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PRODUCTION POTENTIAL AND CROP EVAPOTRANSPIRATION ESTIMATION FOR BEAN, SOYBEAN, AND MAIZE USING THE SEBAL ALGORITHM

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1 ABSTRACT

The replacement of satellite images by those obtained using unmanned aerial vehicle (UAV) can increase the level of detail of field information, since surface images reach precision of centimeters and can be taken at any time, generating advantages over some orbital platforms that are dependent on time and space. The objective of this work was to estimate the crop evapotranspiration (ETc) for irrigated common bean, soybean, and maize, using the Surface Energy Balance Algorithms for Land (SEBAL), through UAV and satellite (Landsat 8) images. The experiment was carried out under field conditions, with common bean, soybean, and maize crops, at the experimental station of the IFGoiano, which is in the Cerrado biome, southwestern state of Goiás, Brazil. The study was conducted using images obtained from the satellite Landsat 8 during the crop cycles. The Landsat 8 and DEM images have been taken as input data for the Surface Energy Balance Algorithms for Land (SEBAL). The mapping of the area with the UAV was conducted on the same day of the passage of the satellite for comparison of ETc values obtained by both approaches. The production potential of common bean, soybean, maize crops based on NDVI can be considered high.

Keywords: *Phaseolus vulgaris* L., *Glycine max* L., *Zea mays* L., satellite.

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2 RESUMO

A substituição de imagens de satélite por aquela obtida via VANT pode elevar o nível de detalhamento das informações de campo, já que as imagens da superfície alcançam precisões de centímetros, além de serem obtidas a qualquer momento, gerando vantagens sobre algumas plataformas orbitais relacionadas ao tempo e espaço. Objetivou-se estimar a evapotranspiração da cultura (ETc) em feijão, soja e milho irrigado utilizando o algoritmo SEBAL por meio de

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imagens de drone e do satélite Landsat 8. O experimento foi conduzido em condições de campo, na estação experimental do Instituto Federal Goiano – Campus Rio Verde – GO, em área inserida no Bioma Cerrado (Sudoeste de Goiás - Brasil) sob cultivo de feijão, soja e milho. Para a realização do estudo foram obtidas imagens do satélite Landsat 8, no decorrer do ciclo das culturas. As imagens do Landsat 8 e o DEM foram utilizados como entrada para algoritmo SEBAL. O mapeamento com o VANT foi realizado sobre as áreas no mesmo dia de passagem do satélite para comparação dos valores de ETc obtidas por ambas as abordagens. O potencial produtivo do feijão, soja e milho com base no NDVI pode ser considerado alto.

Palavras-chave: *Phaseolus vulgaris* L., *Glycine max* L., *Zea mays* L., satélite.

3 INTRODUCTION

Common bean, maize, and soybean stands out as the main agricultural products in Brazil, presenting high economic and social importance; thus, the development of new techniques for monitoring and planning these crops are important to assist in the decision making for management of irrigation (Mercante, 2007; Alves *et al.*, 2023).

Alternatives are being researched to enhance the spatial or temporal resolution of images., such as the combination of satellite data (Semmens *et al.*, 2016), interpolated data (Campos *et al.*, 2017), and combination of data from different platforms (Gao *et al.*, 2006; Cavalcante *et al.*, 2022). Techniques that use remote sensing should be evalueted in different edaphoclimatic conditions, favoring the adaptation and improvement of models to localized conditions. The CentralWest region of Brazil stands out by its high grain production; however, it presents low hydrometeorological data availability.

In this context, the replacement of satellite images by those obtained using unmanned aerial vehicle (UAV) can increase the level of detail of field information, since surface images can be obtained at any time with a precision of centimeters., generating advantages over some orbital platforms that are dependent on time and space.

Considering the demand for accurate data on crop water requirements, the development of tools that make available data with high resolution, frequency, and precision is needed. This need led to the development or adaptation of innovative technologies, such as UAV, to provide data with speed and representativeness of actual conditions, such as ETc.

