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Article

Net radiation partitioning, evapotranspiration, and crop coefficients of the green dwarf coconut in Santa Izabel do Pará, Brazilian Amazon

Erika de Oliveira Teixeira de Carvalho[1], Gabriel Siqueira Tavares Fernandes[1], Matheus Lima Rua[1], Adrielle Carvalho Monteiro[1], Denilson Barreto da Luz[1], Stefany Porcina Peniche Lisboa[1], João Vitor Ferreira da Silva[1], João Vitor de Nóvoa Pinto[1], Fábio Rodrigues de Miranda[2], Paulo Manoel Pontes Lins[3], Paulo Jorge de Oliveira Ponte de Souza[1,*]

1. Universidade Federal Rural da Amazônia – Instituto Socioambiental e dos Recursos Hídricos – Laboratório de Agrometeorologia – Belém (PA), Brazil.
2. Embrapa Agroindústria Tropical – Fortaleza (CE), Brazil.
3. Sococo S/A Agroindústrias Alimentícias – Santa Izabel do Pará (PA), Brazil.

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***Corresponding author:** paulo.jorge@ufra.edu.br

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ABSTRACT: Inadequate management of the irrigation system has compromised yield and favoured the degradation and waste of water resources. To ensure efficient irrigation management, providing yield increases, sustainability in the use of water resources and reduction of production costs, studies about the water demand of coconut palms are needed. The objective of this study was to determine the energy partition, crop evapotranspiration (ET_c), and the simple crop coefficients (K_c) of the green dwarf coconut palms in Santa Izabel do Pará, Pará, Brazil. The experiment was carried out in a coconut plantation at Reunidas Sococo Farm, with an area of approximately 7 ha in a triangular spacing of 7.5 × 7.5 m, during 2020 and 2021. The ETc was determined by the Bowen ratio method, with measurements of temperature and relative humidity at two levels above the crop canopy and reference evapotranspiration (ET_o) by the FAO Penman-Monteith method, using data from the National Institute of Meteorology. The K_c was determined by the ratio between ETc and ETo. The total water demand of the coconut palm was 489 (2020) and 480 mm (2021), with a daily average of 4.21 (2020) and 4.14 mm (2021) for the dry season. The mean value of K_c was 1.06 (± 0.12). Evapotranspiration was driven mainly by energy availability, associated with a control of atmospheric demand on K_c values, suggesting a possible influence of coconut trees on Kc values even under good water availability and small variability in vegetation cover.

Key words: *Cocos nucifera*, water resources, sustainability, irrigation.

INTRODUCTION

The coconut (*Cocos nucifera* L.) is a palm of high socioeconomic importance, mainly for tropical countries that present climate and soil conditions favourable to its cultivation, contributing to the generation of employment and income (Kumar et al. 2021, Sousa et al. 2011).

In Brazil, although the Northeast is the main producing region, its cultivation has reached great economic importance in other regions, such as in the North, due to the growing demand for green coconut production (Miranda et al. 2019, Santos et al. 2020). Pará is the largest producer in the North, with a production of around 189.6 million fruits and an average yield of 9.9 thousand fruits·ha^{-1} (IBGE 2020).

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Because it has high transpiration rates, the coconut palm is more susceptible to water deficit than other palm species (Cintra et al. 2009). Under water deficit, the coconut palm reduces the growth and the number of flowers (Silva et al. 2017). Also, a decrease in the fruit size, as well as the abortion of fruits, may happen, which results in low yield (Araújo et al. 2022, Câmara et al. 2019). Thus, irrigation has been used as management practice to minimize these effects and allow the expansion of its cultivation in regions with seasonal water deficit (Santos et al. 2020) when water demand is not met by rain events.

Although the use of irrigation is possible for agricultural intensification, contributing to increased yield, especially in places where rainfall distribution is irregular (Santos et al. 2020), the poor use of water resources has resulted in its degradation and waste (Fito and Van Hulle, 2021).

Knowledge of the evapotranspiration of coconut palm (ET_c), as well as its crop coefficient (K_c), is needed for the correct management of irrigation, since the water consumption of crops varies according to their phenological characteristics, atmospheric demand, and water availability in the soil (Abdelkhalik et al. 2020).

Although some studies on the water demand of coconut palm have already been carried out in the country and there are values of K_c in the literature such as 0.9 (Sousa et al. 2011) and 1 (Miranda et al. 2007), the determination of K_c should be performed for each crop and region, since there are differences in the management practices that can influence the values of this coefficient (Pereira et al. 2015, Alves et al. 2017).

There are several techniques to measure the evapotranspiration of a crop. Among them, there are lysimetric/water balance (Miranda et al. 2007, Sousa et al. 2011, Abdelkhalik et al. 2020), eddy covariance (Ortega-Farias et al. 2010), and energy balance based on the Bowen ratio method (Souza et al. 2018, Sousa et al. 2021), the latter being one of the most used to estimate ET_c because it is more practical and less costly (Dicken et al. 2013).

Several studies carried out around the world prove the accuracy of the results obtained by the Bowen ratio method (BRM) in relation to the turbulent vortices method in determining the components of the energy balance (Allen et al. 2017, Tie et al. 2018), allowing the BRM to be used as a relatively practical and reliable tool.

Therefore, studies that allow the knowledge of the water requirement of coconut in other producing regions are fundamental to provide information necessary for the efficient management of irrigation, avoiding the application of water above or below the necessary amount, promoting the sustainability of water resources and contributing to the reduction of financial damage. Testing alternative and less expensive measurement and estimation methods becomes a challenge for advancing research on coconut farming in the region due to the lack of technical information and limited support.

