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THORNTHWAITE AND MATHER SOIL WATER BALANCE MODEL ADAPTED FOR ESTIMATION OF REAL EVAPOTRANSPIRATION OF THE PASTURE

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Single Crop Coefficient

ABSTRACT

Determining the real water requirement for pastures is essential for the rational use of irrigation. The aim of this work was to assess the crop coefficient and performance of the Thornthwaite and Mather soil water balance (ThM) adapted to estimate the daily actual evapotranspiration (ET_a) of a pasture in relation to the Bowen ratio - energy balance method (BREB). The experiment was carried out from July 2018 to June 2019 in Cachoeiras de Macacu, Rio de Janeiro State (RJ) (22º 27'S; 42º 45'W and 30 m altitude). Micrometeorological and meteorological measurements were conducted in a micrometeorological tower installed in the pasture and also in an automatic weather station, located 1 km from the pasture area. The ThM model was evaluated using linear regression between ET_a determinate from BREB and the estimates from ThM using its coefficient of determination (R^2) and the modified Willmott agreement index (d_m). The ThM model underestimated (between 11 and 16%) the ET_a for all seasons, except for spring, which overestimated by 1%. The highest precision and accuracy of the estimates were observed in autumn (R^2 = 0.84 and d_m = 0.68) and spring (R^2 = 0.83 and d_m = 0.82). In summer (R^2 = 0.56 and d_m = 0.73) and winter (R^2 = 0.43 and d_m = 0.66), the lower performance was caused by the inability of the model to represent water extraction from the soil in dry periods.

Palavras-chave:
Razão de Bowen
Modelagem Agrometeorológica
Coeficiente de Cultivo Único
Consumo Hídrico de Pastagens

MODELO DE BALANÇO DE ÁGUA NO SOLO DE THORNTHWAITE E MATHER (ThM) ADAPTADO PARA ESTIMATIVA DA EVAPOTRANSPIRAÇÃO REAL (ETR) DE PASTAGEM

RESUMO

Conhecer a real demanda de água das pastagens é essencial para o uso racional da irrigação. O objetivo do presente trabalho foi avaliar o coeficiente de cultivo e o desempenho do modelo de balanço de água de Thornthwaite e Mather (ThM) adaptado para estimativa da evapotranspiração real (ETR) diária de uma pastagem em relação ao método do balanço de energia – razão de Bowen (BERB). O experimento foi conduzido no período de julho de 2018 a junho de 2019 no município de Cachoeiras de Macacu, RJ (22º 27' S; 42º 45' W e 30 m de altitude). Medidas micrometeorológicas e meteorológicas foram realizadas em uma torre instalada na pastagem e por uma estação meteorológica automática, localizada a 1 km da área de pastagem. O modelo ThM foi avaliado por meio da regressão linear entre ETR determinada pelo BERB e as estimativas pelo ThM, por seu coeficiente de determinação (R^2) e o índice de concordância de Willmott modificado (d_m). O modelo de ThM subestimou (de 11 a 16 %) as estimativas de ETR para os períodos analisados, com exceção da primavera, que superestimou em 1 %. As maiores precisões e exatidões das estimativas foram observadas no outono (R^2 = 0,84 e d_m = 0,68) e primavera (R^2 = 0,83 e d_m = 0,82). No verão (R^2 = 0,56 e d_m = 0,73) e inverno (R^2 = 0,43 e d_m = 0,66), o menor desempenho foi devido a inabilidade do modelo em representar a extração de água do solo em períodos de ausência de chuvas.

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INTRODUCTION

According to the prediction made by the Food and Agriculture Organization of the United Nations (FAO), it is estimated that by 2050, the world population will be approximately 9.7 billion (FAO, 2018). Thus, it is essential to increase agricultural productivity, associated with the rational and optimized use of natural resources, in order to supply the demand for food sustainably.

In this context, pastures are decisive in the Brazilian agricultural sector, as they are characterized as the basis for feeding the Brazilian herds (RETORE *et al*., 2019). Thus, the correct management of forage becomes essential, as it directly provides an increase in the productivity of livestock activity (AGUIAR *et al*., 2017).

Irrigation is a practice that can be used to optimize crop management, as it allows the reduction of losses caused by water deficit and, as a consequence, increased productivity (ANTONIEL *et al*., 2016; SANCHES *et al*., 2017b). However, it is among agricultural activities with the highest water consumption, requiring the control of water supply and demand, optimizing decision-making (BOSI *et al*., 2020). Therefore, for the practice to reach its potential, it is necessary to know the real water demand of the crops.

