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Reference evapotranspiration during rainy and dry seasons in Mossoró, RN, Brazil

Evapotranspiração de referência nos períodos chuvoso e seco em Mossoró-RN

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Highlights:
The studied methods presented a better performance in the rainy year.
The Hargreaves-Original method presented a good estimate for both studied years.
The Hargreaves-Samani method showed no viability for use in the region.

Abstract

Mossoró, RN, Brazil, is considered one of the fruit growing centers of the Northeast region. This municipality has a persistent water deficit, with the need to develop irrigated agriculture with efficient water use and rational management of irrigation. The objective of this study was to evaluate estimation methods of reference evapotranspiration (ETo) for different climate conditions of Mossoró, comparing them with the standard Penman-Monteith-FAO 56 method. A daily data series of two distinct years, a rainy (2011) and a dry year (2012), was used. The data were obtained from the weather station of the Federal Rural University of the Semi-Arid Region (UFERSA). An analysis was performed to identify methods that best fit those of Penman-Monteith-FAO 56, and for this, ten methods were evaluated using statistical indices. The Penman-Original, Radiation-Temperature, and Hargreaves-Original methods stood out and satisfactorily met ETo estimation for the rainy season, while the Jensen-Haise, Radiation-Temperature, and Hargreaves-Original methods achieved satisfactory performance for the dry season. The Hargreaves-Samani method did not demonstrate viability in the use of ETo estimation, as it was the worst method in both studied periods and is not recommended for irrigation management.
Key words: Agrometeorology. Irrigation management. Empirical methods.

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Resumo

O município de Mossoró-RN é considerado uns dos polos fruticultores da região Nordeste. O município apresenta constante déficit hídrico, sendo necessário o desenvolvimento da agricultura irrigada com o uso eficiente da água, sendo fundamental o manejo racional da irrigação. Este trabalho objetivou avaliar para as condições climáticas de Mossoró-RN, diferentes métodos de estimativa da evapotranspiração de referência (ETo), comparando-os com o método padrão de Penman-Monteith-FAO 56. Foi utilizada uma série de dados diários de dois anos distintos, um ano chuvoso (2011) e outro seco (2012). Os dados foram obtidos na estação meteorológica da Universidade Federal Rural do Semi-Árido (UFERSA). Foi realizada análise visando identificar os métodos que melhor se ajustam ao de Penman-Monteith-FAO 56, e para isto, foram avaliados 10 métodos mediante índices estatísticos. Destacaram-se os métodos de Penman-Original, Radiação-Temperatura e Hargreaves-Original, os quais atenderam satisfatoriamente a estimativa da ETo para o período chuvoso, enquanto que os métodos de Jensen-Haise, Radiação-Temperatura e Hargreaves-Original obtiveram desempenho satisfatório para o período seco. O método de Hargreaves-Samani não demonstrou viabilidade na utilização de estimativa da ETo, pois foi o pior método em ambos os períodos estudados, não sendo recomendado para o manejo da irrigação.

Palavras-chave: Agrometeorologia. Manejo da irrigação. Métodos empíricos.

Introduction

The state of Rio Grande do Norte has favorable edaphoclimatic conditions for the cultivation of fruit plants, and irrigation allows producing a great variety of fruits with high economic return. However, drought events have inhibited the expression of this potential, which makes irrigation an indispensable activity, but this resource should be saved due to the current water scarcity.

Estimation of water consumption by crops stands out as one of the important variables to elaborate an irrigation project when the rational water use and maximization of production are desired.

Irrigation management requires, in addition to appropriate methods and technology, specific studies of water consumption for each crop at different times, places, and stages of development. An alternative for the efficient management of irrigation systems is to estimate reference evapotranspiration (ETo) (Silva, Carvalho, Silva, Camargo, & Teodoro, 2011).

ETo is measured using relatively complex physical principles and techniques (Allen, Pereira, Howell, & Jensen, 2011), and the most accurate direct form for its estimation is soil water balance using lysimeters. However, due to limitations associated with the method, the use of physical-mathematical models has become a practical alternative for ETo estimation (Carvalho, Rocha, Bonomo, & Souza, 2015).

Among the various methods developed for estimating ETo using weather data, some of them may be inaccurate when the equation is not suitable for local conditions. Therefore, in an attempt to choose the best ETo estimation method for a given location, several studies comparing ETo estimation methods with the FAO-parameterized Penman-Monteith method have been performed for different regions as a way to verify the efficiency of methods, seeking the ETo estimation method that best represents the local conditions.

