

Original Research Article

METHODS OF ESTIMATING REFERENCE EVAPOTRANSPIRATION FOR

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 methods of evapotranspiration reference estimation of Blaney-Cridlle, Solar Radiation and Ivanov with the Penman-Monteith standard method (FAO 56). The experiment was carried out under cerrado conditions in the state of Mato Grosso, Brazil. It is used a biannual set of daily data (2010 and 2011) of maximum and minimum temperatures, wind speed, sunshine and relative humidity. 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. The best index of agreement (d), confidence (c) and correlation (r) was obtained for the Blaney-Cridlle method. It was concluded that the reference evapotranspiration, on a daily scale, can be quantified using the Blaney-Cridlle method instead of the Penman-Monteith method (FAO 56) in that it has the same estimation accuracy and requires more data easily found in the agricultural areas of the cerrado. On the other hand, the solar radiation and Ivanov methods, despite the good agreement and performance indexes, present the greatest distortions during the year.

Key words: Blaney-cridlle; agricultural meteorology; penman-monteith; solar radiation; ivanov.

27 1. INTRODUCTION

28 Water is the most limiting resource for crop production (Mueller *et al.*, 2012) and
 29 projections by the World Water Council (Oecd, 2015) indicate that water scarcity will affect
 30 2/3 of the world's population by 2050. Furthermore, the world population is expected to
 31 increase to 9.1 billion people by 2050 (Un desa, 2009). This scenario suggests that water use
 32 should be increasingly optimized.

33 Of the 200 million tons of grain produced in the country in 2015/2016, about 24%
 34 originates in the state of Mato Grosso (MT) (Ibge, 2016). In relation to the irrigated area, the
 35 state has approximately 178 thousand ha irrigated (3.1% of the total of the country) (Ana,
 36 2013). The cerrado of the Mato Grosso state, Brazil, is recognized as one of the regions with
 37 the largest irrigated area in Brazil, entering the area of occurrence of the Brazilian Tropical
 38 Rainforest, suggesting the occurrence of quite distinct environmental scenarios, especially
 39 regarding climatic variables (Tanaka, 2013). However, despite the importance of cerrado in
 40 national agricultural production, few studies allow efficient quantification of reference
 41 evapotranspiration for the regional edaphoclimatic cerrado conditions.

42 In this context, there are several methods to calculate the E_{t0} , the main one being the
 43 method proposed by Penman-Monteith, which is considered by many, the standard method to
 44 be used anywhere without calibration (Raziei and Pereira , 2013; Valiantzas, 2013).
 45 However, this method requires a high number of climatic variables and this has made it
 46 unfeasible in many cerrado regions. Contrary to this, several publications point to other
 47 methods, which have a lower requirement and complexity, which could be used (depending
 48 on the edaphoclimatic conditions of the region) in some Brazilian regions, such as the
 49 Blaney-Criddle, Radiation Solar and Ivanov equations (Todorovic *et al.*, 2013; Tanaka *et al.*,
 50 2016). Some of these methods are based on a single climatic variable such as solar radiation
 51 (Blaney and Criddle, 1950; Makkink, 1957) or temperature (Hargreaves and Samani, 1985).

52 In this sense, the evaluation and comparison of different methods of estimating
53 evapotranspiration in the state of Mato Grosso could contribute to reduce water consumption,
54 optimize irrigation systems and increase the efficiency of water use, resulting in
55 environmental and economic benefits for irrigated agriculture (Croitoru *et al.*, 2013).

56 The objective of this work was to compare the E_{t0} estimation methods of Blaney
57 Criddle (BC), Solar Radiation (RS) and Ivanov (IV) with the Penman Monteith standard
58 Method (PNM) (FAO 56) and to identify, through different indices, the method that can
59 replace the Penman Monteith method in the conditions of the irrigated agriculture of the
60 cerrado of the state of Mato Grosso, Brazil.

61

62 2. MATERIAL AND METHODS

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



67

Fig 1. Climatological station code OMM 83363, located in the municipality of Santo Antônio do Leverger, MT, Brazil (15° 49 'S and 55° 25' W with 790 m altitude).

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The data series used referred to the period of 2010 and 2011. 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 (Carvalho *et al.*, 2015).

