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Evapotranspiration of banana using the SEBAL algorithm in an irrigated perimeter from the Northeastern Brazil[1]

Evapotranspiração da bananeira através do algoritmo SEBAL em perímetro irrigado do Nordeste brasileiro

Tainara T. S. Silva[2*], Hugo O. C. Guerra[3], Bernardo B. da Silva[4], Cris L. M. Santos[3], Jean P. Guimarães[3] & Joelma S. dos Santos[5]

[1] Research developed at Barbalha and Missão Velha, CE, Brasil
[2] Instituto Federal Goiano, Campos Belos, GO, Brazil
[3] Universidade Federal de Campina Grande/Unidade Acadêmica de Engenharia Agrícola, Campina Grande, PB, Brazil
[4] Universidade Federal de Campina Grande/Centro de Tecnologia e Recursos Naturais, Campina Grande, PB, Brazil
[5] Universidade Federal de Campina Grande/Centro de Desenvolvimento Sustentável do Semiárido, Sumé, PB, Brazil

HIGHLIGHTS:

The use of an efficient technique to determine evapotranspiration is essential for a rational management of soil water.
Remote sensing has a great potential to determine it over large areas.
Evapotranspiration was compared using the SEBAL model with that estimated by Penman-Monteith, obtaining adequate results.

ABSTRACT: The study aimed to estimate the evapotranspiration of banana (*Musa* spp.) in an irrigated perimeter of the municipality of Barbalha, CE, Brazil, using the Surface Energy Balance Algorithm for Land (SEBAL) model and to compare these results with those estimated using the Penman-Monteith method. Landsat-8 OLI/TIRS satellite images of May 22, 2016, August 10, 2016, and October 29, 2016 and data on temperature, relative humidity, wind speed and solar irradiance, obtained from an automatic weather station, installed close to the experimental area were used. The bands were stacked, and the stacked images were cut, then mathematical operations and evapotranspiration estimation were performed, whose actual daily banana values, estimated by the SEBAL algorithm, were 4.70; 5.00 and 6.50 mm, respectively, for May 22, August 10, and October 29, 2016. Comparing the daily ETr given by SEBAL with that obtained by the Penman-Monteith method, absolute errors of 0.26, 0.44, and 0.64 mm d^{-1} were observed for May 22, August 10, and October 29, 2016, respectively. These errors are within the ranges accepted in the literature.

Key words: *Musa* ssp., consumptive use of water, energy balance, remote sensing

RESUMO: Objetivou-se com este estudo estimar a evapotranspiração da bananeira (*Musa* spp.) num perímetro irrigado do município de Barbalha, CE, utilizando o modelo Surface Energy Balance Algorithm for Land (SEBAL) e comparar estes resultados com os estimados através do Método de Penman-Monteith. Foram utilizadas imagens de satélite Landsat-8 OLI/TIRS dos dias 22/05/2016, 10/08/2016 e 29/10/2016 e os dados de temperatura, umidade relativa do ar, velocidade do vento e irradiância solar, obtidos de uma estação meteorológica automática, instalada próxima da área experimental. Foi feito o empilhamento das bandas e o recorte das imagens empilhadas, em seguida, realizaram-se as operações matemáticas e a estimativa da evapotranspiração, cujos valores reais diários da bananeira, estimados pelo algoritmo SEBAL foram de 4,70; 5,00 e 6,50 mm, respectivamente, para os dias 22/05/2016, 10/08/2016 e 29/10/2016. Comparando a ETr diária dada pelo SEBAL com a obtida pelo método de Penman-Monteith, observaram-se erros absolutos de 0,26; 0,44 e 0, 64 mm d^{-1} para os dias 22/05/2016, 10/08/2016 e 29/10/2016, respectivamente. Estes erros estão dentro dos intervalos aceitos na literatura.

Palavras-chave: *Musa* ssp., uso consuntivo de água, balanço de energia, sensoriamento remoto

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* Corresponding author - E-mail: tainara.eng.agri@gmail.com
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Introduction

The banana (*Musa* spp.) is a fruit of great economic importance. It is estimated that the planted area reached 469.5 thousand hectares, with an average production of 6.7 million tons, with 187,96 thousand hectares in the Northeast region, and the State of Ceará has a production of 394 thousand tons (IBGE, 2017).

Determining the water needs of crops and understanding the spatial and temporal distribution of evaporative depletion is essential for proper management of water use. In this way, information about evapotranspiration is essential (Silva et al., 2012).