The correct ETo estimation is used as a basis for quantifying the actual water depth to be supplied to the soil during irrigation. Thus, estimating ETo accurately contributes to the rational use of natural water resources and reduces production costs (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2010).

This study aimed to evaluate different ETo estimation methods for the climate conditions of Mossoró, RN, Brazil, and compare them with the standard Penman-Monteith-FAO 56 method.

Material and Methods

This study was developed from meteorological data obtained through the weather station Jerônimo Rosado belonging to the Federal Rural University of the Semi-Arid Region (UFERSA), whose geographical coordinates are 5°12′49″ S and 37°19′43″ W, with an altitude of 18 m, in Mossoró in the state of Rio Grande do Norte.

According to the Köppen climate classification, the climate in the region is BSwh′, i.e., warm and dry, with a rainy season in the summer until the autumn (Carmo, Espínola, & Amorim, 1987).

The daily data used were mean, maximum, and minimum temperature (°C) and relative humidity (%), wind speed (m s^{-1}), and global radiation (MJ m^{-2} day^{-1}) for the period from January 1, 2011, to December 31, 2012. The year 2011 was considered rainy, with annual precipitation of 974.42 mm, while 2012 was considered dry, with annual precipitation of 199.41 mm. La Niña and El Niño occurred in 2011 and 2012, respectively. ETo calculations for all studied methods were performed using a spreadsheet.

Statistical analysis was performed to identify the methods that best fit that of Penman-Monteith-FAO 56, searching for the method that best represented local conditions with a simpler methodology for estimating ETo. Ten methods were selected for this study: Penman-Original (Penman, 1948), Makkink (Makkink, 1957), Turc (Turc, 1961), Jensen-Haise (Jensen & Haise, 1963), Garcia-Lopez (Garcia & Lopez, 1970), Priestley-Taylor (Priestley & Taylor, 1972), Hargreaves-Original (Hargreaves, 1974), Linacre (Linacre, 1977), Hargreaves-Samani (Hargreaves & Samani, 1985), Radiation-Temperature Oudin, Michel and Anctil (2005).

The evaluation of results of ETo estimation was performed for the daily period using regression analysis according to the linear model y = ax + b. The methodology adopted for the comparison of results was proposed by Allen, Jensen, Wright and Burman (1989) and is based on the standard error of the estimate (SEE), calculated by Eq. 1.

$$SEE = \left[\frac{\sum_{i=1}^{n}(Y_i - X_i)^2}{n}\right]^{1/2} \tag{1}$$

where SEE is the standard error of the estimate (mm d^{-1}), Y_i is the reference evapotranspiration estimated by the standard method (mm d^{-1}), X_i is the reference evapotranspiration obtained by the tested method (mm d^{-1}), and n is the number of observations.

The approximation of ETo values, estimated by the studied methods in relation to the values obtained from the standard method, was obtained by an index of agreement (d) (Willmott, Ackleson & Davis, 1985), whose values vary from zero (no agreement) to 1 (perfect agreement). The concordance index was obtained by Eq. 2. The model was validated by Pearson's correlation coefficient (r) (Eq. 3) and coefficient of confidence or performance (c) (Eq. 4).

$$d = 1 - \frac{\sum_{i=1}^{n}(Y_i - X_i)^2}{\sum_{i=1}^{n}\left[\left(|Y_i - \bar{x}|\right) + \left(|X_i - \bar{x}|\right)\right]^2} \tag{2}$$

$$r = \frac{\sum_{i=1}^{n}\left(|X_i - \bar{X}|\right)\left(|Y_i - \bar{Y}|\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}\ \sqrt{\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2}} \tag{3}$$

$$c = r \cdot d \tag{4}$$

where d is Willmott's index of agreement or adjustment, Y_i is the reference evapotranspiration estimated by the standard method (mm d^{-1}), X_i is the reference evapotranspiration obtained by the tested method (mm d^{-1}), X is the mean of reference evapotranspiration values obtained by the tested method (mm d^{-1}), n is the number of observations, r is the Pearson's correlation coefficient, Y is the mean of reference evapotranspiration values obtained by the standard method (mm d^{-1}), and c is the coefficient of confidence or performance.

