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COEFICIENTE DE CULTIVO PARA CENOURA SOB A PERSPECTIVA DE DIFERENTES MODELOS MATEMÁTICOS DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA

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1 RESUMO

O coeficiente de cultivo (Kc) é um parâmetro essencial para o dimensionamento e manejo dos sistemas de irrigação e uso racional da água. Dessa forma, o objetivo neste trabalho foi determinar o coeficiente de cultivo da cenoura (*Daucus carota* L.) por meio de diferentes modelos matemáticos da evapotranspiração de referência no Agreste alagoano. O experimento foi realizado na área experimental do *Campus* da Universidade Federal de Alagoas (UFAL), Arapiraca-AL. Foram utilizados três lisímetros de drenagem, instalados em canteiro com dimensões de 3,5 x 1,0 m de comprimento e largura respectivamente com área total de 3,5 m^2. O Kc foi obtido pela relação entre a evapotranspiração da cultura (ETc) e a evapotranspiração de referência (ETo) estimada pelos métodos de Penman-Monteith, padrão-FAO (PM), Hargreaves-Samani (HS), Radiação Solar (RS), Blaney-Criddle (BC) e de Priestley-Taylor (PT). Os valores de Kc obtidos foram: KcPM (0,61; 1,00; 1,26 e 0,99), KcHS (0,63; 1,09; 1,27 e 0,94), KcRS (0,65; 1,03; 1,36 e 1,06), KcBC (0,69; 1,11; 1,52 e 118) e KcPT (0,67; 1,08; 1,25 e 0,99) para as fases inicial, crescimento, intermediária e final, respectivamente. Na ausência de informações agrometeorológicas para se estimar a ETo pelo método padrão, recomendam-se utilizar os valores de obtidos pelo método de Blaney-Criddle.

Keywords: *Daucus carota*, lisimetria, dados climáticos, manejo da irrigação.

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2 ABSTRACT

The crop coefficient (Kc) is an essential parameter for the design and management of irrigation systems and rational reasonable water. Thus, the aim of the present work was to determine the crop coefficient of the carrot (Daucus carota L.) through different mathematical models of the reference evapotranspiration in the Agreste alagoano. The experiment was performed in the experimental area of the Campus of the Federal University of Alagoas (UFAL), Arapiraca-AL, Brazil. Three lysimeters of drainage were used, installed on a bed with dimensions of 3.5 x 1.0 m in length and width, respectively, with a total area of 3.5 m2. The Kc was obtained from the relationship between crop evapotranspiration (ETc) and reference evapotranspiration (ETo) estimated using the methods of Penman-Monteith-FAO (PM), Hargreaves-Samani (HS), Solar Radiation (SR), Blaney-Criddle (BC) and Priestley-Taylor (PT). The values of Kc obtained were KcPM (0.61; 1.00; 1.26 and 0.99), KcHS (0.63; 1.09; 1.27 and 0.94), KcSR (0.65; 1.03; 1.36 and 1.06), KcBC (0.69; 1.11; 1.52 and 118) and KcPT (0.67; 1.08; 1.25 and 0.99) for the initial, growth, intermediate and final phases, respectively. In the absence of agrometeorological information to estimate ETo by Penman-Monteith-FAO method, it is recommended to use the values obtained by Blaney-Criddle ETo method.

Keywords: *Daucus carota*, lysimetry, climate data, irrigation management.

3 INTRODUCTION

The carrot *Daucus carota* L., which belongs to the Apiaceae family, is native to Southwest Asia, Afghanistan (FILGUEIRA, 2008). It is cultivated on a large scale in the Central-West, Southeast, Northeast and South Regions of Brazil (CARVALHO; SILVA; RESENDE, 2017). In the Agreste region of Alagoas, carrot production has favorable climatic conditions for its development. However, since water is such a scarce and limited resource in this region, the use of irrigation is essential to increase productivity, since precipitation is scarce or irregular and the evapotranspiration rate is high (LUCENA et al., 2016).

Identifying the correct amount and time of irrigation for carrots, as well as for other crops, is not easy, as there are factors such as the climatic conditions of the region, the soil water balance and the physiological characteristics of the plant that must be considered, as they are important in calculating irrigation depths (CARVALHO; OLIVEIRA, 2012).

Irrigation management depends mainly on knowledge of the real needs of crops. Therefore, the use of the cultivation coefficient (Kc) is highly important. This coefficient is obtained on the basis of crop evapotranspiration (ETc) and reference evapotranspiration (ETo). Its estimates allow the determination of the amount of water to be used during all phases of crop development (SILVA et al., 2018). It is, therefore, an essential parameter for the sizing and management of irrigation systems and the rational use of water (ALVES et al., 2017; DIVINCULA et al., 2019). One of the methods used to determine crop evapotranspiration (ETc) is through lysimeters, which, in turn, are considered the main equipment for direct measurement of evapotranspiration and for determining the water balance, with the main advantages of promoting reliable estimates and more accurate readings. (MIRANDA et al., 2016).

The Penman–Monteith method, parameterized by the Food and Agriculture Organization (FAO) (ALLEN et al., 1998), is recommended for estimating reference evapotranspiration (ET0). It requires a greater number of meteorological elements, which are often unavailable, thus leading to the search for simpler estimation methods that employ fewer variables, such as the Hargreaves-Samani, Solar Radiation, Blaney-Criddle, and Priestley-Taylor methods (LUCENA et al., 2016).

Therefore, the objective of this work was to determine the carrot cultivation coefficient through different mathematical models of reference evapotranspiration in the Agreste region of Alagoas.

4 MATERIALS AND METHODS

4.1 Characterization of the experimental area

The experiment was carried out in the experimental area of the Irriga Group, Arapiraca Campus of the Federal University of Alagoas (UFAL) in the municipality of Arapiraca-AL, with the following geodetic coordinates (latitude 9° 45' 09” South, longitude 36° 39' 40” W and altitude of 264 meters). The climate in the region is tropical 'As', according to the classification of (KÖPPEN, 1949). The rainy season begins in May and lasts until the first half of August, with an average rainfall of 854 mm year^{-1}, with May to July being the rainiest months and September to December the driest (XAVIER; DORNELLAS, 2010). The soil is classified as Dystrophic Red Argisol (EMBRAPA, 2013).

To determine crop evapotranspiration (ETc), three drainage lysimeters were constructed from circular plastic containers with dimensions of 0.30 × 0.30 m in diameter and depth, corresponding to an area of 0.07 m². The installation of the equipment began with the manual excavation of trenches with dimensions of 0.50 × 0.50 m, and the soil was removed in two layers (0–15 cm and 15–30 cm). As these layers were removed from the soil, they were identified and stored on site so that the initial soil conditions could later be reconstituted.