There are direct and indirect methods for calculating evapotranspiration, the direct methods being more accurate than the indirect ones, but they also have field scale restrictions, and their monitored data are scarce (Allen et al., 2007). To overcome the limitations of these methods, methods based on remote sensing were created (Bastiaanssen et al., 1998; Coaguila et al., 2017; Lima et al., 2020).

For Ferreira Júnior & Dantas (2018), the study of remote sensing is extremely important in the management of watersheds since it can contribute to the identification and monitoring of changes in water resources.

The Surface Energy Balance Algorithm for Land (SEBAL) follows a sequence of steps using satellite images, with the basic principle of determining the energy balance, which predicts that from the total energy available on the surface, a part is destined to the heating of the soil, part for the air heating and the rest is used in evapotranspiration (Bastiaanssen et al., 1998).

The objective of the present study was to estimate the evapotranspiration of banana plants in the municipality of Barbalha, CE, Brazil, using the SEBAL model and to compare these results with those estimated by the Penman-Monteith method.

Material and Methods

The research area is on the border of the municipalities of Barbalha and Missão Velha (Figure 1), in the State of Ceará, Brazil, in the following geographical coordinates: 7°33' S, 39°26' W, and altitude of 414 m.

According to Vieira et al., (2017), the region has Thornthwaite B1 W A' a' and Köppen Aw climate classification. The soil is classified as Oxisol.

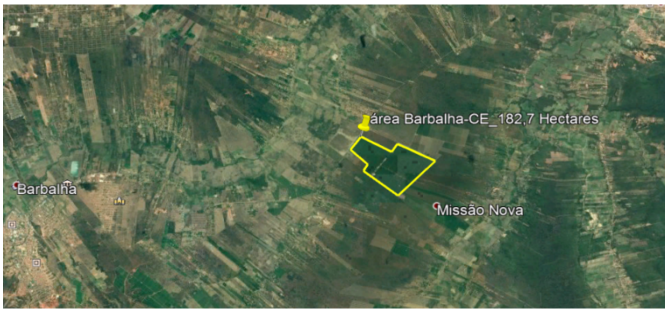

Figure 1. Location of the area of interest, highlighting the sample plot in the irrigated banana plantation (Adapted from Google Earth, 2018)

Image processing started after obtaining, stacking, and orthorectification the Landsat 8 satellite images OLI/TIRS, acquired on the USGS (United States Geological Survey) website on the Earth Explorer platform.

The images used corresponded to the dates of May 22, August 10, and October 29, 2016. Their choice was conditioned to the representation of soil cover conditions in the rainy and dry period, in addition to presenting low cloud cover, perfectly meeting the research requirements.

Tabular data from the automated meteorological data collection platform, obtained in parallel to the images, were used, requiring data from at least one station, close to the cold and hot points selected within the image area (Allen et al., 2007).

The meteorological data were collected in an automatic meteorological station located near the area, as well as on the website of the National Institute of Meteorology - INMET (http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep, 2016).

The ERDAS software was used to perform the processes of stacking the bands, clipping the stacked images, and then processing the images, using the Model Maker tool, in which the mathematical operations were performed for each step assigned to the research.

Subsequently, the Qgis 3.0 software was used to edit the images. Evapotranspiration was determined using the SEBAL algorithm following a sequence of steps that consist of calculating the irradiance balance from the spectral irradiance of the orbital data.

The residual energy balance methods consist of estimating its R_n, G, and H components from remote sensing and meteorological data, generating evapotranspiration as the residual latent heat flow from Eq. 1:

$$LE = R_n - G - H \quad (1)$$

where:

LE - instantaneous latent heat flow;
G - instantaneous heat flow in the soil;
H - instantaneous flow of sensible heat; and,
R_n - irradiance balance; all in W m^{-2}.

Images of the Landsat-8 satellite from the OLI/TIRS sensor (Operational Land Imager/Thermal Infrared Sensor) were used to estimate the different components of the energy balance at the surface and with the respective bands from 2 to 7 and the thermal band 10 of the sensors.

The processing steps for obtaining the irradiance balance and the heat flow in the soil are described in Figure 2.

