)}{C - Tm} \tag{3}$$

$$ET_o = A\ (\frac{N}{12})^2\frac{B\ exp^{(C\ Tm)}}{100}D \tag{4}$$

$$ET_o = A\frac{Ra}{2.45}Tm \tag{5}$$

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma(\frac{900}{Tm+273})U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{6}$$

where:

A, B, C and D - adjusted coefficients;

Ra - solar radiation in absence of atmosphere (MJ m^{-2} d^{-1});

alt - altitude (m);

lat - latitude (degrees);

N- photoperiod (h);

Δ- tangent to the saturation pressure curve of water vapor (kPa $°C^{-1}$);

γ - psychrometric constant (0.0662 kPa $°C^{-1}$);

Rn - radiation balance (MJ m^{-2} d^{-1});

G - soil heat flux density (MJ m^{-2} d^{-1});

e_s - saturation pressure the surface temperature (kPa $°C^{-1}$);

e_a - vapor pressure of the air (kPa $°C^{-1}$).

The data from the period from July 2008 to December 2015 were used to calibrate the parameters of the equations; the equations from January 2016 to December 2019 were used to validate those parameters.

The parameter calibration was performed by minimizing the square sum of the error obtained by comparing the ET_o estimated by the alternative methods and by the FAO-56 PM standard method, using the Solve activation within the Excel software and the open-source program R Core Team (2020). The performance of the alternative ET_o methods was evaluated by the correlation coefficient (Eq. 7), the root of normalized mean square error (Loague & Green, 1991) (Eq. 8), Willmott's index of agreement (Willmott *et al.*, 1985) (Eq. 9) and confidence coefficient (Camargo & Sentelhas, 1997) (Eq. 10).

$$r = \frac{\sum_{i=1}^{n} \quad (|E_i - \bar{E}|)(|O_i - \bar{O}|)}{\sqrt{\sum_{i=1}^{n} \quad (E_i - \bar{E})^2}\sqrt{\sum_{i=1}^{n} \quad (O_i - \bar{O})^2}} \tag{7}$$

$$RMSE = \sqrt{\sum_{i=1}^{n} \quad \frac{(O_i - E_i)^2}{N}} \tag{8}$$

$$d = 1 - \frac{\sum_{i=1}^{n} \quad (O_i - E_i)^2}{\sum_{i=1}^{n} \quad (|E_i - \bar{O}| + |O_i - \bar{O}|^2)} \tag{9}$$

$$c = r\ d \tag{10}$$

where:

E_i - value obtained by means of the alternative methods (mm d^{-1});

O_i - value estimated through the Penman-Monteith standard method (mm d^{-1});

E - mean of the estimated by means of the alternative methods (mm d^{-1});

O - mean of the estimated by means of the Penman-Monteith standard method (mm d^{-1});

n - number of values;

r - Pearson correlation index;

d - Willmott's index of agreement;

c - confidence coefficients.

The performance of alternative methods was classified based on the variation of the confidence index (c) as: "excellent" (c>0.85); "very good" (c between 0.76 and 0.85); "good" (c between 0.66 and 0.75); "intermediate" (c between 0.61 and 0.65); "tolerable" (c between 0.51 and 0.60); "poor" (c between 0.41 and 0.50) and "very poor" (c<0.40).

Results and discussion

During the period studied, the average annual rainfall was 862.73 mm, with a period of highest concentration between October and March, and a period of drought between April and September (Fig. 2). These results corroborate those reported by Alves *et al.* (2005) who observed a period of higher rainfall in the Southeast region of Brazil, occurring normally between October and March, with approximately 80% of the annual total. At the state level, Uliana *et al.* (2013) identified two distinct periods for Espírito Santo: the first between October and April, which concentrates a large part of the precipitation, and the second between May and September, with a marked decrease in rainfall.

Table 2 shows the descriptive statistics of the weather data collected in the town of Nova Venécia and used in the ET_o calculation. It shows that the dry and rainy periods are well defined with regular temperature and air humidity and with low variation, while data on wind speed and global solar radiation show high variation, similar to what was observed by Gurski *et al.* (2016) in Curitiba, Paraná, Brazil.

