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ESTIMATIVA DA DEMANDA DE ÁGUA DA CULTURA DA CANA-DE-AÇÚCAR IRRIGADA UTILIZANDO SENSORIAMENTO REMOTO

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1 RESUMO

O presente trabalho teve como objetivo estimar as demandas hídricas da cultura da cana-de-açúcar irrigada pelo sistema pivô central, por meio da aplicação do algoritmo SAFER (*Simple Algorithm for Evapotranspiration Retrieving*). O estudo foi realizado em área comercial, no município de Nova Independência - SP, compreendendo a safra de 2020/21. Foram utilizadas imagens dos satélites Landsat 8 e Sentinel 2 e dados agrometeorológicos na estimativa da relação ETa/ETo e evapotranspiração atual (ETa). Os maiores valores de ETa observados foram entre 3,4 e 4,4 mm dia^{-1}, enquanto os maiores valores da relação ETa/ETo foram de 0,7 e 0,8 e, apesar de comportamento similar a trabalhos semelhantes, são menores que os indicados em literatura.

Palavras-chave: SAFER, evapotranspiração, pivô central.

OLIVEIRA, D. A.; HERNANDEZ, F. B. T.; BISPO, R. C.; GOMES, R. N.; TEIXEIRA, A. H. C.
ESTIMATION OF THE WATER DEMAND OF THE IRRIGATED SUGARCANE USING REMOTE SENSING

2 ABSTRACT

This work aimed to estimate the water demands of the sugarcane crop irrigated by the central pivot system, through the application of the SAFER (Simple Algorithm for Evapotranspiration Retrieving) algorithm. The study was conducted in a commercial area, in the city of Nova Independência, SP, comprising the 2020/21 harvest. Images from the Landsat 8 and Sentinel 2 satellites and agrometeorological data were used to estimate the ETa/ETo ratio and actual evapotranspiration (ETa). The highest values of ETa observed were between 3.4 and 4.4 mm day^{-1}, while the highest values of the ETa/ETo ratio were 0.7 and 0.8, and

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despite similar behavior to similar works, they are smaller than those indicated in the literature.

Keywords: SAFER, evapotranspiration, central pivot.

3 INTRODUCTION

Sugarcane, whose main derivative is sugar and ethanol, is a crop of great importance to Brazil's socioeconomic status, as the country is the world's largest producer. Brazil's estimated production for the 2021/2022 harvest was 628.1 million tons, with the Southeast Region being the country's main producer and approximately 5.2 million hectares being cultivated (CONAB, 2021).

According to Avilez et al. (2018a), the water requirement of sugarcane can reach 1595 mm per harvest in the Northwest Region of the State of São Paulo, depending on the variety, total cycle and reference evapotranspiration (ETo) of the location where it is inserted. Knowledge of crop evapotranspiration (ETc) is essential in irrigated cultivation, as this variable represents the water demand of the crop. Correct irrigation management avoids water and energy waste and decreases productivity (SALES et al., 2017).

Crop evapotranspiration consists of the product of ETo and a crop coefficient (Kc), which varies according to the crop's growth phase, taking into account ideal conditions for its development in the field (ALLEN et al., 1998). However, when a crop is planted in the field, it is subject to pests and diseases, water deficits or excesses, low soil fertility, and other setbacks that prevent it from reaching its maximum evapotranspiration potential. Under these conditions, when a crop's evapotranspiration is estimated, it is called actual evapotranspiration or current evapotranspiration (ETa).

The quantification of current evapotranspiration and the ETa/ETo ratio can be performed through remote sensing with the application of algorithms in satellite images. Among these algorithms, SAFER (*simple algorithm for evapotranspiration retrieval*) (TEIXEIRA, 2010) stands out for being a simplified algorithm and for presenting good results on a large scale (SALES et al., 2017). According to Teixeira, Hernandez and Lopes (2012), the model has the advantage of simplicity of application, and there is no need to classify crops or extreme conditions, in addition to using daily agrometeorological variables from conventional or automatic agrometeorological stations. SAFER has as input variables global radiation, the average daily air temperature obtained from agrometeorological stations and the reference evapotranspiration, which, together with data obtained by remote sensing, estimate the ETa/ETo ratio (current crop coefficient) and subsequently the ETa.

