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CONSUMO HÍDRICO E EXIGÊNCIA TÉRMICA DA PALMA FORRAGEIRA EM AMBIENTE SEMIÁRIDO

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1 RESUMO

O objetivo deste estudo foi avaliar o consumo hídrico e estabelecer a exigência térmica de três variedades de palma forrageira nas diferentes fases de desenvolvimento em ambiente semiárido. O experimento foi desenvolvido em condições de campo no munícipio de Santa Luzia, PB, Fazenda Poço Redondo. Para a determinação da evapotranspiração da cultura (ETc), foram utilizados três lisímetros de drenagem localizados no centro da área experimental. Cada lisímetro continha quatro plantas com características semelhantes e sob o mesmo sistema de manejo das plantas externas. Um quarto lisímetro foi utilizado com grama para determinar a evapotranspiração de referência ET_0. Cada lisímetro representa uma área efetiva de evaporação de 1,17 m^2. Pela ordem de emissão dos cladódios juntamente com o somatório de graus dias determinou-se as quatro fenofases da palma forrageira. A evapotranspiração de referência foi de 7,2 mm dia^{-1}. Os valores de evapotranspiração da cultura ETc e coeficiente de cultivo (Kc), foram respectivamente: 4,8; 4,8 e 4,6 mm dia^{-1} e 0,72; 0,70 e 0,70, para as variedades orelha de elefante, baiana e miúda. A temperatura basal foi de 18 °C e a soma térmica acumulada no período foi superior a 4000 °C.

Keywords: coeficiente de cultivo, fases fenológicas, graus-dias, temperatura base.

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WATER CONSUMPTION AND THERMAL REQUIREMENT OF THE FORAGE PALM IN A SEMIARID ENVIRONMENT

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2 ABSTRACT

This study aimed to evaluate the water consumption and establish the thermal requirement of three varieties of forage palm in different stages of development in a semiarid environment. The experiment was conducted under field conditions in the municipality of Santa Luzia, PB, Poço Redondo Farm. To determine the culture evapotranspiration (ETc), three drainage lysimeters located in the center of the experimental area was used. Each lysimeter contained four plants with similar characteristics and under the same management system as the external plants. The fourth lysimeter was used with grass to determine the reference evapotranspiration ET_0. Each lysimeter represents an effective evaporation area of 1.17 m^2. By the order of emission of the cladodes with the sum of degree days, the four phenophases of the forage palm were determined. The reference evapotranspiration was 7.2 mm dia^{-1}. The evapotranspiration values of ETc culture and cultivation coefficient (Kc), were respectively: 4.8; 4.8 and 4.6 mm dia^{-1} and 0.72; 0.70 and 0.70, for Orelha the Elefante, Baiana and Miúda varieties. The basal temperature was 18 °C and the thermal sum accumulated in the period was over 4000 °C.

Keywords: cultivation coefficient, phenological phases, degree-days, base temperature.

3 INTRODUCTION

The edaphoclimatic conditions of the semiarid environment and the management practices adopted affect the development of plants and their phenology and, consequently, the productivity of crops, which is not different for cacti, such as forage palm (AMORIM et al., 2017).

The water scarcity scenario in the semiarid region of Brazil confirms the need for crops with species adaptable to the region's climatic conditions due to their crassulacean acid metabolism (CAM), which results in high water use efficiency, such as the forage cactus species *Opuntia* and *Nopalea* (BAYAR; FRIJI; KAMMOUR, 2018). These cacti are well adapted to regions with water deficits (SILVA et al., 2015).

For Marques et al. (2015), even species adapted to regions with water deficit require studies that indicate the correct irrigation management aiming to replenish the water needs of crops in the different phenological phases. Pereira, Villa Nova and Sediyama (2013) reported in their study on the water balance in soil cultivated with forage palm clones under irrigation that for correct irrigation management, it is essential to use crop coefficients (Kc) in the different phases of crop development. These Kc values must originate from the relationship between crop evapotranspiration (ETc) and reference evapotranspiration (ET_0), whose calculations allow quantification of the water volume to be made available to crops.

The Food and Agriculture Organization of the United Nations (FAO), in its bulletin 56 (ALLEN et al., 1998), suggests average Kc values for various crops throughout the year. This information is the first step toward rational irrigation management; however, there is a notable lack of research data on these coefficients, especially for cacti and, especially, for the forage cactus varieties Orelha de Elefante Mexicana (*Puntia stricta*) (Haw.) Haw and Baiana and Miúda (*Nopallea cochenillife ra*).

There are a wide variety of methods for determining ETc, ranging from the Bowen ratio, water balance, sap flow, and remote sensing to lysimeters. The crop coefficient, on the other hand, is a parameter related to environmental and plant physiological factors and is most commonly obtained via lysimeters (MEDEIROS et al., 2004). According to Marques et al. (2015), drainage lysimeters can provide reliable estimates of Kc, allowing accurate accounting of water balance terms. Lysimeters can be divided into two categories: weighing and drainage.

As stated by Rodrigues, Souza and Lima (2013), another widely used way to estimate the time needed to reach each phenological phase of crops, which contributes to establishing the duration of each phase, is the use of thermal units (degree-days) or the thermal requirement of the crop, which represents the need for energy above the minimum condition and below the maximum required by the plant.

Knowledge of the water requirements and thermal sum of forage palm can help in planning agricultural activities, such as planting, water consumption at each stage of development, harvesting and cultural treatments, as well as indicating the climatic potential of a region for cultivation.