Soil heat flux was obtained according to Eq. 2, developed by Bastiaanssen (2000), which represents values close to noon.

$$G = \left[\frac{T_{sup}}{\alpha_{sup}} \left(0.0038\alpha_{sup} + 0.0074\alpha_{sup}^2 \right) \left(1 - 0.98 NDVI^4 \right) R_n \right] \quad (2)$$

where:

T_{sup} - surface temperature (Kelvin);
α_{sup} - surface albedo corrected each day;

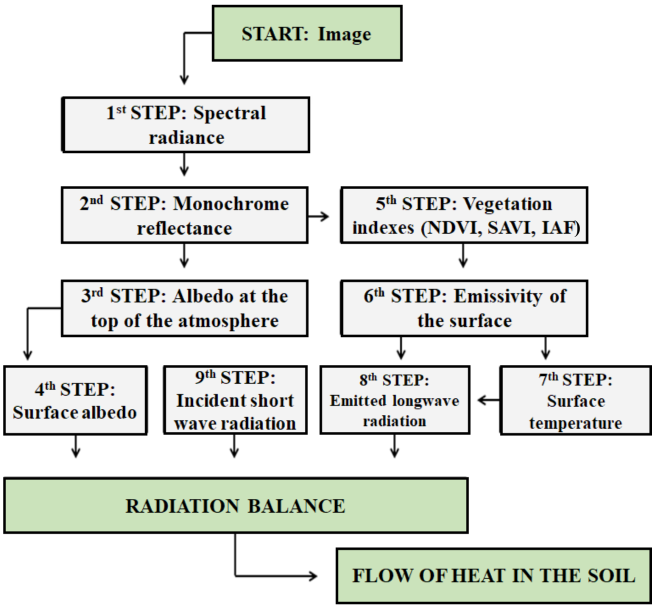

Figure 2. Flowchart of the computational steps of the process of obtaining the surface irradiance balance and heat flow in the soil

NDVI - vegetation index of the normalized difference; and,
Rn - irradiance balance; all in W m^{-2}.

The sensible heat flow H (W m^{-2}) was estimated based on wind speed and surface temperature using an internal calibration of the difference in temperature close to the surface between two levels of the surface, according to Eq. 3 (Bastiaanssen et al., 1998):

$$H = \rho c_p \frac{\left(a + bT_{sup}\right)}{r_{ah}} \tag{3}$$

where:
ρ - specific air mass;
c_p - specific air heat;
a and b - temperature difference calibration constants between two levels Z_1 and Z_2;
T_{sup} - surface temperature, °C; and,
r_{ah} - aerodynamic resistance to heat transport, s m^{-1}.

In this phase of SEBAL, the calculation of latent heat considers the already known variables: the flow of sensible heat, the flow of heat in the soil, and the balance of irradiance, calculated from Eq. 1.

Using the SEBAL algorithm, evapotranspiration daily ETr24h, (mm d^{-1}) was determined based on the instantaneous evaporative fraction (FE_i) defined by the ratio between LE and (Rn - G).

$$FE_i = \left(\frac{LE}{R_n - G}\right) = FE_{24h} = \frac{LE_{24h}}{R_{n24h}} \tag{4}$$

where:
FE_i - instantaneous evaporative fraction;
FE_{24h} - daily evaporative fraction;
LE_{24h} - daily latent heat flow (W m^{-2}); and,
R_{n24h} - daily irradiance balance (W m^{-2}).

Some studies confirm that FE_i is approximately equal to FE_{24h} (Bastiaanssen et al., 1998; Bezerra, 2013)

$$LE_{24h} = FE_i R_{n24h} \tag{5}$$

The conversion of the daily latent heat flow (LE_{24h}) into real daily evapotranspiration (ETr_{24h}) was given by Eq. 6, in which 86400 and 2450000 correspond to the transformation of LE into mm d^{-1}.

$$ET_{24h} = \frac{86,400 FE_i R_{n24h}}{2,450,000} \tag{6}$$

The reference evapotranspiration (ET_0) in mm d^{-1}, was estimated, throughout the study period, by the Penman-Monteith method, expressed by Eq. 7:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma\left(\frac{900}{T+273}\right)U_2}{\Delta + \gamma\left(1 + 0.34U_2\right)}\left(e_s - e_a\right) \tag{7}$$

where:
R_n - irradiance balance, MJ m^{-2} d^{-1};
G - heat flow in the soil, MJ m^{-2} d^{-1};
U_2 - average daily wind speed at 2 m high, m s^{-1};
e_s - average daily vapor saturation pressure, kPa;
e_a - current average daily vapor pressure, kPa;
γ - psychrometric coefficient, kPa °C^{-1}; and,
Δ - slope of the vapor pressure curve, kPa °C^{-1}, determined by Eq. 8:

$$\Delta = \frac{4,098\left[0.6108e^{\left(\frac{17.27T}{T+237.3}\right)}\right]}{\left(T+237.3\right)^2} \tag{8}$$

where:
T - average daily air temperature at 2 m high, °C.