The objective of this study was to determine the ET_c in the absence of restrictions regarding the supply of water, as well as the single K_c of green dwarf coconut, in a commercial plantation in the municipality of Santa Izabel do Pará, Pará, Brazil. To achieve this aim, the Bowen-ratio energy balance method was used.

MATERIALS AND METHODS

Characterization of the study area

The experiment was carried out at Fazenda Reunidas Sococo, in the municipality of Santa Izabel do Pará (01°13’40.16”S and 48°02’54.35”W), in a commercial planting of green dwarf coconut with approximately 7 ha, from August 2020 to December 2021 (Fig. 1).

The plants of the experimental area were 7 years old in the experiment period, with an average height of 7.3 m, planting density of 7.5 × 7.5 m in an equilateral triangle (205 plant·ha^{-1}), and they were in the fifth harvesting year. The cultivar used was the green-dwarf-of-brazil-jiqui (AVeBrJ). The vegetation cover of the soil is the tropical kudzu (*Pueraria phaseoloides*), a perennial herbaceous legume which was planted simultaneously with the coconut. The crowning was carried out under the canopy of the coconut tree to keep the soil uncovered and free of weeds.

According to the Köppen-Geiger climate classification, the climate of the region is characterized as humid tropical, with climatic subtype Am. The region receives annual rainfall above 2,000 mm with a moderate dry season, average annual temperature of approximately 26°C and relative humidity around 80% (Alvares et al. 2013). The period from January to July is the wet season, and the period from August to November is the dry season, with periods with monthly rainfall below 130 mm (August to November), being harmful to the crop (Passos et al. 2018).

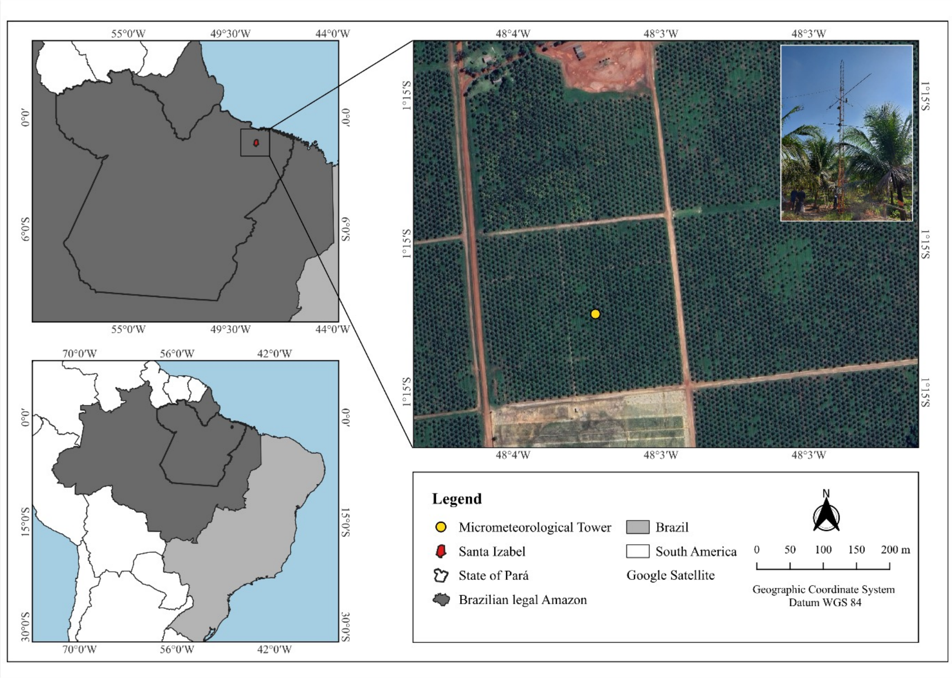

Figure 1. Experimental area, Santa Izabel do Pará, Pará, Brazil.

The soil of the area is classified as Arenosol (Embrapa 2018), and its characteristics are presented in Table 1. The physical and chemical characteristics of the soil were determined at the Soil Laboratory of Embrapa Amazônia Oriental, from samplings carried out at a depth of 0 to 20 cm.

Table 1. Physicochemical and water characterization of the soil of the experimental area.

Characteristics	Depth (cm)	
	0–20	20–40
pH ($CaCl_2$)	4.43	4.10
Organic matter (g·dm^3)	8.75	3.25
Organic carbon (g·dm^3)	5.00	2.00
P (mg·dm^3)	111.92	7.05
Ca^{+2} (mmol$_c$·dm^3)	10.7	4.00
Mg^{+2} (mmol$_c$·dm^3)	5.50	2.30
K$^+$ (mmol$_c$·dm^3)	2.10	0.90
H$^+$ + Al^{+3} (mmol$_c$·dm^{3}dm^3)	33.7	32.7
Cation exchange capability (mmol$_c$·dm^3)	52.5	40.10
Base saturation (%)	34.85	17.95
Al Saturation (%)	6.48	31.76
Sand (%)	70	-
Silt (%)	12	-
Clay (%)	18	-
Field capacity (m^3·m^{-3})	0.195	-
Permanent wilting point (m^3·m^{-3})	0.098	-

The plants were fertilized twice each year with 3.3 kg of the Formulation NPK (10-07-20 + 1.0% magnesium + 5.5% sulfur + 3.5% calcium and 0.10% boron + 0.11% manganese). During the experimental period, all management procedures adopted by the company were maintained, such as: weeding, pest control, and disease control.

