

**Comparison of Reference Evapotranspiration Estimates obtained by Different Methods
in relation to the Penman-Monteith Method in Cerrado Environment, Brazil**

ABSTRACT

Water is the most limiting resource for crop production, however, erroneous estimates of the amount needed to be applied can increase production costs, influence plant nutrition and contaminate the ecosystem. Thus, the objective of this work was to compare the values of E_t obtained by the methods of Blaney-Criddle, solar radiation and Ivanov with the values resulting from the use of Penman-Monteith method in cerrado environment, Brazil. To estimate evapotranspiration values were used the daily data of the maximum and minimum temperatures, wind speed, amount of daylight hours and relative humidity of the years of 2010 and 2011. To compare the estimated values, the parameters of the regression equation a and b, coefficient of determination (r^2), correlation coefficients (r), agreement (d) and confidence (c) were considered. Based on the Penman-Monteith method, it was verified that all the other methods evaluated overestimate the values of E_t during the whole evaluated period. Despite this, it was founded a good correlation between the Blaney-Criddle method and the Penman-Monteith method. The solar radiation and Ivanov methods presented low coefficient of determination when compared to the PNM method. It was concluded that the reference evapotranspiration, on a daily scale, can be quantified using the Blaney-Criddle method instead of the Penman-Monteith method. Furthermore, the solar radiation and Ivanov methods, despite the good agreement and performance indexes, present the greatest distortions during the year.

Key words: Agricultural meteorology; Blaney-criddle; Ivanov; Penman-Monteith; solar radiation.

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28 1. INTRODUCTION

29 Water is the most limiting resource for crop production [19] and projections by the
30 Organisation for Economic Co-operation and Development [21] indicate that water scarcity
31 will affect 2/3 of the world's population by 2050. Furthermore, the world population is
32 expected to increase to 9.1 billion people by 2050 [30]. This scenario suggests that water use
33 should be increasingly optimized.

34 Of the 200 million tons of grain produced in the country in 2015/2016, about 24%
35 originates in the state of Mato Grosso (MT) [5]. In relation to the irrigated area, the state has
36 approximately 178 thousand ha irrigated (3.1% of the total of the country) [1]. The cerrado of
37 the Mato Grosso state, Brazil, is recognized as one of the regions with the largest irrigated
38 area in Brazil, entering the area of occurrence of the Brazilian Tropical Rainforest, suggesting
39 the occurrence of quite distinct environmental scenarios, especially regarding climatic
40 variables [28]. However, despite the importance of cerrado in national agricultural
41 production, few studies allow efficient quantification of reference evapotranspiration for the
42 regional edaphoclimatic cerrado conditions.

43 Evapotranspiration is defined as being the phenomenon that occurs from the
44 combination of two processes: i) evaporation, in which the passage of water from the liquid
45 to the gaseous state occurs, after the water vapor absorbs the energy of the medium called
46 latent heat of evaporation and, ii) transpiration, which is the evaporation of water used in the
47 various metabolic processes of plants [24].

48 The reference evapotranspiration (E_{t0}) is related to the effect of the atmospheric
49 demand on the water requirements of the plants, being estimated from the elements of the
50 climate [24]. Therefore an accurate determination of E_{t0} is of fundamental importance for
51 good irrigation management.

In this context, there are several methods to calculate the E_{t0} , the main one being the method proposed by Penman-Monteith, which is considered by many, the standard method to be used anywhere without calibration [22, 31]. However, this method requires a high number of climatic variables and this has made it unfeasible in many cerrado regions. Contrary to this, several publications point to other methods, which have a lower requirement and complexity, which could be used (depending on the edaphoclimatic conditions of the region) in some Brazilian regions, such as the Blaney-Criddle, Radiation Solar and Ivanov equations [26, 29]. Some of these methods are based on a single climatic variable such as solar radiation [4, 16] or temperature [12].

In this sense, the evaluation and comparison of different methods of estimating evapotranspiration in the state of Mato Grosso could contribute to reduce water consumption, optimize irrigation systems and increase the efficiency of water use, resulting in environmental and economic benefits for irrigated agriculture [9].

. Thus, the objective of this work was to compare the values of E_{t0} obtained by the methods of Blaney-Criddle, solar radiation and Ivanov with the values resulting from the use of Penman-Monteith method in cerrado environment, Brazil.