The insolation was measured using the heliograph. Estimates of reference evapotranspiration (E_t_0) were obtained by the Penman-Monteith (FAO 56) methods parameterized by Allen *et al.* (1998) for the 24 hour time interval (Eq. 1), Blaney-Criddle (Blaney and Criddle, 1950), modified by Doorenbos and Pruitt (1977) (Eq. 2), Solar Radiation (Eq. 3) and Ivanov (Jensen, 1973) (Eq. 4).

$$E_{t_0} = \frac{0,408\Delta(R_n - G) + \frac{900\gamma u_2(e_s - e_a)}{(T+273)}}{\Delta + \gamma(1 + 0,34u_2)} \quad \text{Eq. (1)}$$

where E_{t_0} is the estimated reference evapotranspiration (mm d^{-1}), R_n is the surface radiation balance ($\text{MJ m}^{-2}\text{d}^{-1}$), G is the sensible heat flux in the soil ($\text{MJ m}^{-2} \text{d}^{-1}$), 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 ($\text{kPa } ^{\circ}\text{C}^{-1}$).

$$E_{t_0} = a + b p (0,46T + 8,13) \quad \text{Eq. (2)}$$

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 $^{\circ}\text{C}$.

$$E_{t_0} = c * W * R_s \quad \text{Eq. (3)}$$

87 where c is the adjustment factor that varies as a function of the average relative humidity of
 88 the air and the average speed of the wind to 2 meters of height (Doorenbos and Kassam,
 89 1994), W is the factor, which includes the effects of temperature and altitude on the
 90 relationship between soil surface radiation and reference evapotranspiration (Doorenbos and
 91 Pruitt, 1977) and R_s is the average solar radiation expressed in equivalent evaporation (mm d⁻¹).
 92 ¹).

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

93 where Et_0 is the Reference evapotranspiration by Ivanov (mm d⁻¹), T is the average air
 94 temperature (°C), and U_R is the relative humidity (%).

95 The radiation balance (R_n) was calculated according to the proposal of Allen *et al.*
 96 (1998), being described as the difference between short-wave radiation and long-wave
 97 radiation, from the estimation of solar radiation by the Angstrom equation, adopting
 98 coefficients a and b of 0.25 and 0.50, respectively, and one Albedo of 0.23. The standardized
 99 equations for the calculation of all the parameters of Eq. 1 are presented in Doorenbos and
 100 Pruitt (1977).

101 Regression analysis was performed between the values estimated by the different
 102 methods, considering the linear model. The analysis of the results was done according to the
 103 agreement index (d) (Eq. 5), according to Willmott's (1982, 1985) and Camargo and
 104 Sentelhas (1997) methodologies, confidence or performance (c) (Eq. 6) (Alencar *et al.*,
 105 2011), in addition to the correlation coefficients (r) and determination (r^2).

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

106 where P_i is the predicted or estimated by the methods of Blaney-Criddle, Solar Radiation and
 107 Ivanov, O_i is the value of Et_0 observed by the Penman-Monteith equation (mm d⁻¹), and O is
 108 the mean of the observed values.

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

109 where c is the confidence index " c ", and d is the Willmott's concordance index (1982).

110 The table 1 presents the criteria used to interpret the performance of the estimation
111 methods of Et_0 by the indices " c " and " r ", respectively.

112 **Table 1. Criteria for interpretation of the performance of the methods of estimation of**
113 **Et_0 by the index " c " and correlation values " r " proposed by Camargo and Sentelhas**
114 **(1997).**

Value of " c "	Performance
> 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 " r "	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

115 Source: Camargo and Sentelhas (1997).

116

117 3. RESULTS AND DISCUSSION

118 The Fig 2 shows the average monthly variations of the climatic elements required to
 119 calculate the reference evapotranspiration, which were obtained at the meteorological station
 120 of the Federal Institute of Mato Grosso, municipality of Santo Antônio do Leverger, MT,
 121 located in the southeast of the state of Mato Grosso, Brazil, in the period of 2010 and 2011.

