Agrometeorological Indicators based on Satellite Imagery in Western Bahia, Brazil

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Abstract**—** *The western region of Bahia stands out for its large-scale agricultural activity, which uses advanced technology and produces high yields of soybeans, corn and cotton, making it the largest grain producer in Northeast Brazil. The aim of this study is to apply the SAFER algorithm to biophysical indicators, in order to analyze the dynamics of natural vegetation and irrigated crops throughout the crop cycle. The model requires data from meteorological stations and satellite images for its application. Sixty-nine MODIS satellite images with a 250-m spatial resolution and a 16-day temporal resolution taken from 2016 to 2018 were used. The method was effective as a tool to monitor agricultural crops, and to distinguish the phases and vigor of the crops according to the spectral characteristics of their surface. The results of this study may assist in the monitoring of crops and in decision making, and may contribute to the rational use of water resources for irrigation and management of rainfed crops.*

Keywords**— *biomass, evapotranspiration, irrigated crop, SAFER, water production.***

I. INTRODUCTION

Western Bahia stands out for its large-scale agricultural activity, which employs advanced technology and produces high yields of soybean, corn, and cotton. Geographical features, soil correction, and public policies have transformed the region's agribusiness, making it one of the most productive in the country, and increasing its relevance for agricultural industry and for exportation, making it the largest grain cluster in the Northeast region of Brazil. Soybean is the region's main crop, and occupies 69% of its agricultural areas. Although crops such as corn and cotton supplement the local productive matrix, soybeans drive the region's economy: 50% of fresh soybeans are sold to industries in the region, and 47% of the production is exported to countries like China (66%), Japan (11%) and the Netherlands (8%) (AIBA, 2016).

Western Bahia has well-defined seasons, flat topography and rainfall indices that contribute to the definition of territory limits, as well as an extensive watershed with perennial rivers over the Urucuia aquifer, which enhances the region's potential for irrigated crops. With a well-defined rainy season, this stretch of large extensions allowed the development of various agricultural activities. Rainfall indexes up to 1,800 mm and other favorable climate and soil conditions contribute to the success of the region's agribusiness.

The scarcity trend in water resources, a counterpoint to the increasing demand for them, has caused serious conflicts over water use. In recent years, the supervision of the Brazilian National Water Agency (ANA) has been more rigorous, and new plantations in irrigated areas have been interrupted due to water scarcity.

The major benefits of irrigated agriculture practices should be opposite to the huge consumption of water demanded by irrigation systems, which consume about 70% of the waters derived from rivers, lakes and aquifers, and require effective management to prevent environmental impacts and water-use conflicts. These conflicts are aggravated especially in years of severe drought like 2014, when water scarcity impacted human use, energy generation, agriculture, navigation and water transport. In Brazil, the situation becomes more complex due to the strong dependence on water resources for the generation of electricity, and the spatial distribution of irrigated areas clearly shows a concentration trend in regions with strong risk of conflict over water use for energy generation and human consumption.

In the last years, in Western Bahia, irrigated crops have quickly replaced natural vegetation. This land-use change highlights the importance of developing tools to quantify large-scale water productivity parameters, enabling dynamic analyses of mixed agroecosystems (Teixeira et al., 2015).

Considering the effects of land-use changes on irrigation perimeters, quantifying biophysical parameters is important for the development and application of tools to evaluate the dynamics of agricultural systems in irrigated areas at Western Bahia, such as in the municipalities of Riachão das Neves and Barreiras.

Evapotranspiration estimation methods generally enable obtaining data on a local scale. However, regions featuring heterogeneous surfaces with different types of soil and vegetation show quite different evaporation rates, which cannot be perceived in traditional estimation methods. Remote sensing enables estimating evapotranspiration over large areas, as a function of the biophysical characteristics detected in each pixel. Another major advantage of the use of satellite imagery to estimate evapotranspiration on a regional scale is that the amount of water consumed in the evapotranspiration process may be detected without the need for quantifying other hydrological parameters, such as soil moisture.