2. MATERIAL AND METHODS

We used daily data of mean air temperature ($^{\circ}\text{C}$), maximum ($^{\circ}\text{C}$), minimum ($^{\circ}\text{C}$), relative humidity (%), wind speed (m s^{-1}) and total sunshine for the years 2010 and 2011 obtained from the climatological station code OMM 83363, located in the municipality of Santo Antônio do Leverger, MT, Brazil ($15^{\circ} 49' \text{S}$ and $55^{\circ} 25' \text{W}$ with 790 m altitude).

It should be emphasized that, despite the data series being only two years, the unavailability of information for studies of this nature has caused several researches to be developed with even smaller series [7].

The insolation was measured using the heliograph. Estimates of reference evapotranspiration (Et_0) were obtained by the Penman-Monteith methods parameterized by Allen *et al.* [3] for the 24 hours' time interval (Eq. 1), Blaney-Criddle [4], modified by Doorenbos and Pruitt [11] (Eq. 2), Solar Radiation (Eq. 3) and Ivanov [14] (Eq. 4).

$$Et_0 = \frac{0,408\Delta(R_n - G) + \frac{900\gamma u_2(e_s - e_a)}{(T+273)}}{\Delta + \gamma(1 + 0,34u_2)} \quad \text{Eq. (1)}$$

where Et_0 is the estimated reference evapotranspiration (mm day^{-1}), R_n is the surface radiation balance ($\text{MJ m}^{-2}\text{day}^{-1}$), G is the sensible heat flux in the soil ($\text{MJ m}^{-2}\text{day}^{-1}$), T is the air temperature ($^{\circ}\text{C}$), u_2 is the wind velocity at 2 m height m s^{-1} , e_s is the saturation pressure of water vapor (kPa), e_a is the partial water vapor pressure (kPa), Δ is the slope of the water vapor saturation pressure curve ($\text{kPa } ^{\circ}\text{C}^{-1}$); and γ is the psychrometric constant ($\text{kPa } ^{\circ}\text{C}^{-1}$).

$$Et_0 = a + b p (0,46 T + 8,13) \quad \text{Eq. (2)}$$

Where a e b are the coefficients of the linear equation, p is the daily percentage of the annual average of hours of solar brightness; and T is the average temperature in $^{\circ}\text{C}$.

$$Et_0 = c * W * R_s \quad \text{Eq. (3)}$$

where c is the adjustment factor that varies as a function of the average relative humidity of the air and the average speed of the wind to 2 meters of height [10], W is the factor, which includes the effects of temperature and altitude on the relationship between soil surface radiation and reference evapotranspiration [11] and R_s is the average solar radiation expressed in equivalent evaporation (mm day^{-1}).

$$Et_0 = 0,006(25 + T)^2 \left(1 - \frac{U_R}{100}\right) \quad \text{Eq. (4)}$$

where Et_0 is the Reference evapotranspiration by Ivanov (mm day^{-1}), T is the average air temperature ($^{\circ}\text{C}$), and U_R is the relative humidity (%).

The radiation balance (Rn) was calculated according to the proposal of Allen *et al.* [3], being described as the difference between short-wave radiation and long-wave radiation, from the estimation of solar radiation by the Angstrom equation, adopting coefficients a and b of 0.25 and 0.50, respectively, and one Albedo of 0.23. The standardized equations for the calculation of all the parameters of Eq. 1 are presented in Doorenbos and Pruitt [11].

Regression analysis was performed between the values estimated by the different methods, considering the linear model. The analysis of the results was done according to the agreement index (d) (Eq. 5), according to Willmott [32, 33] and Camargo and Sentelhas [6] methodologies, confidence or performance (c) (Eq. 6) [2], in addition to the correlation coefficients (r) and determination (r^2).

$$d = 1 - \left[\frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i - O| + |O_i - O|)^2} \right] \quad \text{Eq. (5)}$$

where P_i is the predicted or estimated by the methods of Blaney-Criddle, Solar Radiation and Ivanov, O_i is the value of E_{t0} observed by the Penman-Monteith equation (mm day^{-1}), and O is the mean of the observed values.

$$c = r \cdot d \quad \text{Eq. (6)}$$

where c is the confidence index "c", and d is the Willmott's concordance index [33].

The table 1 presents the criteria used to interpret the performance of the estimation methods of E_{t0} by the indices "c" and "r", respectively.

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Table 1. Criteria for interpretation of the performance of the methods of estimation of E_{t0} by the index "c" and correlation values "r" proposed by Camargo and Sentelhas [6].