Given the above, the present work aimed to estimate the water demands of the sugarcane crop irrigated by the central pivot system throughout its production cycle, represented by the current evapotranspiration and the ETa/ETo ratio, through the application of the SAFER algorithm (*simple algorithm for evapotranspiration retrieval*) in satellite images.

4 MATERIALS AND METHODS

This work was carried out in a commercial sugarcane area located in the municipality of Nova Independência - SP, with the following geographic coordinates: latitude 21° 01' 29" S, longitude 51° 23' 52"

W and altitude 338 m. Between August 2, 2020, and August 1, 2021, the area was cultivated with sugarcane variety RB 985476, the third harvest, and irrigation was carried out fully through a central pivot system, totaling 84 hectares.

The satellite images used were acquired free of charge from the *United States Geological Survey image bank* and used as criterion images of the region completely free of clouds throughout the harvest. Images from the Landsat 8 satellites (08/31/2020, 09/25/2020, 10/02/2020, 12/21/2020, 02/07/2021, 02/23/2021, 04/05/2021, 04/28/2021, 06/15/2021 and 07/26/2021) and Sentinel 2 (11/23/2020, 05/17/2021 and 07/06/2021) were used.

The daily agrometeorological variables used to apply the SAFER algorithm were obtained from the stations that make up the Northwest São Paulo Agrometeorological Network and published on the UNESP CLIMA Channel (UNESP, 2021), including ETo, which was calculated via the Penman–Monteith equation (ALLEN et al., 1998). To model the components obtained via remote sensing, the methodology described by Teixeira (2010) and Teixeira et al. (2013) was applied, and the parameters obtained via Equation 1 were used to calculate the ETa/ETo ratio via SAFER, which is based on modeling the ratio between actual evapotranspiration and reference evapotranspiration.

$$ETa/ETo = \exp\left[a + b\left(T0/(\propto 0 \times NDVI)\right)\right] \quad (1)$$

And in that,
T_0 = Surface temperature (K);
$\propto_0$ = Albedo;
NDVI = normalized difference vegetation index;
Coefficient "a" = Adjusted as 1.0 for Northwest São Paulo (HERNANDEZ et al., 2014); and
Coefficient "b" = Adjusted to -0.008 (TEIXEIRA, 2010).

Current evapotranspiration (mm day $^{-1}$) was obtained by multiplying the instantaneous values of the ETa/ETo ratio by the daily ETo values, according to Equation 2:

$$ETa = ETo \times (ETa/ETo) \quad (2)$$

In which,
ETo = Reference evapotranspiration (mm day $^{-1}$).

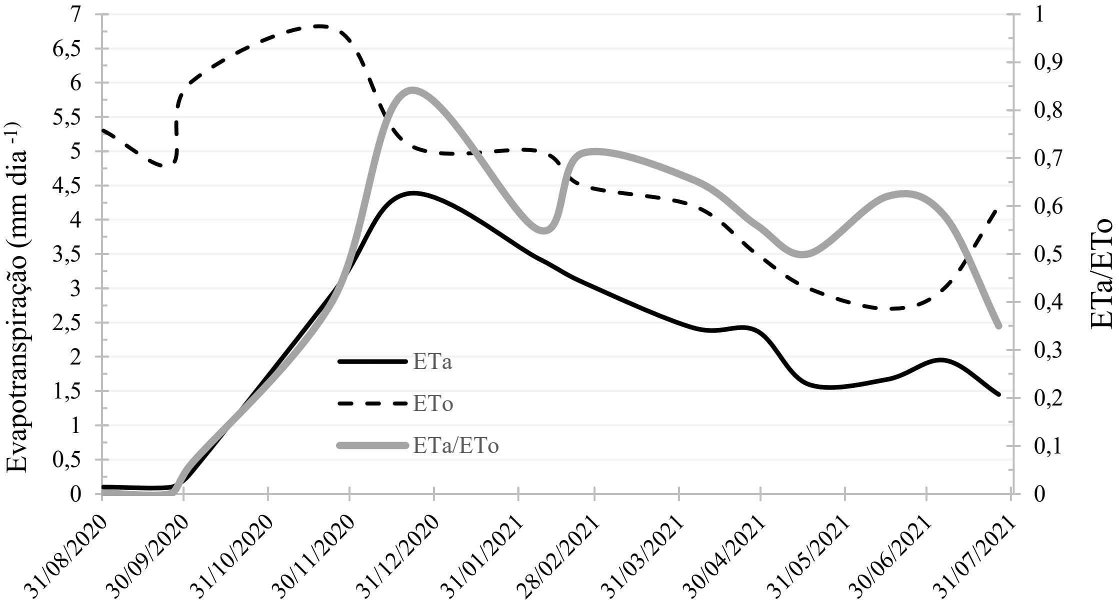
The accumulated degree days were calculated with a basal temperature of 10°C and together with the *enhanced vegetation index* (EVI) throughout the sugarcane cultivation cycle, with data from the central pivot irrigation management platform *"FieldNET Advisor by* Lindsay".