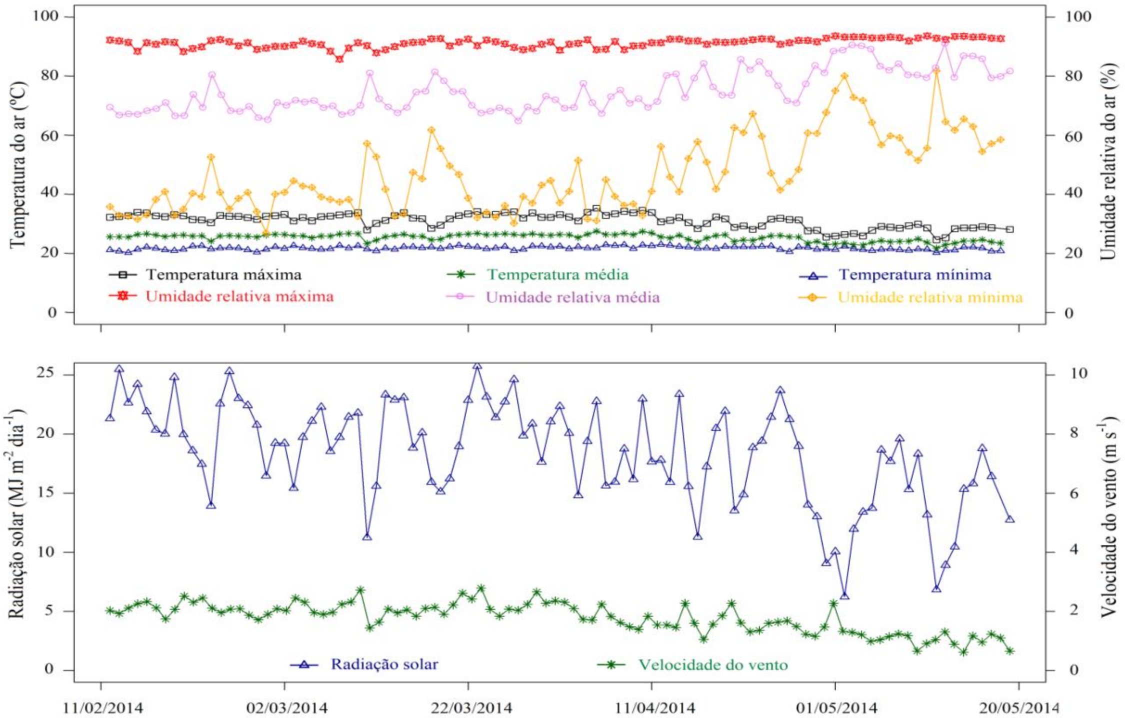
The experiment was conducted in a plot measuring 3.5 × 1.0 m in length and width, with a total area of 3.5 m², where three drainage lysimeters were installed. The plot consisted of three rows of plants spaced 0.25 m apart. The lysimeters were installed in the center row, which corresponds to the second row. A drip irrigation system with a flow rate of 1.0 L h^{-1} was used to irrigate the carrot growing area and supply water to the lysimeter array.

Carrots (cultivar Brasília) were planted on February 10, 2014. Thirty days after planting (DAP), thinning was carried out, and the plants were spaced 5.0 cm apart. The lysimeters were saturated for 24 hours, and then, the drains were opened to allow free water to drain; thus, the soil reached field capacity. Carrots were then planted, and the first water was applied to the lysimeters.

4.2 Meteorological variables

The average minimum, mean and maximum daily temperatures during the growing period were 21.80, 25.39 and 31.11 °C, respectively. The average minimum, mean and maximum relative humidities were 47.00, 75.08 and 91.29%, respectively. The average wind speed was 1.77 ms^{-1}, and the average radiation was 18.38 MJ m^{-2} (Figure 1).

Figure 1 Data on relative air humidity (maximum, average and minimum), air temperature (maximum, average and minimum), solar radiation and wind speed of the experimental area of the Irriga Group of the Arapiraca Campus, UFAL**.**



4.3 Estimation of reference evapotranspiration (ETo)

To estimate the reference evapotranspiration (ETo), the Penman–Monteith (FAO standard), Hargreaves–Samani, Solar Radiation, Blaney–Criddle and Priestley–Taylor methods were used to correlate the FAO standard with the other methods.

4.3.1 Penman–Monteith

The Penman–Monteith model (FAO-standard) is described by Allen et al. (1998), Equation 1:

$$\text{ETo} = \frac{0{,}408\,\Delta\,(\text{Rn}-\text{G}) + \gamma\left(\frac{900\,\text{U}_2}{\text{T}+237}\right)\text{U}_2\,(\text{e}_a - \text{e}_s)}{\Delta + \gamma\,(1+0{,}34\,\text{U}_2)} \quad (1)$$

where ETo = reference evapotranspiration (mm day $^{-1}$); Rn = daily radiation net (MJ m $^{-2}$ day $^{-1}$); G = total daily soil heat flux (MJ m $^{-2}$ day $^{-1}$); T = mean daily air temperature (°C); U_2 = mean daily wind speed at a height of 2 m (ms $^{-1}$); e_s = mean daily vapor saturation pressure (kPa); ($e_a - e_s$) = mean daily vapor saturation deficit (kPa); Δ = slope of the vapor pressure versus temperature curve (kPa°C^{-1}); and γ = psychrometric coefficient (kPa°C^{-1}).

4.3.2 Hargreaves–Samani

The Hargreaves–Samani method for estimating daily (ETo) in mm day-1 (Equation 2) is as follows according to Pereira, Vila Nova and Sediyama (1997):

$$\text{ETo} = 0{,}0023\ \text{Ra}\,(T_{med} + 17{,}8)\sqrt{\text{T}_{\max} - \text{T}_{\min}} \quad (2)$$

where ETo = reference evapotranspiration (mm day $^{-1}$); Ra = extraterrestrial radiation (MJ m^{-2} day^{-1}); T_{med} = average daily temperature (°C); T_{max} = maximum temperature (°C); and T_{min} = minimum temperature (°C).