Value of "c"	Performance
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> 0,85	Great
0,76 a 0,85	Very good
0,66 a 0,75	Good
0,61 a 0,65	Median
0,51 a 0,60	Affordable
0,41 a 0,50	Bad
- 0,40	Terrible
Value of “ <i>r</i> ”	Precision
0,9-1,0	Almost perfect
0,7-0,9	Very high
0,5-0,7	High
0,3-0,5	Moderate
0,1-0,3	Low

Source: Camargo and Sentelhas [6].

3. RESULTS AND DISCUSSION

The Fig 1 shows the daily values of reference evapotranspiration (E_t) calculated by the PNM, IV, RS and BC methods for the years 2010 and 2011, in four seasons of the year, being chosen according to their importance in defining The seasons by the solstices (winter/June and summer/December and equinoxes (autumn/March and spring/September).

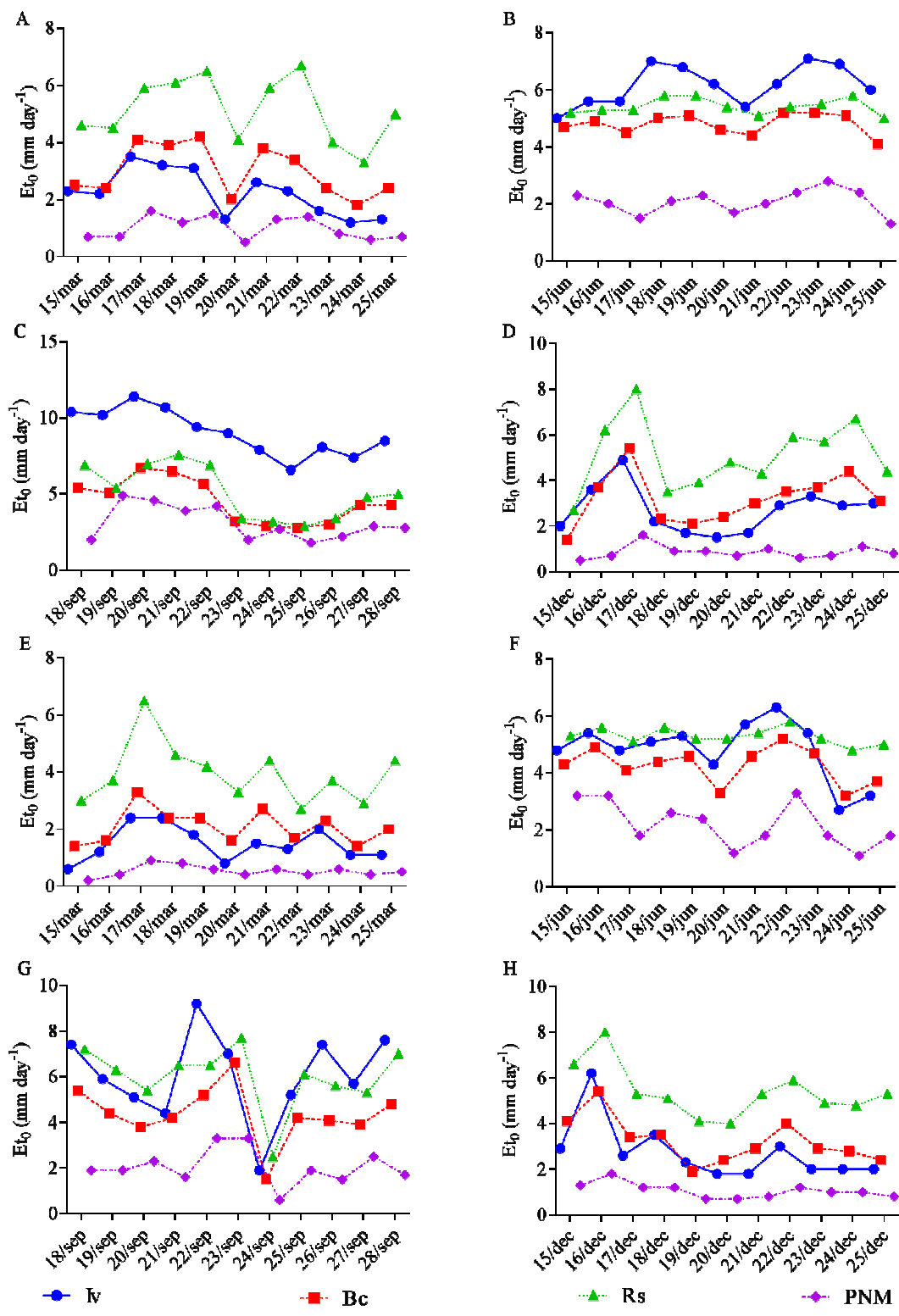


Fig 1. Daily behavior of reference evapotranspiration (E_t) by Penman-Monteith (PNM) (PMN), Blaney-Criddle (BC), Solar Radiation (RS) and Ivanov (IV) for 2010 (A, B, C and D) and 2011 years (E, F, G and H).

Based on the PNM method, it was verified that all the other methods evaluated overestimate the values of E_t during the whole evaluated period. The method IV overestimated mainly in June (winter solstice) and September (spring equinox) (Figs 1B, 1C, 1F and 1G), suggesting that the method, based on the use of only the temperature and relative humidity of the air, does not allow adequate inferences in the months that comprise the dry season of the region. These results were also observed by Alencar *et al.* [2] evaluating the IV method in Uberaba, MG, which observed an overestimation of E_t in the period of lower relative humidity. The BC method was the one that had the least variable behavior throughout the year, but presented an overestimate behavior throughout the year (Figs 1A to 1H). Similar behavior was observed by Alencar *et al.* [2].

