Edição especial – VI Winotec

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

EVAPOTRANSPIRAÇÃO DE REFERÊNCIA PARA A REGIÃO DO CARIRI, CE: CALIBRAÇÃO E VALIDAÇÃO DE MODELOS ALTERNATIVOS

ANA ALICE CARDOSO CARNEIRO[1]; ANA CÉLIA MAIA MEIRELES[2]; CARLOS WAGNER OLIVEIRA[2]; ANTÔNIA RAQUEL DE MORAIS ALCÂNTARA[1]; EVERTON ALENCAR PATRICIO[1] E JOSÉ BANDEIRA BRASIL[3]

[1] Centro de Ciências Agrárias e da Biodiversidade (CCAB), Universidade Federal do Cariri (UFCA), Rua Ícaro de Sousa Moreira, n.126, Muriti, CEP: 63130-025, Crato, Ceará, Brasil, ana.carneriro@aluno.ufca.edu.br, https://orcid.org/0009-0008-0964-9873, everton.alencar@aluno.ufca.edu.br, https://orcid.org/0009-0001-8625-9739, raquel.morais@aluno.ufca.edu.br, https://orcid.org/0009-0007-1991-8785
[2] Centro de Ciências Agrárias e da Biodiversidade (CCAB), Universidade Federal do Cariri (UFCA), Rua Ícaro de Sousa Moreira, n.126, Muriti, CEP: 63130-025, Crato, Ceará, Brasil. carlos.oliveira@ufca.edu.br, https://orcid.org/0000-0003-1013-297, ana.meireles@ufca.edu.br, https://orcid.or/ 0000-0002-8860-2043
[3] Pós-Graduação em Desenvolvimento Regional Sustentável (PRODER), Universidade Federal do Cariri (UFCA), Rua Ícaro de Sousa Moreira, n.126, Muriti, CEP: 63130-02, Crato, Ceará, Brasil, josebbrasil@gmail.com, https://orcid.org/0000-0003-4335-7838

1 RESUMO

A evapotranspiração de referência (ETo) é uma variável meteorológica fundamental para planejamento hidrológico e agroclimático de uma região. Assim, esse trabalho teve por objetivo calibrar e validar modelos alternativos para o cálculo da evapotranspiração de referência na região do Cariri cearense. Para tanto, foi utilizado um período de 3 anos (2021 a 2023), sendo dois anos para calibração e um ano para validação dos coeficientes obtidos. O método da FAO (Penman-Monteith) foi usado como padrão de comparação para os métodos: Hargreaves e Samani, Priestley e Taylor, Jensen-Haise e Blaney-Criddle. O desempenho dos métodos foi analisado por meio de indicadores estatísticos, sendo estes: coeficiente de determinação, erro médio, raiz quadrara do erro quadrado médio, coeficiente de correlação de Pearson, índice de exatidão de Willmont e o índice de exatidão descrito por Camargo e Sentelhas. A calibração dos modelos alternativos de estimativa da ETo para a região do cariri cearense possibilitou medidas mais precisas. Os modelos ajustados de Jensen-Haise e Preiestley e Taylor apresentaram estimativas mais precisas e exatas, podendo ser utilizados, quando necessário, em substituição ao modelo da FAO Penman Montheith. Os métodos de Hargreaves e Samani e Blaney-Criddle foram menos precisos na estimativa de ETo.

Palavras-chave: demanda evapotranspiratória, índices estatísticos, ajuste linear.

CARNEIRO, A. A. C.; MEIRELES, A. C. M.; OLIVEIRA, C.W.; ALCÂNTARA, A. R. M.; PATRICIO, E. A.; BRASIL, J. B.

REFERENCE EVAPOTRANSPIRATION FOR THE CARIRI REGION, CE: CALIBRATION AND VALIDATION OF ALTERNATIVE MODELS

Recebido em 03/12/2024 e aprovado para publicação em 12/12/2024
DOI: http://dx.doi.org/10.15809/irriga.2024v29p149-154

2 ABSTRACT

Reference evapotranspiration (ETo) is a fundamental meteorological variable for hydrological and agroclimatic planning in a region. Therefore, this work aimed to calibrate and validate alternative models for calculating reference evapotranspiration in the Cariri region of Ceará. To this end, a period of 3 years was used (2021--2023), with two years for calibration and one year for validation of the obtained coefficients. The FAO method (Penman–Monteith) was used as a comparison standard for the methods of Hargreaves and Samani, Priestley and Taylor, Jensen–Haise and Blaney–Criddle. The performance of the methods was analyzed via statistical indicators, namely, the coefficient of determination, mean error, square root of the mean square error, Pearson's correlation coefficient, Willmont's accuracy index and the accuracy index described by Camargo and Sentelhas. The calibration of alternative ETo estimation models for the Cariri region of Ceará allowed more precise measurements. The adjusted Jensen–Haise and Preiestley and Taylor models presented more precise and accurate estimates and can be used, when necessary, to replace the FAO Penman–Monteith model. The Hargreaves, Samani and Blaney–Criddle methods were less accurate in estimating ETo.