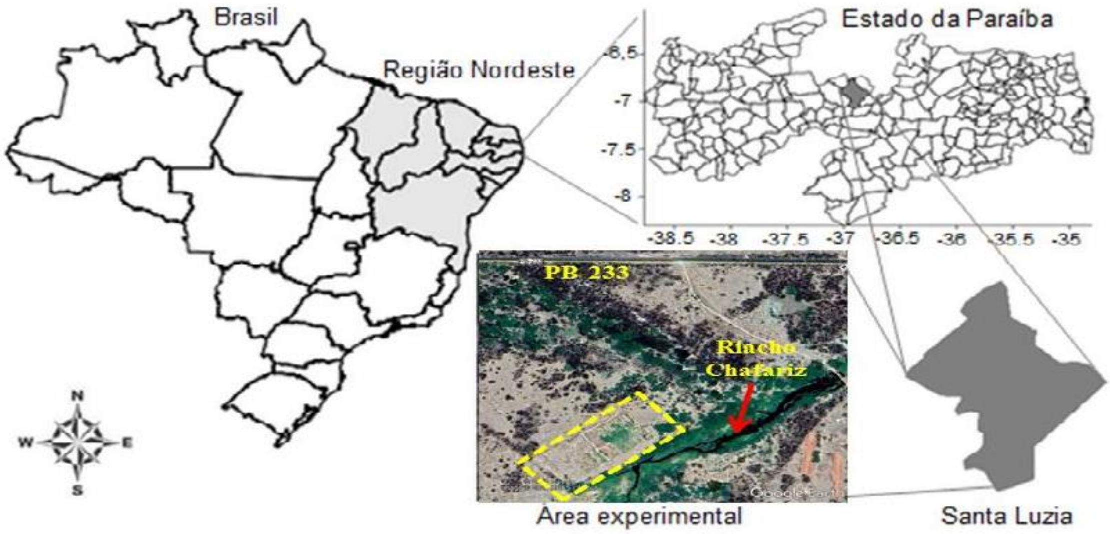
Given the relevance of this topic, the objective of this study was to evaluate water consumption and establish the thermal requirements of three varieties of forage palm at different stages of development in a semiarid environment.

4 MATERIALS AND METHODS

4.1 Research location and characterization

The study was conducted under field conditions at the Poço Redondo farm, which is located 2 km from the municipality of Santa Luzia, PB, on the banks of the Chafariz stream (Figure 1). The geographic coordinates of the site are as follows: 06° 51' 30.3” South latitude and 36° 56' 9.7” West longitude, at an average altitude of 299 m. The predominant climate is Bsh, hot, dry, semiarid with summer rains, according to the Köppen climate classification (KÖPPEN; GEIGER, 1928). The research began in September 2016 and ended in August 2017.

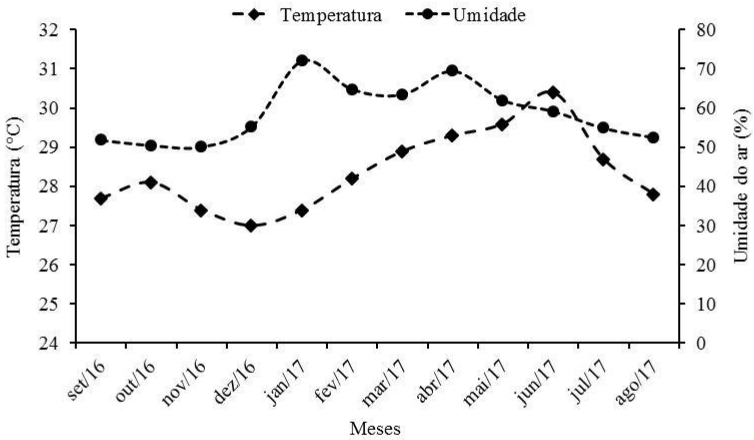
Figure 1. Location of the experimental area, Poço Redondo farm, municipality of Santa Luzia-PB.



Source: SILVA (2017).

The average annual rainfall in the region during the study period was 446.9 mm, with the heaviest rainfall occurring between January and May. The relative humidity ranged from 70% to 50%, while the temperature ranged from 22.4 °C to 33 °C, with an annual average of 27.6 °C (SILVA, 2017). The predominant vegetation in the experimental area is the Caatinga-Seridó type, subxerophilous, consisting mostly of cacti and small trees or shrubs, which are generally thorny and form dense clusters in some areas and scattered trees in others (DAMASCENO; SOUTO; SOUTO, 2010). Meteorological variables such as temperature and humidity were monitored throughout the research period, and the monthly averages were expressed in a climogram, as shown in Figure 2.

Figure 2. Climogram of the meteorological variables recorded during the experimental period. Santa Luzia, PB.



4.2 Soil characterization

The soil material used to fill the lysimeters was classified as Fluvic Neosol, with a sandy loam texture, according to the criteria of the Brazilian Soil Classification System (EMBRAPA, 2013). The physical-hydric characterization of the soil at depths of 0–20 cm is presented in Table 1.

Table 1. Physical-hydric characterization of the soil in the experimental area, Santa Luzia, PB.

Depth	CC	PMP	Ds	Dp	Total	AD
m	-----%------		---g cm $^{-3}$ ----		%	
0.0 – 0.20	24.8	5.4	1.56	1.39	44.23	10.4

CC corresponds to a field capacity of 0.10 atm; PMP corresponds to a matric potential of 15 atm; available water (AD); soil density (Ds); soil particle density (Dp); and total soil porosity (Ptotal).

4.3 Manufacturing and handling of lysimeters

Four drainage lysimeters were constructed from polyethylene boxes with an upper diameter of 1.22 m, a lower diameter of 0.95 m, a depth of 0.60 m, a volumetric capacity of 554.5 L, and an effective evaporation area of 1.17 ^{m2}. A 32 mm diameter PVC drain was inserted into one of the lower edges of the lysimeters and connected to a 1.5 m deep observation and drainage collection well. Through this well, the volume of percolated water after the previous irrigation, which was carried out to increase the soil to field capacity with a 15% surplus, was collected and measured daily (Figure 3).

Figure 3. Diagram of the installation of drainage lysimeters for forage palm cultivars in the experimental area. Santa Luzia, PB.

The lysimeters had a gentle slope toward the drain. Prior to filling, a 10 cm layer of No. 1 gravel was placed at the bottom of the box, which was covered with a geotextile blanket (Bidim-RP07®). The lysimeters were then filled with the soil layers, following the reverse order of removal during excavation.