4.3.3 Solar Radiation

To calculate the ETo estimate via the solar radiation method, which was proposed by Doorenbos and Pruitt (1977), Equations 3 and 4 were used:

$$ETo = a + b\,W\,\frac{Rs}{\lambda} \quad (3)$$

$$b = b_0 + b_1\,UR_{med} + b_2\,U + b_3\,UR_{med}\,U + b_4\,UR^2 + b_5\,U^2 \quad (4)$$

where ETo = reference evapotranspiration (mm day^{-1}); a = linear coefficient of the straight line (a = -0.3 mm day^{-1}); b = angular coefficient of the straight line (b_0 = 1.0656; b_1 = -0.0012795; b_2 = 0.044953; b_3 = -0.00020033; b_4 = -0.000031508; b_5 = -0.0011026); W = weighting index dependent on the average temperature, where W = 0.407 + 0.0145 T_{med} (for 0°C < T_{med} < 16°C); W = 0.483 + 0.01 T_{med} (for T_{med} ≥ 16°C); Rs = shortwave solar radiation received by the Earth's surface in a horizontal plane, expressed in evaporation equivalent (MJ m^{-2} day^{-1}); λ = latent heat of evaporation (MJ kg^{-1}); RH_{med} = average relative humidity (%); U = average wind speed at a height of 2 m (ms^{-1}); and T_{med} = average temperature (°C).

4.3.4 Blaney-Criddles

The Blaney-Criddle estimate of ETo, the version of Doorenbos and Pruitt (1977) modified by Frevert, was used. et al . (1983) according to Equations 5, 6 and 7, with the “tabulated p” value adapted by the southern latitude coefficient and time of year (Julian day), as per Equation 8:

$$ETo = A + B\,p\,(0{,}457\,T_{med} + 8{,}13) \quad (5)$$

$$A = a_0\,UR_{min} + a_1 - \frac{n}{N} \quad (6)$$

$$B = b_0 + b_1\,UR_{min} + b_2\,\frac{n}{N} + b_3\,U_2 + b_4\,UR_{min}\,\frac{n}{N} + b_5\,UR_{min}\,U_2 \quad (7)$$

$$p = -3\,.\,10^{-11}\,.\,J^4 + 2\,.\,10^{-8}\,.\,J^3 - 4\,.\,10^{-6}\,.\,J^2 + 5\,.\,10^{-5}\,.\,J + C \quad (8)$$

where ETo = reference evapotranspiration (mm day^{-1}); “A” and “B” = adjustment coefficients (correction factor), where a_0 = 0.0043, a_1 = -1.41, b_0 = 0.81917, b_1 = -0.0040922, b_2 = 1.0705, b_3 = 0.065649, b_4 = - 0.0059684 and b_5 = - 0.0005967; p = correction factor depending on latitude and time of year, J = Julian day; C = coefficient of latitude and time of year (C= 0.26 for 270 ≤ J ≤ 330; C= 0.27 for 91 < J < 120, 210 < J < 270, J > 330; C= 0.28 for J ≤ 91, 151 ≤ J ≤ 210 and C= 0.29 for 120 ≤ J ≤ 150); T_{med} = average temperature of the period (°C); RH_{min} = minimum relative humidity of the period (%); U_2 = average wind speed at a height of 2 m (ms^{-1}); and n/N = ratio of insolation of the period by the photoperiod (hours), where

4.3.5 Priestley–Taylor

The physical method of Priestley and Taylor (1972), developed in Australia, uses the radiation balance variable (Rn) to estimate ETo, considering it to come from the aerodynamic term, that is, from the evaporating power of the air, with a percentage of ETo being conditioned by an energy term based on the original Penman method. Thus, even when the energy balance is considered, this method presents an empirical component (equation (9)).

$$\mathrm{ETc} = \alpha \left(\frac{\Delta}{\Delta + \gamma}\right)\left(\frac{Rn - G}{\lambda}\right) \quad (9)$$

where ETo = reference evapotranspiration (mm day^{-1}); α = adjustment factor universally known as the Priestley-Taylor parameter, α = 1.26; Δ = slope of the vapor pressure curve in relation to temperature (kPa $°C^{-1}$); γ = psychrometric coefficient (kPa $°C^{-1}$); Rn = net radiation (MJ m^{-2} day^{-1}); and G = soil heat flux (MJ m^{-2} day^{-1}), with G = 0 and λ = latent heat of evaporation (MJ kg^{-1}).

4.4 Determination of crop evapotranspiration (ETc)

To determine the ETc of carrots, daily irrigation depths were applied, always at 10:00 a.m., and drainage lysimeters were used to measure the amount of water supplied in the lysimeters and drain the excess water. ETc was calculated via the methodology described by Alves et al. (2017), Equation 10:

$$\mathrm{ETc} = \frac{\mathrm{I} + \mathrm{P} - \mathrm{D}}{A} \quad (10)$$

where ETc = Crop evapotranspiration (L); P = Rainfall (L); I = Water depth applied by irrigation (L); D = Water drained from the lysimeter (L); and A = Lysimeter area (m^2).

ETo methods

For analysis and comparison between the ETo methods, criteria involving the standard error of estimate (EPE), adjusted standard error of estimate (EPEa), adjustment coefficients of the linear equations and respective correlation (r) and determination (r^2) coefficients were used (JENSEN; BURMAN; ALLEN, 1990). The statistical software RStudio® was used for correlation and linear regression analyses and to construct their respective graphs between the ETo methods analyzed.

The performance index (c) was determined via the product of Pearson's correlation coefficient (r) and the concordance index (d) of Willmott et al. (1985). A correlation was performed between the Hargreaves–Samani, Solar Radiation, Blaney–Criddle and Priestley–Taylor methods in relation to the standard Penman–Monteith method to obtain the precision given by the correlation coefficient (r), which is associated with the deviation between estimated and measured values, indicating the degree of dispersion of the data obtained in relation to the mean. The values found for “r” and “c” were classified according to Willmott et al. (1985).

4.6 Cultivation coefficient (Kc)

From the values of ETo and crop evapotranspiration (ETc), the crop coefficients were determined for each water balance under the experimental conditions through the relationship between ETc, which was obtained from the water balance in the lysimeters, and ETo (Equation 11). A Kc value was determined for each phenological phase of the carrot crop.

$$Kc = \frac{ETc}{ETo} \quad (11)$$

where Kc = the crop coefficient (dimensionless), ETc = crop evapotranspiration (mm day^{-1}), and ETo = reference evapotranspiration (mm day^{-1}).

For the purpose of calculating carrot cultivation coefficients (average values), the crop cycle was divided into four phenological phases, defined according to the methodology of Doorenbos and Pruitt (1975), as follows: initial phase (0--20 days); II) growth phase (21--50 days); and III) intermediate phase (51--80 days) and IV) final phase (81--99 days).