Evapotranspiration (ET) represents the transfer of water from the surface to the atmosphere through the simultaneous occurrence of evaporation and transpiration processes (CRUZ *et al*., 2017). As a result, ET is an essential factor in estimating the crop water demand. Several approaches have been proposed to obtain it, among them, direct methods (lysimeters), empirical models (e.g., Thornthwaite, Camargo, Hargreaves-Samani, Jensen-Haise, Makkink) or physical-physiological (Penman-Monteith), micrometeorological (e.g., Bowen ratio – energy balance, eddy correlation, aerodynamic method) and through the soil water balance (GOMES et la., 2015a; SILVA *et al*., 2016).

The Bowen ratio – energy balance (BREB) is a micrometeorological method that has been widely used as a standard in determining the flux of latent heat (LH) and sensitive heat (H) of several crops and allows to obtain the evapotranspiration (ET) (SILVA *et al*., 2018; WALLS *et al*., 2020). However, BREB requires measurements of micrometeorological elements, resulting in its limitation, especially for small and medium farmers. Alternatively, the soil water balance (SWB) allows estimating ET by quantifying the inflows and outflows of water in the soil, as it is based on the mass conservation principle (O'REILLY *et al*., 2020). As it only requires soil and weather (rain and evapotranspiration) physical-hydric parameters, SWB is characterized by being a more accessible approach.

Thus, the aim of this study was to evaluate the crop coefficient and the performance of the Thornthwaite and Mather BH model adapted to estimate ETR of a pasture area, in relation to the estimates obtained by the BREB method, from July 2018 to June 2019.

MATERIAL AND METHODS

Study area and micrometeorological/meteorological measurements

The experiment was carried out on a pasture area located in the municipality of Cachoeiras de Macacu, Rio de Janeiro State (RJ) (22º 27' S; 42º 45' W and 30 m altitude). The area covered 30 hectares cultivated with Brachiaria and fortnightly occupied, on average by 160 Nellore animals. The climate in the region, according to Köppen's classification, is Aw –a Humid Tropical Mega-thermal, with a dry season in winter (ALVARES *et al*., 2013).

For soil classification, six trenches were opened around the micrometeorological mast (MM). The profiles were described morphologically according to the methodology of Santos *et al*. (2018) and the soil was classified as typical Tb Melanic Gleisol with a texture between loam sandy and sand (Table 1). Such types of soil are characterized by occurring in flat terrains of floodplains and presenting a high level of the water table.

For physical-water analyses, three points were randomly selected around the MM. Three undisturbed samples were collected at each point at the depths of 0.10, 0.30, and 0.60 m, and later, the samples were taken to the Soil and Water Quality Laboratory at the Escola Superior de Agricultura "Luiz de Queiroz", ESALQ. Moisture at the field

capacity (0.42 $m^3 m^{-3}$) and permanent wilting point (0.19 $m^3 m^{-3}$) was obtained through the soil water retention curve. Analyses of hydraulic conductivity and infiltration rate were also carried out.

Micrometeorological measurements were performed in a 4 m high MM installed on the pasture area. The micrometeorological station was composed of several instruments, described in Table 2. Rainfall data from an automatic meteorological station, installed 1 km from the experimental area were also used. For this experiment, it was evaluated the period from June 2018 to July 2019, which covered winter, spring, summer, and autumn.

Bowen ratio -Energy balance (BREB)

The energy balance consists of the energy conservation law. It is made up of the radiation balance, heat flux in the soil, sensitive heat flux and latent heat flux, which corresponds to ET (Equation 1). To obtain the energy balance, data from the MM were used, which were stored every 10 seconds and, subsequently, an average was performed every 30 minutes. The collected data were analyzed according to the methodology (PEREZ *et al*., 1999) proposed for disposal and selection (Equation 1).

$$R_n - H - LE - G = 0 \quad (1)$$

Where,
R_n = net radiation, $W.m^{-2}$;
H = sensitive heat flux, $W.m^{-2}$;
LE = latent heat flux, $W.m^{-2}$; and
G = heat flux in the soil, $W.m^{-2}$

Bowen (1926) incorporated the ratio between the fluxes of sensitive and latent heat. This relationship was denominated Bowen's ratio (β), which can also be determined by the relationship between the vertical gradients of temperature (ΔT, °C) and air humidity (Δe, kPa) (Equation 2).

$$\beta = \frac{H}{LE} = \gamma \frac{\Delta T}{\Delta e} \quad (2)$$

Where,
γ = Psychometric coefficient, $kPa.^oC^{-1}$.