The objective of this work was to estimate the crop evapotranspiration (ETc) for irrigated common bean, soybean, and maize, using the Surface Energy Balance Algorithms for Land (SEBAL), through UAV and satellite (Landsat 8) images.

4 MATERIAL AND METHODS

The experiment was conducted under field conditions, with common bean, soybean, and maize crops, at the experimental station of the Federal Institute Goiano (IFGoiano), Rio Verde campus, which is in the Cerrado biome, southwestern state of Goiás, Brazil.

The geographic coordinates of the experiment area are 17°48'28"S and 50°53'57"W, and the mean altitude is 720 m above sea level. The climate of the region was classified as Aw, tropical, according to Köppen and Geiger (1928), with a rainfall season from October to May and a dry season from June to September. The mean annual temperature varies from 20 to 35 °C, the annual rainfall depths vary from 1,500 to 1,800 mm, and the relief is slightly wavy (6% slope).

The study was conducted using images obtained from the satellite Landsat 8 (orbit 222, point 72) during the crop cycles. The images were obtained from atmospherically corrected reflectance provided by the Landsat Surface Reflectance Climate Data Records (CDR) of the United States Geological Survey (USGS). A Digital elevation model (DEM) was obtained from the National Aeronautics and Space Administration website (Nasa, 2017).

The Landsat 8 and DEM images were used as input data for the Surface Energy Balance Algorithms for Land (SEBAL). This algorithm was developed by (Bastiaanssen *et al.*, 1998) to obtain evapotranspiration estimates through satellite (Landsat 8) images with 16-day intervals. However, ETc estimates through Landsat images with a frequency of 16 days compromise operational applications for scheduling irrigation; therefore, the ETc was estimated daily.

The acquisition of ETc values in periods of data scarcity was done by analyzing values of Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI). NDVI is expressed by:

$$NDVI = (NIR - R)/(NIR + R) \quad (1)$$

Where NIR and R correspond to the near-infrared and red bands, respectively (Tucker, 2003). SAVI is formulated as follows:

$$SAVI = (1 + L) \times (NIR - R)/(NIR + R + L) \quad (2)$$

Where L is the adjustment factor for the canopy substrate, varying from 0 to 1 (Huete, 1988), and the Growing Degree-Day (GDD), as proposed by (Campos *et al.*, 2017).

The vegetation indices (VI) were used to obtain the basal crop coefficient (KCB).

An exponential equation was used to determine VI for the initial stages of the common bean, soybean, and maize crops:

$$VI = m \times e(c \times GDD) \quad (3)$$

Where m and c are constants of the crop stage.

The Gompertz sigmoidal function was utilized to model both the development and senescence stage:

$$VI = K \times \left(-e^{(a - b \times GDD)}\right) \quad (4)$$

Where K is the maximum VI and a and b are constants of the crop stage.

Both equations are aligned so that the curves were reconstructed by correlating ln (VI) or ln (VI/K) with the GDD data. The information regarding the linearization of the equations and details on the interpolation algorithm were presented by Campos *et al.* (2017).

The weather data needed for estimating ETc were collected from automatic stations installed next to the experimental area, preferably from stations standardized by the Brazilian National Institute of Meteorology (INMET). The standard method of the FAO (Penman-Monteith method) was used for calculating the ETc.