Irrigation system

The irrigation system used was pressure regulating microsprinkler with a flow rate of 96 $L{\cdot}h^{-1}$ and uniformity coefficient of 96%, with one emitter per plant, positioned 1 m from the base of the stipe (tree trunk). Irrigations were scheduled based on the reference evapotranspiration (ET_o), calculated through the Penman-Monteith-FAO-56 method proposed by Allen et al. (1998), with data from the company's meteorological station, installed about 2 km from the experimental area. The irrigation frequency was used on a daily scale depending on the atmospheric demand of the previous day.

Tower instrumentation and data collection

For the acquisition of data necessary for the determination of rhe ET_c by the BRM, a metal tower with 12-m height was installed in the experimental area, obeying the minimum requirements of fetch, with a ratio greater than 1:100, so that there was no influence of advective effects, and the measurements were representative of the study area.

The tower was instrumented with incident global radiation sensors (CMP3), net radiation (NR-LITE2), wind speed and direction (05106), rainfall (TB4), (Campbell Scientific Instrument, Logan, UT, United States of America), temperature and relative humidity (MeteoTemp, Barani Design Technologies, United States of America) positioned at 0.7 and 2.1 m above the canopy of the coconut tree, volumetric soil water content (CS615) based on time-domain reflectometry and heat flux in the soil (HFP01SC), (Campbell Scientifc Instrument, Logan, UT, United States of America) on the row of trees and between rows at 0.08-m depth. The accuracy of the thermohygrometers was ± 0.2°C for air temperature and ± 1.8% for relative humidity.

The sensors were connected to two data acquisition and storage systems (Datalloger CR 1,000 and CR 10x, Campbell Scientific, Inc., Logan, UT, United States of America) and a multiplexer (AM416, Campbell Scientific, Inc., Logan, UT, United States of America), programmed to perform readings every 30 seconds and recording averages and totals every 20 minutes.

Energy balance-Bowen ratio

The BRM is based on the principle of energy conservation, and the determination of its components was obtained according to the following simplified Eq. 1 (Souza et al. 2018):

$$R_n = LE + H + G \tag{1}$$

where: R_n: the net radiation; LE: the latent heat flux; H: the sensible heat flux; G: the heat flux in the soil. All the terms of Eq. 1 were expressed in $W{\cdot}m^{-2}$.

The heat stored in the soil layer above the levels of the soil heat flux plates was estimated according to Borges et al. (2008).

Bowen's ratio (β) was obtained through Eq. 2:

$$\beta = \frac{H}{LE} = \frac{\rho_a c_p}{\rho_a \lambda}\left(\frac{K_h}{K_w}\right)\frac{\frac{\Delta T}{\Delta z}}{\frac{\Delta e}{\Delta z}} \tag{2}$$

Considering the equality between turbulent diffusivity coefficients K_h e K_w, Eq. 2 is simplified to Eq. 3:

$$\beta = \gamma \frac{\Delta T}{\Delta e} \tag{3}$$

where: $\Delta T = T_{0,7} - T_{2,1}$ and $\Delta e = e_{0,7} - e_{2,1}$: the differences between the two air temperature levels and water vapor pressure in the layer above the coconut palm canopy, respectively; γ: the psychometric coefficient ($kPa°C^{-1}$)

The latent heat flow (LE) was obtained by replacing the Bowen ratio (H = LE.β) in the Eq. 1, that is (Eq. 4):

$$\frac{R_n + G}{1 + \beta} \tag{4}$$

The sensitive heat flow (H) was obtained as residue of Eq. 1, that is (Eq. 5):

$$H = R_n - LE - G \tag{5}$$

The data were tested by the criteria established by Perez et al. (1999). In addition, Bowen ratio values close to -1 were rejected, since they incur a physical inconsistency.

Crop evapotranspiration

To determine coconut ET_c, only positive values of LE were considered, between the hours of 6 a.m. to 6 p.m. (R_n - G > 0). ET_c was estimated according to Eq. 6:

$$ETc = \frac{LE}{\lambda} \tag{6}$$

where: ET_c: the evapotranspiration of the crop ($mm \cdot day^{-1}$); LE: the average LE in the 20-minute interval ($MJ \cdot m^{-2}$); λ: the average latent heat of vaporization ($J \cdot Kg^{-1}$).

Single crop coefficients of the green dwarf coconut

The simple K_c was obtained from ET_c and ET_o (Allen et al. 1998), according to Eq. 7:

$$Kc = \frac{ET_c}{ET_0} \tag{7}$$

Phenological monitoring

Twenty-four green dwarf coconut palm plants were randomly selected in the homogeneous orchard. Phenological observations were carried out every two weeks from August/2020 to December/2021, analysing the number of leaves and live bunches.

RESULTS

For the period from August to November (dry season), the average global solar radiation (R_g) was 18.62 $MJ \cdot m^{-2} \cdot day^{-1}$, and the average net radiation (R_n) was 11.94 $MJ \cdot m^{-2} \cdot day^{-1}$. For the period from December to July (which comprehends most of the wet season), the R_g value was 15.34 $MJ \cdot m^{-2} \cdot day^{-1}$ and the R_n was 9.40 $MJ \cdot m^{-2} \cdot day^{-1}$ (Fig. 2a).