The psychrometric coefficient was obtained using

Table 1. Particle size analysis and textural classification per horizon, performed on the six profiles located in the pasture area in Cachoeiras de Macacu, RJ

Horizon	Clay	Silt	Sand	Textural Class
		$dag.kg^{-1}$		
A	26	37	37	Loam
Bg	17	31	52	Sandy Loam
B/C	27	28	45	Loam
Cg	8	19	73	Loamy Sand

Table 2. Description of the sensors installed in the experimental area

Parameter	Sensor	Model	Brand	Country	Depth (m)
Liquid radiation	Radiation balace	LP-NET-14	Delta Ohm	Itália	1.5
Air humidity and temperature	Thermohygrometer	DB-TH1-SDI	dualBASE	EUA	1.15 e 1.58
Wind speed	Anemometer	GILL-1405	Gill instruments	Reino Unido	1.23; 1.68; 2.34 e 3.00
Soil heat flux	Flow plate	HFP01	Hukseflux Thermal Sensors	EUA	0.05
Data acquisition and storage	Data logger	CR3000	Campbell Scientific Inc	EUA	-

Equation 3

$$\gamma = 0.00067 P_{atm} \quad (3)$$

where,
P_{atm} = Atmospheric pressure, kPa.

By replacing equation 2 into the 1 and reorganizing it, the ET_a-BREB (ETa_β) was obtained:

$$ETa_\beta = \frac{1800}{\lambda}\frac{(Rn - G)}{(1+\beta)} \quad (4)$$

Where,
λ = latent heat of vaporization, 2,45 MJ.kg^{-1};
1800 =mean time in seconds, from which data were obtained.

Selection of the observations

To ensure consistent estimates, the criterion established by Perez *et al*., (1999) was used. Thus, data collected at night and in the early morning were discarded. In addition, to avoid the effects of horizontal gradient fluxes, the sensors were installed within the constant or equilibrium limit layer (MONTEITH; UNSWORTK,1990), with a border of approximately 300 m, determined according to (LYRA; PEREIRA, 2007).

Soil water balance – Thornthwaite and Mather

The soil water balance is based on the law of mass conservation, represented by the variation of soil water storage (Equation 5). The real evapotranspiration (ETa-ThM) was obtained through the modified WB (LYRA *et al*., 2020).

$$ALT_i = (SW_i - SW_{i-1}) = P_i - ETa_i - EXC_i \quad (5)$$

Where,
ALT = change in water storage in the soil, mm;
SW = soil water storage, mm;
P = precipitation, mm;
ETa = actual evapotranspiration, mm; and
EXC = water surplus, mm.

Storage was calculated using Equation 6, and according to the methodology, it is penalized according to water availability, denominated accumulated negative (ACN) (Equation 7).

$$SW = \begin{cases} CAD \exp\left[\frac{NAC}{CAD}\right] & \text{for } (P_i - ETc_i) < 0 \\ SW_{i-1} + (P_i - ETc_i) & \text{for } (P_i - ETc_i) \geq 0 \end{cases} \quad (6)$$

$$NAC = \begin{cases} NAC_{i-1} - (P_i - ET_{c_i}) & \text{for } (P_i - ET_c) < 0 \\ CAD \ln\left[\frac{SW}{CAD}\right] & \text{for } (P_i - ET_c) \geq 0 \end{cases} \quad (7)$$

Where,
ET_c = crop evapotranspiration.

The Available Water Capacity (AWC) was calculated using Equation 8:

$$AWC = 1000\,(\theta_{fc} - \theta_{pwp})Z_r \quad (8)$$

Where,
AWC = Available water capacity, mm;
θ_{cc} = soil moisture at field capacity, (0.42) m^3.m^{-3};
θ_{pmp} = soil moisture at permanent wilting point, (0,23) m^3.m^{-3}; e
Z_r = effective root depth, m.

Once the K_c was obtained, ET_c was estimated using the single crop coefficient method suggested in FAO 56 (Equation 9).

$$ET_c = ET_o \cdot Kc \quad (9)$$

Reference evapotranspiration (ET_o) was calculated using the Penman-Monteith FAO 56 method (Equation 10).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (10)$$

Where,
ET_o = reference evapotranspiration, mm.d^{-1};
R_n = net radiation at surface, MJ.m^{-2}d^{-1};
G = soil heat flux density, MJ.m^{-2}d^{-1};
T = mean daily air temperature, °C;
u_2 = wind speed at 2 meter height, m.s^{-1};
e_s = saturation vapor pressure, kPa;
e_a = actual vapor pressure, kPa;
Δ = slope of the vapor pressure curve, kPa.°C^{-1};
γ = psychrometric coefficient, kPa.°C^{-1}; and
0.408 = conversion factor for the term (R_n - G), of MJ.m^{-2} d for mm.day^{-1}.