Remote sensing using satellites is an efficient tool for estimating water parameters, and provides spatial information, location, and status on different agroecosystems (Teixeira et al., 2010).

Remote sensing techniques make it possible to obtain surface information without making direct measurements. Instead, they are obtained by capturing the converted energy as digital information. Thus, information on crops obtained from satellite images may be coupled to data obtained by meteorological stations, and used for estimating parameters, such as evapotranspiration and biomass, on a large scale. To obtain biophysical parameters, the agrometeorological-spectral model SAFER (Simple Algorithm for Retrieving Evapotranspiration) was applied to MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images (Teixeira et al., 2013).

The SAFER algorithm was developed and validated using data from field experiments and Landsat images depicting natural vegetation and irrigated crops under Brazilian semi-arid conditions.

Monitoring actual evapotranspiration using remote sensing on irrigated crops is an important tool for applications such as agricultural management, water resources monitoring, analysis of water productivity, biomass estimates and agricultural production (Morris et al., 2013).

The model proposed for estimating biomass production (BIO) and the development of plant canopies based on global solar radiation (RG) has acceptable accuracy, and may be used remotely, with any satellite imagery, for different ecosystems (Bastiaanssen, 2003). Although several studies have already been conducted on large scales, research on the use of models for the combination of evapotranspiration (ET) and BIO are still needed, especially for applications on different surfaces under conditions of water scarcity and rational use of water resources.

The purpose of this study was to apply SAFER along with satellite images and meteorological data, made available by INMET (Brazilian National Institute of Meteorology), to quantify evapotranspiration and biomass on a large scale at irrigated areas in Western Bahia, to analyze the dynamics of natural vegetation and irrigated crops throughout the crop cycle.

II. MATERIAL AND METHODS

The study area comprises part of the municipalities of Barreiras (12° 8' 54" S, 44° 59' 33" W, 454-m altitude) and Riachão das Neves (11° 44' 49" S, 44° 54' 23" W, 501-m altitude), in Western Bahia (Fig.1). According to the Koeppen classification, the study area's climate is Aw, typical for savannahs, and features dry winters, average air temperature above 18°C in the coldest month, and rainfall rates of 1,800 mm.

The analysis period ranged from 2016 to 2018, and used meteorological data – air temperature, relative humidity, wind and solar radiation – from INMET (Brazilian National Institute of Meteorology) stations, and 69 processed MODIS (Moderate Resolution Imaging Spectroradiometer) data – product MOD13Q1, tiles H13V10, reflectance bands 1 ($\alpha1$) and 2 ($\alpha2$), with a spatial resolution of 250 m and a temporal resolution of 16 days –. The SAFER (Simple Algorithm for Retrieving Evapotranspiration) model, which requires agrometeorological data and satellite images, was used to obtain evapotranspiration and biomass rates (Teixeira, 2012).