In fact, the Penman-Monteith method was an improvement on Penman's original method, and several studies in Brazil and in the world have proven that the Penman-Monteith method is quite accurate [13, 15, 34, 35], being, for this reason, widely used as a standard of comparison with the other methods.

Despite the overestimation of evapotranspiration (mm day^{-1}) obtained by the Blaney-Criddle, solar radiation and Ivanov methods, these methods were found to present, if necessary, a potential for use in a closed environment. That is, the calibration should be carried out for the local conditions in order to improve them to the point where they can be used even in substitution for the Penman-Monteith method. In this sense, in a study by Sentelhas *et al.* [24] for 12 locations in southern Ontario, Canada, studying methods that use only temperature data and the Penman-Monteith method, which uses only maximum and

148 minimum temperatures [3], observed that the Hargreaves method, after some adjustments,
149 was the best option to estimate E_{t0} .

150 The values for the parameters of the regression equation (a and b) were significant
151 ($P < 0.05$) in all cases. It is also observed that the Blaney-Criddle method presented the best
152 performance compared to other methods, with linear coefficients (b) with values close to 1
153 (Figs 2A and 2E).

154 The determination coefficients obtained between the reference evapotranspiration
155 estimated on a daily scale by the PNM method and by the BC, RS and IV methods for the
156 years 2010 and 2011 (Fig 2) were 0.80, 0.78 (Fig 2A, 2E), 0.69, 0.78 (Fig 2B, 2F) and 0.59,
157 0.55 (Fig 2C, 2G), for the BC, RS and IV methods, respectively.