The air temperature (Tar) varied little throughout the experiment, with maximum monthly Tar of 27.4°C (September/2021) and minimum of 25.1°C (March/2021), showing an average value during the less and wettest period of 26.8 and 25.8°C (Fig. 2a), respectively. On the other hand, wind speed (U2) was greater in the dry season (August–December, 0.56 $m \cdot s^{-1}$) compared to the wet season (January–July, 0.31 $m \cdot s^{-1}$), contributing to the renewal of air masses and to the increase in the vapor-pressure deficit (VPD), which was 0.44 and 0.33 kPa, respectively (Fig. 2b).

The accumulated rainfall for the period studied (August-2020 to December-2021) was 3,317 mm, of which 60% of this total corresponded to the period from December-2020 to July-2021. The largest rainfall occurred in March-2021, with a monthly total of 389 mm (Fig. 2c).

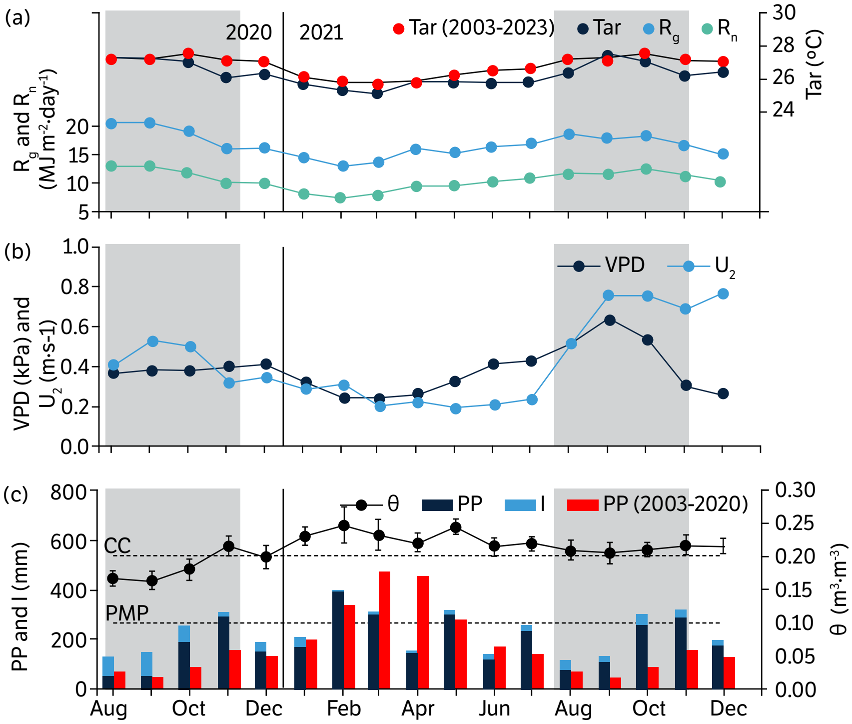

Figure 2. Variation of (a) global incident radiation (Rg), net radiation (R_n) and air temperature (Tar); (b) vapor pressure deficit (VPD) and wind speed (U2); and (c) rainfall (PP), irrigation (I) and volumetric soil moisture (θ), during the period from August 2020 to December 2021.

The volumetric soil content of water during the dry season (August–December) ranged from 0.164 to 0.216 $m^3 \cdot m^{-3}$, reaching the lowest values at this time, while in the period of higher precipitation these values were higher, varying from 0.199 to 0.247 $m^3 \cdot m^{-3}$ (Figure 2c). Except for the months of August to October 2020, soil moisture always remained above the field capacity, especially during the wet season, indicating water saturation events, considering that field capacity and permanent wilting point were 0.195 and 0.098 $m^3 \cdot m^{-3}$, respectively (Table 1). On the other hand, the good drainage of the soil (70% sand) prevented more serious problems for the development of the coconut palm.

Irrigation was applied throughout the studied period (Fig. 2c), being much more intensive during the dry season (August–December), when the correct determination of the ET_c is necessary. The monthly irrigation depth values applied ranged from 6.65 (April-2021) to 93.77 $mm \cdot month^{-1}$ (September-2020), with a total value of 249.37 and 137.30 mm, during the period from August to November, for the years 2020 and 2021, respectively.

The mean value of R_n during the dry season, when irrigation is necessary, was 13.61 and 13.36 MJ m-2·day^{-1}, for the years 2020 and 2021, respectively (Table 2).

Table 2. Average values of global incident radiation (R_g); net radiation (R_n); latent heat flux (LE); sensitive heat flux (H); and soil heat flux (G) in $MJ \cdot m^{-2} \cdot day^{-1}$, during the period of use of the irrigation system in the years 2020 and 2021, in Santa Izabel do Pará, Pará, Brazil.

Year	Months	R_g	R_n	LE	H	G	R_n/R_g	LE/R_n	H/R_n	G/R_n
2020	August	20.68	14.77	11.32	3.12	0.34	71.46	76.67	21.05	2.28
	September	20.80	14.78	11.26	3.03	0.49	71.04	76.19	20.50	3.30
	October	19.20	13.56	10.17	2.86	0.53	70.61	75.05	21.06	3.89
	November	16.25	11.32	8.72	2.08	0.53	69.12	77.04	18.29	4.67
2021	August	18.73	13.28	10.08	2.91	0.28	70.73	75.94	21.94	2.12
	September	18.07	13.30	10.11	2.75	0.44	73.55	76.04	20.67	3.29
	October	18.31	14.02	10.68	2.85	0.49	76.51	76.20	20.32	3.48
	November	16.95	12.86	9.81	2.62	0.43	75.69	76.40	20.37	3.23

The average proportion of energy used by the components of the energy balance, during the dry season (August–December), in which the correct estimate of the ET_c is required, in order to keep the irrigation system working efficiently, corresponded to 76.2% (LE), 20.2% (H) and 3.6% (G) for 2020 and 76.1% (LE), 20.8% (H) and 3% (G) for 2021 (Table 2). The correction applied in the estimation of soil heat flow with the inclusion of heat stored in the soil provided an increase of 0.23 $MJ \cdot m^{-2} \cdot day^{-1}$ in the mean value of each month (Table 2).