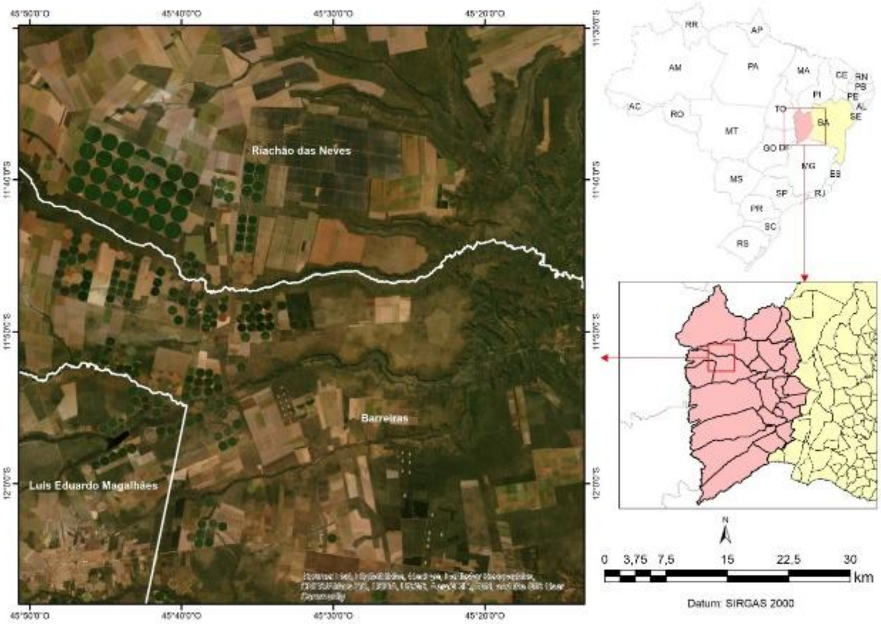

FIGURE 1: Location of the study area, area with central pivots, agricultural areas, and natural vegetation in Western Bahia, Brazil.

Daily weather data on global solar radiation (Rg), air temperature (Ta) and reference evapotranspiration (ET0) were used, and averages were calculated for 16 days, to correspond to the temporal resolution of the MODIS images, for the purpose of obtaining evapotranspiration (ET) and biomass (BIO) parameters on a large scale. The parameters calculated using remote sensing for input in the models were surface albedo (α0), surface temperature (To) and NDVI. ET was obtained by applying the SAFER algorithm (Teixeira, 2012). The Python programming language was used to process the model.

III. RESULTS AND DISCUSSION

The temporal variability of the meteorological data provided by INMET from 2016 to 2018 (Fig. 2), for 16-day periods (which coincide with the temporal scale of the MODIS images used). A period of low rainfall, and high air evaporative demand due to high solar radiation values was observed. The highest solar radiation values occurred in October, and reached 25 MJ, causing high rates of ET0 for the period of 16 days. Low rainfall rates occurred in few days and were concentrated along the year, interspersed with long periods of drought and high temperature, which are characteristic of the El Niño event (Silva et al., 2009). These weather conditions have favored drought occurrence, for the longer periods without presence of clouds and with high atmospheric demand and high values of solar radiation.

The effects of El Niño's latest most active period (ENOS) of 2016/2017 (until the beginning of 2018) on the vegetation in Western Bahia was verified. Meteorological data indicate an intense incidence of solar radiation (Rg) and decreased rainfall (P). NDVI and BIO were of 0.26-0.50 and 20-40 kg ha-1 day-1, respectively, over the studied period in areas occupied by central pivots. The lack of rain occurred when most areas were in the grain filling period, thus influencing their agricultural productivity. In January 2016, intense rains were registered in Western Bahia, but throughout the year only about 800 mm of rainfall were registered, which damaged the region's agricultural production, since it is directly dependent on rainfall.

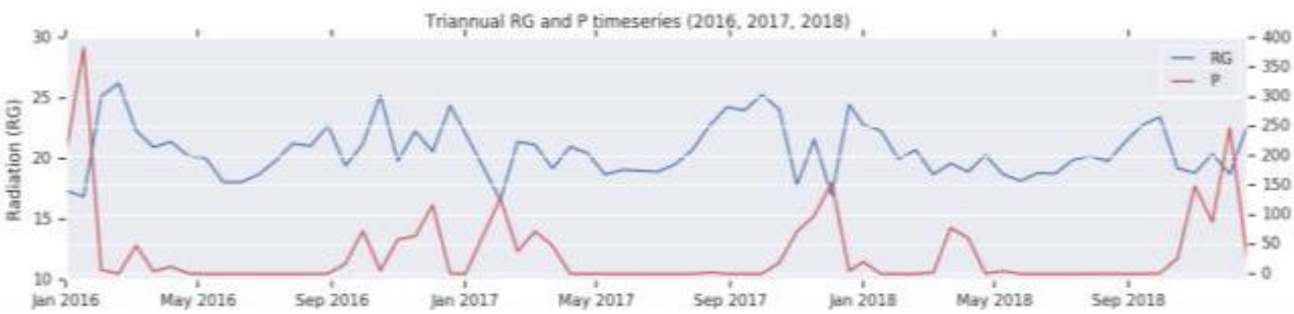

FIGURE 2: Rainfall (precipitation) – P (mm) – and global average solar radiation – Rg (W.m-2) –, from 2016 to 2018 in Western Bahia, Brazil, in 16-day intervals.