5 RESULTS AND DISCUSSION

The results of the estimates of the current evapotranspiration of sugarcane, the ETa/ETo ratio via the SAFER algorithm and the reference evapotranspiration are presented in Figure 1. Notably, the lowest ETa values occur at the beginning of the harvest, as it is the period of lowest water demand of the crop and still has a thick layer of straw on the soil, whereas the highest values are observed in the middle of the production cycle, with the highest ETa value being 4.4 mm day $^{-1}$ on 12/21/2020, in response to the demand of the phase called high growth of the crop and a greater volume of water in the soil, owing to the adequate water supply through irrigation and high rainfall in the month of December (327 mm).

These data corroborate those of Mussi et al. (2020), who reported the same trend of variation in the crop development stage and evapotranspiration when SAFER was used to determine ETa in sugarcane. Conversely, low ETa values may indicate low soil water storage or the initial or final phase of the crop (OLIVEIRA et al., 2019a). For irrigation management and ETc estimation purposes, a high-growth period with a 90-day cycle starting on January 15, 2021, was considered. Therefore, the data obtained show an anticipation of the crop cycle and allow adjustments to the crop coefficient for the 2021/22 harvest. In the last 15 days of December 2021, the average ETc (ALLEN et al, 1998) was estimated at 3.2 mm day $^{-1}$ and then classified into a tillering period, while the high growth cycle had an average ETc estimated at 5.1 mm day $^{-1}$.

Figure 1. Current evapotranspiration, ETa/ETo and reference evapotranspiration in sugarcane cultivation.