The mother cladodes were obtained from rural producers in municipalities in Paraíba in partnership with the National Institute of the Semiarid Region (INSA). The forage cactus variety used was Mexican elephant ear (*Opuntia stricta* [Haw.] Haw.), Baiana, and Miúda (*Nopallea*), which are widely cultivated in the semiarid region of Northeast China because they are resistant to carmine scale insects.

To determine crop evapotranspiration (ETc), three drainage lysimeters located in the center of the experimental area were used. Each lysimeter contained four plants with similar characteristics under the same management system as the external plants. A fourth lysimeter was used with grass to determine the reference evapotranspiration (ET_0) (Figure 3).

The excavations for the installation of the lysimeters were carried out manually, and the soil was separated into 13 cm layers to the depth of the boxes. Each layer of soil was wrapped in plastic tarpaulin and identified for later repositioning inside the boxes, aiming to achieve an approximation of the original soil conditions (Figure 3).

4.4 Lysimeter fertilization

Fertilization in the lysimeters was carried out according to soil analysis, taking into account the recommendation of Santos et al. (2006) for forage cactus. Foundation fertilization was carried out five days before the mother cladodes were planted; 100 kg ha^{-1} P_2O_5 and 65 kg ha^{-1} K_2O were applied, and 200 kg ha^{-1} monoammonium phosphate (MAP) and 108.33 kg ha^{-1} potassium chloride (KCl) were used as sources of these nutrients. Nitrogen fertilization was carried out with 150 kg ha^{-1} nitrogen, corresponding to 333.33 kg ha^{-1} urea.

The basal cladodes or mother plants used for planting were treated to eliminate pests and diseases, especially scale insects, which are among the most common pests of palm groves in the semiarid region of Brazil. Furthermore, after these basal cladodes were cut and selected, they were placed in a shaded location to heal any cut injuries for a seven-day curing period. For planting, the basal/mother plants were arranged in the drainage lysimeters in a bilateral row facing the sun, i.e., 50% buried and inclined at a 45° angle (SUASSUNA, 2007). Planting was performed with a spacing of 0.25 m between rackets within the lysimeter.

4.5 Irrigation of lysimeters

Irrigation management was carried out by estimating soil moisture via false discovery rate (FDR) capacitance probe data at depths ranging from 0--5 cm, considering the 0--20 cm layer for irrigation purposes. To begin the evaluations, the probe was previously calibrated for the area's soil via the standard greenhouse method. The soil moisture was increased to field capacity in all the lysimeters. Soil moisture measurements were taken every seven days. On the basis of the probe readings, the irrigation depth needed to replenish the soil water content to field capacity (FC) for each lysimeter was calculated. Water replenishment was performed to provide a drainage depth corresponding to 15% (leaching fraction) of the applied water depth (PEREIRA; VILLA NOVA; SEDIYAMA, 2013). The calculations to obtain the volume of water to be replaced in the lysimeters were performed via Equations 1, 2 and 3.

$$LL = (\theta CC - \theta at) * Z \quad (1)$$

$$V = LL * A_L \quad (2)$$

$$V_R = V + (15\% * V) \quad (3)$$

where:
LL - irrigation depth (mm);
θcc is the moisture at the average field capacity along the profile ($cm^3\ cm^{-3}$);
θat is the average current humidity along the profile ($cm^3\ cm^{-3}$);
Z is the depth of the root zone (cm);
L represents the area of the lysimeter (m^2);
V - the volume required to return soil moisture to field capacity (L); and

VR - the volume to be replaced in the lysimeter soil necessary for leaching to occur (L).

Precipitation data were obtained from a meteorological station installed adjacent to the experimental area. The calculated replacement water volume was applied manually via a watering can. Drainage water was collected via observation collectors, and the drained volume was quantified in graduated cylinders. This volume was recorded as water accumulation between application and the subsequent cessation of drainage during the experimental period.

4.6 Determination of parameters (ETc, ET $_0$, Kc)

Crop evapotranspiration (ETc) was determined by accounting for water inflows and outflows in the drainage lysimeters, according to Equation (4).

$$ET_C = P + I - D \quad (4)$$

ETc – crop evapotranspiration in the period, mm lysimeter $^{-1}$;
I – total irrigation volume in the period, mm;
P – total precipitation in the period within the lysimeter, mm; and
D – drainage volume in the period, mm.

Reference evapotranspiration (ET $_0$) was determined via a lysimeter, with grass used as the reference crop. For this purpose, the grass was maintained completely covering the soil, with a height between 12 and 15 cm, without water restriction. All water inputs and outputs in the root system were accounted for, and via Equation 5, ET $_0$ was determined in mm, considering precipitation (P), irrigation (I), and drainage (D), both in mm.

$$ET_0 = P + I - D \quad (5)$$

Estimates of the values of the crop coefficient Kc for the studied varieties were performed through the relationship between the values of crop evapotranspiration ETc and the reference evapotranspiration ETo measured in the lysimeter according to Equation 6.

$$Kc = \frac{ET_C}{ET_0} \quad (6)$$

where:
Kc – Crop coefficient, dimensionless;
ETc – crop evapotranspiration, in mm day $^{-1}$ and
ET $_0$ – reference evapotranspiration, in mm day $^{-1}$.

4.7 Determination of crop phenophases

By the order of cladode emission together with the sum of degree days, it was possible to determine four phenophases of forage cactus for 12 months of cultivation (FV1, FV2, FV3 and FV4), as shown in Table 2. From planting to the emission of the 2nd-order cladode, the crop was in phenophase one (FV1) of its vegetative development. The prolongation of this phase can be explained by the fact that the plant consists only of the basal cladode until the emission of the first-order cladode. During the period between the emission of the 2nd-order and 3rd-order cladodes, the crop passed to phenophase two (FV2). Phenophase three (FV3) consisted of the interval between the emission of the 3rd-order and 4th-order cladodes. Phenophase four (FV4) began after the emission of the 4th-order cladode and continued until the end of the study (Table 2). Importantly, at this stage, the plants were already adults, highlighting that after the emission of the 4th-order cladode, the plants began to emit flowers and fruits.