Finally, ETa was obtained employing the relationship shown in Equation 11.

$$\begin{aligned} ETa &= ET_c && \text{for } (P - ET_c) \geq 0 \\ ETa &= P + |ALT| && \text{for } (P - ET_c) < 0 \end{aligned} \quad (11)$$

Single crop coefficient (K_c)

For the calculation of ETc, the crop coefficient

was used, which was obtained based on experimental data. Therefore, it was selected days considered without water deficit, characterized on the basis of the fraction of water available in the soil (FDA) (Equation 12).

$$fDA = \frac{(\theta - \theta_{pwp})}{(\theta_{fc} - \theta_{pwp})} \quad (12)$$

Where,
θ = soil moisture, $m^3.m^{-3}$;
θ_{pmp} = permanent wilting point, $m^3.m^{-3}$; and
θ_{cc} = field capacity, $m^3.m^{-3}$.

The days without water deficit were those that met the criterion $0.8 \leq fDA \leq 1.1$. In these conditions, $ET_c = ET_a$ was characterized (PEREIRA; SEDIYAMA; NOVA, 2013). Next, a linear regression model was used between ET_o (independent variable) and ET_c (dependent variable) forced to pass through the origin, so that K_c was determined by the angular coefficient of the line (Equation 13).

$$Y = \beta_1 X \quad (13)$$

Where,
$Y = ET_c$, $mm.d^{-1}$;
$X_i = ET_o$, $mm.d^{-1}$; and
β_1 = angular coefficient.

Data normality was assessed through the Kolmogorov-Smirnov test ($p < 0.05$), and subsequently the significance of the regression was analyzed using the analysis of variance (ANOVA). The quality of the model adjustment was observed using the coefficient of determination (R^2) and the standard error of estimate (SES).

Statistical analysis

The accuracy of the ETa-ThM and ETa_β estimates were assessed based on the modified Willmott concordance index (d_m) (WILLMOTT; ROBESON;MATSURA, 2012), (Equation 14). The simple linear regression analysis forced to pass at the origin between ETa_β (standard) and ETa-ThM was also applied as well as the coefficient of determination (R^2) (Equation 15) and the root mean squared error (RMSE) (Equation 16).

$$d_m = 1 - \frac{\sum_{i=1}^{N}(|P_i - Oi|)}{\sum_{i=1}^{N}[(|P_i - \bar{O}|) + (|O_i - \bar{O}|)]} \quad (14)$$

Where,
d_m = index of agreement or adjustment;
P_i = values of predictable ETa_ThM, $mm.d^{-1}$;
O_i = values of observed ETa_β, $mm.d^{-1}$;
$\bar{O}$ = means of the ETa_β, $mm.d^{-1}$ values; and
N = number of observations.

$$R^2 = \left(\frac{\sum_{i=1}^{N}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\left[\sum_{i=1}^{N}(O_i - \bar{O})^2\right]\left[\sum_{i=1}^{N}(P_i - \bar{P})^2\right]}} \right)^2 \quad (15)$$

Where,
$\overline{O}$ = mean of the values of ETR_β, $mm.d^{-1}$; and
$\overline{P}$ = mean of the estimated values of ETR_ThM, $mm.d^{-1}$.

$$RMSE = \sqrt{\sum_{i=1}^{N}\left[\frac{(O_i - P_i)^2}{N}\right]} \quad (16)$$

Error indices were also used to assess whether the error was related to the model, through systematic error (MSEs) (Equation 17), or whether it was conditioned to external factors, through random error (MSEu), (Equation 18).

$$MSEs = \sqrt{\left[\frac{\sum_{i=1}^{N}(\hat{P}_i - O_i)^2}{N}\right]} \quad (17)$$

$$MSEu = \sqrt{\left[\frac{\sum_{i=1}^{N}(\hat{P}_i - P_i)^2}{N}\right]} \quad (18)$$

Where,
$\hat{P}_i$ = P value estimated by linear regression ($\hat{P}_i = a + b\,O_i$).

RESULTS AND DISCUSSION

Climatic conditions and crop coefficient (K_c)

Total rainfall of 245.6 mm was recorded in winter, distributed over 44 days; the average ET_o for the period was 2.76 (± 0.97 $mm.d^{-1}$). Regarding spring, a greater total of rainfall of 767.6 mm was

observed in 56 days and the average ET_o for the period was 4.03 (± 1.84 mm.d^{-1}). The total rainfall for the summer was 693.4 mm, which occurred for 59 days. In the same period, an average ET_o of 4.49 (± 1.52 mm.d^{-1}) was obtained. Autumn had a total rainfall of 582.2 mm, distributed over 55 days, and an average ET_o of 2.78 (± 0.85 mm.d^{-1}). The highest mean magnitude per event was observed in spring, followed by summer, while the lowest occurred in winter (Table 3 and Figure 1).