The real evapotranspiration was obtained by multiplying the reference evapotranspiration determined by the Penman-Monteith method by the crop coefficient of the plant.

To compare the evapotranspiration obtained by SEBAL and Penman-Monteith, the mean absolute error (MAE) and the relative mean error (RME) were used in which: ETSebal and ETPenman correspond, respectively, to the values of evapotranspiration according to SEBAL and the Penman-Monteith method, described in Eqs. 9 and 10:

$$MAE = \frac{1}{n}\sum_{1=1}^{n}\left|ET_{sebal} - ET_{Penman}\right| \tag{9}$$

$$RME = \frac{100}{n}\sum_{1=1}^{n}\frac{\left|ET_{sebal} - ET_{Penman}\right|}{ET_{Penman}} \tag{10}$$

where:

MAE - mean absolute error;

ET_{Sebal} - evapotranspiration according to SEBAL algorithm;

ET_{Penman} - evapotranspiration inferred through the Penman-Monteith method;

RME - relative mean error; and,

n - number of pairs of variables.

Results and Discussion

The Thematic charts (Figure 3) show the balance of instantaneous irradiance.

On May 22, instantaneous irradiation balance values were around 526.17 W m^{-2}, on August 10, 447.283 W m^{-2}, and on October 29, 669.29 W m^{-2}.

Based on the results from the areas with banana cultivation on the different dates, it can be seen that on October 29, 2016, a higher value of the instant irradiance balance was found, when compared with the areas on the other dates. This may be due on this date the temperature of the soil surface was higher due to the higher air temperature, less vegetation cover, and increased areas of exposed soil.

According to Allen et al. (2005, 2007) and Bezerra et al. (2008), the irradiance balance is related to the configuration of the local soil-plant system, varying according to the type of soil, the amount of water in the soil, the type of cover and local microclimate. The thematic charts of the daily irradiance balance are shown in Figure 4.

There were daily irradiance balance values, between 132.34 and 141.03 W m^{-2}, 132.76 W m^{-2}, and 164.62 and 175.84 W m^{-2}, for the dates of May 22nd (A), August 10th (B) and October 29th (C) of the year of 2016, respectively. The highest values of daily irradiance balance found to offer greater energy for the evapotranspiration of the banana.

The results obtained are in accordance with Silva et al. (2012) who found values of daily irradiance balance between 146.87 and 164.70 W m^{-2}, determining evapotranspiration with the SEBAL model in an area of the Brazilian semiarid neighboring to the present study.

Figure 5 shows the thematic charts of the heat flow in the soil in W m-2 in the municipality of Barbalha on May 22nd (A), August 10th (B) and October 29th (C), 2016.

The heat flow on May 22nd, 2016 was between 35.45 and 46.75 W m^{-2}, for August 10th, 2016 it was between 53.71 and 63.32 W m^{-2} and for October 29th, 2016 was between 69.19 and 83.92 W m^{-2}. The lowest values of heat flow in the soil were found in the area with denser banana vegetation and lower soil surface temperatures, when compared to the flow values found on October 29th, 2016.

These results agree with those found by Arraes et al. (2012), who found the lowest G values in the irrigated areas and the highest in the exposed soil area. Silva et al. (2012) also observed G values, in general, lower than 150 W m^{-2}, similar to those verified in this study. Lima et al. (2014) observed mean G between 76.26 and 134.06 W m^{-2}. According to Allen et al. (2005, 2007) and Bezerra et al. (2008), the variation in the ratio of heat flow in the soil/irradiance balance is related to the