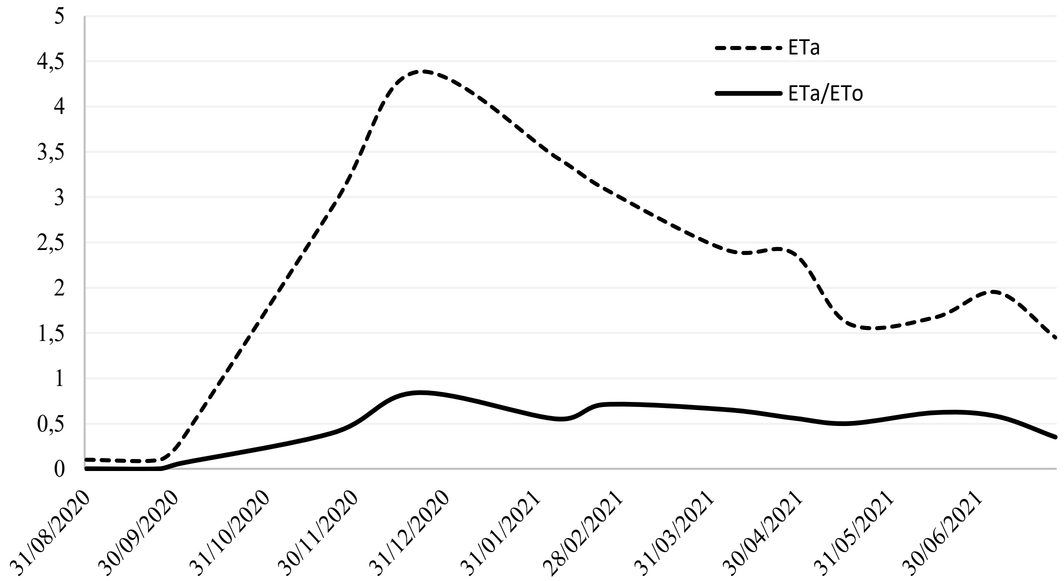


At the beginning of the cycle, immediately after harvesting, ETa remained very close to zero, possibly because the straw from the previous harvest was still in the area, covering the soil and preventing water evaporation. As the ratoon crop resprouts and establishes itself in the area, the ETa values increase until they reach a maximum and then decrease again. Since SAFER calculates ETa by multiplying the ETa/ETo ratio by ETo, the same trend is observed between rows in phases where the crop is well established and has higher evapotranspiration demand, distancing themselves at the beginning and end of the cycle owing to low demand. The increase in ETa/ETo values at the end of the cycle can be attributed to the 30 mm of rain that occurred on June 11, 2021, which allowed conditions to return to vegetative conditions. The irrigation had been cut off since June 6, initiating the *dry-off process*, which resumed after the rains.

The highest ETo values were observed in the months of September to November, corroborating the data of Silva Júnior et al. (2018), who classified the months of September and October among the three most critical months for irrigated agriculture in the Northwest Region of São Paulo. Santos, Hernandez and Rossetti (2010) described Northwest São Paulo with eight months of annual water deficiency in the soil. As a result, producers in the region have increasingly invested in irrigation systems to ensure crop productivity, since the area irrigated by central pivots in Northwest São Paulo has been growing by approximately 611 hectares per year (OLIVEIRA; HERNANDEZ, 2019).

The distribution of the ETa/ETo ratio throughout the analyzed images is shown in Figure 2, and Figure 3 presents the ETa/ETo and EVI data in relation to the accumulated degree days for sugarcane cultivation. The highest value of the ETa/ETo ratio was 0.84, which was close to that reported by Mussi et al. (2020), which was 1.02 for sugarcane irrigated by a central pivot in the state of Goiás, similar to the cycle evolution reported by Avilez et al. (2020) in northwestern São Paulo. These values are considered low compared with the Kc of Allen et al. (1998), and the same was also observed by Avilez (2018b) and Oliveira et al. (2019) when determining the ETa/ETo ratio through SAFER in sugarcane in areas of Northwest São Paulo.

Figure 2. ETa/ETo ratio and ETa (mm day $^{-1}$) during sugarcane cultivation.