Also, according to the accumulated total for each season, it is observed that rainfall showed greater values than ET_o and ETa_β and this difference was more accentuated in the spring. As for the accumulated ET_o, ETa_β, and ETa_ThM, they presented higher values in the summer, 408.5 (± 1.52 mm.d^{-1}), 377.9 (± 1.39 mm.d^{-1}) and 411.5 (± 1.71 mm.d^{-1}), respectively.

Regarding the ET_o variation during the analyzed period, a trend of higher values was observed in the spring and summer, and a decrease in the values in the winter and autumn seasons. This fact indicated that ET_o showed a relationship with the availability of solar radiation, as expected. A similar pattern was observed by Bueno *et al*. (2019), when evaluating the effect of irrigation on two grass species during the period from May/2018 to June/2019. The authors found that ET_o was influenced by incident solar radiation and air temperature. Alencar *et al.* (2015) also found that solar radiation was the parameter that influenced ET_o estimates the most.

Table 3. Precipitation (P), reference (ET_o) real (ET_a) evapotranspiration from Thornthwaite e Mather model (ET_a_ThM) and Bowen ratio – energy balance (ETa_β) data description according to each season

Time Couse	ETo	ETR_ThM	ETR_β	P	P-ETo	$P\text{-}ETR_\beta$	N° rainy days	Magnitude
				mm				
Winter	231.9	199.9	210.6	245.6	13.7	35	44	5.6
Spring	362.4	342.5	323	767.6	405.2	444.6	56	13.7
Summer	408.5	377.9	411.5	693.36	284.9	281.8	59	11.8
Autumn	252.6	243	285	582.2	329.6	297.3	55	10.6
Year	1255.4	1163.3	1230.1	2288.76	1033.36	1058.66	214	10.7

Magnitude = total rainfall/number of rainy days; P = precipitation; ETa_ThM = evapotranspiration estimated by the water balance of Thornthwaite and Mather (1955); ETa_β = evapotranspiration determined by the Bowen ratio.

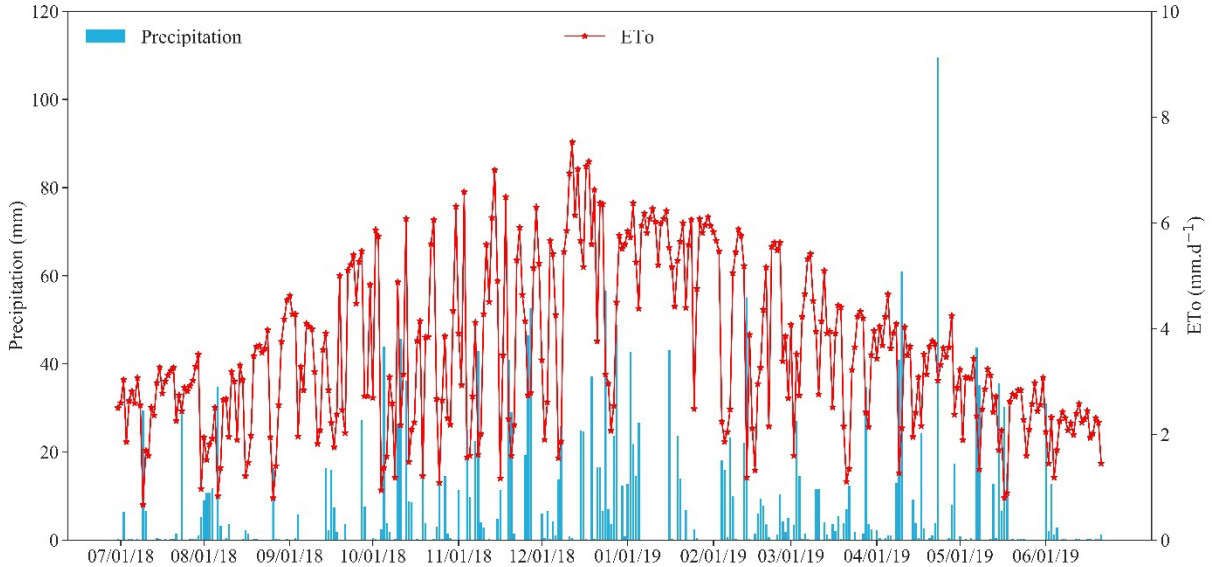


Figure 1. Rainfall variation and reference evapotranspiration (ET_o) for the period from July 2018 to June 2019, corresponding to the winter; spring; summer, and autumn

The fit of the linear regression used to determine the K_c showed high precision, being able to explain 97% of the data variability with EPE of 0.0052 (Figure 2). When assessing the relationship between ET_c and ET_o, Graham *et al*., (2016) found that ET_c explained 97% of ET_o. Santos *et al*. (2017) evaluated the regression between ET_c and ET_o for three of the phenological stages of Moringa, and observed an R^2 of 0.99 for all stages.