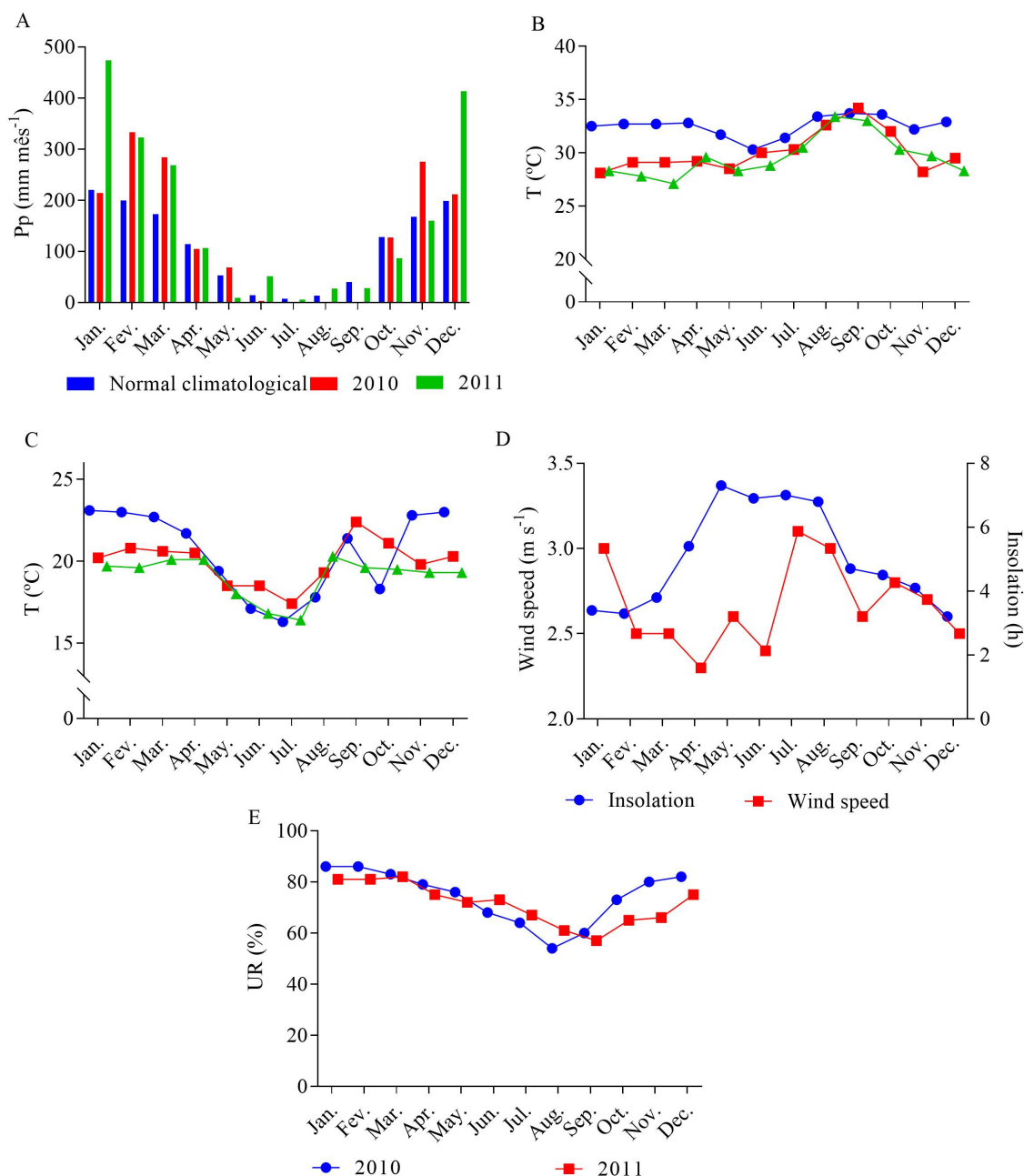


Fig 2. Precipitation values (A), maximum temperature (B), minimum temperature (C), wind speed and solar insolation (D) and relative humidity (E) from the main climatological station of São Vicente da Serra, in Years of 2010 and 2011, as well as the normal climatological in terms of rainfall (1961-1991).

The precipitation during the period of the experiment, in general, had a behavior close to that of the climatological normal, with the rainy season comprising the months of october to april and the dry season the months of may to september. The intensity of the precipitation in the period of the experiment exceeded the climatological normal in the months of january, february, march, november and december, highlighting the month of january of 2011 in which the total precipitation corresponded to more than twice the rain expected for the normal climatic conditions (Fig 2A).