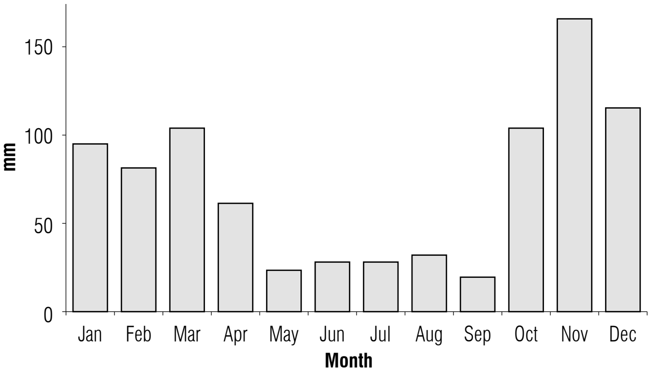

FIGURE 2. Monthly average rainfall in the municipality of Nova Venécia, Espírito Santo, Brazil, between 2008 and 2019.

TABLE 2. Average, standard deviation (SD) and coefficient of variation (CV%) of the meteorological data of the dry and rainy period used in the estimation of ET_0 in the municipality of Nova Venécia, Espírito Santo, Brazil, between 2008 and 2019.

Climatic variable	Dry season			Rainy season		
	Average	SD	CV	Average	SD	CV
Rg	15.04	5.73	38.11	19.74	6.15	31.13
Tx	29.22	2.90	9.93	32.02	3.30	10.40
Tn	17.99	2.14	11.87	20.97	1.48	7.05
Tm	23.60	2.07	8.77	26.50	2.06	7.78
To	15.73	1.78	11.31	16.97	1.82	10.73
URx	93.37	3.45	3.70	93.34	2.60	2.79
URn	45.83	4.18	9.12	45.32	5.31	11.71
URm	69.60	5.77	8.30	69.33	6.90	9.95
U_2	2.00	0.66	32.91	2.18	0.67	30.73

Rg - global solar radiation; Tx - maximum air temperature; Tn - minimum air temperature; Tm - average air temperature; To - average dew point temperature; URx - maximum relative humidity; URn - minimum relative humidity; URm - average relative humidity; U_2 - wind speed at 2 m above ground level.

Oliveira *et al.* (2017), studying the influence of meteorological elements on the reference evapotranspiration estimated by FAO-56 PM, observed that variations greater than 10% cause different behavior in the method estimates due to the high sensitivity of the equation, which was also observed by Lemos *et al.* (2010).

Table 3 shows the values of the original and calibrated coefficients during the dry period and rainy season in the study region. For accuracy purposes, the calibrated coefficients of the alternative methods were presented rounded to 4 decimal places.

TABLE 3. Values of the coefficients of the original and calibrated alternative methods for the municipality of Nova Venécia, Espírito Santo, Brazil, for the period from 2008 to 2015.

Coefficients	HS	Li	BL	Ho	Ca
		Original coefficients			
A	0.0023	500.0000	1.2100	0.5500	0.0100
B	17.8000	15.0000	0.2100	4.9300	
C		80.0000	2.3000	0.0620	
D				25.4000	
		Calibrated coefficients for the dry period			
A	0.00195	105.0919	1.8959	0.6466	0.0122
B	20.6636	8.9986	0.0276	5.7959	
C		46.3108	0.0000	0.0521	
D				29.8610	
		Calibrated coefficients for the rainy period			
A	0.0034	175.2910	2.0580	0.3956	0.0111
B	0.0000	13.2440	0.0428	3.5460	
C		53.0670	0.0000	0.1053	
D				18.2694	

Alternative methods to estimate evapotranspiration: HS - Hargreaves and Samani; Li - Linacre; BL - Benevides and Lopes; Ho - Hamon; Ca - Camargo.

Table 4 presents the average ET_o estimates, the root of normalized mean square error (RMSE), the Willmott's index of agreement (d), the Pearson correlation index (r), the confidence coefficients (c) and performance, obtained from the correlations between ET_o values by the FAO-56 PM method and those obtained by alternative methods during the dry and rainy periods. It shows that the average ET_o of the region is higher during the rainy season, with an average of 4.74 mm d^{-1}, while in the dry period the average is 3.39 mm d^{-1}. This is because global solar radiation and air temperature are the variables with the greatest influence on ET_o calculations (Ismael *et al.*, 2015) since the rainy period in Nova Venécia covers the spring and summer seasons and is characterized by high temperatures and high energy flow from solar radiation, while the dry period spans fall and winter seasons, which present milder conditions.