Keywords: evapotranspiration demand, statistical indices, linear adjustment.

3 INTRODUCTION

The rapid growth of the world population has increased the need to optimize food production systems as well as rationalize available natural resources. Irrigation plays an important role in reducing losses and maximizing crop productivity, ensuring the security of agricultural production (Menezes *et al*., 2024). Therefore, water management practices for irrigated crops require that crop water needs and the volume of irrigation water be accurately estimated, which, in turn, requires precise knowledge of crop evapotranspiration (Paredes *et al*., 2020). Reference evapotranspiration (ETo) is one of the main factors that interferes with the water depth available for irrigation in arid and semiarid regions, as ETo presents great spatial–temporal variability in precipitation; therefore, a correct determination of ETo is extremely important for better planning water resources.

ETo estimation is essential for irrigation management and for monitoring the hydrological cycle at the river basin level. However, the availability of climate data, which are sometimes limited, restricts the application of the FAO standard model (Penman–Monteith), which requires the use of alternative models that are easy to apply. The Penman–Monteith method (FAO) is considered the most appropriate method internationally because it uses several meteorological parameters and has a high level of accuracy. However, this factor limits the ability to obtain all the parameters used in the equation (Carvalho *et al*., 2011). Given the above, the objective was to calibrate and validate alternative models for estimating ETo for the Cariri region, the CE.

4 MATERIALS AND METHODS

The study was conducted at the Center for Agricultural and Biodiversity Sciences (CCAB), Campus of the Federal University of Cariri, located in the municipality of Crato, CE. The region is located in the subbasin of the Salgado River basin in the Cariri region of Ceará and has a Köppen classification of tropical climate, Aw. The study area has humid climate characteristics, with well-defined rainy and dry seasons and annual temperatures ranging from 24 °C to 27 °C. The municipality of Crato has a particular climate because it is located at the base of the Araripe National Forest (FLONA) in the extreme southern part of the state. These characteristics cause temperatures to be relatively lower in winter despite the high temperatures in the dry period of the year.

The data used in the research were obtained through an automatic meteorological station, model HOBO RX3000, installed according to the following geographic coordinates: 7°14' S and 39°22' W, with an altitude of 425 m above sea level. The data series used corresponded to the period from 2021--2023, of which the years 2021 and 2022 were used to calibrate the parameters of the alternative models, and the data for the year 2023 were used to validate the calibration of the models. The meteorological variables used were air temperature (average, minimum and maximum, in °C), solar radiation (MJ m $^{-2}$ day $^{-1}$), wind speed (ms $^{-1}$), precipitation (mm) and relative humidity (average, minimum and maximum, in %). The equations used to calculate ETo are described in Table 1.

Table 1. Methods for estimating reference evapotranspiration (ETo) and their respective equations

Métodos	**Equações de estimativa da ETo**	**Variáveis de Entrada**
Penman-Monteith (PM), Allen et al. (1998)	$ETo = \dfrac{0,408\Delta(Rn - G) + \gamma + \dfrac{900}{(T+273)} U_2 (ea - es)}{\Delta + \gamma + (1 + 0,34 U_2)}$	Tmed, Rg, UR, V
Hargreaves e Samani (HS), Pereira et al. (1997)	$ETo = A\, R_a (Tmed + 0,17)(T\,max - T\,min)^c$	Tmax, Tmed, Tmin
Priestley e Taylor (PT), (1972)	$ETo = \mathrm{A}\left(\dfrac{\Delta}{\Delta + \gamma}\right)\left(\dfrac{Rn - G}{\lambda}\right)$	Tmed, Rg
Jensen-Haise (JH), (1963)	$ETo = Rs\ (\mathrm{A}\ \mathrm{x}\ Tmed + B)$	Tmed, Rg
Blaney-Criddle (BC), (1977)	$ETo = a + bp(0,457xTmed + 8,13)$	Tmed

Source: Authors (2025)

ETo: reference evapotranspiration (mm d $^{-1}$); Tmax, Tmin, and Tmed represent the maximum, minimum and average temperatures, respectively (°C); Rg: global solar radiation (MJ m $^{-2}$ d $^{-1}$); Rn: net radiation (MJ m $^{-2}$ d $^{-1}$); V: wind speed at 2 m height (ms $^{-1}$); RH: relative humidity (%); Δ: tangent to the water vapor saturation pressure curve (kPa °C $^{-1}$); γ: psychrometric constant (0.0662 kPa °C $^{-1}$); ea: air vapor pressure (kPa °C $^{-1}$); es: saturation pressure at surface temperature (kPa °C $^{-1}$); Ra: extraterrestrial radiation (mm d $^{-1}$); G: soil heat flux density (MJ m $^{-2}$ d $^{-1}$), considered zero to estimate daily ETo.