The spatial distribution for NDVI, ET and BIO over two distinct periods (DOY – day of the year – 049 and 321) for the years 2016, 2017 and 2018, and cover agricultural area (pivots and plots) and natural vegetation in Western Bahia (Fig. 3 and Fig. 4). NDVI is an indicator for the quantity and condition of green vegetation, therefore its value shows crop vigor. NDVI values reached close to 0.9 at the pivot areas, thus enabling an analysis of the crops' dynamics over time. In 2016, the vegetation showed lower greenness than in 2017 and 2018.

ET analysis in the period between February 2 to 18 (DOY 049), from 2016 to 2018, showed differences between the plants' response to irrigation. Pixels of higher values depict irrigated areas, which reached ET values higher than 5 $mm.d^{-1}$. Biomass showed higher values in 2017 and 2018.

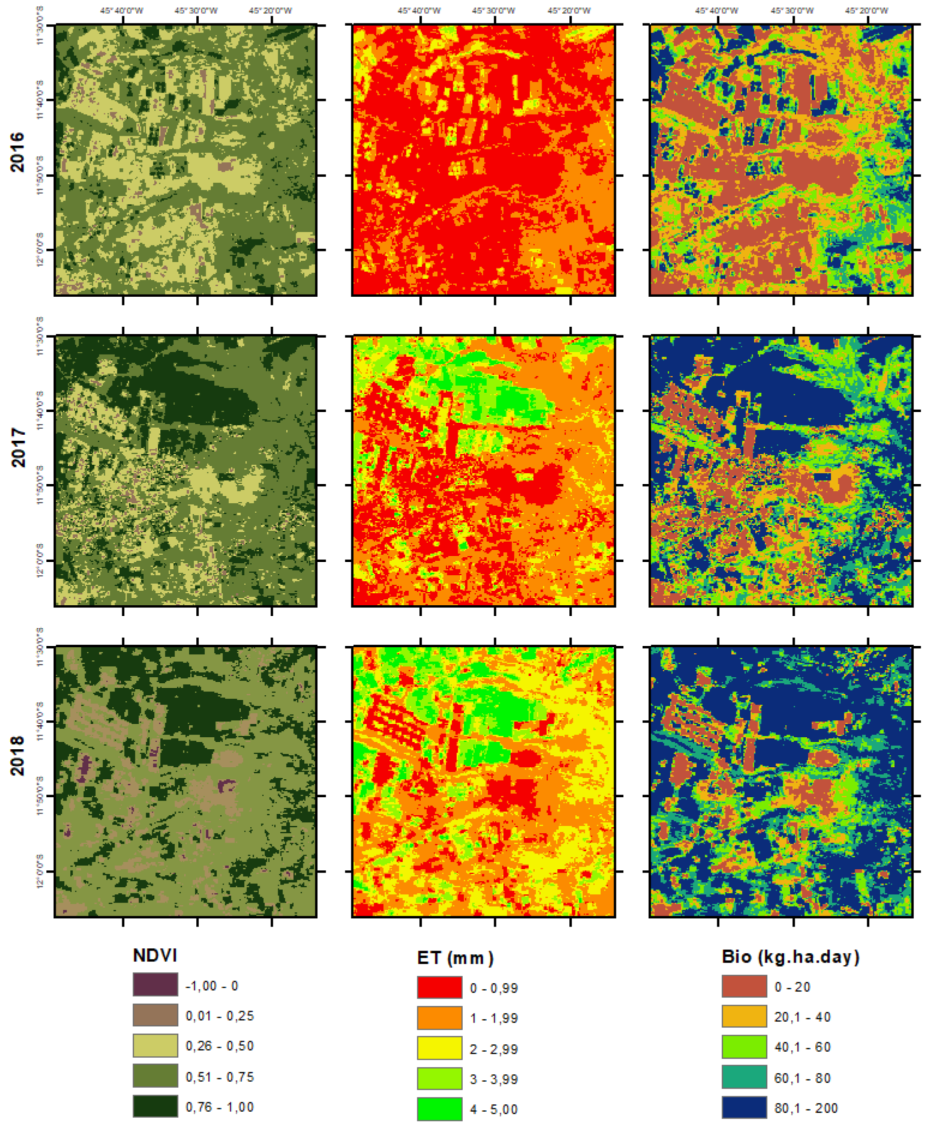

FIGURE 3: Spatial distribution of NDVI, daily average evapotranspiration (mm) (ET) and biomass (BIO), on DOY 049, in the years 2016, 2017 and 2018, in Western Bahia

In November (DOY 321) (Fig. 4), due to the occurrence of rainfall, the natural vegetation's response was similar to that of irrigated areas, and there was a reduction in contrast between the analyzed surfaces. Evapotranspiration rates increased, due to the high evaporative demand. In areas without irrigation, ET was lower and showed less variation, due to the conversion of the energy available for heating the air in the driest periods of the year. During the dry season, the natural vegetation converts part of the energy available to sensible heat (H), while irrigated crops show high ET values (Teixeira et al., 2008).

These analyses agree with the highest water demand of crops in the flowering and grain development period. Many applications of MODIS satellite images combined with meteorological data were used to obtain BIO. At the Submédio São Francisco river basin, Brazil, BIO estimates were made using Landsat to obtain large-scale water productivity data (Teixeira, 2009).

Dependence between BIO and water conditions (Figures 3 and 4) for the year 2016 was observed: high solar radiation and low rainfall caused contrast between natural vegetation and irrigated crops. The BIO daily averages in irrigated areas were below 120 kg ha-1.d-1. BIO values for both ecosystems are sensitive to the spatial distribution of precipitation and soil moisture (Claverie et al., 2012). In the 2017 and 2018 harvests, biomass reached values above 200 kg ha-1.d^{-1}. Data from the Institute of Agricultural Economics show that Bahia had a 45.5% increase in soybean productivity during this period. Nebraska features the largest irrigated cultivated area in the United States (3,357,903 ha in 2013; USDA NASS). In a study carried out using empirical modeling, seeking to understand how irrigated crops respond to various climatic scenarios, in order to anticipate changes in food security and in the state's agricultural economy, Lu et al (2017) showed that irrigated crops are less sensitive to climate change than rainfed crops.