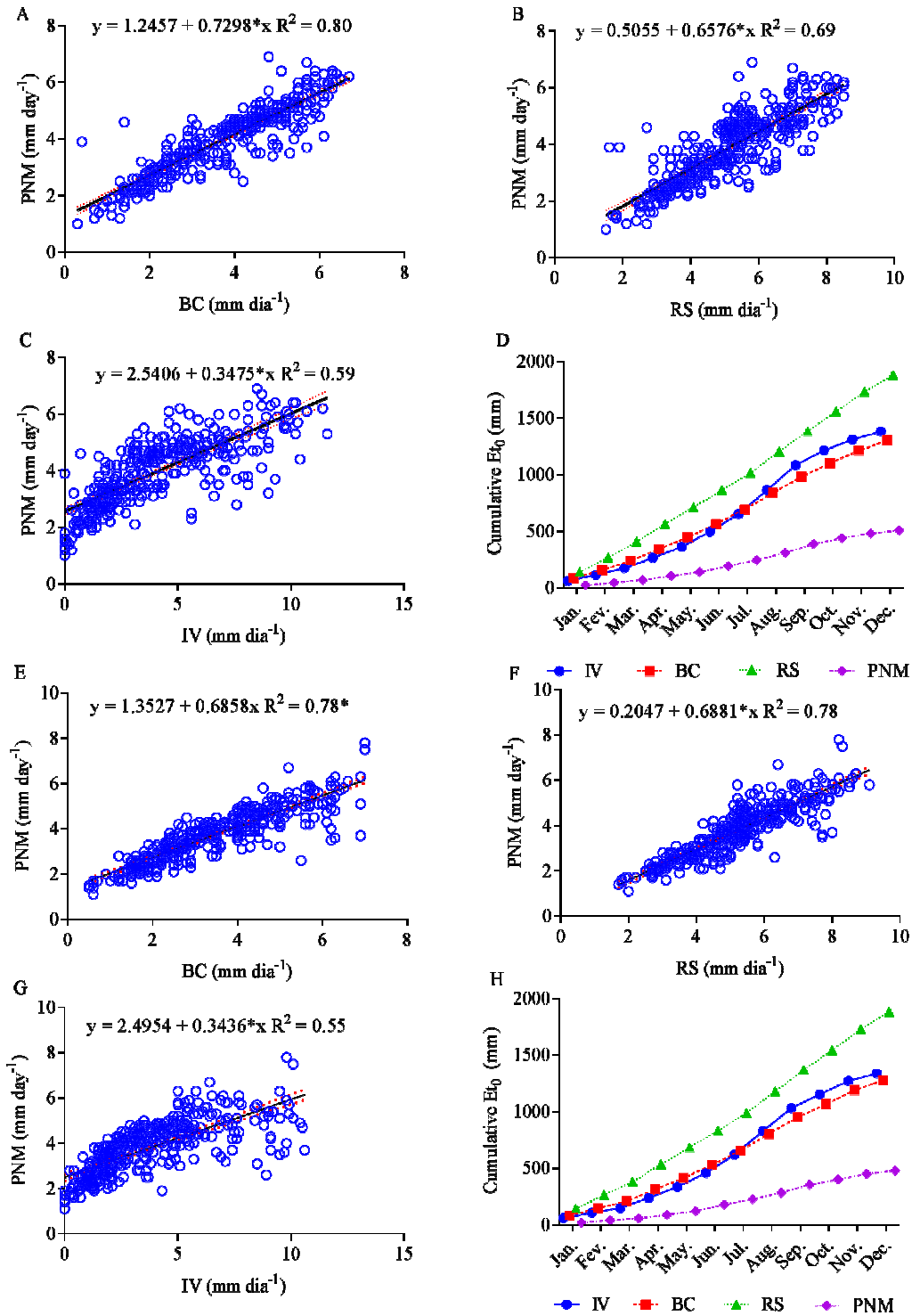


Fig 2. Coefficient of determination (r^2) between the reference evapotranspiration values obtained by the Penman-Monteith method (PNM) and the reference evapotranspiration

obtained by the Blaney-Criddle (BC) method (A); Penman-Monteith method (PNM) (mm day⁻¹) and the reference evapotranspiration obtained by the Solar Radiation (RS) method (mm day⁻¹) (B); Penman-Monteith method (PNM) (mm day⁻¹) and the reference evapotranspiration obtained by the Ivanov (IV) method (mm day⁻¹) (C); and the cumulative average evapotranspiration by the different methods in 2010 (D) and 2011 (E, F, G and H). **(P<.05)*.

According to Fig 2A and 2E, a good correlation was found between the BC method and the Penman-Montheith method; on the other hand, the RS and IV methods presented low coefficient of determination when plotted using the PNM method.

Although the RS and IV methods showed the lowest correlation indices with the standard Penman-Montheith method, they were classified as "very good" by the classification of index c and as "very high" in the index R of Camargo and Sentelhas [6]. Furthermore, the RS and IV methods showed concordance indices, according to Willmott [33], of 0.97 and 0.97, respectively (Table 2).

These results indicate that the method that suggests the equally relevant potential to estimate the reference evapotranspiration among the methods studied, when compared to the FAO standard of Penman-Montheith, is the Blaney-Criddle method (Figs 2A and 2E). This is justified by the fact that the Blaney-Criddle method obtained higher coefficient of determination in both years (2010 and 2011). In addition, the lowest coefficient of determination, in the estimates for the year 2010 and for 2011, was obtained by the Ivanov method (Figs 2C and 2G). The solar radiation method, in turn, despite having a coefficient of determination identical to that of Blaney-Criddle in 2011, presented a low value for the year 2010 ($r^2 = 0.69$) (Figs 2B and 2F).