According to the ANOVA, the ET_o, ET_c data showed a significant relationship ($p < 0.01$). The K_c value of 1.04 corroborates the K_c values for pastures shown in the literature (ANTONIEL *et al*., 2016; BARNOSA; OLIVEIRA; DE FIGUEIREDO, 2015; SANCHES *et al*., 2017a; SANTANA *et al*., 2016). Sanches *et al*. (2017b) when evaluating the average K_c of Mombasa grass, also found values similar to those in this study (1.07). In addition, the authors observed that the K_c values were not influenced by seasonality.

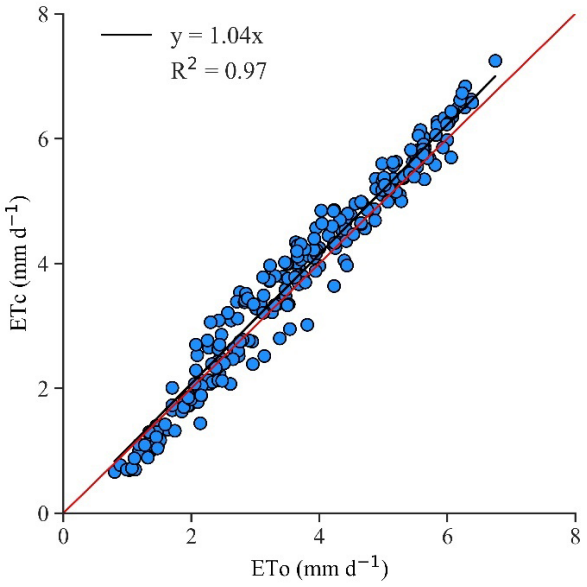
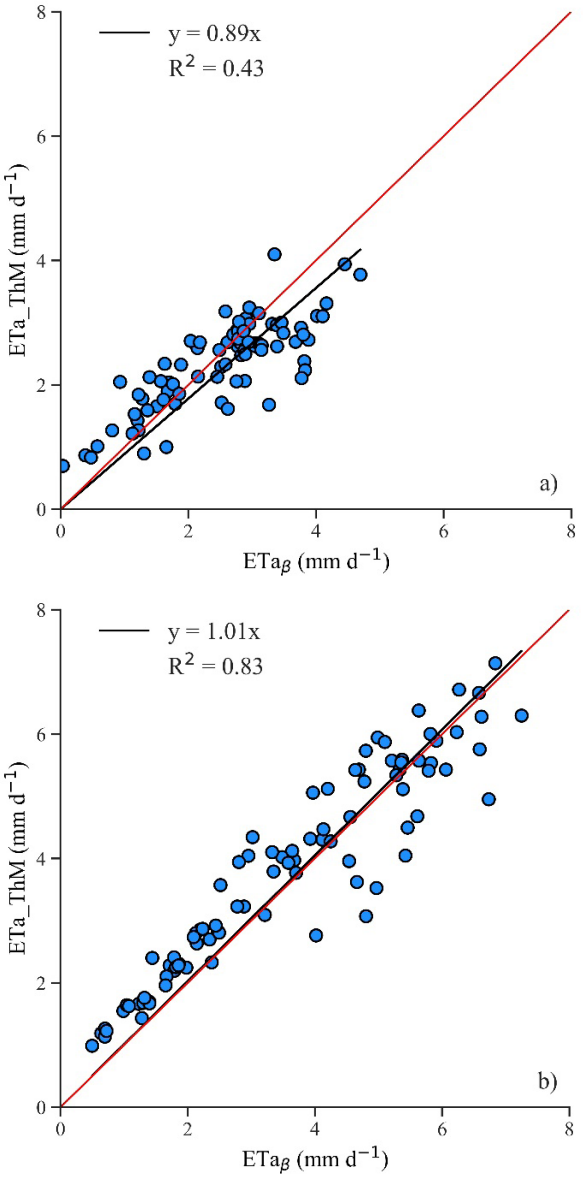


Figure 2. Linear regression between the observed values of reference evapotranspiration (ET_o) by the Penman-Monteith FAO56 method, and the values determined by ET_c by the Bowen ratio – energy balance method for the fraction of available water between 0.8 and 1.1

Performance of the Thornthwaite and Mather model

In general, ET_a estimates were less dispersed in autumn and spring, which presented R^2 of 0.84 and 0.83, respectively. The season with the largest dispersion was winter, followed by summer, with R^2 of 0.43 and 0.56, respectively. Except for the spring, it was observed that the ET_a estimated by the ThM model was underestimated concerning the ET_a determined by the BREB (Figures 3 and 4). For winter and summer, an average underestimation of 11% was observed, while in the autumn period, the underestimation was 16%. Silva *et al*. (2016) found an R^2 of 0.83 in the winter period when evaluating the ET estimate calculated using Penman-Monteith and Bowen's ratio in an area cultivated with Bahia grass. Gomes *et al*. (2015b), when evaluating ET estimates of *brachiaria decumbens* performed using a simulation model of energy flux transfer, in relation to ET determined by Bowen's method, found a higher R^2 value, of 0.91.