For the whole period of the experiment, the maximum temperatures were below the climatological normal, except in the period from june to september. The behavior of the minimum temperatures for the period of the experiment was close to that of the climatological normal, except in the months of January, February and March with values below the normal climatological. Among the months, the highest and lowest temperatures were observed between september and april, corresponding to the rainy season, and milder temperatures in the months of may to august (Fig 2A).

The behavior of the sunshine indicated that the smallest number of hours of sunshine occurred in the period from october to april, due to increased cloudiness in the rainy season of the region that is characterized by the presence of intense convective activity in the months of higher radiative heating (Fig 2B). The wind speed over the months studied varied around 2.7 m s^{-1} (Fig 2B).

The behavior of medium air (Fig 2C), precipitation and maximum and minimum temperatures characterize the rainy summer with high temperatures and a dry winter with milder temperatures in the studied region. Similar results were found by Souza *et al.* (2013) when, studying the 13 climatological stations of the state of Mato Grosso, proposed the climatic water balance and the climatic classification of the state.

152 The Fig 3 shows the daily values of reference evapotranspiration (E_{t0}) calculated by the
 153 PNM, IV, RS and BC methods for the years 2010 and 2011, in four seasons of the year, being
 154 chosen according to their importance in defining The seasons by the solstices (winter/June
 155 and summer/december and equinoxes (autumn/march and spring/september).