Table 2. Phenophases of forage cactus varieties determined by cladodes and the sum of degree days for a 12-month period. Santa Luzia, PB.

Varieties	Phenophases	Stadiums	Duration of phases (days)	Degree days	Kc
Ear	I	From planting to the emission of the 2nd order cladode	1 to 71	835	0.78
	II	And mission of the 2nd order cladode to the 3rd order	72 to 121	1,383	0.72
	III	And mission of the 3rd order cladode and the 4th order	122 to 178	2,942	0.56
	IV	Emission of the 4th order cladode until the emission of flowers and fruits	179 to 365	4,471	0.65
Bahian	I	From planting to the emission of the 2nd order cladode	1 to 70	823	0.74
	II	And mission of the 2nd order cladode to the 3rd order	71 to 119	1,373	0.59
	III	And mission of the 3rd order cladode and the 4th order	120 to 177	2.031	0.69
	IV	Emission of the 4th order cladode until the emission of flowers and fruits	178 to 365	4,471	0.69
Girl	I	From planting to the emission of the 2nd order cladode	1 to 70	823	0.73
	II	And mission of the 2nd order cladode to the 3rd order	71 to 118	1,363	0.54
	III	And mission of the 3rd order cladode and the 4th order	119 to 170	1941	0.60
	IV	Emission of the 4th order cladode until the emission of flowers and fruits	170 to 365	4,471	0.69

The thermal requirements of forage cactus were determined on the basis of the sum of degree days (GD), according to Equations 7, 8 and 9, proposed by Villa Nova et al. (1972), for the four phenological phases of forage cactus varieties.

$$GDi = (T_m - T_b) + \frac{(T_M - T_m)}{2} \rightarrow \text{para } T_m > T_b \quad (7)$$

$$GDi = (T_M - T_b)^2 + 2(T_M - T_m) \rightarrow \text{para } T_m < T_b \quad (8)$$

$$GDi = 0 \rightarrow \text{para } T_M < T_b \quad (9)$$

where:
GD – degree days;
TM – maximum daily temperature (°C);
Tm – minimum daily temperature (°C) and
Tb – basal temperature (°C).

The accumulated degree days (GD, °C day) were obtained by summing the degree days from the planting date to harvest, Equation 10, obtained by summing the GDi.

$$GD = \sum GDi \quad (10)$$

The methodology proposed by Arnold (1959) was used to estimate the basal temperature (Tb) of forage cactus via the standard deviation method in degree days (DPgd), according to Equation (11). The temperatures used to determine the base temperature were 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22 and 24 °C.

$$DPgd = \sqrt{\frac{\sum_{i=1}^{n}(GD_i - MGD)^2}{n-1}} \quad (11)$$

where:
DPgd - standard deviation in degree days;
GDi - accumulated degree days from planting to harvest via a Tb series;
MGD - average degree-days accumulated from planting to harvest;
n - number of days from planting to harvest.

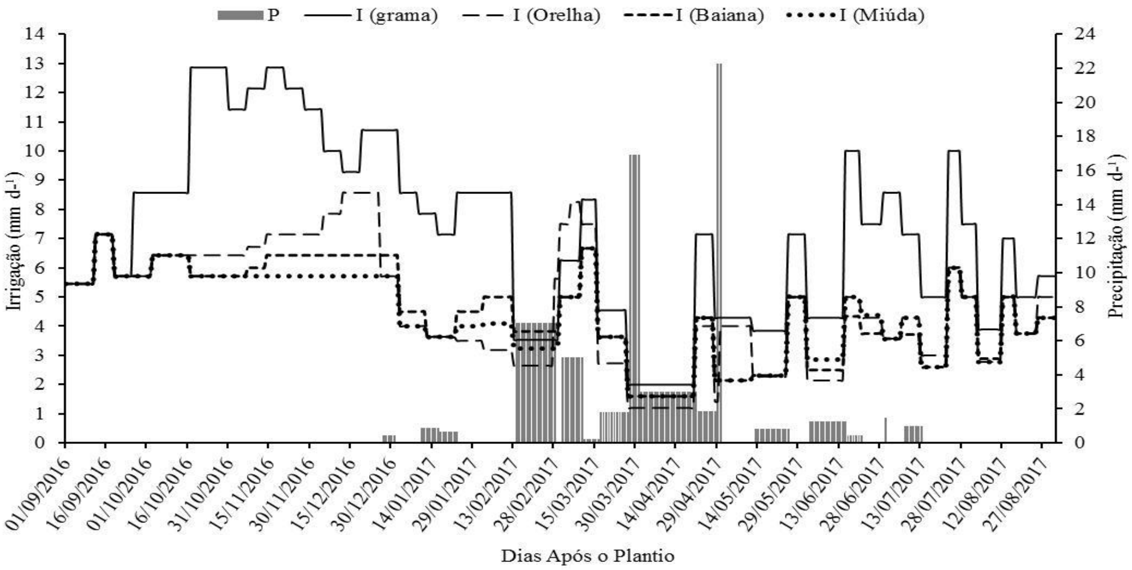
The data and temperatures were subjected to the Shapiro–Wilk test (P>0.01) and Levene test (P>0.01) to verify residual normality and homoscedasticity, respectively; subsequently, the data were subjected to analysis of variance, with quantitative effects in orthogonal polynomials, according to their significance according to the F test. For this purpose, the SAS statistical program was used.

5 RESULTS AND DISCUSSION

5.1 Determination of the total volume of water applied

During the forage palm cultivation period, 389.3 mm of rainfall, concentrated from February to April 2017, was recorded. This implied the need for irrigation, which was applied during the 365 days after planting (DAP), as illustrated in Figure 4.