The variables were analyzed using descriptive statistics. The following hypothesis was verified for each simple linear regression of reference evapotranspiration: Ho: there is no simple linear regression ($\beta = 0$) and H_1: there is simple linear regression ($\beta \neq 0$) between the variables studied using the Student's t-test, according to the equation at significance level of 1 and 5% probability.

$$t_{(test)} = \frac{\hat{b} - \beta}{s_{(\hat{b})}} \quad (5)$$

where $\hat{b}$ (regression or angular coefficient) is the estimator of the parameter β of the linear regression equation and $s_{(\hat{b})}$ is the standard deviation of $\hat{b}$.

The coefficient of confidence or performance (c) is classified according to Camargo and Sentelhas (1997) as excellent (c > 0.85), very good (0.76 < c < 0.85), good (0.66 < c < 0.75), median (0.61 < c < 0.65), poor (0.51 < c < 0.60), bad (0.41 < c < 0.50), and very bad (c < 0.40).

Results and Discussion

Rainy season

Figures 1A and 1B illustrate the monthly distribution of ETo by different estimation methods, as well as compared with the standard model Penman-Monteith-FAO 56 for the rainy season. ETo showed throughout the year different ranges of variation. The tested methods showed a high similarity of temporal distribution with the Penman-Monteith-FAO 56 method. For all models, ETo estimations were lower in the period of highest precipitation and coldest of the year (first semester), while the highest values were recorded from August to December, which refers to the period of higher temperatures and lower humidity in the region under study.

Table 1 shows the values of the statistical indices between methods compared to the standard method, referring to the rainy year and for Mossoró, RN. The results show that the Radiation-Temperature, Hargreaves-Original, and Penman-Original methods had the lowest SEE, with values of 0.543, 0.591, and 0.659 mm day^{-1}, respectively. On the other hand, Makkink, Garcia-Lopez and Jensen-Haise methods showed the highest SEE, with values of 1.403, 1.295, and 1.176 mm day^{-1}, respectively. Pearson's correlation coefficient (r) indicates the degree of correlation between the ETo estimation models tested in relation to the Penman-Monteith-FAO 56 method under local climate conditions. According to the correlation coefficient, all methods showed values around 0.815 to 0.933, indicating they present a very strong correlation when compared to the FAO method.

Among the evaluated models, the Radiation-Temperature, Penman-Original, and Hargreaves-Original methods presented the best adjustments, being classified as very good by the coefficient of performance or confidence c, with values of 0.840, 0.830, and 0.804, respectively. It evidenced that these methods can be used in the proposed form to estimate the ETo under the conditions of Mossoró, RN, while the Hargreaves-Samani method presented the worst performance, with index c = 0.301, being classified as very bad.

Lucena, Silva, Ribeiro, Simeão and Lucena (2016) evaluated ETo estimations for the municipality of Bom Jesus, PI, and found that the Hargreaves-Samani method had a poor performance in the rainy season (c = 0.575). The Hargreaves-Samani method is recommended for the semi-arid condition and hence its performance presents a reduction in the accuracy of evapotranspiration estimation during rainy months (Alencar, Delgado, Almeida, & Wanderley, 2011).