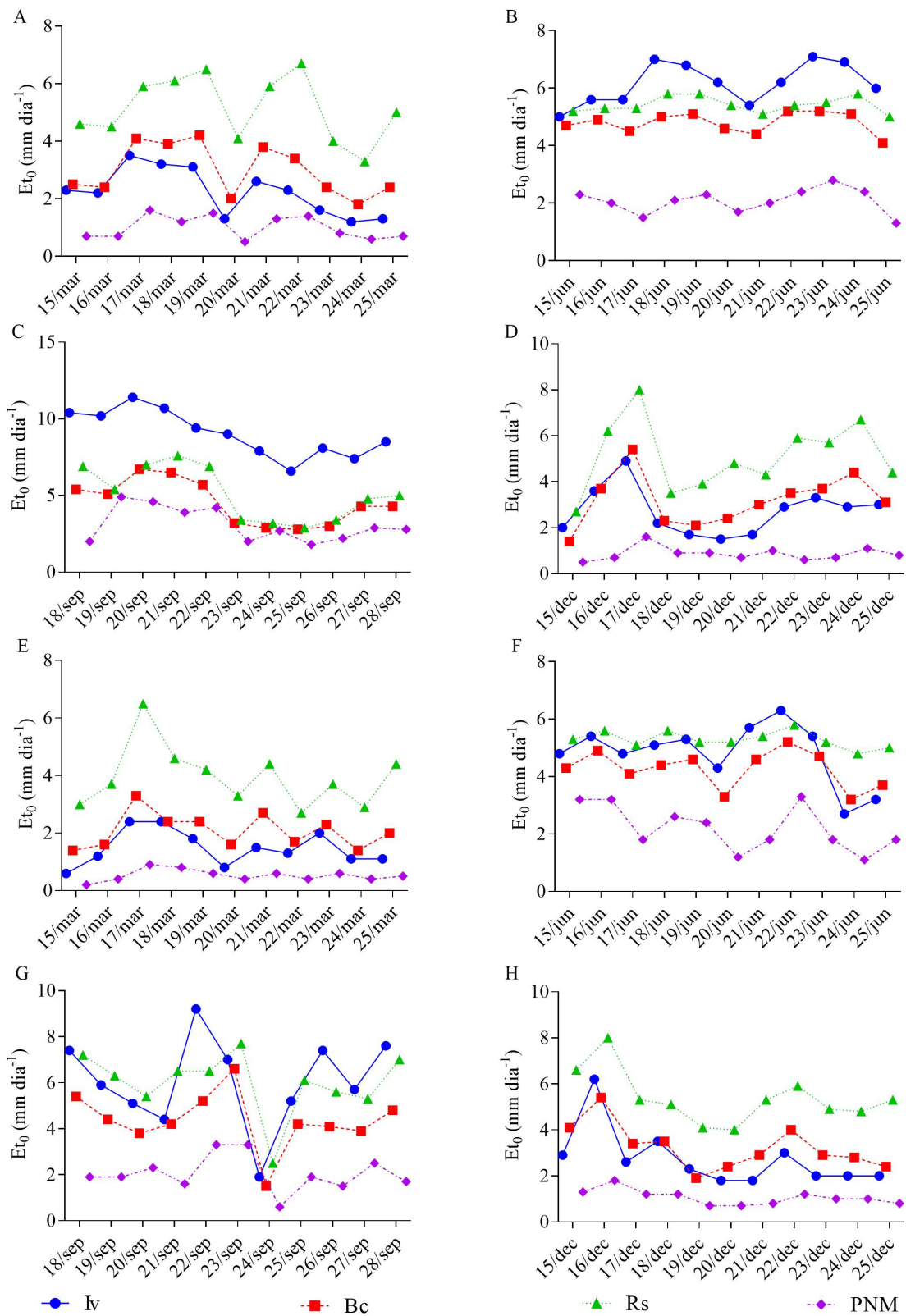


Fig 3. Daily behavior of reference evapotranspiration (E_t) by Penman-Monteith (PNM-FAO 56) (PMN), Blaney-Criddle (BC), Solar Radiation (RS) and Ivanov (IV) for 2010 (A, B, C and D) and 2011 years (E, F, G and H).

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), 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.* (2011) 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. Similar behavior was observed by Alencar *et al.* (2011).

The values for the parameters of the regression equation (a and b) were significant ($P < 0.05$) in all cases. The determination coefficients obtained between the reference evapotranspiration estimated on a daily scale by the PNM method and by the BC, RS and IV methods for the years 2010 and 2011 (Fig 4) were 0.80, 0.78 (Fig 4A, 4E), 0.69, 0.78 (Fig 4B, 4F) and 0.59, 0.55 (Fig 4C, 4G), for the BC, RS and IV methods, respectively.