Figure 4. Precipitation and irrigation of the grass and palm varieties Orelha de Elefante, Baiana and Miúda over 365 days after planting – DAP. Santa Luzia, PB.



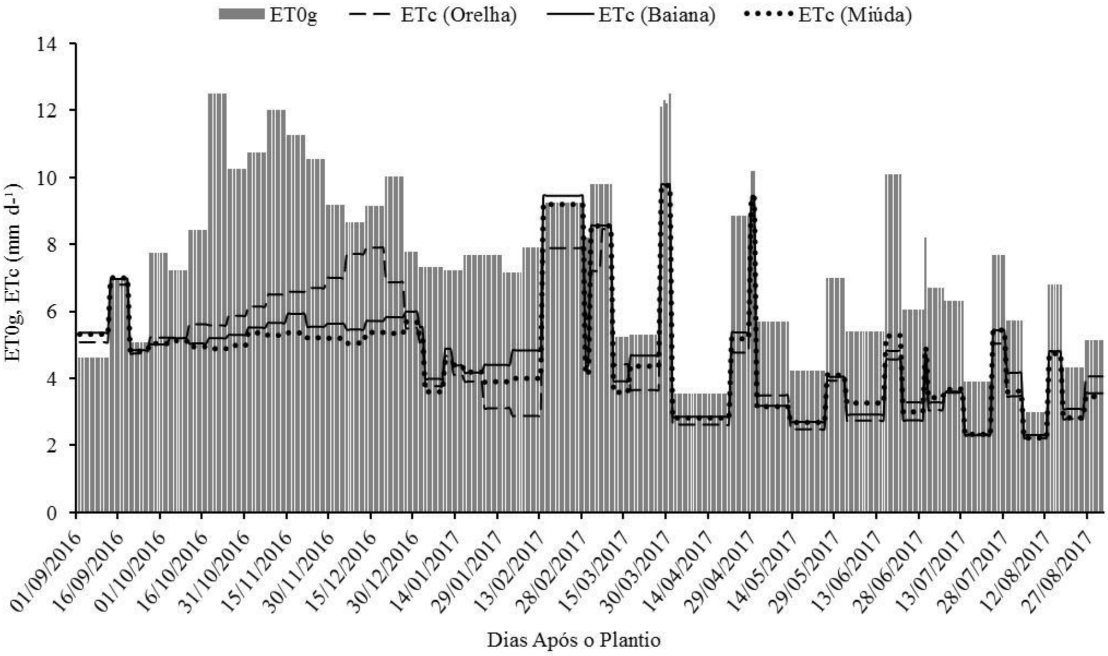
The accumulated volume totaled irrigation depths of 2615.0, 1693.6, 1631.0 and 1581.0 mm year-1 for the grass, Mexican elephant ear, Baiana and Miúda, respectively, with daily irrigation averages of 7.2, 4.6, 4.5 and 4.3 mm day-1, respectively, for the grass, Mexican elephant ear, Baiana and Miúda (Figure 4). The highest rainfall volumes were 115.6 and 125.1 mm month-1, respectively, for the months of March and April 2017.

The average annual rainfall in the semiarid region of Brazil varies between 300 and 700 mm, with high concentrations occurring during certain periods of the year (SILVA et al., 2012). Therefore, one alternative for producers in the region to cope with water shortages is the cultivation of forage palms. However, for this crop to achieve high productivity levels, the correct use and management of irrigation is necessary (SILVA, 2017).

5.2 Determination of ET0 and ETc

With respect to the reference evapotranspiration calculated with grass as the reference crop, an average value of 7.2 mm day $^{-1}$ and a maximum value of 12.5 mm day -1 were obtained (Figure 5). The highest $ET_{0\ values}$ were recorded for the months of October, November, and December 2016 and March 2017. This fact is probably related to the greater atmospheric demand for these periods of the year in the region. The accumulated ET0 during the entire experimental period was 2576.5 mm year $^{-1}$.

Figure 5. Reference evapotranspiration (ET $_0$) for grass and crop evapotranspiration of the Orelha de Elefante, Baiana and Miúda varieties over 365 days after planting (DAP). Santa Luzia, PB.



The ET $_0$ of 7.2 mm d $^{-1}$ determined in this research is in agreement with the study developed by Divincula et al. (2019), who, in the state of Alagoas, reported reference evapotranspiration ET values of 0 to be 7.4 mm d $^{-1}$. These values are also in agreement with Cavalcante Junior et al. (2010) and Borges Júnior and Pinheiros (2019), who reported an average ET of 0.5 mm d $^{-1}$ for the regions of Mossoró-RN and Petrolina-PE. Therefore, the ET $_0$ values of the present study are in line with those mentioned in the literature for regions with similar climatic characteristics (semiarid regions).

Crop evapotranspiration of different forage cactus varieties was obtained through a water balance over 365 days after planting (DAP) (Figure 5). The highest levels of ETc occurred when the crop was over 170 DAP. The average water consumption during crop management for the Orelha de Elefante, Baiana, and Miúda varieties was 4.8, 4.8, and 4.6 mm day $^{-1}$, respectively. The maximum water consumption was 16.5, 16.7, and 16.7 mm day $^{-1}$ for the three varieties studied (Figure 5). This variation in water consumption, in terms of crop evapotranspiration, can be associated with the climatic variations observed during the experiment.

The determined ETc values differ from those reported by Pereira et al. (2017) and by Han and Felker (1997), who, studying the species *Opuntia and Nopalea,* obtained ETc *values* equivalent to the average of 1.5 mm d $^{-1}$. The same occurs when we compare the results of the present study with those reported by Consoli, Inglese and Inglese (2013), Silva et al. (2015) and Queiroz et al. (2016), who, when working with plants of the same genus, reported average ETc values equal to 2.5, 2.4 and 2.6 mm d-^{1}, respectively.