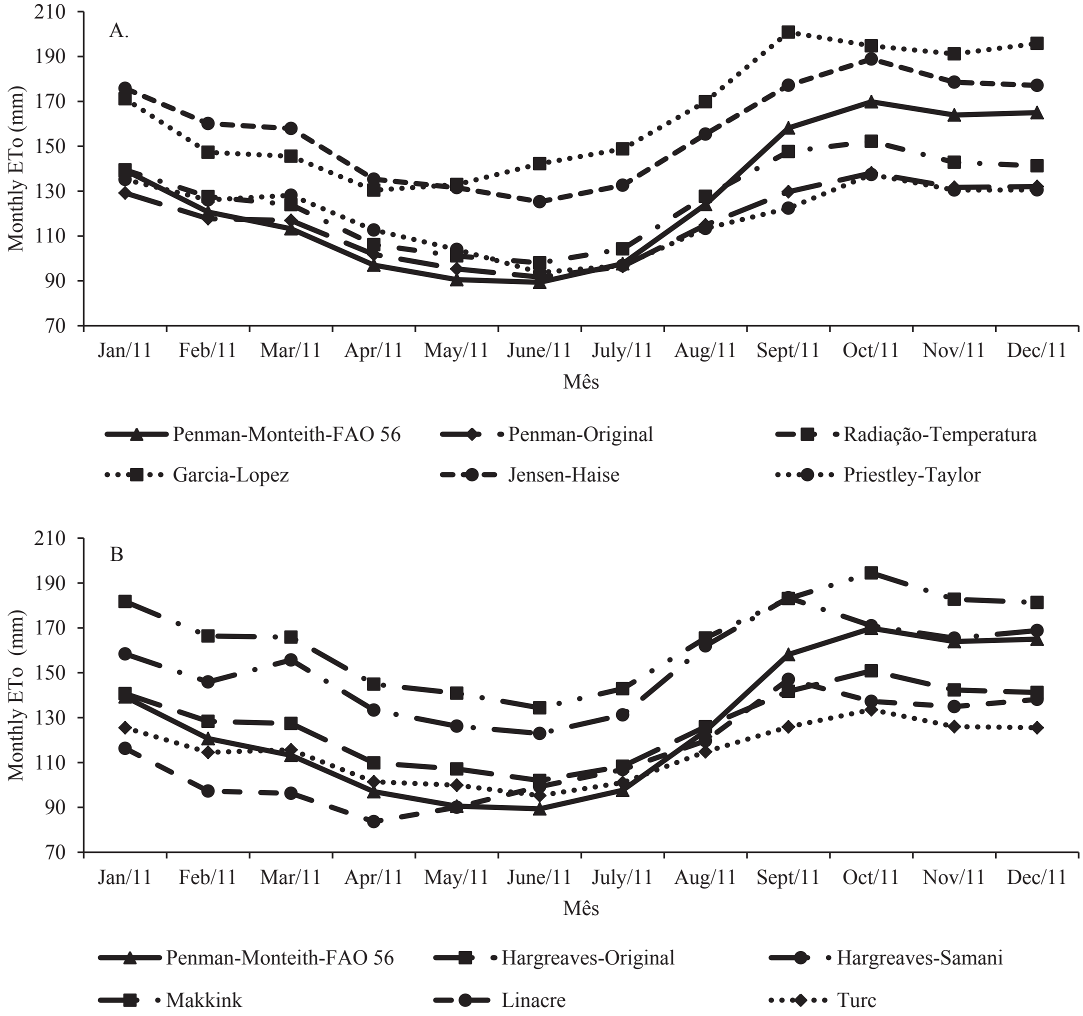


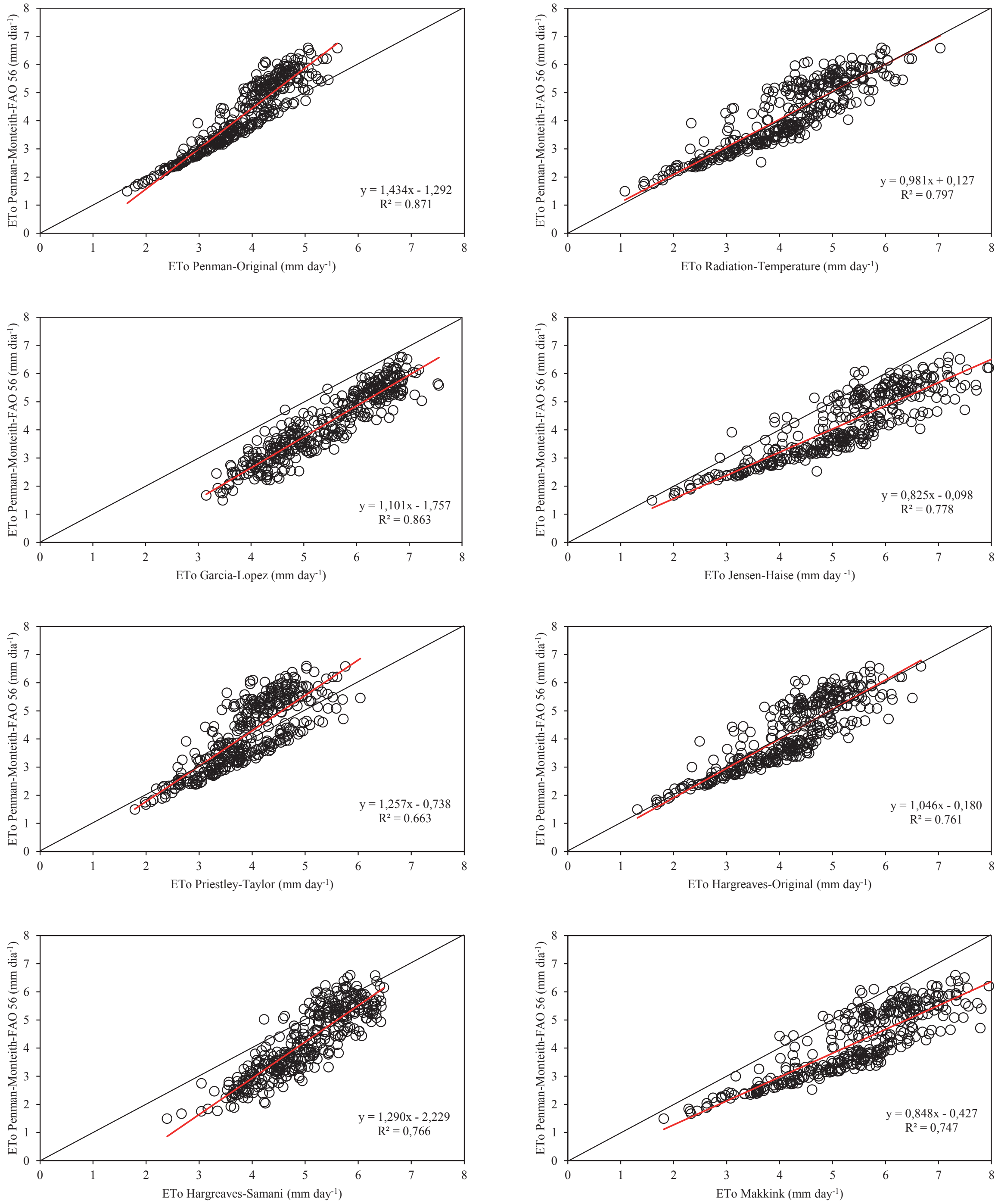
Figure 1. Monthly distribution of ETo estimated through indirect methods during a rainy year in Mossoró, RN, Brazil.