LE was the component that used most of the R_n in relation to H and G, regardless of the year. The mean LE estimated during most of the dry season (August to November) was 10.33 and 10.17 $MJ \cdot m^{-2} \cdot day^{-1}$ for the years 2020 and 2021, respectively. The average H for the irrigation period was 2.76 (2020) and 2.78 $MJ \cdot m^{-2} \cdot day^{-1}$ (2021), and the heat flux in the soil (G) corresponded to 0.48 (2020) and 0.41 $MJ \cdot m^{-2} \cdot day^{-1}$ (2021).

The small variation in the percentage of the incident solar radiation in net radiation (3.6%) between the years analyzed suggests that the characteristics of the surface may have less influence on the radiative balance than the characteristics of the atmosphere, judging by the regularity of the number of leaves present in the canopy throughout the year, when the number of leaves ranged from 29 to 32, with an average value of 30.3 leaves (Fig. 3).

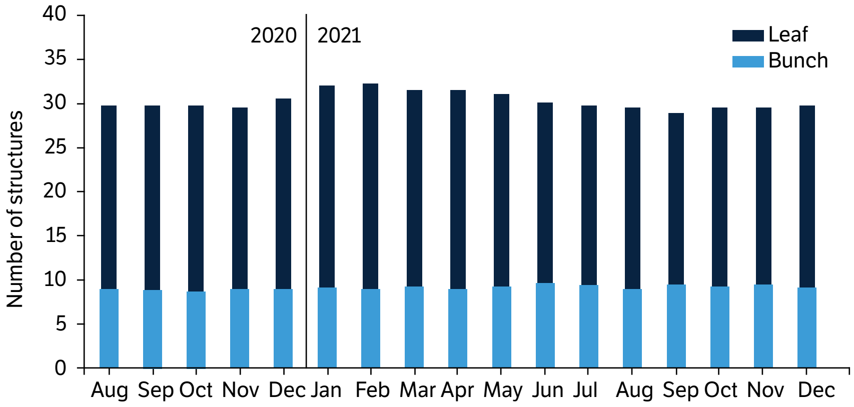

Figure 3. Seasonal variation in number of bunch and leaves of green dwarf coconut trees, between August 2020 and December 2021, Santa Izabel do Pará, Pará, Brazil.

During most of the dry season (August to November) in both years, a period in which the estimation of ET_c becomes necessary for rational management in the area, the daily ET_c values of the green dwarf coconut tree were generally greater than the ET_o. The mean daily ET_c for both periods corresponded to 4.18 mm (± 0.75), while the mean ET_o corresponded to 3.97 (± 0.77) mm (Fig. 4).

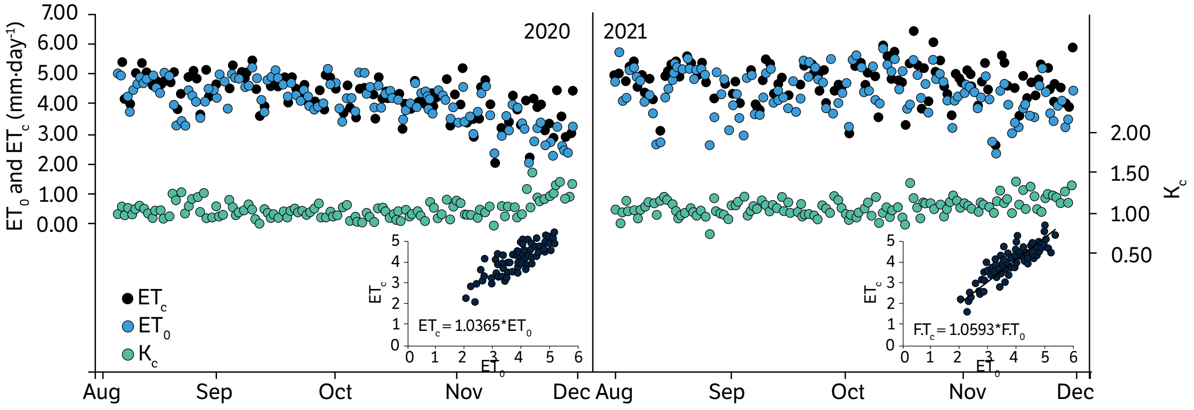

Figure 4. Daily average of reference evapotranspiration (ET_o) and crop evapotranspiration (ET_c) in an irrigated plantation of green dwarf coconut palms in Santa Izabel do Pará, Pará, Brazil, during the period from August to November, in the years 2020 and 2021.