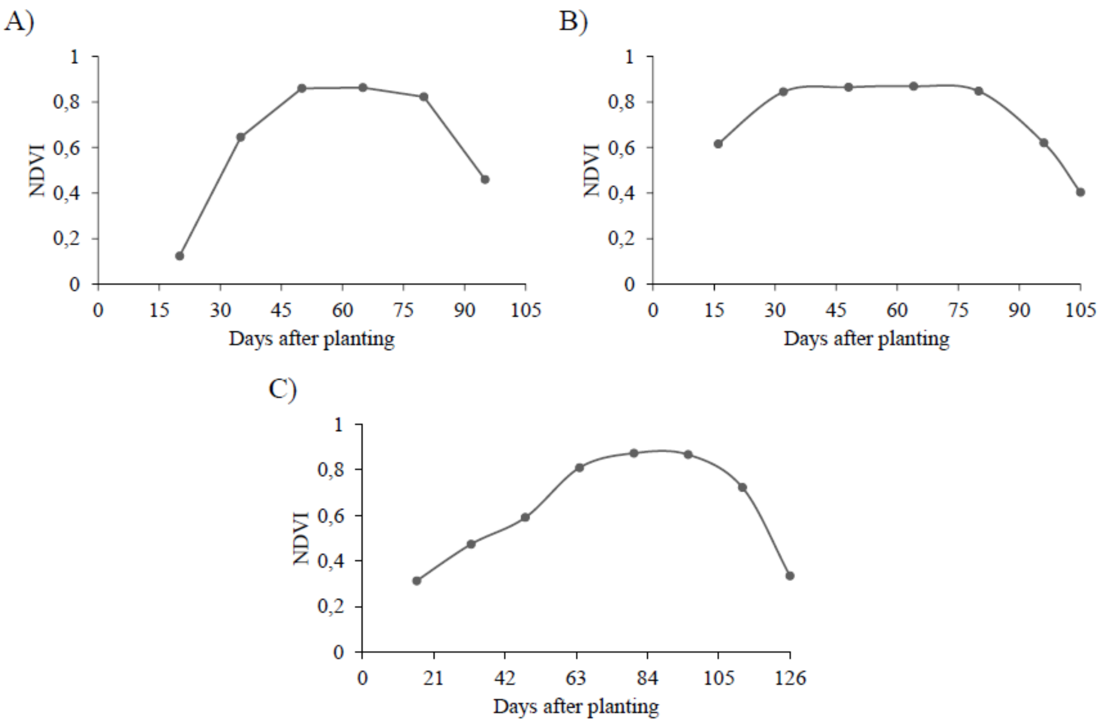
The mapping of the area with the unmanned aerial vehicle (UAV) was conducted on the same day of the passage of the satellite for comparison of ETc values obtained by both approaches. The UAV records visible and infrared wavelengths, allowing the obtaining of NDVI and SAVI. The UAV used was a Ebee model, manufactured by the senseFly SA company, with a 16 MP RGB or NIR camera with resolution of 3 to 30 cm (Sensefly, 2023).

The comparison of ETc were carried out using Landsat images, which are connected to a methodology based on surface energy balance (SEB) models with thermal bands, and images obtained by the UAV, which can be connected to models of coefficients of basal crop reflectance (KCB) based on vegetation indexes (Campos *et al.*, 2017).

5 RESULTS AND DISCUSSION

The minimum Normalized Difference Vegetation Index (NDVI) was 0.36, which was approximately 40.70% lower than the NDVI found at 16 days after planting (DAP); the NDVI increased 27.06% between 16 and 32 DAP, whereas the increase was only 2.37% at 48 DAP; NDVI was practically stabilized between 32 and 80 DAP, showing values above 0.84 (Figure 1A).

Figure 1. Normalized Difference Vegetation Index (NDVI) obtained through satellite (Landsat 8) images and complemented with UAV images for the Common Bean (A), Soybean (B), and Maize (C) crop as a function of the days after planting. Rio Verde, GO, Brazil.



NVDI tends to present significant decreases from 80 DAP onwards; these decreases were 26.82% and 34.93% at 96 and 105 DAP, respectively. NDVI presented a stabilization between 64 and 96 DAP, with values above 0.8 (spectrum-temporal profile of NDVI during the days after soybean planting) (Figure 1B). NDVI over the soybean crop cycle presented a coefficient of variation of 30.92%, whereas this variation was only 1.44% in the NDVI stabilization period, between 32 and 80 DAP.