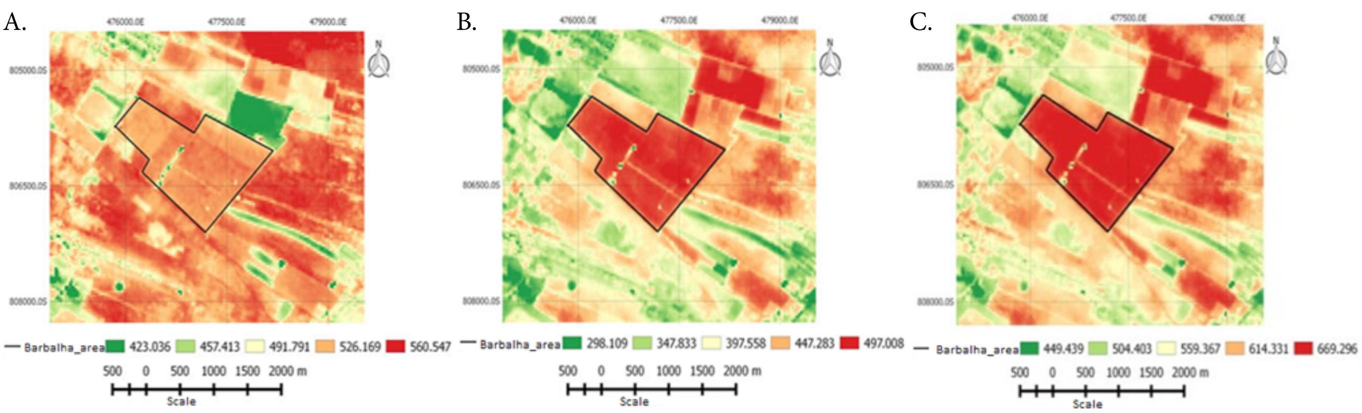

Figure 3. Spatial variation of the surface irradiance balance (W m^{-2}) in the municipality of Barbalha, CE, Brazil, on May 22 (A), August 10 (B), and October 29 (C), 2016

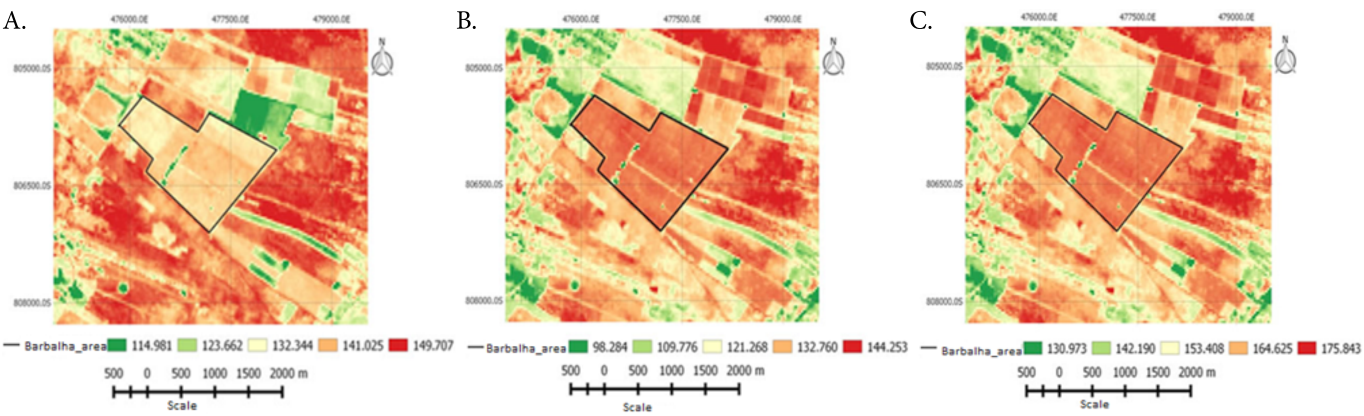

Figure 4. Spatial variation of the daily irradiance balance (W m^{-2}) in the municipality of Barbalha, CE, Brazil, on May 22 (A), August 10 (B), and October 29 (C), 2016