The accumulated ET_c of the green dwarf coconut tree in the period from August to November 2020 was 489 mm, corresponding to an average ET_c of 4.21 $mm \cdot day^{-1}$ (206.9 L·plant-1·day^{-1}), reference surface (ET_o) totaled about 469 mm, with an average of 4.04 $mm \cdot day^{-1}$ (197.2 $L \cdot plant^{-1} \cdot day^{-1}$). In 2021, the total water use in the same period of irrigation was 480 mm, with an average ET_c of 4.14 $mm \cdot day^{-1}$ (202.0 $L \cdot plant^{-1} \cdot day^{-1}$). The accumulated total ET_o was 449 mm, indicating an average of 3.87 $mm \cdot day^{-1}$ (189.9 $L \cdot plant^{-1} \cdot day^{-1}$) (Fig. 4 and Table 3). The K_c varied little over time (Fig. 4). The mean K_c value found during the study period was 1.05 (± 0.12), ranging from 1.04 in the period of 2020 to 1.06 in 2021.

Table 3. Mean values of reference evapotranspiration (ET_o); crop evapotranspiration (ET_c); and simple crop coefficient (K_c) for green dwarf coconut in the meteorological conditions of Santa Izabel do Pará, Pará, Brazil, during the period of use of the irrigation system in 2020 and 2021.

Year	Months	ET_o	ET_c	K_c
2020	August	4.35	4.62	1.07
	September	4.52	4.60	1.02
	October	4.16	4.15	1.00
	November	3.18	3.56	1.12
2021	August	4.02	4.11	1.03
	September	3.90	4.13	1.07
	October	4.16	4.36	1.05
	November	3.49	4.01	1.15

Although this value does not seem to vary based on the daily scale (Fig. 4), it is possible to notice a moderate decrease when the plant is subjected to different atmospheric conditions (Fig. 5) even considering water availability due to imposed irrigation. Figure 5 shows the K_c values obtained in both years for different classes of VPD in the atmosphere, suggesting that, as atmospheric demand increases, there is a reduction in K_c values. K_c values ranged from 1.09 (± 0.12) under VPD below 0.6 to 1.03 (± 0.08) under VPD higher than 0.6.

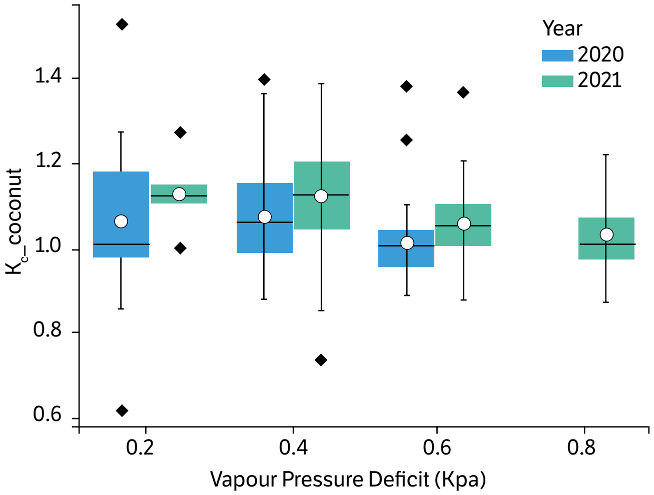

Figure 5. Daily average value of coconut palms crop coefficient (K_c) for different classes of vapor-pressure deficit in Santa Izabel do Pará, Pará, Brazil, during the period from August to November, in the years 2020 and 2021.

DISCUSSION

In the wet season (January to July), the R_g and R_n reduced by 17.62 and 21.27%, respectively, as a result of the greater presence of cloudiness, which promotes the spread of radiation, reducing its incidence on the surface (Souza et al. 2018).

The small temperature variation indicates that the crop did not suffer thermal limitation, since it was accordingly the recommended value (27°C) for coconut tree culture (Passos et al. 2018). The highest temperature during the dry season (August–December) occurs due to the lower volume of rainfall and the increase in solar radiation that reaches the surface (Ataide et al. 2020). The highest VPD in the dry season (August–December) tied to the high availability of water in the soil results in a higher water demand by the atmosphere, causing an increase in ET_c rates in this period by coconut tree (Brum et al. 2021).

The experiment may have suffered from the influence of La Niña, from December 2020, with intensification of volume and prolongation of rains (Moreira et al. 2018, NOAA 2022). The identification of the actual amount of water that reaches the surface of the soil also allows for an adequate supply of water, promoting an efficient management of the irrigation system, avoiding water waste and financial resources (Velasco-Muñoz et al. 2019).

Irrigation was performed to avoid possible damages to the crop, such as leaf senescence and abortion of fruits, due to the water deficit induced by the low rainwater availability between August and November (Fig. 2c), which is lower than the crop requirement, defined as 130 $mm{\cdot}month^{-1}$ (Passos et al. 2018). Furthermore, most of the monthly rainfall during the dry season occurs in only a few days, which reinforces the severity of the water deficit experienced by the plants. Such damages caused by the water deficit are the main driving factors of yield losses (Miranda et al. 2019).

The number of leaves found in this study (Fig. 3) constitutes a good vegetative aspect of coconut trees, besides being above the values found in the literature, once, according to Castro et al. (2009), when environmental conditions favor the canopy development, the coconut tree may reach between 25 and 30 leaves, and the authors observed between 18 and 27 live leaves. Ferreira Neto et al. (2007) and Câmara et al. (2019) in studies with coconut trees in the Northeast region accounted for an average of 22.25 and 22.28 leaves, respectively.