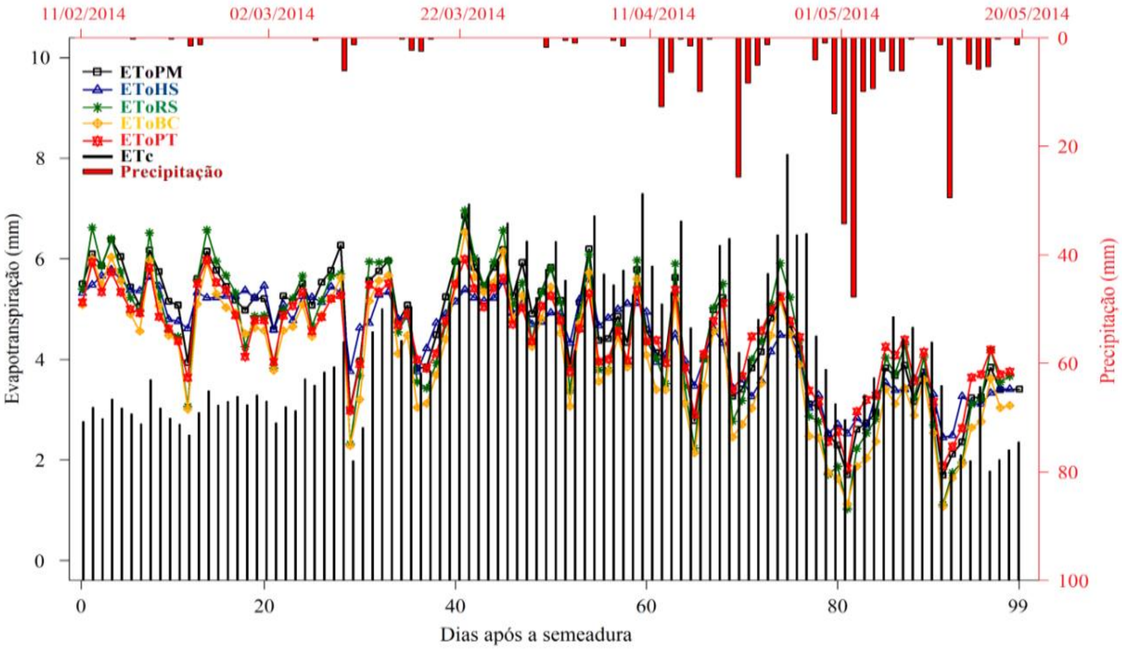
5 RESULTS AND DISCUSSION

5.1 ETo and ETc in carrot cultivation

The ETo estimates via the Penman–Monteith, Hargreaves–Samani, Solar Radiation, Blaney–Criddle and Priestley–Taylor methods, the ETc and the rainfall distribution for the period from February 11--May 20, 2014, are shown in Figure 2. The ETo values estimated by the standard FAO Penman–Monteith method varied between 1.69 mm day $^{-1}$ and 6.86 mm day $^{-1}$ for May 12 and March 23, respectively, with an average value of 4.58 mm day $^{-1}$. Throughout the crop cycle, the ETo estimated by the solar radiation and Priestley-Taylor methods had greater similarities to the FAO standard method (Penman–Monteith), with the first overestimating it at the beginning of the cycle (with a difference between the total ETs of 13.89 mm) and the second overestimating it at the end of the cycle (with a difference of 15.89 mm). The Hargreaves–Samani method overestimated the FAO standard method, presenting the smallest difference throughout the cycle (13.88 mm between the ETs). The Blaney–Criddle method had the largest difference from the FAO standard method (50.70 mm), underestimating it throughout the cycle.

The Penman–Monteith method (FAO standard) had a lower maximum value for ETo than did the solar radiation method and a higher minimum value than did the Hargreaves–Samani method, with the average and total ETo values being higher than those of all the other methods, thus indicating that if any of the other methods are to be used, equational adjustments will be necessary (Figure 2). Estimation methods that use only air temperature as a climate variable limit the representativeness of climate conditions for the purpose of estimating reference evapotranspiration, since depending on humidity and wind conditions, the atmospheric water demand will be different for the same air temperature values (CONCEIÇÃO, 2003).

Figure 2. Evapotranspiration: reference (ETo) estimated by the Penman–Monteith (EToPM) method; Hargreaves–Samani (EToHS) method; Solar Radiation (EToRS) method; Blaney–Criddle (EToBC) method; Priestley–Taylor (EToPT) and carrot crop (ETc) methods; and rainfall distribution (precipitation) during the experimental period.



The crop evapotranspiration (ETc) of the carrot cultivar Brasília in the Agreste region of Alagoas was 425.45 mm (Table 2). These values are close to those reported by Rocha (2003), who reported an ETc of 466.92 mm for carrots (cultivar Brasília) in Viçosa, Minas Gerais. In the same region of the present study and with a similar rainfall period, Silva et al. (2018) obtained a water consumption, measured with drainage lysimeters, of 421.00 mm for carrots (91-day cycle). Santos et al. (2009), under the edaphoclimatic conditions of the Agreste region of Pernambuco, reported that the average water consumption of carrot crops was much greater than that reported in the present study, with a value of 811.84 mm for a 98-day cycle. This high value can be explained by the high ETo in the cultivation period, which presented a greater scarcity of rain, climatic conditions that differ from those found in the period of this work (Figure 2).