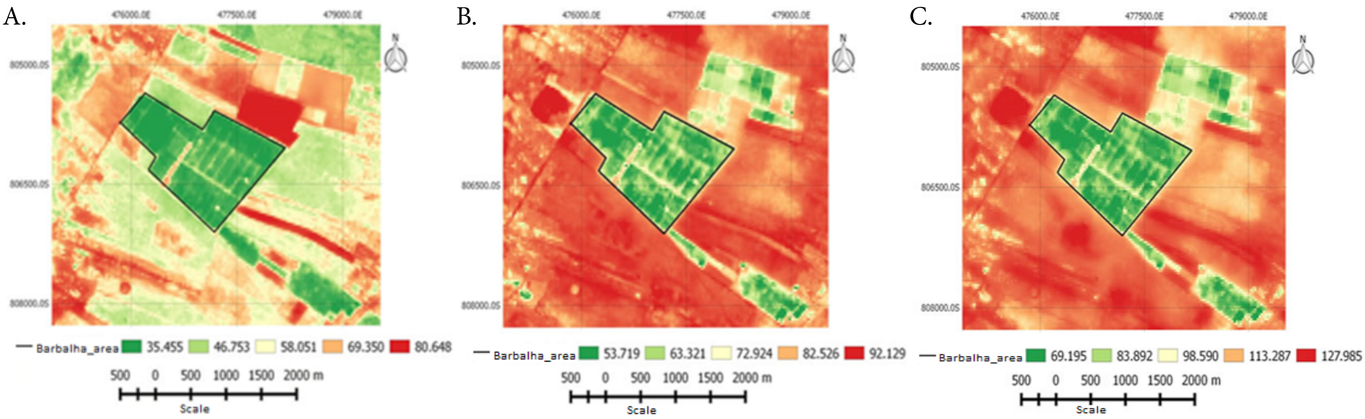

Figure 5. Spatial variation of the heat flux in the soil (W m^{-2}) in the city of Barbalha, CE, Brazil on May 22 (A), August 10 (B), and October 29 (C), 2016

configuration of the local soil-plant system, varying according to the type of soil, the amount of water in the soil, the type of cover and the local microclimate.

The ETr24h thematic charts in mm d^{-1} are shown in Figure 6.

The daily evapotranspiration of the banana plantation was 4.70 mm d^{-1} for May 22, 5.00 mm d^{-1} for August 10, and 6.50 mm d^{-1} for October 29, 2016.

May 22nd had real daily evapotranspiration lower than that observed for October 29th, the latter date with less water availability and higher air temperatures. Evapotranspiration on May 22 was lower, probably because the area is irrigated, the air has higher relative humidity and therefore a lower gradient and demand for evapotranspiration.

Evapotranspiration on October 29 was higher, probably due to the date the soil surface temperature was higher since the lower vegetation cover and the increase in exposed soil areas. In October, the intensity of the blue was visually higher, which indicates a greater number of pixels with ETr values greater than 5.00 mm d^{-1}.

In a study by Costa (2009), he found an ETc value of 4.84 mm d^{-1} for the second production cycle for the banana Pacovan Apodi cultivar and Barroso et al. (2011) found real evapotranspiration of 5.68 mm in the third production cycle^{-1}.

Freitas et al. (2009) found that the average annual ETc of banana cultivation in the São Francisco Basin, PE, Brazil, was 5.20 mm d^{-1}. For the municipality of Pentecoste, CE, Brazil, Silva & Bezerra (2009) obtained ETc values of 5.80 mm d^{-1} for two banana cultivars Pacovan in the first cycle.

Table 1 shows the daily reference evapotranspiration (mm d^{-1}) for the dates of May 22, August 10 and October 29, 2016 determined by multiplying the reference evapotranspiration, obtained by Penman-Monteith, by the crop coefficient, Kc = 1.21 recommended by Costa (2009).

In Table 2 it is possible to observe the comparison between the real daily evapotranspiration obtained by the SEBAL algorithm and the estimated by the Penman-Monteith method in the banana area, in the municipality of Barbalha, CE, Brazil, for the dates of May 22, August 10, and October 29, 2016.