The radiation balance showed small seasonal variability for the two years evaluated in the studied area. Changes in cloud cover, due to periods with higher and lower precipitation, may have been the main cause in changes in radiation balance directly influencing the variation of available energy to perform processes related to the surface-atmosphere system (Querino et al. 2017), since both the fraction of the land covered by the canopy of the coconut palms (Fig. 3) and the water availability remained practically uniform over time (Fig. 2c).

The standard deviation found for volumetric water content over the months confirmed the uniform distribution along the coconut cycle, mainly in 2021. Despite the uniformity presented by the volumetric content on a monthly scale during the wet season, its stability is confirmed by the low standard deviation values (Fig. 2c) due to the frequency of irrigation events, as well as rainfall. The small contribution of stored heat to soil heat flow estimates may be related to the volumetric water content present in the soil, influencing the decrease in soil temperature and stored heat (Santos et al. 2010).

The difference between the LE values during the dry season (August–December) in both years was minimal (0.16 $MJ{\cdot}m^{-2}{\cdot}day^{-1}$). Although 2021 presented a volume of rainfall around 22.8% higher than in 2020, in the dry season (August–December) the value of LE was lower. Situation resulting from greater cloud cover caused the reduction of solar radiation and, consequently, of the net energy available for partitioning (Ataide et al. 2020).

The low variability of H occurred due to the high availability of water present in the environment, due to the irrigation system, contributing to the greater use of available energy in the form of latent heat than for air heating in both years (Souza et al. 2018), as well as the little variability of canopy characteristics (Fig. 3).

In addition, the high soil moisture content swelled in both periods, caused by rainfall and irrigation, reducing the variability of soil temperature, and promoting the reduction of the energy available for its heating (Santos et al. 2010).

ET_o indicated a water depth (193.7 $L{\cdot}plant^{-1}{\cdot}day^{-1}$) 5.1% lower than the average actual water consumption of the green dwarf coconut trees (204.0 $L{\cdot}plant^{-1}{\cdot}day^{-1}$) for the experimental conditions during the four months evaluated in the two years.

This reinforces the importance of considering the ET_c for the correct management of irrigation, given that irrigation management based on ET_o and the use of $K_c = 1$, as recommended by Allen et al. (1998) and by Miranda et al. (2007), would underestimate the water need of the green dwarf coconut tree, and its use could lead to an inadequate supply of water to carry out the metabolic processes of the crop.

The mean ET_c determined in this study for the green dwarf coconut trees differs from the values found by other authors such as Sousa et al. (2011) in studies with coconut tree in Sergipe, Brazil, which presented an average ET_c of 3.90 $mm{\cdot}day^{-1}$

using weight lysimeters. Miranda et al. (2007), in research with coconut-dwarf in Ceará, Brazil, found an average of 3.86 mm·day^{-1} using the soil water balance method for a 0.6-m depth, and Jayakumar et al. (1988) in studies with giant coconut tree in India found an average ET_c of 3.30 mm·day^{-1} using the volumetric lysimeter approach.

Different methodologies such as weight lysimeters, soil water balance method, and volumetric lysimeter approach, characteristics of the plant itself, managements, and cultural treatments adopted, as well as the climatic condition itself, may have caused such differences.

The small difference in water consumption by the green dwarf coconut tree during the dry season (August–December) observed between years is due to the natural variability of atmospheric conditions during the periods, since throughout the year the coconut tree remains practically with the same plant structure, presenting all bunches at the same time and with minimal variation in the number of leaves (Fig. 3).

This low change in the structure of the vegetative canopy corroborates the hypothesis that the vegetation of the green dwarf coconut tree presents low seasonality in its maximum ET_c, being much more dependent on the energy availability than on the plant characteristic itself. This occurs because, in areas where the moisture present in the soil is favorable for the crop, the variation in stomatic conductance is small (Silva et al. 2017), and solar radiation becomes the main controlling agent of water losses, differing from what occurs in places where the amount of water available the crop is limited (Silva et al. 2021, de Souza et al. 2019).

Marques et al. (2020) in studies in tropical forests observed that in environments of low water availability stomatic conductance is the one that controls ET_c. Silva et al. (2021), studying the behavior of evapotranspiration in flooded forests, stated that the vegetation presented poor coupling with the atmosphere, indicating that ET_c is more dependent on the R_n.

Studies conducted with other fruits in the Amazon region indicate that, due to the enormous water availability in the region, the vegetation practically acts in a decoupled way from the atmosphere, being, therefore, the energy availability one of the main factors responsible for gas exchange under such conditions. Sousa et al. (2021) found a state of decoupling of the açai palm with the atmosphere, where ET_c values were mainly controlled by solar radiation in the region.

The K_c value found in this study (1.05 ± 0.12) differs from the one recommended by Allen et al. (1998) for palm trees in general ($K_c = 1$), from that found by Miranda et al. (2007) in studies with irrigated green dwarf coconut tree in Ceará, in the third year of production ($K_c = 1$), from that obtained by Sousa et al. (2011) for green dwarf coconut in Sergipe ($K_c = 0.90$), and used by Surendran et al. (2019) for giant coconut tree in India ($K_c = 0.75$). As shown in Fig. 4, both irrigated periods presented small daily variability over the months availed, with average values for K_c of 1.04 (± 0.12) in 2020 and 1.06 (± 0.11) in 2021.

The edaphoclimatic conditions of each region, the variations of meteorological elements over the years, and the local ecosystem have great influence on the ET_c of a crop and consequently on its K_c (Araújo et al. 2022). The irrigation depths associated with the frequency of rainfall, as well as the vegetation present in the mainline, contribute to the prolongation of the good level of moisture in the soil, enhancing the ET_c and favoring a higher K_c (Seva and Pascual 2021).