However, the crop evapotranspiration values determined in the present study (Figure 5) are in agreement with those reported by Divincula et al. (2019) (average ETc of 4.2 mm d $^{-1}$) and are close to those reported by Meirelles et al. (2011) and Santana et al. (2016) for the forages Brachiaria brizantha and Tifton-85. Silva et al. (2012) reported a similar value for the C4 sugarcane ratoon plant (average ETc of 4.7 mm d $^{-1}$).

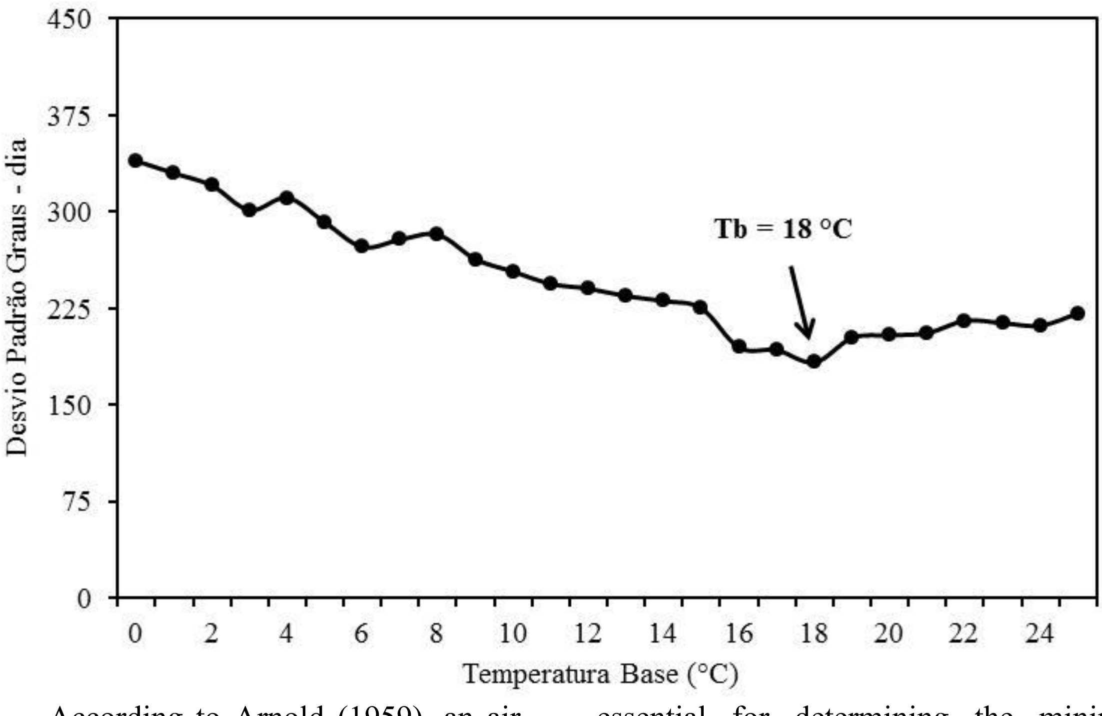
Queiroz et al. (2016) reported that the variation in water consumption of forage cactus grown in a semiarid environment is due to climate variation, which can increase water consumption (evapotranspiration) or supply (rainfall). Corroborating this statement, Freire (2012) ensures that forage cactus, when grown with high water availability, begins to function as C3 plants.

According to Taiz et al. (2017), some plants are considered to have obligate crassulacean acid metabolism (CAM), which always functions via this mechanism. Other species, such as *Ananas comosus* (pineapple), *Agave sisalana* (Sisal), and *Opuntia fícus-indica* (forage palm), develop with the C3 pathway for their metabolism when grown in the presence of water. However, when grown under water deficit, a saline environment, or even under inadequate photoperiod conditions, crassulacean acid metabolism occurs. Thus, plants are considered facultative CAMs; when the water supply is sufficient for their full development, they change from CAM to C3 metabolism, thus opening their stomata and fixing CO2 throughout the day via rubisco.

5.3 Determination of the base temperature and thermal sum

The basal temperature (Tb) determined by the standard deviation method on degree days revealed that the Tb value was 18 °C (Figure 6); for all varieties studied, this value differed from the base temperature of 22 °C adopted by Araújo Junior et al. (2017).

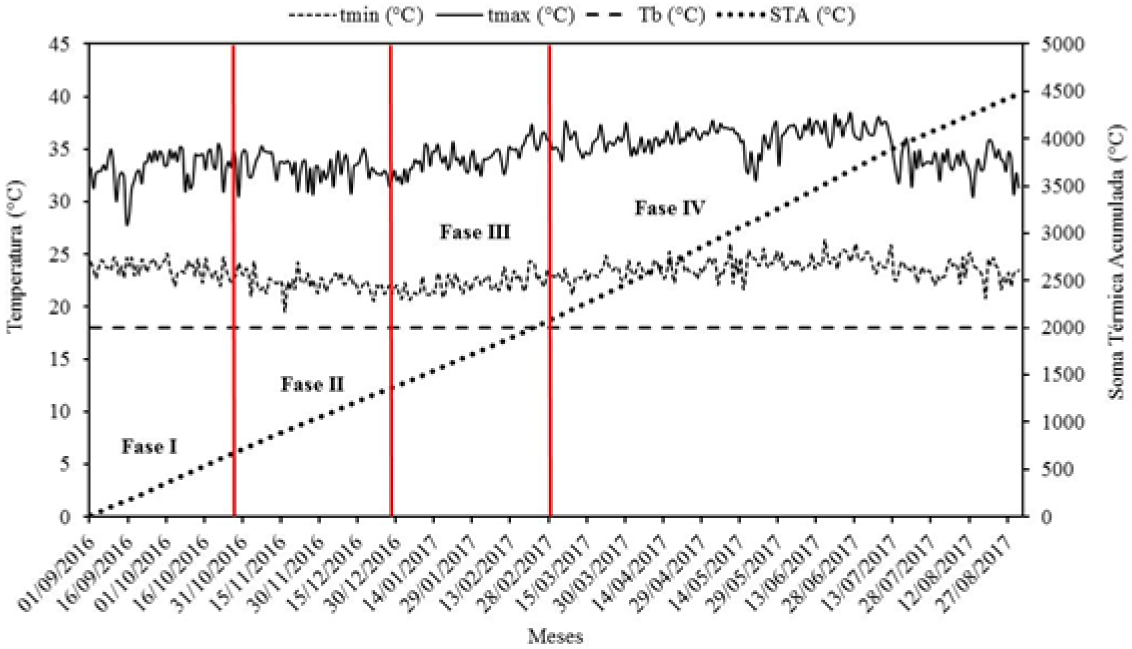
Figure 6. Graphical representation of the estimated basal temperature - Tb for forage cactus using the standard deviation method in degree days - DPgd. Santa Luzia, PB.