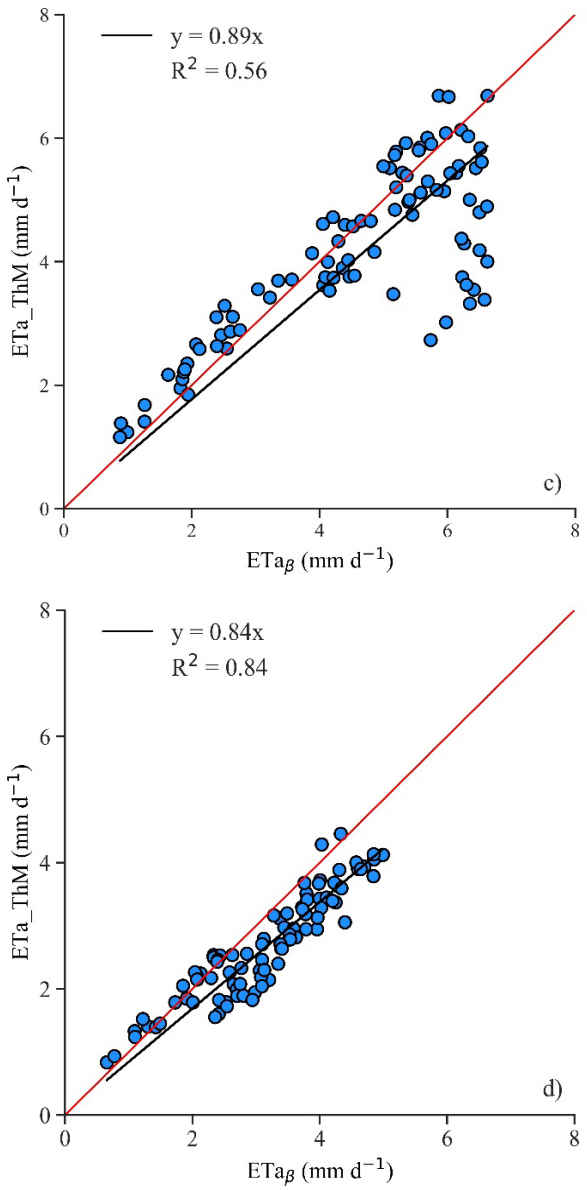


Figure 3. Linear regression between the actual daily evapotranspiration values (ETa, mm d^{-1}) observed by the Bowen ratio method in relation to the ETa estimated by the soil water balance model for winter (a); spring (b); summer (c) and autumn (d)

In relation to the accuracy of the ET_a ThM estimates, the highest d_m value was observed in the spring (0.82), followed by summer (0.73). Autumn and winter showed less accuracy, with values of 0.68 and 0.66, respectively (Table 4). As for the error, the months corresponding to spring presented lower RMSE% and the lowest error related to the model and its parameters, that is, systematic error, MSEs%. In contrast, the period with the highest RMSE% was winter.

The highest values of systematic error were observed in autumn and winter. It is worth mentioning that both periods are characterized by a lower incidence of solar radiation and air temperature, which provides a slower pasture growth in relation to spring and summer, and reflects in a smaller leaf area of the canopy and height of the crop (ZHUANG *et al*., 2020). Thus, the higher MSEs% values are probably the result of the use of a constant K_c, considering that it is intrinsically related to the ratio between the total area of the canopy and the occupied area of the soil, defined as the leaf area index (LAI) and the height of the crop. Bueno *et al*. (2019) found that after eight cuts of two pasture species, the largest dry and fresh matter yield occurred in the period from November to January, corresponding to summer, which indicates that seasonality influences the forage.

Although summer had a higher total rainfall than autumn, the greater dispersion of the ET_a estimates observed in the summer can be explained by the lower frequency between the occurrence of the rainfall. This fact may have corroborated the greater ETR penalty estimated by the BH method, due to the low storage of water in the soil, which also explains the greater dispersion obtained in winter, which was the period of lowest total rainfall observed.

The method proposed by Thornthwaite and Mather when adapted to the crops penalizes the ET_a more rigorously than other models, such as, for example, the dual Kc Furtado (2017), considering that the removal of water from the soil is caused by the exponential and the initial penalty immediately when soil water storage is less than the available water capacity, while the replacement is carried out directly, through the sum between the storage value and the positive balance between precipitation and ET (PEREIRA; SEDIYAMA; NOVA, 2013).