According to Allen et al. (1998), places where the soil remains moist for longer the K_c can exceed the unit value, due to greater evaporation. This emphasizes the importance of K_c determination for each cultivation condition, due to its specificity, as well as the need to differentiate the processes of loss that are occurring in the environment, both by evaporation and mainly by transpiration.

The adequate level of soil moisture during the experiment may have favored the increase in stomatic conductance and transpiration (Silva et al. 2017), promoting the absorption of water and nutrients by the coconut tree (Santos et al. 2020), ensuring values of K_c above 1. Brum et al. (2021) confirmed the increased in transpiration with the maintenance of drip irrigation in oil palm even during El Niño Southern Oscillation 2015.

Sousa et al. (2021) in studies with palm tree also found the increase in K_c values with the highest amount of available water. This is due to the absence of water deficit, and the high availability of energy favors gas exchange between the atmosphere and culture (Silva et al. 2017), contributing to a lower resistance to stomatic opening, and with the increase in transpiration and photosynthetic rates, resulting in higher productivity (Santos et al. 2020).

The dependence of K_c on climatic conditions is something that must always be considered (Allen et al. 1998) since, under conditions of high atmospheric demand (ET_o), there is an increase in surface resistance on gas exchange, leading to a reduction in transpiration, even under adequate water conditions, resulting in a decrease in K_c (Marin et al. 2016). As seen in Fig. 5, the coconut tree also seems to follow the same pattern found in other sparse crops such as coffee and citrus, where it was observed a control in the transpiration process with the increase in ET_o, leading to a compensation in the ET_c value due to the loss by evaporation (Marin et al. 2016).

Based on the results found, we may argue that the recommendation proposed by Allen et al (1998) and Miranda et al. (2007) of using K_c equals to 1 for coconut trees would only be valid under conditions of high atmospheric demand (VPD > 0.7), with underestimation occurring when in conditions of moderate and low atmospheric demand, leading to possible risks in irrigation management.

Increasingly accurate estimates of the crop coefficient for irrigated fruit trees are indispensable for the correct management of the irrigation system, especially in localized irrigations when water is applied directly near the root system of the plant. Additionally, there is also the importance of adopting strategies aimed at reducing evaporation losses, as it is an unusable amount of water in the CO_2 assimilation process by the coconut tree, directing efforts and financial resources to the rational and efficient use of water in the region.

Despite the presence of vegetation cover (tropical kudzu – *Neustanthus phaseoloides*), which contributes to the maintenance of water in the soil, the area does not present a complete closure of the surface, collaborating with a greater exposure of the soil to solar radiation, reducing the surface resistance to the losses of water available in the soil by evaporation, as well as with the loss of water through its transpiration (Faria Junior et al. 2019, Fenner et al. 2016), which unfortunately was not monitored. Future studies involving the dimensioning of surface runoff and soil evaporation in the area may better explain the effective contribution of K_e within the K_c of the green dwarf coconut tree in the region.

CONCLUSION

This work showed the pattern of energy partition and water consumption of green dwarf coconut trees produced in the Northern region of Brazil, in a 5-year-old plantation with an area of approximately 7 ha. The energy balance and ET_c were determined using the BRM.

The average water consumption of the green dwarf coconut palm in the dry season in Santa Izabel do Pará was 4.21 and 4.14 $mm{\cdot}day^{-1}$, in the years 2020 and 2021, respectively. The availability of energy was the main driving force of ET_c during the studied period. The simple K_c of the green dwarf coconut was found to be 1.06 (± 0.12) (dimensionless), with the environmental and management conditions of the current research. Despite the condition of relatively adequate water availability, a possible control of the high atmospheric demand in K_c values was noticed, with lower values under high evaporative demand.

CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTION

Conceptualization: Carvalho, E. O. T., Fernandes, G. S. T. and Souza, P. J. O. P.; **Methodology:** Carvalho, E. O. T., Fernandes, G. S. T., Rua, M. L., Monteiro, A. C., Luz, D. B., Lisboa, S. P. P., Silva, J. V. F., Pinto, J. V. N. and Souza, P. J. O. P.; **Investigation:** Carvalho, E. O. T., Fernandes, G. S. T., Rua, M. L., Monteiro, A. C., Luz, D. B., Lisboa, S. P. P., Silva, J. V. F., Pinto, J. V. N. and Souza, P. J. O. P.; **Data curation:** Carvalho, E. O. T., Fernandes, G. S. T., Rua, M. L., Monteiro, A. C., Luz, D. B., Lisboa, S. P. P., Silva, J. V. F., Pinto, J. V. N. and Souza, P. J. O. P.; **Visualization:** Carvalho, E. O. T., Fernandes, G. S. T. and Souza, P. J. O. P.; **Project administration:** Lins, P. M. P. and Souza, P. J. O. P.; **Resources:** Lins, P. M. P. and Souza, P.

J. O. P. **Supervision:** Lins, P. M. P. and Souza P. J. O. P.; **Funding acquisition:** Souza, P. J. O. P.; **Writing – Original Draft:** Carvalho, E. O. T., Fernandes, G. S. T. and Souza, P. J. O. P. **Writing – Review & Editing:** Carvalho, E. O. T., Lins, P. M. P., Miranda, F. R. and Souza, P. J. O. P; **Final approval:** Souza, P. J. O. P

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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