Table 1
Statistical indicators of the comparison between different methods of ETo estimation with the standard method Penman-Monteith-FAO 56 on a daily scale for the rainy season in Mossoró, RN, Brazil

Method	SEE (mm dia^{-1})	R^2	r	d	C	Performance
Penman-Original	0.659	0.871	0.933	0.890	0.830	Very good
Makkink	1.403	0.746	0.864	0.741	0.641	Median
Turc	0.778	0.740	0.860	0.756	0.650	Median
Jensen-Haise	1.176	0.778	0.882	0.808	0.713	Good
Garcia-Lopez	1.295	0.863	0.929	0.743	0.691	Good
Priestley-Taylor	0.772	0.663	0.815	0.839	0.683	Good
Hargreaves-Original	0.591	0.761	0.872	0.922	0.804	Very good
Linacre	0.786	0.750	0.866	0.773	0.670	Good
Hargreaves-Samani	1.052	0.702	0.838	0.359	0.301	Very bad
Radiation-Temperature	0.543	0.797	0.893	0.941	0.840	Very good

Standard error of the estimate (SEE), coefficient of determination (R^2), Pearson's correlation (r), Willmott agreement (d), and coefficient of confidence and performance (c).

Figure 2 shows linear regressions between daily reference evapotranspiration values estimated by the methods analyzed in this study as a function of the standard method Penman-Monteith-FAO 56 for the rainy season. The Penman-Original method presented the highest coefficient of determination (r^2 = 0.871). The lowest coefficient was presented by the Priestley-Taylor method (r^2 = 0.663). The Penman-Original method presented values closest to those estimated by the Penman-Monteith-FAO 56 method, with a good adjustment to the standard method in ETo determination for Mossoró, RN, during the rainy season, which could have been presumed since Penman-Monteith-FAO 56 is a method adjusted from the Penman-Original method.



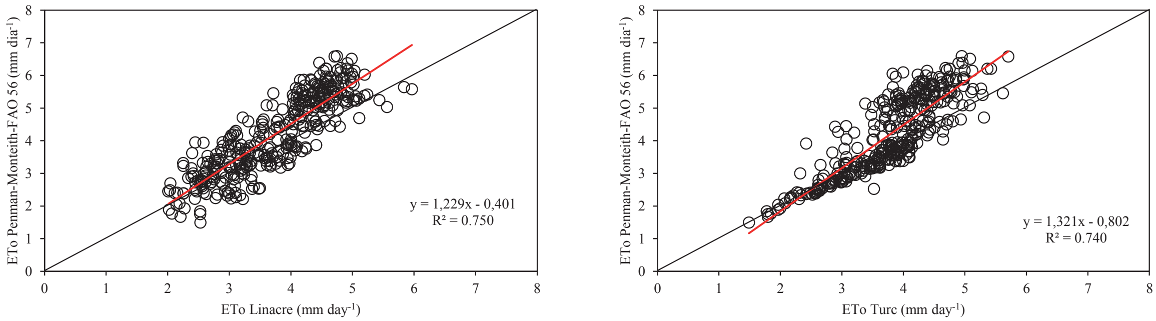


Figure 2. Linear regression between the daily values of reference evapotranspiration (ETo) estimated by different methods and compared to the standard method Penman-Monteith-FAO 56 during the rainy year of 2011 in Mossoró, RN, Brazil.