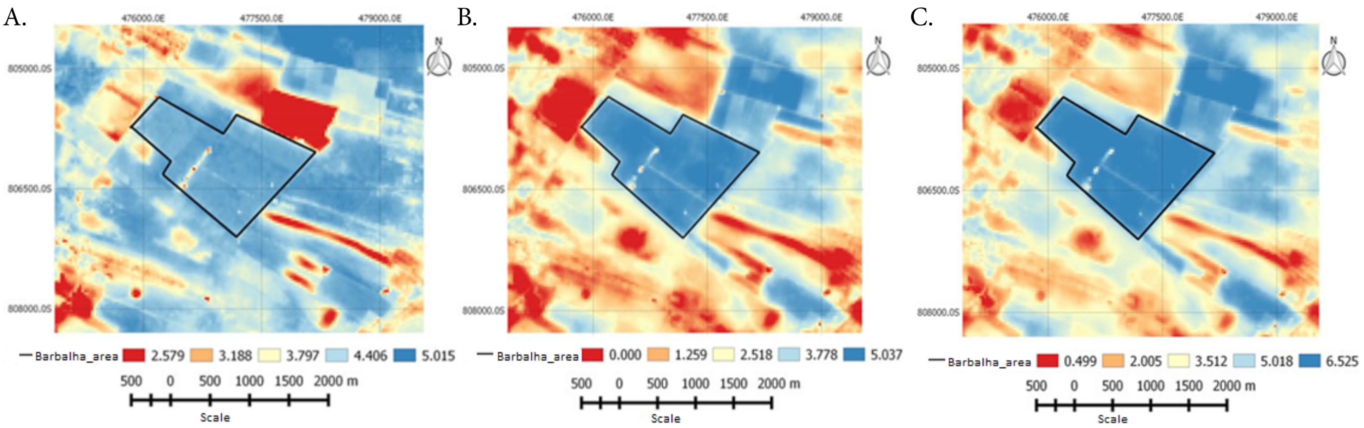

Figure 6. Spatial variation of real daily evapotranspiration (mm d^{-1}) in the city of Barbalha, CE, Brazil on May 22 (A), August 10 (B), and October 29 (C), 2016

Table 1. Real daily evapotranspiration of banana area

Date	Temperature (°C)		Relative air humidity (%)		Wind speed (m s^{-1})	Global radiation (MJ m^{-2} d^{-1})	ET_0	ETr
	Max.	Min.	Max.	Min.			(mm d^{-1})	
05/22/2016	28.4	26.7	75.0	71.0	2.10	22.9	4.10	4.96
08/10/2016	23.3	19.1	69.0	63.3	2.20	23.5	4.50	5.44
10/29/2016	24.8	21.0	57.6	51.3	2.10	27.9	5.90	7.14

ETr (Penman) = ETo (Penman) * crop coefficient Kc = 1.21 (Costa, 2009)

Table 2. Comparison between the daily evapotranspiration obtained by the SEBAL algorithm and the daily evapotranspiration estimated by the Penman-Monteith method, for the banana area in the municipality of Barbalha, CE, Brazil

Image date	ETr (SEBAL)	ETr (Penman-Monteith)	Absolute error	Relative error (%)
		(mm d^{-1})		
05/22/2016	4.70	4.96	0.26	5.24
08/10/2016	5.00	5.44	0.44	8.08
10/29/2016	6.50	7.14	0.64	8.96

It was observed for May 22, 2016, an absolute error of 0.26 mm d^{-1} and error relative value of 5.24%.

For August 10th, 2016, absolute error value of 0.44 mm d^{-1} and a relative error of 8.08% were observed. For October 29, 2016, the absolute error value of 0.64 mm d^{-1} and a relative error of 8.96% were obtained.

The differences found between the evapotranspiration values obtained by both methods are within the accepted ranges and agree with those found in the literature. Folhes et al. (2009) found that the real evapotranspiration of banana 'Pacovan' was less than the evaporative demand determined by the FAO-Penman-Monteith method.

Machado et al. (2014) working with sugar cane found relative errors of 10.80 and 9.75%. Relative errors between 4.00 and 10.00% were found by Bezerra et al. (2008) when comparing the results obtained from Bowen and SEBAL ratios in castor and cotton crops.

The differences found could be justified by probable inaccuracies in the SEBAL model, in the estimation of the aerodynamic resistance to the moment transport between the vegetation and a level above it. In the case of bananas, the estimate is difficult to characterize due to the roughness of the vegetation, due to the difficulty in establishing the thickness of the internal boundary layer in this situation.

In calculating the transfer of sensible heat to the atmosphere and evapotranspiration, as the vegetation roughness increases, the estimate of sensible heat increases, decreasing the estimation of evapotranspiration (Folhes et al., 2009).

Conclusions

1. The use of the SEBAL algorithm allowed the quantification and analysis of the components of the irradiance and energy balances in an irrigated banana area during three dates in the year 2016.

2. The daily evapotranspiration values of the banana for the studied area and dates sampled, estimated by SEBAL, ranging between 4.70 and 6.50 mm, also corroborate the results found in the literature.

3. When comparing the daily ETr obtained with the SEBAL algorithm with the value given by the Penman-Monteith method, the absolute errors varied between 0.26 to 0.44 mm d^{-1} and the relative errors from 5.24 to 8.96%.

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