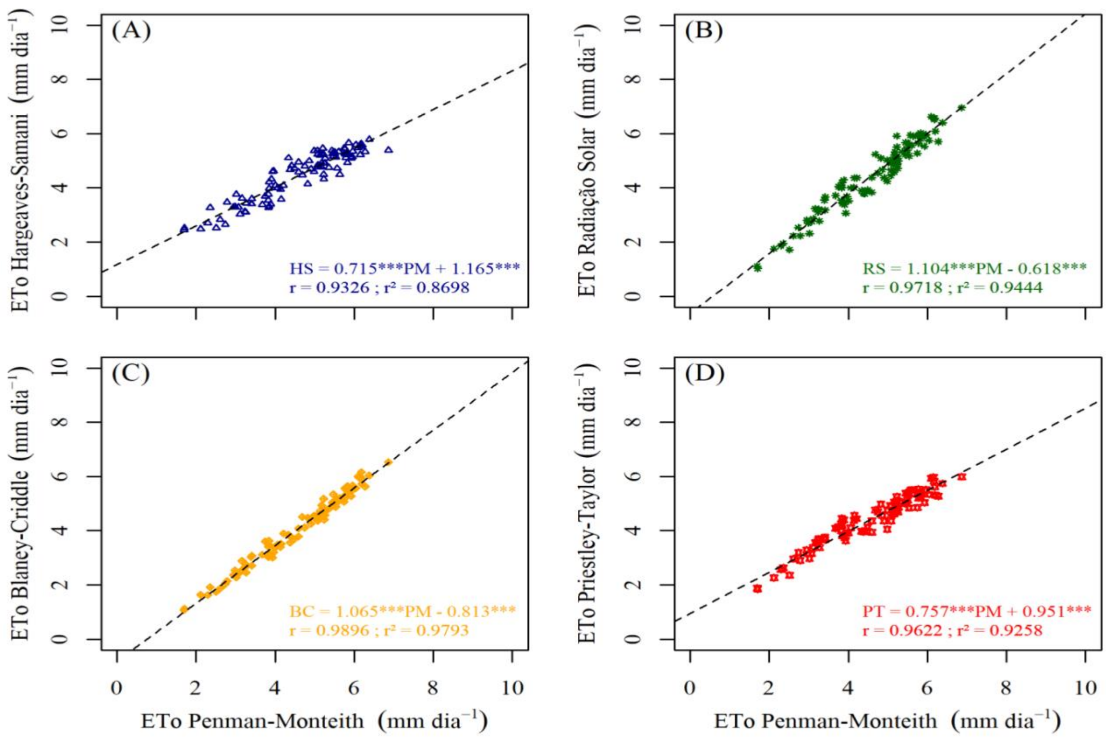
Initially, small variations in crop water demand were observed, with values always below EToPM during the first 30 days after sowing (DAS), since during this period, there was greater loss through evaporation due to the minimum percentage of soil cover. After 30 DAS, a gradual increase in consumption was observed, with values close to those of EToPM and exceeding those of EToPM after 50 DAS (Figure 2). At 50 DAS, the vegetative growth and flowering phases occur. During this period, the plants present a greater number of leaves, consequently increasing the area of soil cover. Thus, water loss through the system occurs mainly through transpiration, unlike the initial phase, in which the process occurs mainly through evaporation and decreases again after 90 DAS (fruiting phase) (Figure 2). According to Bezerra and Mesquita (2000), the variation in water consumption, in terms of ETc, observed during crop development can be associated solely with variations in climatic conditions.

Importantly, during this period, the highest rainfall rates occurred, with the highest rainfall of 47.75 mm (02/05/2014) and a total of 277.11 mm. It can also be observed that the highest ETo and ETc values occurred at the beginning (last month of summer), decreasing with the beginning of autumn and the rainy season in the semiarid region.

5.2 ETo methods

Figure 3 presents the correlation analysis performed by comparing the Hargreaves-Samani, Solar Radiation, Blaney-Criddle, and Priestley-Taylor methods with the standard Penman–Monteith method, which is used to calculate ETo during the carrot growing season. The angular coefficients of the lines obtained via the ETo equations Hargreaves-Samani x ETo Penman–Monteith and ETo Priestley - Taylor x ETo Penman–Monteith presented values less than 1 (at ~ 0.7), indicating that the values contained in the ETo Penman–Monteith method are superior to those found via the Hargreaves-Samani and Priestley - Taylor methods (Figures 3A and 3D). The angular coefficients of the equations obtained by the ETo Solar Radiation x ETo correlations Penman–Monteith and ETo Blaney-Criddle x ETo Penman–Monteith present higher values very close to 1, indicating that the ETo values found by the Solar Radiation and Blaney-Criddle methods are close to those of Penman–Monteith (Figures 3B and 3C).

Figure 3. Correlation between the daily values of reference evapotranspiration (mm day $^{-1}$) estimated via the Penman–Monteith method and the Hargreaves–Samani (A), Solar Radiation (B), Blaney–Criddle (C) and Priestley–Taylor (D) methods.

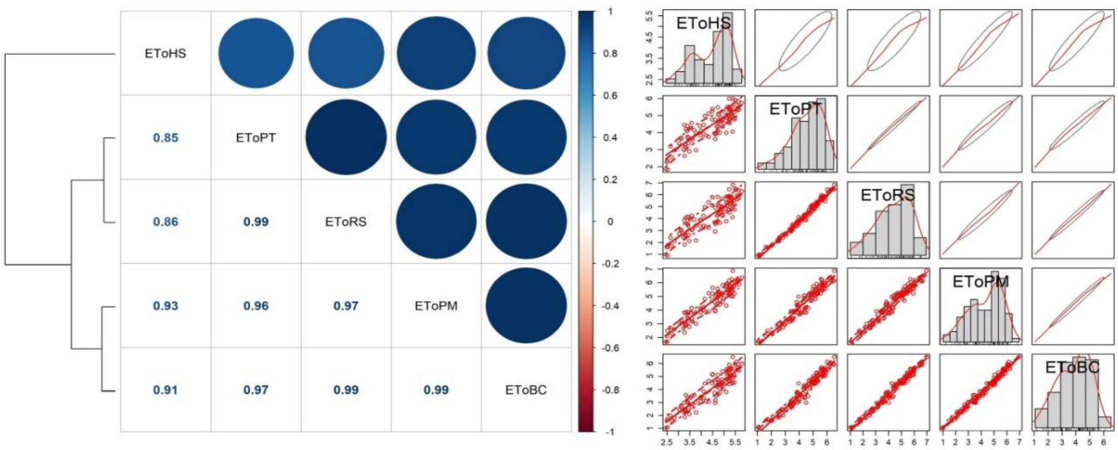


*** significant at the 0.01% level according to the F test.

Silva et al. (2018) evaluated the carrot crop coefficient in the Agreste region of Alagoas and reported angular coefficients of the lines similar to those reported in this research. When comparing the same ETo methods analyzed here, the authors obtained angular coefficients greater than 1 for the Solar Radiation, Blaney-Criddle, and Priestley-Taylor methods (the latter with values very close to 1) and less than 1 for the Hargreaves-Samani method. Similarly, Santos et al. (2020), researching the irrigation management of malagueta pepper in the Agreste region of Alagoas, performed correlations with the same ETo methods studied in this research, finding values of angular coefficients of the lines less than 1 (underestimating) for the Hargreaves–Samani and Priestley–Taylor methods (a ≈0.6) and values greater than 1 for the Solar Radiation and Blaney–Criddle methods. Therefore, the ETo values are correlated between the methods, even though they were analyzed in different growing seasons.