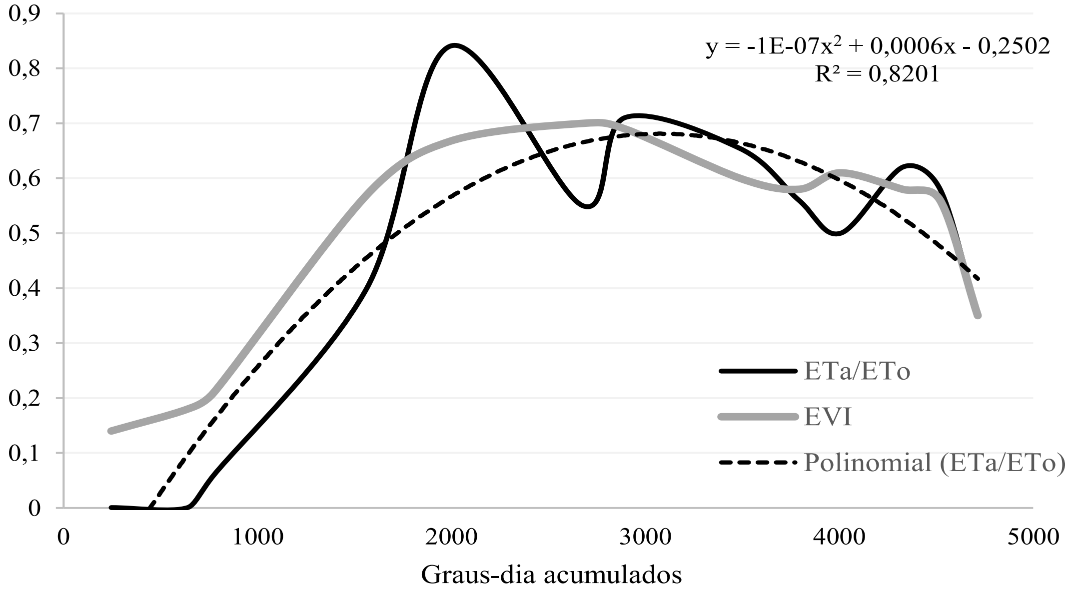


From these data, it is clear that there is an anticipation of the maximum demands projected in the management plan that must be considered in subsequent harvests. In other words, instead of the high growth phase starting 158 days after harvest, it is reasonable to suggest that it would in fact start 130 days after cutting. However, it was not possible to identify with certainty the extent of this vegetative cycle.

In addition to the fact that soil and climate conditions in the field are different from optimal and can interfere with the results, Avilez et al. (2020) suggest calibrating the coefficients (Equation (1)) of the SAFER algorithm to obtain better results, since these coefficients change according to the region, as in Northeast Brazil, where those from the original article by Teixeira (2010) are used.

Figure 3 shows an adequate fit between the accumulated degree-days and the ETa/ETo ratio, corroborated by the EVI, which is a good indicator of photosynthetic activity. This is important because, by incorporating a climatic parameter into the abscissa axis, the empirical analysis used to determine the phenological phases by days after harvest is minimized. In this study, 2,000 accumulated degree days represent the beginning of the phase with the highest crop coefficient—the high-growth phase—starting 135 days after harvest, leading to the conclusion that the phenological phases were indeed brought forward in relation to the irrigation management plan.

Figure 3. ETa/ETo ratio, EVI and accumulated degree days in sugarcane cultivation.



According to Bispo, Hernandez, and Teixeira (2017), when conducting a study on the estimated relative water consumption of sugarcane, this crop presents a greater risk of loss of productivity if there is water deficiency in the tillering and stalk growth phases. In the study area, it was found that in the high growth phase, which lasted 90 days (January 15, 2021, to April 14, 2021), there were 24 days in which the soil water reserves decreased, resulting in a water deficit, which may also have resulted in a decrease in the ETa/ETo ratio during this period.

EVI data range from 0 to 1 and are used to observe vegetation vigor throughout the production cycle, as they minimize the effects of soil and atmospheric response and present a high return to variations in phenological phases and green cover (JUSTICE et al., 1998). Figure 3 shows that the EVI values range from 0.14 at the beginning of the cycle, peaking in the phase of great crop growth, reaching 0.7 (the period of greatest vegetation), and ending the production cycle at 0.35.

One of the greatest, if not one of the greatest, challenges facing irrigated agriculture is establishing and applying coefficients that reflect the actual water consumption of crops. Therefore, accurate estimation of crop evapotranspiration depends on adequate estimates of reference evapotranspiration, represented by investments in agrometeorological stations properly installed in representative locations and the selection of representative crop coefficients. These, together with daily water balance and soil water storage calculations, should support the decision of which irrigation depth to apply so that the plant does not suffer water stress and compromise its productive potential. This accurate monitoring, when combined with weather forecasting, allows for better use of rainwater and, therefore, reduced use of irrigation systems, minimizing costs and increasing water productivity, with economic and environmental gains. Hence, the importance of analyzing plant behavior, as performed in this study.

6 CONCLUSION

The values of current evapotranspiration and the ETa/ETo ratio in the sugarcane cycle estimated by the SAFER algorithm were similar to those of studies carried out in the region and were consistent with the phenological phases reported in the literature. However, these values are lower than those indicated for management in the classical reference literature, but they allow for the subsidy of adjustments in subsequent irrigation management plans, either on the basis of the days after cutting or on the basis of accumulated degree days.

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