The calibrated equations presented better statistical parameters than the original equations (Tab. 4). In descending order, the best methods for estimating ET_o were: HS, BL, Li, Ho, and Ca.

The HS, BL and Li methods showed similar performance after calibration. In the rainy season (Tab. 4), the RMSE

TABLE 4. Evaluation and performance of alternative ET_0 estimation methods (mm d^{-1}), relative to standard method, FAO-56 PM before (original) and after the calibration (calibrated) of the parameters for the Municipality of Nova Venécia, Espírito Santo, Brazil, for the period from 2008 to 2015.

	Method	ET_0m	RMSE	r	d	c	Performance
				Rainy season			
Original	FAO-56 PM	4.74	-	-	-	-	-
	HS	4.73	0.75	0.85	0.88	0.75	Good
	BL	5.36	0.99	0.82	0.83	0.68	Good
	Li	5.00	0.84	0.81	0.86	0.70	Good
	Ho	4.00	1.30	0.68	0.57	0.40	Very poor
	Ca	4.31	1.21	0.66	0.52	0.34	Very poor
Calibrated	HS	4.77	0.72	0.85	0.90	0.77	Very good
	BL	4.73	0.73	0.84	0.91	0.76	Very good
	Li	4.73	0.76	0.84	0.90	0.76	Very good
	Ho	4.73	0.96	0.70	0.81	0.57	Tolerable
	Ca	4.78	1.11	0.66	0.59	0.39	Very poor
				Dry season			
Original	FAO-56 PM	3.39	-	-	-	-	-
	HS	3.25	0.65	0.72	0.83	0.60	Tolerable
	BL	4.37	1.03	0.64	0.62	0.40	Poor
	Li	4.00	0.96	0.64	0.71	0.45	Poor
	Ho	2.65	1.07	0.58	0.52	0.30	Very poor
	Ca	2.78	0.97	0.61	0.60	0.37	Very poor
Calibrated	HS	3.39	0.63	0.74	0.85	0.63	Intermediate
	BL	3.38	0.66	0.73	0.83	0.61	Intermediate
	Li	3.38	0.68	0.74	0.84	0.62	Intermediate
	Ho	3.40	0.76	0.60	0.69	0.41	Poor
	Ca	3.39	0.75	0.61	0.74	0.45	Poor

Methods to estimate evapotranspiration: FAO-56 PM - Standard method 56 from FAO Penman-Monteith HS - Hargreaves and Samani; Li - Linacre; BL - Benevides and Lopes; Ho - Hamon; Ca - Camargo; ET_0m - average ETo estimates; RMSE - root of normalized mean square error; r - Pearson correlation index; d - Willmott's index of agreement; c - confidence coefficients.

decreased by 0.03, 0.26, and 0.08 mm d^{-1} and the "c" index increased by 2.66, 11.76, and 8.57% in the respective methods, reclassifying them as "very good".

In the dry period (Tab. 4), the RMSE decreased by 0.02, 0.37, and 0.28 mm d^{-1} and the "c" index increased by 1.61, 52.50, and 37.77%, respectively, reclassifying them as "intermediate". While these methods performed best among those studied, the average error remained elevated, between $0.72<\text{RMSE}<0.76$ mm d^{-1} during the rainy season and $0.63<\text{RMSE}<0.68$ mm d^{-1} during the dry period. Sales *et al.* (2018), when calibrating these methods for the city of São Mateus, Espírito Santo State, found RMSE values equal to 24.6, 21.6, and 23.7%, respectively, but with a "d" index greater than 0.80, which indicates discrepant errors in some data pairs and loss of efficiency at some time of the year. Therefore, the subdivision of the estimated period was recommended. By subdividing the data analysis period into dry and rainy seasons, it was possible to reduce the error; however a larger subdivision is preferred.

For the less precise methods Ho and Ca during the rainy season, RMSE decreased by 0.34 and 0.09 mm d^{-1} and the "c" index increased by 42.50 and 14.70%, reclassifying them as "tolerable" and "very poor", respectively, whereas in the dry period, RMSE decreased by 0.31 and 0.22 mm d^{-1} and the "c" index increased by 36.66 and 21.62%, reclassifying them as "poor". The high estimation error between $0.96<\text{RMSE}<1.11$ mm d^{-1} during the rainy season and $0.75<\text{RMSE}<0.76$ mm d^{-1} during the dry season demonstrates the inefficiency of the methods even after calibration.