Figure 4 presents the evaluation and quality of the adjustment, observed by the correlation between the ETo values for the Penman–Monteith, Hargreaves–Samani, solar radiation, Blaney–Criddle and Priestley–Taylor methods through hierarchical cluster analysis, correlation coefficient, dispersion, confidence regions, histogram, density estimation and ellipses.

Figure 4. Cluester clustering, correlation coefficient, dispersion, confidence regions, histogram, density estimate, ellipses of ETc (mm day^{-1}) and ETo values via the Penman–Monteith, Hargreaves–Samani, solar radiation, Blaney–Criddle and Priestley–Taylor methods.



The correlation metric predictions demonstrate that cluster grouping indicates that the best correlation found between the methods was between solar radiation and Priestley-Taylor (r^2 = 98.25%), followed by Penman–Monteith (FAO standard) and Blaney-Criddle (r^2 = 97.91%). Hargreaves-Samani, on the other hand, was distant and isolated from the other methods, indicating that it would be the last correlation option. The scattered points, along with the trend line, confidence region, and ellipses, indicate that the observed values have a strong positive correlation with the ETo method values, confirming the results obtained via cluster grouping.

Research carried out in the Agreste region of Alagoas by Santos et al. (2016) revealed that the estimate via the Hargreaves–Samani method was lower than that via the Penman–Monteith method. In the study developed in Ceará by Lima Junior et al. (2016), the Hargreaves–Samani method was found to underestimate ETo in relation to that of the FAO standard Penman–Monteith method. Tagliaferre et al. (2010) reported that the Priestley-Taylor method underestimated the evapotranspiration values obtained via the FAO standard method for the climatic conditions of the municipality of Eunápolis, BA. Moreover, in the work of Moura et al.

(2013), in Vitória de Santo Antão-PE, an overestimation of the Blaney-Criddle method in relation to the FAO standard Penman–Monteith method was observed.

The EPE and EPEa values were less than 0.55, indicating a good correlation between the ETo methods Hargreaves-Samani, Solar Radiation, Blaney-Criddle and Priestley-Taylor and the FAO standard (Penman--Monteith) (Table 1). Similarly, the coefficients of determination (r^2) and correlation (r) and the indices of agreement (d) and performance (c) were classified as good.

Table 1. Standard error of estimate (EPE) and adjusted estimate (EPEa), coefficients of determination (r^2) and correlation (r), agreement (d) and performance (c) indices between the Hargreaves-Samani (EToHS), Solar Radiation (EToRS), Blaney-Criddle (EToBC) and Priestley-Taylor (EToPT) methods and the standard Penman–Monteith method (EToPM).

ETo $_{(PM)}$ x ...	**EPE**	**EPEa**	**r^2**	**r**	**D**	**w**
EToHS	0.4981	0.3737	0.8720	0.9338	0.9435	0.8811
EToRS	0.3697	0.1860	0.9452	0.9722	0.9789	0.9517
EToBC	0.5524	0.5200	0.9792	0.9895	0.9529	0.9429
EToPT	0.4214	0.3354	0.9274	0.9630	0.9612	0.9257

Silva et al. (2018), studying the same region as the present study, reported that the ETo correlation of the Hargreaves–Samani method with the FAO standard (Penman–Monteith) presented high values of EPE and EPEa, with low values of correlation coefficients (r) and determination (r^2), also indicating poor performance (d; c). For the solar radiation method, high values of correlation coefficients (r) and determination (r^2) were found, and the method was classified as having good performance; however, for the errors (EPE and EPEa), high values were found, indicating that the method was not suitable for the region or period of study. For the Blaney-Criddle method, high values of correlation coefficients (r) and determination (r^2) were found, and the method was classified as having very good performance for the values of "d" and "c". However, the authors state that the highest values of correlation coefficients (r) and determination coefficients (r^2) were obtained via the Priestley–Taylor method in relation to those of the Penman–Monteith method and that there was reasonable precision (r), as well as accuracy (d), with the lowest values of EPE and EPEa, demonstrating that this method most closely matches the FAO standard.

Santos et al. (2020) reported high values of EPE, EPEa, and correlation coefficients (r) and determination (r^2) for the relationship between the Hargreaves–Samani and Penman–Monteith methods, with good performance (d; c), indicating that the ETo estimates obtained via this method are accurate for estimating ETo for the study period and region. This result can be explained by the favorable conditions for influencing the adjustment parameters of the Hargreaves–Samani method, although this method is not recommended for arid regions. For ETo obtained by the Blaney-Criddle and Priestley-Taylor methods, high values of correlation coefficients (r) and determination (r^2) were found' with the methods being classified as very good and good performance, respectively. However, when the errors, EPE, and EPEa were analyzed, high values were found, indicating that the methods are not suitable for the region or study period.

5.3 Cultivation coefficient (Kc)

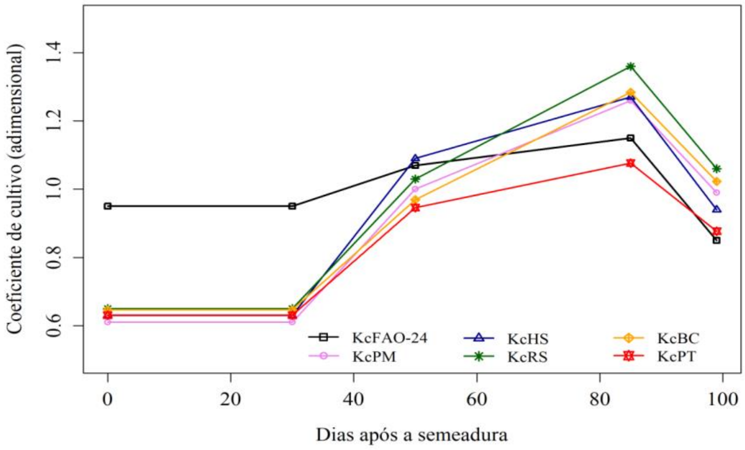
Table 2 and Figure 5 show the Kc values throughout the crop phenological cycle obtained via the ETc ratio (lysimetry) and ETo estimation via the Penman–Monteith, Hargreaves–Samani, solar radiation, Blaney–Criddle and Priestley–Taylor methods. In the tests by Silva et al. (2018), the Kc values obtained in the initial phase were similar for all methods, with the following values being found: 0.46, 0.49, 0.44, 0.46 and 0.46 for the Penman–Monteith (FAO-56), Hargreaves-Samani, solar radiation, Blaney-Criddle and Priestley-Taylor methods, respectively, with the Kc values being different in the other phases and higher than those of this study.