Dry season

The monthly distribution of ETo models compared to the standard model Penman-Monteith-FAO 56 for the dry season is shown in Figures 3A and 3B. During the dry year, ETo also showed similarity in the trend of curves for all models. ETo estimations were more constant when compared to the rainy year due to the small annual variability of climate input parameters. A slight decrease was also observed in values only in the coldest period of the year, i.e., from May to July.

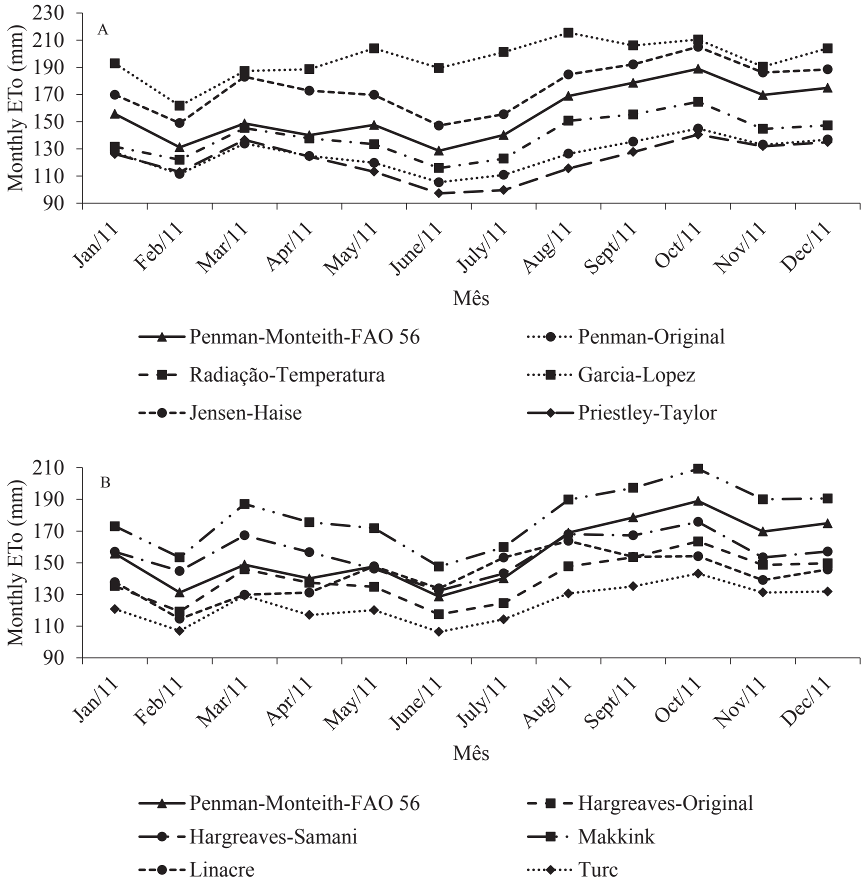


Figure 3. Monthly distribution of ETo estimated through indirect methods during a dry year in Mossoró, RN, Brazil.

The results of the statistical indicators of performance analysis of the ETo estimation methods for the dry season in Mossoró, RN, are shown in Table 2. The Hargreaves-Samani, Radiation-Temperature, and Hargreaves-Original methods presented the lowest SEE, with values of 0.665, 0.782, and 0.792 mm day^{-1}, respectively. On the other hand, Garcia-Lopez, Priestley-Taylor and Turc methods presented the highest SEE, with values of 1.456, 1.304, and 1.211 mm day^{-1}, respectively.