According to Arnold (1959), an air temperature above the lower basal temperature implies an accumulation of degree days. Therefore, quantifying the basal temperature of the forage cactus is essential for determining the minimum temperature that the cactus can withstand without stopping its development.

The maximum temperatures observed in each stage of palm development were 35.49, 35.03, 37.33 and 38.45 °C, and the minimum temperatures were 25.05, 24.24, 24.31 and 26.36 °C for phenophases I, II, III and IV, respectively (Figure 7).

Figure 7. Maximum (tmax) and minimum (tmin) air temperatures recorded, basal temperature (Tb) and accumulated thermal sum (STA) for the 1st, 2nd, 3rd and 4th phenophases throughout the cultivation cycle. Santa Luzia, PB.



According to Bezerra et al. (2014) and Rocha (2012), the greatest productive potential of forage cactus occurs in regions where the average temperature ranges between 16.1 °C and 25.4 °C, with maximum temperatures between 28.5 °C and 31.5 °C and minimum temperatures ranging from 8.6 °C to 20.4 °C. However, the maximum and minimum temperatures of cactus determined in the present study were higher than those reported by the previously cited authors. The high temperature values determined in this research are related to the fact that the experimental area has high temperatures and relatively low air humidity.

In all the phenophases of the forage cactus, the minimum air temperature was always above the basal temperature (18 °C), meaning that the plant did not experience growth arrest in any of the phenological phases, allowing for faster and more efficient cladode emission (Figure 7). Arnold (1960) stated that basal temperature can be defined as the temperature below which the plant has no or even negligible growth and development; this action generally occurs in the winter period. This basal temperature is essential for determining the degree-days of crops, with degree-days being calculated as a function of the difference between the average air temperature during the day and the basal temperature of the species studied.

Notably, this information is relevant to vegetative growth and development, and estimates of the basal temperature of species such as forage cactus are relevant for determining the water needs of crops in the soil and climate conditions, which differ from the center of the origin of the crop.

The thermal sums in periods I, II, III and IV were 835, 1383, 2043 and 4471 °C, respectively, for the Orelha de Elefante variety; 823, 1373, 2031 and 4471 °C, respectively, for the Baiana variety; and 823, 1363, 1941 and 4471 °C, respectively, for the Miúda variety (Figure 7). The difference in the thermal sum values between the varieties is possibly related to the time each variety took to emit the 1st-, 2nd-, 3rd- and 4th-order cladodes.

This time criterion is for the emission of 1st-, 2nd-, 3rd- and 4th-order cladodes, according to Silva et al. (2015), is considered subjective for determining the different development phases of forage palm varieties. Another factor that may be associated with this difference is the intrinsic genetic characteristics of each variety, which belong to different species.

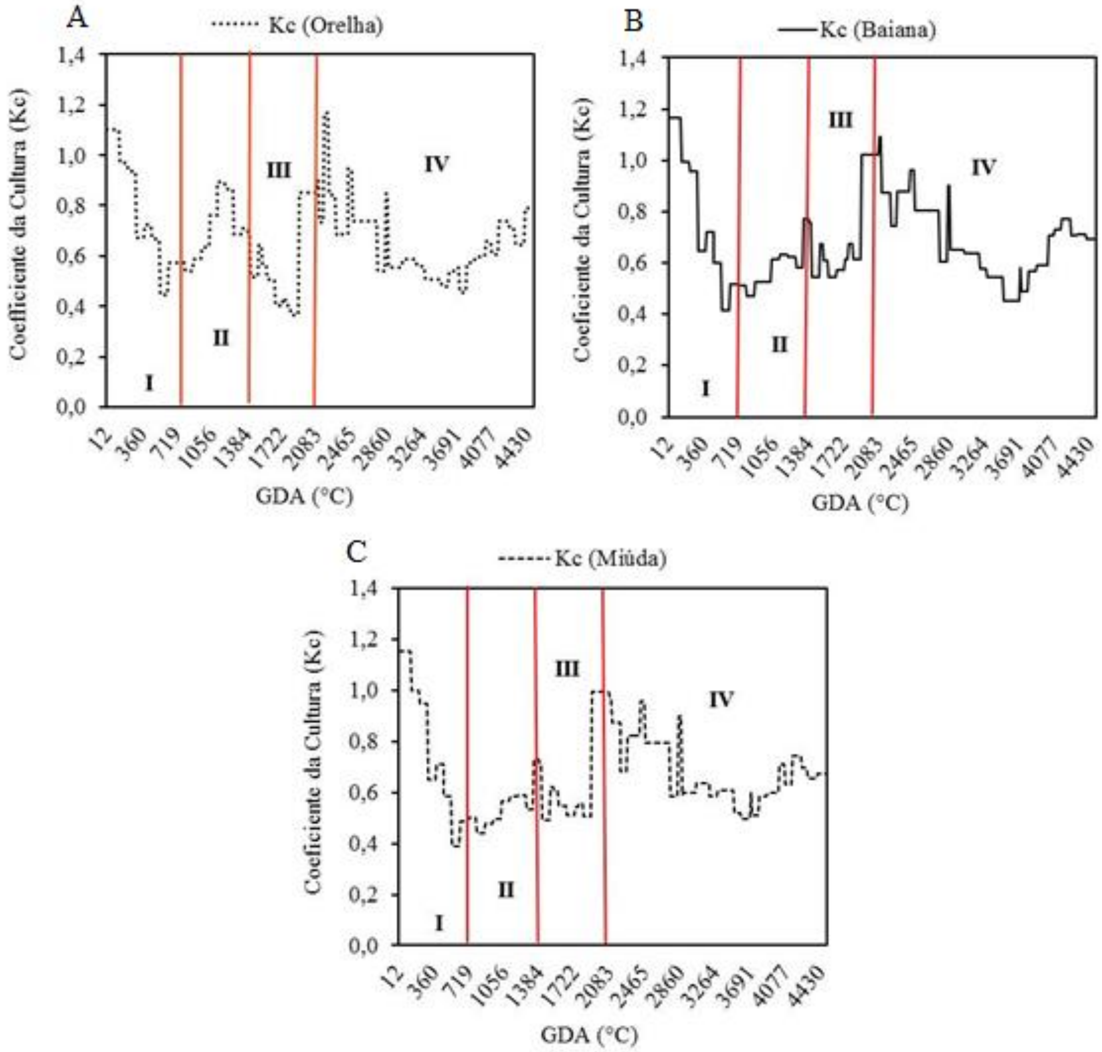
Similarly, Araújo Júnior et al. (2017), analyzing the forage cactus Orelha de Elefante, obtained a thermal sum of 3,178 °C at the end of a 380-day cycle. Silva et al . (2015), when evaluating the thermal requirements of the forage cactus in exclusive cultivation, an annual thermal requirement equal to 2,767 °C was obtained. This shows that each variety has different thermal sums, depending on the genetic characteristics that influence the duration of cladode emission.