According to Souza *et al.* (2019), as these methods only use the average air temperature as a variable in their equations, they have a certain dependency resulting in unsatisfactory performance, as observed in studies carried out in different regions of Brazil (Fanaya *et al.*, 2012; Bezerra *et al.*, 2014; Silva *et al.*, 2017).

Figure 3 shows the average monthly evapotranspiration estimated by alternative methods in their original (Fig. 3A) and calibrated (Fig. 3B) equations, compared to the FAO-56 PM. It shows graphically the effect of the RMSE decrease in the behavior of alternative methods over the periods of the year. It evidences the closeness of the calibrated equations to the FAO-56 PM, emphasizing an improvement in performance in the dry and rainy periods.

In addition, all methods presented index (d), (r), and RMSE values close to the series used to calibrate them, with an

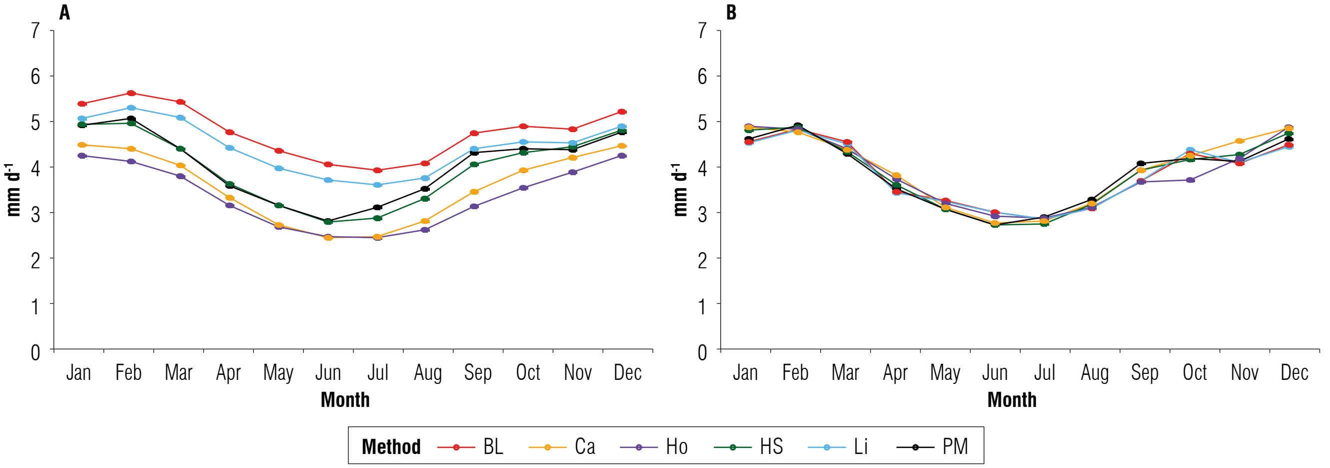

FIGURE 3. Average monthly evapotranspiration estimated by the FAO-56 PM method and by alternative methods with the original (A) and calibrated (B) equations in Nova Venécia, Espírito Santo, Brazil, between 2008 and 2015.