Table 2. Phases and their respective Kc values for carrot crops were proposed by FAO-24 and determined by means of the ETc ratio (lysimetric) via the ETo methods Penman–Monteith (KKPM), Hargreaves-Samani (KcHS), Solar Radiation (KcRS), Blaney-Criddle (KcBC) and Priestley-Taylor (KcPT).

PHASE	DAT	KcFAO	KcPM	KcHS	KcRS	KcBC	KcPT
I	1 – 30	0.95	0.61	0.63	0.65	0.69	0.67
II	31 – 50	1.07	1.00	1.09	1.03	1.11	1.08
III	51 – 85	1.15	1.26	1.27	1.36	1.52	1.25
IV	86 – 99	0.85	0.99	0.94	1.06	1.18	0.99

Phase: I = sowing to germination; II = crop development; III = root formation; IV = maturation.

Figure 5. The Kc of carrot crops was proposed by FAO-24 and estimated via the Penman–Monteith (KcPM), Hargreaves–Samani (KcHS), Solar Radiation (KcRS), Blaney–Criddle (KcBC) and Priestley–Taylor (KcPT) ETo methods.



The Kc values obtained via the relationship between ETc (Lysimetry) and ETo (FAO standard, Penman–Monteith) presented more reliable values than those reported by Silva et al. (2018), who developed tests at UFAL, the Agreste region of Alagoas, and through the relationship between ETc (drainage lysimetry) and ETo (Penman–Monteith), found Kc values of 0.46 (constant) for the first 30 DAS (from sowing to germination), from 0.46 to 1.31 from 30 to 45 DAS (crop development), and 1.31 (constant) from 45 to 80 DAS (root formation), ending with a decreasing Kc from 1.31 to 1.09 from 80 to 90 DAS (maturation and harvest phase).

The crop coefficients estimated by the methods of this study were lower only in the initial phase and at the beginning of the crop development phase than the values proposed by FAO-24, which resembled those at the end of the crop development phase and was greater in the root formation and maturation phases. The Kc values varied for each phenological phase depending on the method evaluated. Silva et al. (2018) reported that these growth, development, and root formation phases are characterized by intense photosynthesis, which is necessary for tissue growth and carbohydrate storage in reserve tissues. In the maturation phase, Kc decreased because the plant was developing and no longer storing energy, in addition to presenting a decrease in leaf area, which resulted in lower water consumption.

The Kc estimates obtained in this study and those suggested by FAO-24 are associated with the effect of horizontal heat advection observed in the area where this study was conducted. This also occurs when a humid area is surrounded by a dry area. Therefore, the transport of energy from dry areas to humid areas contributes to increased evapotranspiration. The advection effects associated with the evaporative demand of the region significantly influenced crop evapotranspiration and, consequently, the respective Kc values, making it necessary to adjust this parameter for each study location.

When the crop coefficients estimated via the empirical methods were compared, the values obtained via the empirical methods were similar in the first two phases; however, KcPM was the lowest of the methods in the first phase, and in the other three phases, KcPT was the lowest. In the second phase, KcPM was lower than KcHS and KcRS, which, in turn, were lower than KcRS and KcBC in the third and fourth phases. These differences can be explained by the estimates of the different ETo methods, since the Penman–Monteith method uses a greater number of variables based on air temperature, solar radiation, wind speed, and relative humidity, making its estimation more reliable.

The different results obtained indicate that crop coefficient values vary depending on the method used to estimate both ETc and ETo, especially the specific soil and climate conditions of each region. In arid regions such as the one in this study, minimal variations in wind speed result in large variations in evapotranspiration rates, as the wind removes water vapor from the air near the plants, favoring the development of a vapor pressure gradient that increases evaporation power at the site.

These differences may be directly related to irrigation management and rational water use, since the use of Kc values obtained via empirical methods results in the application of larger or smaller irrigation depths, given that all methods presented similar values in some phases and different values in others. The use of Kc values obtained via the Penman–Montheith method results in greater application of water to meet the water needs of the crops; however, if Kc values obtained via other methods are used, a larger or smaller water depth may be applied than necessary to meet the water needs of the crops.

In a study developed in the Alto Parnaíba-MG region, Oliveira et al. (2003) obtained the following Kc values for carrot crops: 1.15 (initial phase), 1.12 (growth phase), 1.12 (intermediate phase), and 1.10 (final phase). The region studied by the authors differs greatly from the conditions of the study area of this work. Comparing the results of that study with those found in this work, differences are observed in all phases (Table 2). Santos et al. (2009) obtained Kc values (lysimetry) for carrot crops in the Agreste region of Pernambuco of 1.08--1.16 in the initial phase, 1.41--1.52 in the growth phase, 1.43--1.55 in the intermediate phase, and 1.40--1.52 in the final phase. These values are higher than those reported in the present study (Table 2). Thus, it is clear that environmental factors can influence the Kc phases in carrot cultivation.

By working with carrot crops (cultivar Brasília) under the soil and climate conditions of the Alto Paranaíba region, Rocha (2003) obtained Kc values of 1.07, 1.14, and 1.10 for development stages II, III, and IV, respectively. These results are similar to those reported for some of the methods employed in this study for the development, root formation, and maturation stages (Table 2).

6 CONCLUSION

The Kc values of carrots, recommended for the Agreste region of Alagoas at the end of the dry season and beginning of the rainy season, are 0.61 (initial phase), 1.00 (growth phase), 1.26 (intermediate phase) and 0.99 (final phase), obtained via the ETo estimated via the FAO standard method;

agrometeorological information to estimate ETo via the FAO standard method for the Agreste region of Alagoas, the recommended Kc values are 0.69, 1.11, 1.52 and 1.18, which are obtained via the Blaney-Criddle ETo method via the adjustment equation obtained via the correlation between EToBC and EToPM.

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8 REFERENCES

ALLEN, RG; PEREIRA, LS; RAES, D.; SMITH, M. **Crop evapotranspiration** : Guidelines for computing crop water requirements . Rome : FAO, 1998. 300 p.

ALVES, ES; LIMA, DF; BARRETO, JAS; SANTOS, DP; SANTOS, MAL Determination of the crop coefficient for radish crop through drainage lysimetry . **Irriga Magazine** , Botucatu, v. 22, n. 1, p. 194-203, 2017.

BEZERRA, FML; MESQUITA, TB Maximum evapotranspiration and crop coefficients of bell pepper grown in drainage lysimeter . **Brazilian Congress of Horticulture** , Recife, v. 8, n. 1, p. 617-618, 2000.