These values are lower than those obtained in the present study since Silva et al. (2015) adopted basal temperatures of 22 and 20 °C. As a result, the cactus palm presented a low daily accumulation of thermal energy; therefore, according to the authors, the cactus palm requires more time to emit a cladode unit. This fact was not observed in this study, since the Tb was 18 °C, which is lower than the minimum temperature throughout the experimental period and favors the emission of cladodes more quickly; in addition, the maximum temperature was above 34 °C, which favors the daily accumulation of thermal energy.

5.4 Determination of crop coefficients

The crop coefficients for the varieties studied over the 365 days after planting in the different development phases are shown in Figure 8. The average crop coefficient values obtained in the first phase were 0.78, 0.74 and 0.73; in the second phase, 0.72, 0.59 and 0.54; in the third phase, 0.56, 0.69 and 0.60; and in the fourth phase, 0.65, 0.69 and 0.69 for the Orelha de Elefante, Baiana and Miúda varieties, respectively.

Figure 8. Crop coefficients of the forage palm varieties Orelha de Elefante (A), Baiana (B) and Miúda (C) as a function of the thermal sum. Santa Luzia, PB.



The degree day (GDA) values for the first phase were 835, 823 and 823; in the second phase, the GDA values were 1383, 1373 and 1363; in the third phase, the values were 2942, 2031 and 1941 GDA; and in the fourth phase, the values were 4471 and 4471 GDA for the varieties Orelha de Elefante, Baiana and Miúda, respectively (Figure 8). At the beginning of the first phase, the Kc values in all varieties were greater than 1, which can be explained by the fact that the plant constituting the initial phase was only the basal cladode. During this period, the absence of cladodes reduces the evapotranspiration area of the plant, increasing the incidence of sunlight directly on the soil and increasing evaporation.

Amorim et al. (2017) reported that they obtained only three development phases in the forage palm variety Orelha de Elefante Mexicana (*Opuntia)*, with the first phase lasting seven months and the second and third phases varying due to the irrigation depth applied. This observed difference may be due to the management offered to the crop and the climatic characteristics of the studied locations.

The crop coefficient of forage cactus, as shown in Figure 8, varied in relation to the development phases, averaging 0.72, 0.70, and 0.70 for the

Mexican, Bahian, and Miúda elephant ear varieties, respectively, for the twelve-month period. The crop coefficient values determined in this research are very similar to those reported by Divincula et al. (2019), who, using drainage lysimeters, obtained average Kc values of 0.72, 0.84, and 0.48 via the Penman–Monteith, Hargreaves–Samani, and FAO–Radiation methods, respectively.

However, these values are greater than those reported by Consoli, Inglese and Inglese (2013), Queiroz et al. (2016) and Jardim et al. (2017), who reported average Kc values of 0.40, 0.52 and 0.57, respectively, for the same palm species used in the present study. However, the Kc values determined in this research are in agreement with those suggested by Arba et al. (2016), who stated that, for the management of palm crops of the genus Opuntia, a Kc of 0.70 should be adopted.

The highest relative water consumption values occurred in phases I and IV, which were 1.10, 1.15, and 1.16, respectively, for Orelha de Elefante, Baiana, and Miúda. Therefore, the Kc value to be used in developing an irrigation project for this crop should be the average of the two phases (Figure 8). This recommendation is related to the fact that the average Kc is based on the minimum and maximum values, which are influenced by the crop's leaf area index and, as irrigation recommendations, are considered representative.

6 CONCLUSION

The evapotranspiration of the three varieties of forage palm was greater than 4.5 mm day $^{-1}$.

Water consumption in cultivation periods I and IV was greater than that in periods II and III for all varieties under study.

The thermal requirements of the three varieties of forage palm from planting to harvest are greater than 4000 °C.

For a twelve-month cycle, the average cultivation coefficients of the Mexican, Bahian and Miúda elephant ear varieties, 0.72, 0.70 and 0.70, respectively, were greater than those reported in the literature for these species.

The crop coefficients adjust satisfactorily to the degree-days of development of the forage palm varieties.

The basal temperature was lower than the minimum air temperature throughout the experimental period.

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