These results agree with those obtained by Reis et al. [23], which, in a comparative study of empirical methods, for estimating E_{t0} , compared to the standard Penman-Monteith universal method, for the climatic conditions of the municipalities of Sooretama, Cachoeira do Itapemirim and Venda Nova do Imigrante, respectively, in the northern, southern and mountainous regions of the State of Espírito Santo, Brazil. For the climatic conditions of the localities where the work was performed, for the dry period, the methods that presented the best estimates followed the following decreasing order: Blaney-Criddle and solar radiation.

The BC method presented the best performance among the methods in that it presented coefficient of determination (r^2) of 0.80 (Fig 2A, 2E) and agreement index of 0.99 (Table 2), confirming good agreement with the standard method (Table 1), according to the interpretation of Camargo and Sentelhas [6].

Comparing PNM with RS, it was obtained the value of 0.97 for the concordance index (d), indicating a good agreement between the methods. For the confidence index (c) and correlation coefficient (r), it was obtained values of 0.83 and 0.85, respectively; therefore, the confidence and high accuracy were lower than the BC method. Although the RS method has performed well, it is a method that requires more meteorological data, which are often not available in the region, making it difficult to use. Tanaka et al. [26] verified an overestimation of E_{t0} with the use of the RS method in evaluations in the state of Mato Grosso, indicating that this method requires local calibrations for reliable estimation of E_{t0} .

Table 2. Results of the concordance (d), correlation (r) and confidence (c) tests for the different methods in relation to Penman-Monteith for São Vicente da Serra, MT, in the period of 2010 and 2011.

Methods	d	r	c
PNM x BC	0,99	0,92	0,92

PNM x RS	0,97	0,85	0,83
PNM x IV	0,97	0,81	0,81

For PNM x IV, the value for agreement (d) observed was 0.97, indicating a near perfect agreement between the methods (Table 2), but, it was noted a lower result for the confidence index (c) and correlation coefficient (R), which were 0.81 and 0.81, respectively, which interpreted, represented high agreement with the Penman-Monteith method, however, when compared to the results in terms of the confidence and precision indices, it was lower than other methods.

Mendonça *et al.* [18], comparing different methods of estimation of reference evapotranspiration and comparing them with the estimation of the class A tank, for the northern region of Rio de Janeiro, Brazil, observed that the solar radiation method tended to overestimate E_{t0} by 25.7 %. In turn, Tagliaferre *et al.* [25] with the same objective, verified that the BC and RS method presented better performances for the estimates of E_{t0} in all the periods studied for the region of Eunápolis, Bahia, differing therefore from the results found in this work.

Alencar *et al.* [2] observed that the BC method presented the best results for the period of high demand, represented by high precision indexes and small associated errors for the region of Uberaba, Minas Gerais. Chauhan and Shrivastava [8] also compared the Blaney-Criddle and solar radiation methods with the standard Penman-Montheith method and the results led to the conclusion that the BC method presented the best performance, followed RS, with efficiencies of 83% and 53.8%, respectively.

The researches with estimates of the E_{t0} translate variation in the behavior of the models in the different Brazilian regions, as reported by Alencar *et al.* [2] beyond Melo and Fernandes [17]. Thus, the selection of the method to be employed depends on locally verified

factors such as climatic conditions, availability of meteorological data, complexity of the method, grouping of the data considered and costs. Therefore, models that do not perform satisfactorily for proper estimates in a region should be evaluated and, if necessary, calibrated for local or regional climatic conditions.

Finally, due to the results presented in this work, with the unavailability of input data for the Penman-Montheith method, it is justified to use alternative methods such as Blaney-Criddle. However, in order to adapt them to the specific condition of the cerrado of the state of Mato Grosso, Brazil, the Blaney-Criddle, Solar Radiation and Ivanov method need to go through adjustments (calibrations), evidencing, therefore, that for the adoption of a method, one should focus on the climatic conditions and/or similarities in which it was developed.

4. CONCLUSIONS

The Blaney-Criddle reference evapotranspiration method was the method that presented the best estimates when compared to the Penman-Montheith standard for the cerrado environment, Brazil, however, it emphasizes the need for method calibration to local conditions. That is, the Blaney-Criddle reference evapotranspiration method can, after undergoing calibration, effectively replace the Penman-Montheith method under Brazilian cerrado conditions.

Solar radiation and Ivanov, although relatively simple methods are not recommended for the cerrado region of Mato Grosso state, Brazil.

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