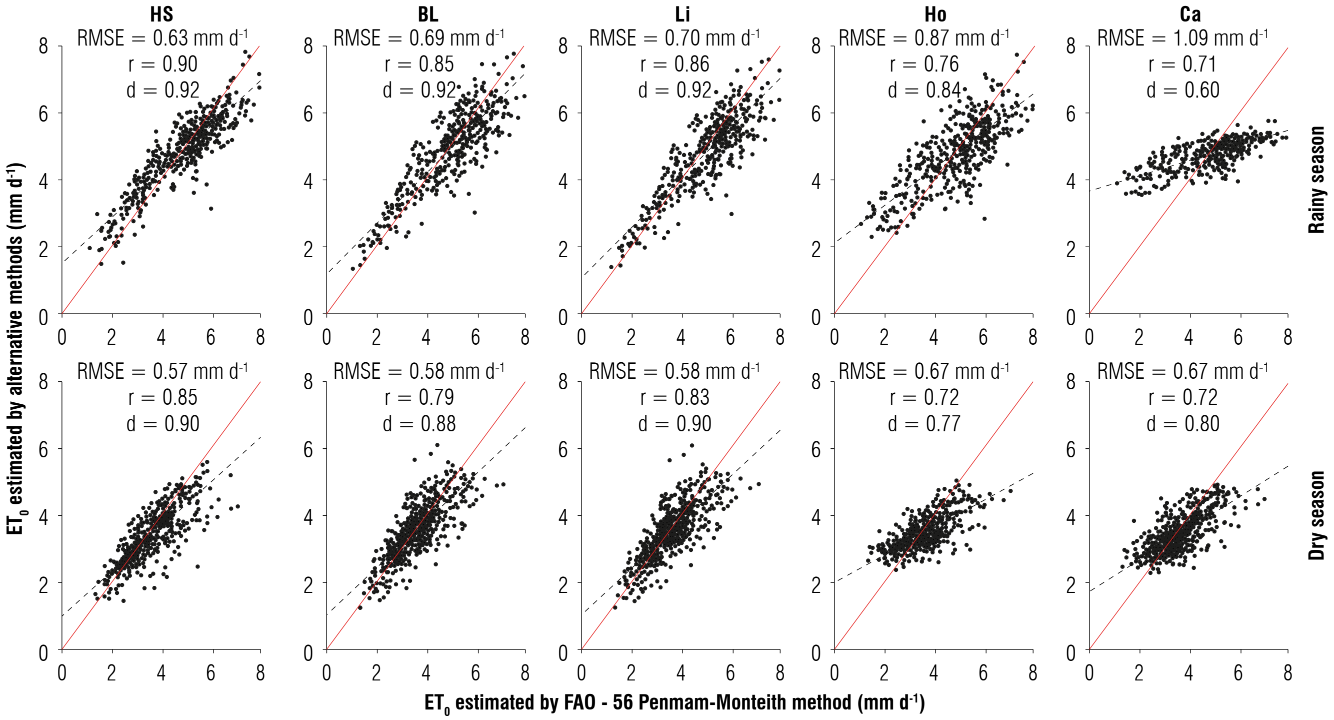

FIGURE 4. Correlations between daily ET_0, estimated by the FAO-56 PM and alternative models (HS, Li, BL, Ho, Ca) for the dry and rainy period of the 2016 to 2019 data series (independent data not used for calibration) in Nova Venécia, Espírito Santo, Brazil. Methods to estimate evapotranspiration: FAO-56 PM - Standard method 56 from FAO Penman-Monteith HS - Hargreaves and Samani; Li - Linacre; BL - Benevides and Lopes; Ho - Hamon; Ca – Camargo. RMSE – root of normalized mean square error. Methods to estimate evapotranspiration: FAO-56 PM - Standard method 56 from FAO Penman-Monteith HS - Hargreaves and Samani; Li - Linacre; BL - Benevides and Lopes; Ho - Hamon; Ca – Camargo.

average variation of 2.19%, 5.12%, and 8.16%, respectively, in the rainy season and 7.27%, 13.57%, and 13.39%, respectively, in the dry season. This confirms the efficiency of the adjustments, making them reliable to use.

The regression analysis of the estimates performed by the HS, BL and Li methods showed dispersion closer to the 1:1 line than those performed by the Ho and Ca methods. This greater homogeneity of data can be verified graphically, by the decreased RMSE values and by the higher r and d indices, revealing the greater accuracy of ET_o estimation in Nova Venécia in both periods of the year.

Conclusions

The HS, BL and Li methods presented the best performances for the region in both the dry and rainy season; the HS method is most interesting because it only requires the use of equipment that measures the air temperature and can be used to replace the standard FAO-56 PM model for estimating irrigation needs in the region.

Alternative methods for estimating ETo, calibrated for the municipality of Nova Venécia in Espirito Santo, Brazil, have a strong potential for use in irrigation projects, since they help in determining the volume of water needed to supply the crop through the use of simple and inexpensive equipment. This, in turn, can help reduce water consumption in agriculture, promote the efficient use of natural resources, as well as enhance the economic exploitation of crops.

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Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

GF and ECO carried out the study planning; GF and MSG participated in data collection; GF, RAS and RAS carried out data analysis, production of figures and tables; MSG and EJAB worked on the first draft of the manuscript; RPP, ECO, MCTL participated in the correction and translation. All authors reviewed the final version of the manuscript.

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