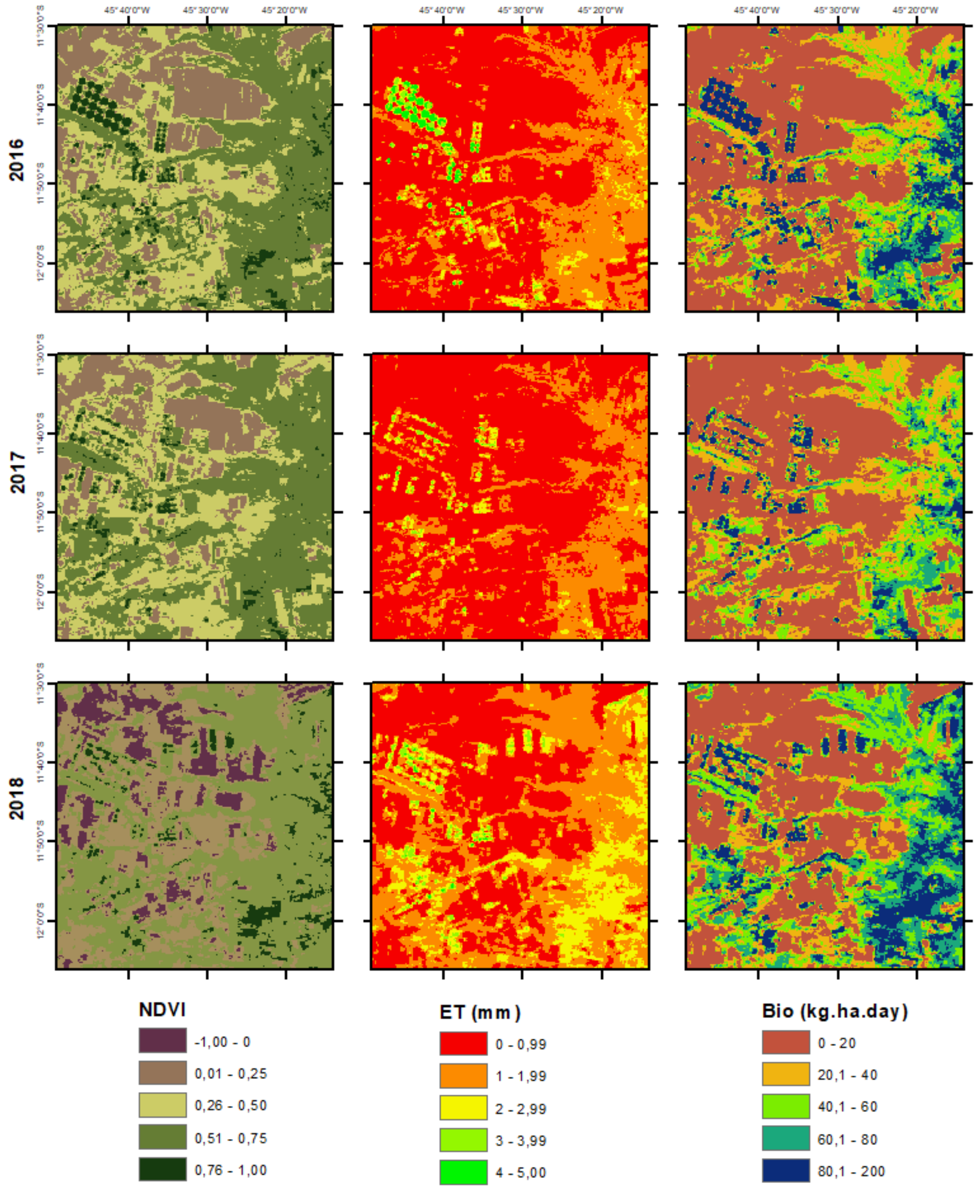

FIGURE 4: Spatial distribution of NDVI, daily average evapotranspiration (mm) (ET) and biomass (BIO), on DOY 321, in the years 2016, 2017 and 2018, in Western Bahia.

Meteorological data used with MODIS satellite images enabled monitoring and evaluating biophysical indicators in agricultural areas, at 16-day intervals. In Western Bahia, there was a significant variation in ET and BIO values throughout the year, in a period of water scarcity. These results enable monitoring the conditions of vegetation vigor throughout the cycle, thus assisting farmers in decision making. This preliminary study is part of a research project that aims to update spectral agrometeorological information for Western Bahia using indicators available every 16 days, thus allowing farmers to monitor crop development and assisting them in decision making regarding agricultural management practices.

IV. CONCLUSION

The results obtained indicate that the method used is an effective tool for monitoring agricultural crops using satellite images and data from meteorological stations. The SAFER model proved effective for estimating biophysical parameters, like evapotranspiration and biomass production, in irrigated areas in Western Bahia, and distinguished crop phases and vigor according to the spectral characteristics observed in the application of the spectral agrometeorological model. These results may assist in the monitoring of crops, in decision making regarding crop vigor (soybean, corn, cotton and others), and may contribute to the rational use of water resources for irrigation purposes and for the management of rainfed crops.

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