The calibration of the empirical coefficients A, B and C of the alternative methods in relation to the standard method was performed according to the methodology described by Wraith and Or (1998) via Microsoft Excel® by adjusting a nonlinear equation via the SOLVER application. The calibration validation was performed via statistical indicators such as the coefficient of determination (R^2); the mean error (ME) and the root mean square error (RMSE), given by equations 1 and 2; the Pearson correlation coefficient (r); the Willmont accuracy index (d), described by equation 3; and the performance or agreement index (c), described by Camargo and Sentelhas (1997) , given by equation 4.

$$EM = \frac{1}{n}\sum_{i=1}^{n}\left(O_i - P_i\right) \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(O_i - P_i\right)} \quad (2)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{\sum_{i=1}^{n}\left(|P_i - \bar{y}| + |O_i - \bar{y}|\right)^2}\right] \quad (3)$$

$$C = r * d \quad (4)$$

where n = the number of observations, O_i = the value estimated by the standard model; P_i = the value estimated by the alternative models; $\bar{y}$ = the mean of the values estimated by the standard model; r = the correlation coefficient; and d = the Willmont index. The Camargo and Sentelhas concordance index (c) can be interpreted according to Table 4.

5 RESULTS AND DISCUSSION

Table 2 lists the original coefficients of the equations used in this study, as well as the coefficients after the calibration process. All the coefficients presented modifications in relation to their original values. This change in value is equivalent to the adjustment for a better estimate of the ETo values.

Table 2. Original and calibrated coefficients of alternative ETo models for the Cariri region, CE.

Methods	Coefficients			
	Originals		Adjusted	
	A	B	A	B
Hargreaves and Samani (HS)	0.0023	0.5	0.001	0.678
Jensen- Haise (JH)	0.025	0.08	0.015	0.146
Priestley and Taylor (PT)	1.26	-	1.182	-
Blaney-Criddle (BC)	0.457	8.13	0.479	9.337

Source: Authors (2025)

After calibration, the models presented good estimates of ETo. The alternative models of JH and PT presented the best results, with excellent performance, *with r values* of 0.960 and 0.899, respectively. Both models obtained *d indices* of 0.98 and 0.97, with error measures representing an overestimation in relation to the standard PM-FAO model, ranging from 0.24 to 0.29 mm day $^{-1}$ (RMSE). With respect to the EM, the JH model tended to overestimate the PM-FAO method by 0.12 mm day $^{-1}$, whereas the PT model tended to underestimate it. According to Celestin *et al.* (2020), methods based on solar radiation tend to underestimate the PM model. The results discussed here are described in Table 1.

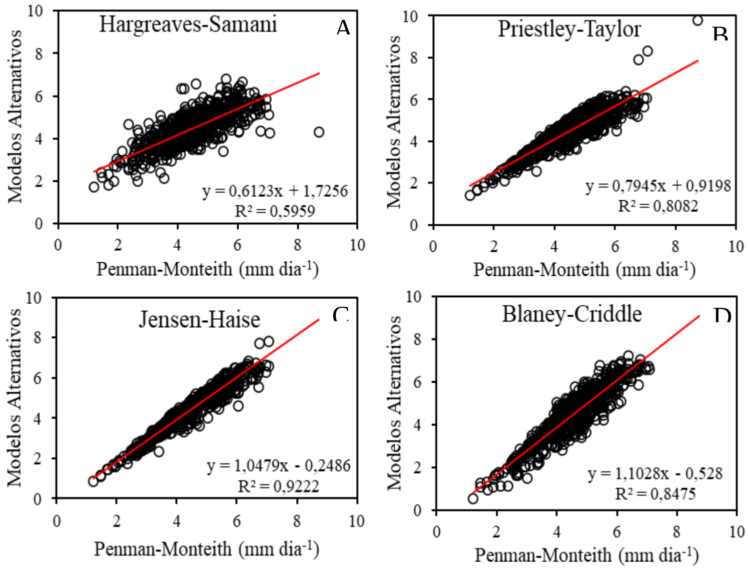
In contrast, the HS and BC methods deviated the most from the standard method, with performances classified as average and very good, respectively, where HS presented *r values of* 0.772 and BC of 0.921. These models achieved *d indices* of 0.817 and 0.932, and their error measures represented underestimations compared with those of the standard PM-FAO method, with variations of 0.876 and 0.534 mm day $^{-1}$ (RMSE). Because these methods use only air temperature as an independent variable, they have a lower adjustment capacity and are considered less efficient (Sales *et al*., 2018). These results can be seen in Table 3.