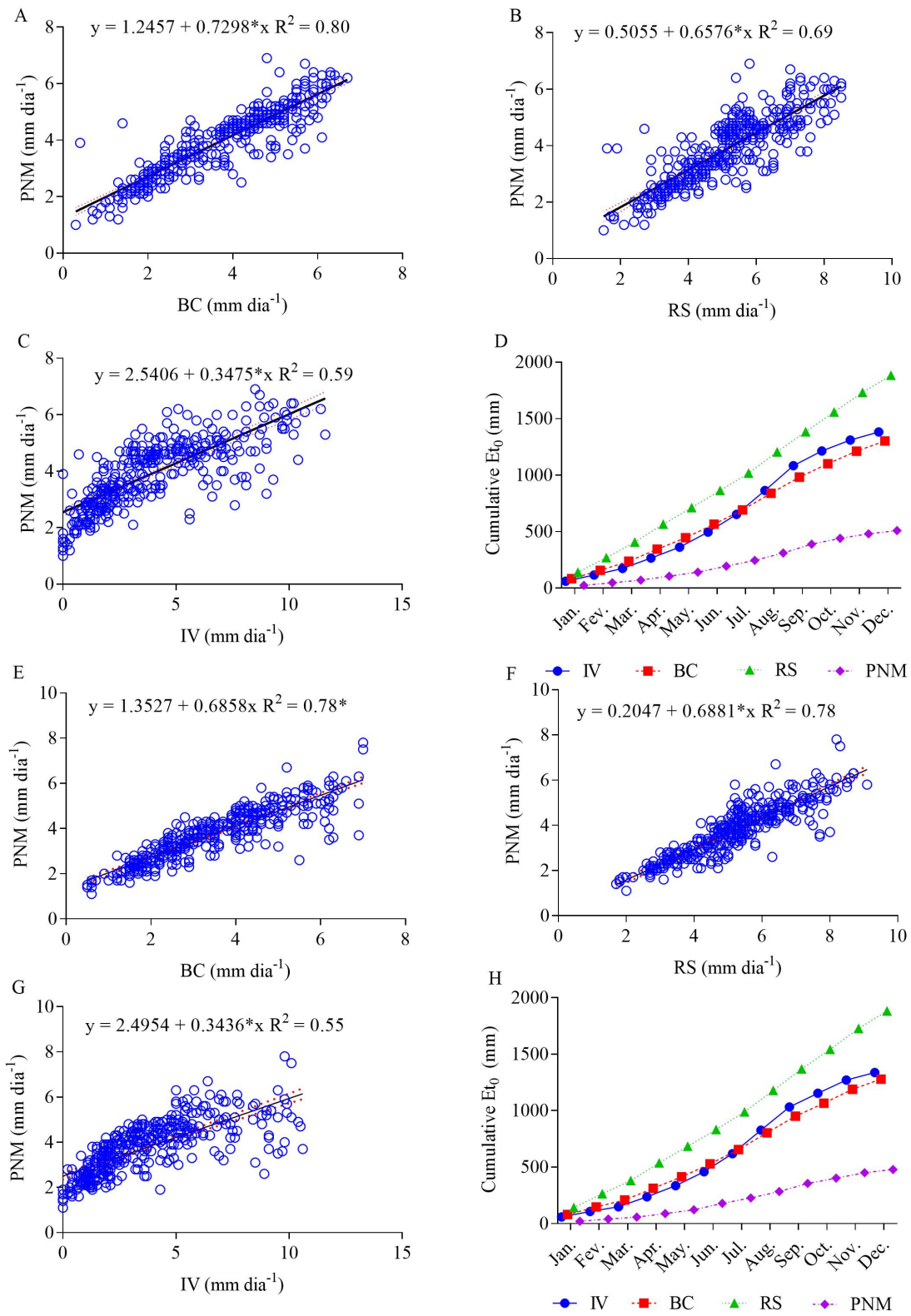


Fig 4. Coefficient of determination (r^2) between the reference evapotranspiration values obtained by the Penman-Monteith method (PNM) and the reference evapotranspiration obtained by the Blaney-Criddle (BC) method (A); Penman-Monteith method (PNM) (mm d^{-1}) and the reference evapotranspiration obtained by the Solar Radiation (RS) method (mm d^{-1}) (B); Penman-Monteith method (PNM) (mm d^{-1}) and the reference evapotranspiration obtained by the Ivanov (IV) method (mm d^{-1}) (C); and the cumulative average evapotranspiration by the different methods in 2010 (D) and 2011 (E, F, G and H). $*(P<0.05)$.

According to Fig 4A and 4E, a good correlation was found between the BC method and the Penman-Monteith method (FAO 56); on the other hand, the RS and IV methods presented low coefficient of determination when plotted using the PNM method (FAO 56).

Although the RS and IV methods showed the lowest correlation indices with the standard Penman-Monteith method (FAO 56), they were classified as "very good" by the classification of index c and as "very high" in the index R of Camargo and Sentelhas (1997). Furthermore, the RS and IV methods showed concordance indices, according to Willmott (1982), of 0.97 and 0.97, respectively (Table 2).

Table 2. Results of the 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

198

199 The BC method presented the best performance among the methods in that it presented
200 coefficient of determination (r^2) of 0.80 (Fig 4) and agreement index of 0.99 (Table 2),
201 confirming good agreement with the standard method (Table 1), according to the
202 interpretation of Camargo and Sentelhas (1997).

203 Comparing PNM with RS, it was obtained the value of 0.97 for the concordance index
204 (d), indicating a good agreement between the methods. For the confidence index (c) and
205 correlation coefficient (r), it was obtained values of 0.83 and 0.85, respectively; therefore, the
206 confidence and high accuracy were lower than the BC method. Although the RS method has
207 performed well, it is a method that requires more meteorological data, which are often not
208 available in the region, making it difficult to use. Tanaka et al. (2016) verified an
209 overestimation of E_{t0} with the use of the RS method in evaluations in the state of Mato
210 Grosso, indicating that this method requires local calibrations for reliable estimation of E_{t0} .

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

217 Mendonça *et al.* (2003), comparing different methods of estimation of reference
218 evapotranspiration and comparing them with the estimation of the class A tank, for the
219 northern region of Rio de Janeiro, Brazil, observed that the solar radiation method tended to
220 overestimate E_{t0} by 25.7 %. In turn, Tagliaferre *et al.* (2010) with the same objective, verified
221 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.* (2011) 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.

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.* (2011) and Melo and Fernandes (2012). 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.

4. CONCLUSIONS

The Blaney-Criddle reference evapotranspiration method was the method that presented the best estimates when compared to the Penman-Montheith (FAO 56) standard for the southeast region of Mato Grosso state.

The Blaney-Criddle reference evapotranspiration method can effectively replace the Penman-Montheith method (FAO 56) for the southeast region of the state of Mato Grosso in that it requires less data and these are easily obtained.

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

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