Table 2
Statistical indicators of the comparison between different estimation methods of ETo with the standard method Penman-Monteith-FAO 56 on a daily scale for the dry season in Mossoró, RN, Brazil

Method	SEE (mm dia^{-1})	R^2	r	d	c	Performance
Penman-Original	1.075	0.768	0.876	0.611	0.535	Poor
Makkink	1.059	0.721	0.849	0.758	0.644	Median
Turc	1.211	0.723	0.850	0.577	0.491	Bad
Jensen-Haise	0.938	0.743	0.862	0.796	0.686	Good
Garcia-Lopez	1.456	0.582	0.763	0.538	0.410	Bad
Priestley-Taylor	1.304	0.538	0.734	0.534	0.392	Very bad
Hargreaves-Original	0.792	0.732	0.855	0.792	0.678	Good
Linacre	0.818	0.458	0.676	0.705	0.477	Bad
Hargreaves-Samani	0.665	0.536	0.732	0.775	0.567	Poor
Radiation-Temperature	0.782	0.852	0.852	0.810	0.690	Good

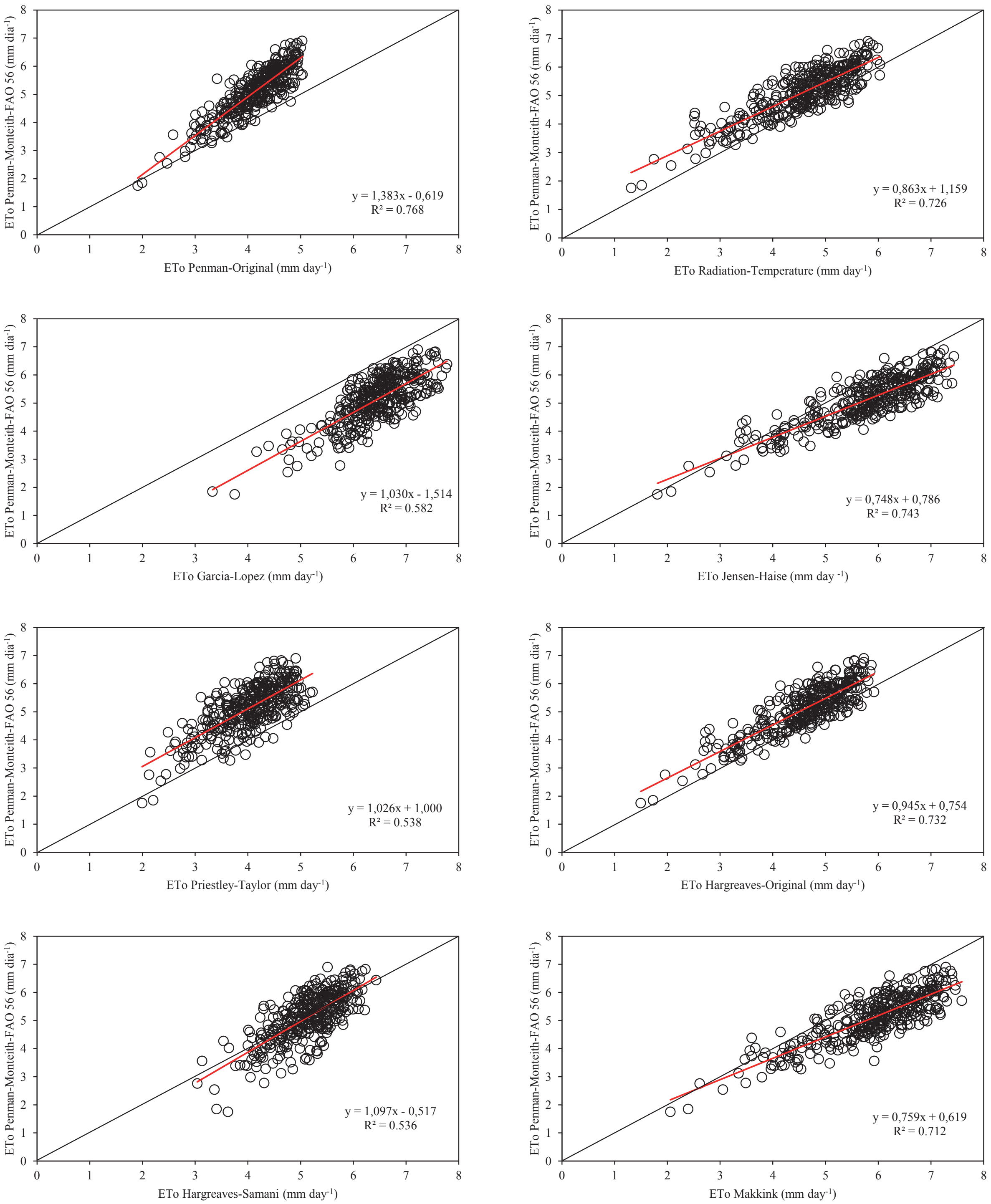
Standard error of the estimate (SEE), coefficient of determination (R^2), Pearson's correlation (r), Willmott agreement (d), and coefficient of confidence and performance (c).