Table 3. Criteria for interpreting the confidence coefficient

Methods	Indices				Error (mm d $^{-1}$)	
	r	d	c	Performance	RMSE	IN
Hargreaves and Samani (HS)	0.772	0.817	0.631	Median	0.876	-0.602
Jensen- Haise (JH)	0.960	0.986	0.947	Excellent	0.242	0.115
Priestley and Taylor (PT)	0.899	0.979	0.880	Excellent	0.299	-0.001
Blaney-Criddle (BC)	0.921	0.932	0.858	Very good	0.534	-0.294

Source: Authors (2025)

Figure 1. Linear regression between daily reference evapotranspiration (ETo) values estimated via the standard FAO Penman method Monteith in relation to the adjusted models of Hargreaves and Samani (A), Priestley and Taylor (B), Jensen–Haise (C), and Blaney–Criddle (D).



Source: Authors (2025)

According to the regression analysis, as previously observed, the JH and PT models presented good accuracy in estimating ETo, with ^{R2} values of 0.92 and 0.81, respectively, for both methods (Figure 1). Notably, for the JH and PT models, the distribution of points around the trend line presented low variation compared to the HS and BC models, which, on the other hand, presented lower performance in estimating ETo, with R^2 values of 0.59 and 0.84, respectively, and it is possible to see greater variations in the distribution of their points around the trend line.

6 CONCLUSIONS

The calibration process of alternative ETo estimation models enabled more precise measurements for the Cariri region of Ceará. The adjusted Jensen–Haise and Preiestley and Taylor models presented more precise and accurate estimates and can be used, when necessary, to replace the FAO Penman model. Montheith . The Hargreaves, Samani and Blaney-Criddle methods were less accurate in estimating ETo because they used only temperature as an independent variable.

7 ACKNOWLEDGMENTS

The authors would like to thank the Center for Agricultural Sciences and Biodiversity (CCAB) of the Federal University of Cariri (UFCA) for the logistics needed to carry out the work; the PETagronomy tutored teaching group for funding the research; the statistics, modeling and geoprocessing laboratory group for technical support; and the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) for its financial support to the postdoctoral fellows participating and supervising this research and to the PROJECT: Notice No. 162022, PDPG – Strategic Postdoctoral Studies.

8 REFERENCES

CAMARGO, AP; SENTELHAS, PC Performance evaluation of different methods for estimating potential evapotranspiration in the State of São Paulo, Brazil. **Brazilian Journal of Agrometeorology** , Serra Talhada, v. 5, n. 1, p. 89-97, 1997.

CARVALHO, LGD; RIOS, GFA; MIRANDA, WL; CASTRO NETO, P. Reference evapotranspiration: a current approach of different estimation methods. **Tropical Agricultural Research** , Goiânia, v. 41, n. 1, p. 456-465, 2011.

CELESTIN, S.; IQ, F.; LI, R.; YU, T.; CHENG, W. Evaluation of 32 simple equations against the Penman – Monteith method to estimate the reference evapotranspiration in the Hexi corridor , Northwest China. **Water** , Basel, vol. 12, no. 10, article 2772, p. 1-22, 2020.

MENEZES, SM; SILVA, GF; SILVA, MM; MORAIS, JEF; VASCONCELOS, MC; SOUZA, CS; ROLIM, MM Pulsed drip irrigation reduces sugarcane water consumption and improves growth , productivity , sugar and ethanol yields . **BioEnergy Research** , New York, vol. 17, no. 3, p. 1413-1424, 2024.

PAREDES, P.; PEREIRA, LS; ALMOROX, J.; DAROUICH, H. Reference grass evapotranspiration with reduced data sets: Parameterization of the FAO Penman–Monteith temperature approach and the Hargeaves -Samani equation using local climatic variables. **Agricultural Water Management** , Amsterdam, v. 240, article 106210, p. 1-23, 2020.

SALES, RA; OLIVEIRA, EC; LIMA, MJA; GELCER, EM; SANTOS, RA; LIMA, CF Adjustment of the coefficients of the reference evapotranspiration estimation equations for São Mateus, ES. **Irrigation** , Botucatu, v. 23, n. 1, p. 154-167, 2018.

WRAITH, JM; OR, D. Nonlinear Parameter Estimation Using Spreadsheet Software. **Journal of Natural Resources and Life Sciences Education** , Madison, vol. 27, no. 1, p. 13-19, 1998.