CARVALHO, ADF; SILVA, GO; RESENDE, FV Adaptability and stability of carrot populations by the REML/BLUP method. **Horticultura Brasileira** , Recife, v. 35, n. 1, p. 69-74, 2017.

CARVALHO, DF; OLIVEIRA, LFC **Water planning and management in irrigated agriculture** . Viçosa: UFV, 2012. 68 p.

CONCEIÇÃO, MAF Estimation of reference evapotranspiration based on air temperature for the conditions of the Lower Rio Grande, SP. **Brazilian Journal of Agrometeorology** , Serra Talhada, v. 11, n. 2, p. 229-236, 2003.

DIVINCULA, J.S.; SILVA, C.B.; SANTOS, M.A.L.; SANTOS, D.P.; SANTOS, L.W. Crop coefficient and water application of prickly pear in the rugged region of Alagoas state , Brazil . **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grade, v. 23, n. 1, p. 925-929, 2019.

DOORENBOS, J.; PRUITT, WO **Crop water requirements** : Revised. Rome: FAO, 1975. 144 p.

EMBRAPA. **Agroecological Zoning of the State of Alagoas** . Recife: Embrapa-Solos, 2013. 238 p.

FILGUEIRA, FAR **New Manual of Olericulture** : Modern agrotechnology in the production and marketing of vegetables. Viçosa : UFV, 2008. 421 p.

FREVERT, DK; HILL, RW; BRAATEN, BC Estimation of FAO evapotranspiration coefficients. **Journal of Irrigation and Drainage Engineering** , Reston, v. 109, no. 2, p. 265-270, 1983.

JENSEN, ME; BURMAN, R.D.; ALLEN, RG **Evapotranspiration and Irrigation Water Requirements** . New York: The American Society of Civil Engineers, 1990. 332 p.

KÖPPEN, W. **Climatology** : conune studio de los climas de la tierra . Mexico: Fondo de Cultura Economica , 1949. 478 p.

LIMA JUNIOR; ARRAES, FDD; OLIVEIRA, JB; NASCIMENNTO, FAL; MACÊDO, KG Parameterization of the Hargreaves and Samani equation for estimating reference evapotranspiration in the State of Ceará, Brazil. **Agronomic Science Journal** , Fortaleza, v. 47, n. 1, p. 447-454, 2016.

LUCENA, FAP; SILVA, EM; RIBEIRO, AA; SIMEÃO, M.; LUCENA, JPAP Comparison between methods for estimating reference evapotranspiration in the municipality of Bom Jesus, PI. **Brazilian Journal of Irrigated Agriculture** , Fortaleza, v. 10, n. 1, p. 663-675, 2016.

MIRANDA, W. L.; CARVALHO, LG; CASTRO NETO, P.; SANTOS, PAB Use of drainage lysimeter to obtain Kc from castor bean in dense planting. **Green Journal of Agroecology and Sustainable Development** , Pombal, v. 11, n. 1, p. 8-13, 2016.

MOURA, AR C; MONTENEGRO, SML; ANTONINO, ACD; AZEVEDO, JRG; SILVA, BB; OLIVEIRA, LMM Reference evapotranspiration based on empirical methods in an experimental basin in the state of Pernambuco – Brazil. **Brazilian Journal of Meteorology** , São José dos Campos, v. 28, n. 2, p. 181-191, 2013.

OLIVEIRA, RA; ROCHA, IB; SEDIYAMA, GC; PUIATTI, M.; CECON, PR; SILVEIRA, SFR Carrot crop coefficients under the soil and climate conditions of Alto Paranaíba, in the State of Minas Gerais. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grade, v. 7, n. 2, p. 280-284, 2003.

PEREIRA, AR; VILA NOVA, NA; SEDIYAMA, GC **Evapotranspiration** . Piracicaba: Luiz de Queiros Foundation for Agrarian Studies, 1997. 183 p.

PRIESTLEY, CHB; TAYLOR, RJ On the assessment of surfasse heat flux and evaporation using large-scale parameters . **Monthly Weather Review** , Boston, vol. 100, no. 1, p. 81-92, 1972.

ROCHA, IB **Carrot production (*Daucus carota* L.) irrigated under the soil and climate conditions of the Alto Parnaíba region** : Economic evaluation and determination of the crop coefficient. 2003. Thesis (PhD in Agricultural Engineering) – Federal University of Viçosa, Viçosa, 2003.

SANTOS, CS; SANTOS, DP; OLIVEIRA, WJ; SILVA, PF; SANTOS, MAL; FONTENELE, AJPB Reference evapotranspiration and cultivation coefficient of pepper in the Agreste region of Alagoas. **Brazilian Journal of Irrigated Agriculture** , Fortaleza, v. 10, n. 1, p. 883-892, 2016.

SANTOS, FX; MONTENEGRO, AAA; SILVA, JR; SOUZA, ER Determination of water consumption of carrots using drainage lysimeters in the agreste region of Pernambuco. **Brazilian Journal of Agricultural Sciences** , Recife, v. 4, n. 3, p. 304-310, 2009.

SANTOS, MAL; SANTOS, DP; SANTOS, CG; SILVA, JV; COSTA, RH; SANTOS, SBT Irrigation management of chili pepper (*Capsicum frutenses* L.). **Brazilian Journal of Development** , Curitiba, v. 6, no. 6, p. 40954-40969, 2020.

SILVA, JC; SILVA, CB; SANTOS, DP; SANTOS, MAL; OLIVEIRA, WJ; REIS, LG Evapotranspiration and crop coefficient of irrigated carrot in the agreste region of Alagoas. **Ceres Journal** , Viçosa, v. 65, n. 4, p. 297-305, 2018.

TAGLIAFERRE, C.; JESUS SILVA, RA; ROCHA, FA; COSTA SANTOS, L.; SILVA, CDS Comparative study of different methodologies for determining reference evapotranspiration in Eunápolis-BA. **Journal Caatinga** , Mossoró , v. 23, n. 1, p. 103-111, 2010.

WILLMOTT, C.J.; ACKLESON, SG; DAVIS, RE; FEDDEMA, JJ; KLINK, KM; LEGATES, DR; ROWE, CM; O'DONNELL, J. Statistics for evaluation and comparisons of models. **Journal of Geophysical Research** , Hoboken , vol. 90, no. 1, p. 8995-9005, 1985.

XAVIER, RA; DORNELLAS, PC Analysis of rainfall behavior in the municipality of Arapiraca, Agreste region of Alagoas. **Geography** , Bela Vista , v. 14, n. 2, p. 49-64, 2010.