According to Pearson's correlation coefficient (r), the studied methods presented values around 0.676 to 0.876, indicating that the methods presented a positive moderate to very strong correlation with the FAO method.

Among the evaluated methods, Radiation-Temperature, Jensen-Haise, and Hargreaves-Original showed the best adjustments, being classified as good by the coefficient of confidence (c), with values of 0.690, 0.686, and 0.678, respectively. Moreover, these models had high values of coefficients of determination (r^2) above 0.7 and Pearson's correlation (r) above 0.80, indicating a very strong positive correlation with the standard method. However, the Priestley-Taylor method was classified as very bad. It is important to highlight that no model had a very good performance index in this dry year.

Figure 4 shows the linear regressions between daily ETo values estimated by the methods as a function of the Penman-Monteith-FAO 56 method for the dry season. The best results of r^2 were found for the Penman-Original method, with a value of 0.768, although its performance was poor for the dry year. The Jensen-Haise method also showed a strong correlation with the Penman-Monteith-FAO 56 method, with an r^2 equal to 0.743. Its good performance in both years allows it to stand out among the other tested models. Gonçalves, Feitosa, Carvalho, Gomes and Valnir (2009) conducted studies in Sobral, CE, and also found a performance classified as good for the Jensen-Haise method, with confidence and performance indices (c) of 0.69, correlation coefficient (r) of 0.76, and standard error of the estimate (SEE) of 0.97 mm day^{-1}.

In the region of Serra da Mantiqueira, MG, Pereira, Yanage, Mello, Silva and Silva (2009) found the same very bad performance for the Priestley-Taylor method, which showed a significant reduction in the statistical indicators in the dry season when compared to those obtained for the rainy season. According to the authors, the variability in the performance of the Priestley-Taylor equation for rainy and dry seasons can be explained by the effect of local precipitation seasonality.



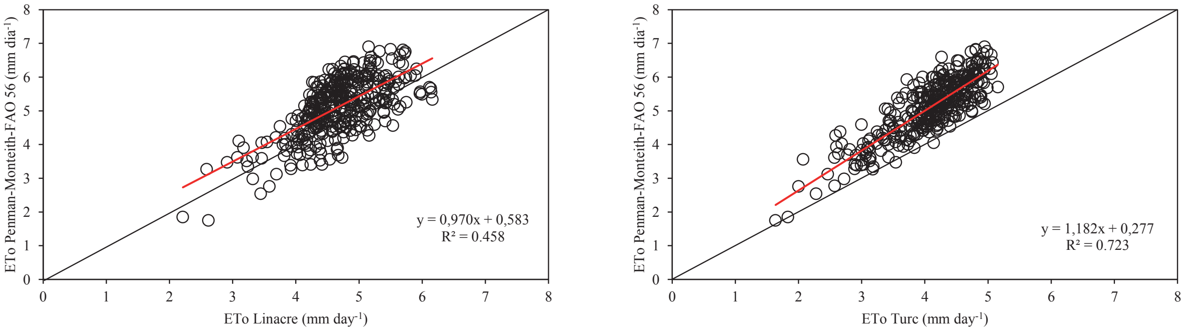


Figure 4. Linear regression between the daily values of reference evapotranspiration (ETo) estimated by different methods and compared to the standard method Penman-Monteith-FAO 56 during the dry year of 2012 in Mossoró, RN, Brazil.

In both periods, the Hargreaves-Samani method had the worst performance, not being recommended to calculate ETo estimation for the studied site. The Garcia-Lopez and Linacre methods presented performance considered as good for the rainy season and bad for the dry season. The Makkink method presented a median performance for both periods.

Conclusions

Among the methods evaluated for the region of Mossoró, RN, the best performances were obtained in the rainy year, ranging from median to very good, with the Penman-Original, Radiation-Temperature, and Hargreaves-Original methods standing out. The exception was observed for the Hargreaves-Samani method, with a very bad performance.

For the dry year, the performance of methods worsened from poor to good, especially the Jensen-Haise, Radiation-Temperature, and Hargreaves-Original methods, which presented a good performance.

The Hargreaves-Samani method presented no viability when using its equation to estimate reference evapotranspiration in both years (rainy and dry) in Mossoró, RN, as it stood out as the worst method in both studied seasons, and is not recommended for irrigation management in the municipality.

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