Another possible factor responsible for the underestimation of the values from the ET_a estimated by SWB is due to the type of soil of the

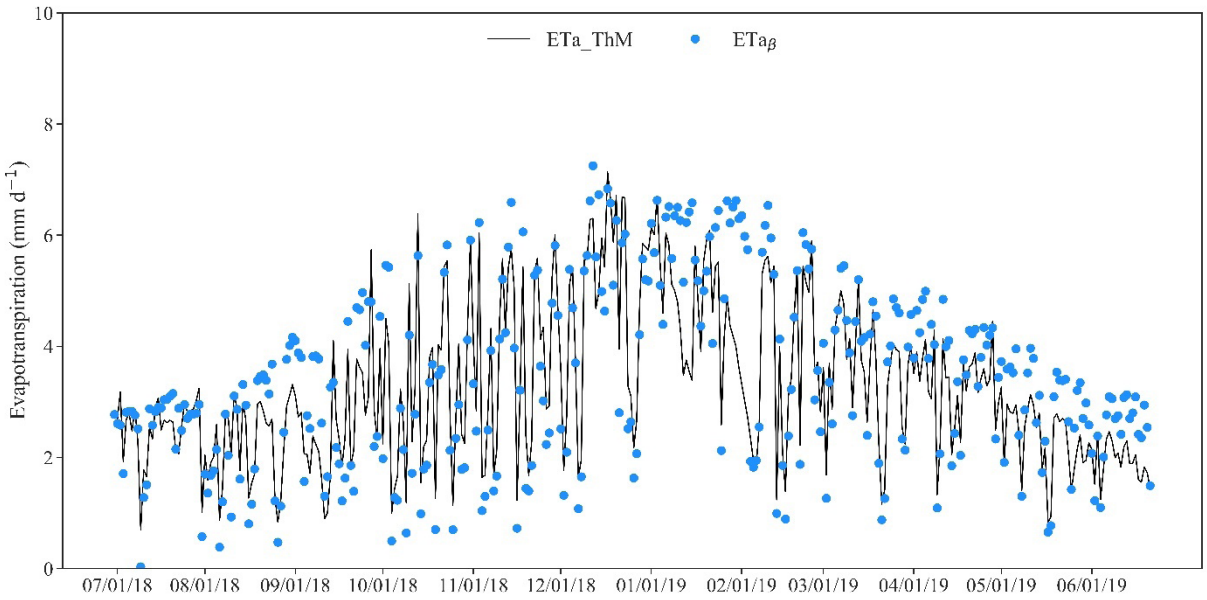


Figure 4. Variation in actual evapotranspiration (ET_a), determined by Bowen (ETaβ) and estimated by BH (ET_a_ThM), analyzed during the period from July 2018 to June 2019, corresponding to the winter; spring; summer, and autumn

Table 4. Results of the statistical indicators used to assess the performance of the ThM water balance model, in the ETa estimate. Modified Willmott agreement index (d_m), root mean square error (RMSE, %), systematic mean square error (MSE_s, %) and unsystematic mean square error (MSE_u, %)

Seasons	d_m	RMSE%	MSEs%	MSEu%
Winter	0,66	24,41	54,81	45,19
Spring	0,82	18,6	32,44	67,56
Summer	0,73	23,76	41,56	58,44
Autumn	0,68	19,66	71,53	28,47

study site, considering that it has a high level of groundwater. This characteristic can contribute to the occurrence of capillary rise, a phenomenon not quantified by the SWB proposed by Thornthwaite and Mather.

CONCLUSIONS

- The Thornthwaite and Mather soil water balance model adapted for pasture presents satisfactory estimates of the real evapotranspiration, particularly in periods with higher rainfall frequency;
- In dry periods and or with less rainfall frequency, the model presents less performance, due to the intrinsic penalty to soil water balance;
- The use of a single crop coefficient constant throughout the year does not represent seasonal variations in leaf area index and crop height; and
- The model is more accurate, especially in the spring and autumn.

AUTHORSHIP CONTRIBUTION STATEMENT

BARROS, F.C.: Data curation, Methodology, Validation, Visualization, Writing – original draft; MARTINS, S.C.F.M.: Data curation, Investigation, Methodology, Writing – review & editing; LYRA, G.B.: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing; SILVA, L.D.B.: Conceptualization, Methodology, Project

administration, Resources, Writing – review & editing; FRANCISCO, J.P.: Data curation, Formal Analysis, Software, Validation, Writing – review & editing; ABREU, M.C.: Formal Analysis, Funding acquisition, Investigation, Software, Visualization; LYRA, G.B.: Data curation, Project administration, Resources, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no knowledge of a conflict of interest that could have appeared to influence the work reported in this paper.

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