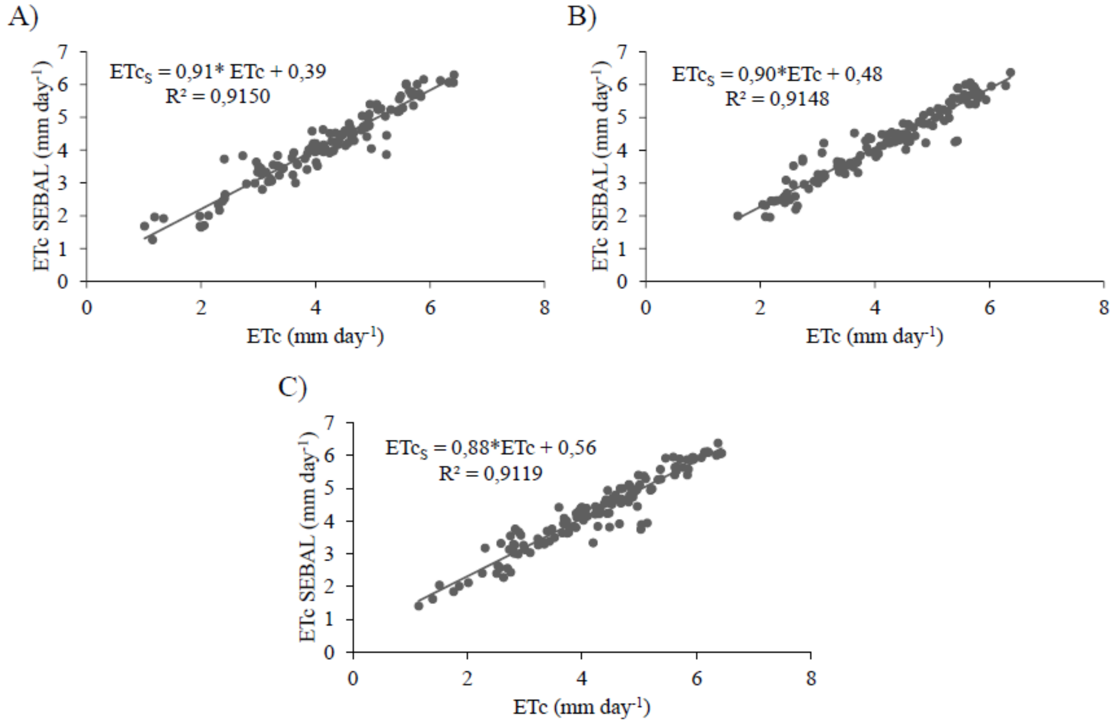
The minimum NDVI was approximately 0.32, which is 2.95% lower than that found at 16 DAPS. NDVI tends to present significant increases from 16 DAP onwards, and these increases were 33.87%, 19.87%, and 27.01% at 32, 48, and 64 DAP, respectively. However, the NDVI between 64 and 96 DAP presented a stabilization with values above 0.8. Araujo (2016) found that models using penalization index and NDVI are the ones that present the lowest deviation values when compared to the observed yield in the field (Figure 1C).

NDVI presented a decrease of 16.67% at 96 DAP and decreased even more from this day onwards, reaching 53%; it was because the harvest was near. NDVI over the maize crop cycle presented a coefficient of variation of 40.20%, whereas this variation was less than 6% in the NDVI maximum period, which presented the highest stability (64 to 96 DAP) (Figure 1C).

The common bean, soybean, and maize production potential found based on NDVI can be classified as high (>110% of the mean yield).

The ETc estimated for common bean through SEBAL, as a function of the ETc observed in the field, showed a R^2 of 91.50%. Thus, (Figure 2A) shows that 8,50% of the difference in estimated ETc using SEBAL remains unexplained by the variation in observed ETc. The estimation of evapotranspiration using the SEBAL algorithm for common bean crops grown under the condition of the Cerrado biome in Brazil showed a more pronounced variation in ETc, mainly in the estimate of intermediate values, between 3.5- and 5.5-mm day^{-1} (Figure 2A).

Figure 2. Common Bean (A), Soybean (B), and Maize (C) crop evapotranspiration estimated through the Surface Energy Balance Algorithms for Land (SEBAL) (ETc_S) as a function of the observed evapotranspiration in the field (ETc) through weather data. Rio Verde, GO, Brazil.



The ETc estimated for soybean through SEBAL, as a function of the ETc observed in the field, showed a R^2 of 91.48%. Thus, 8.52% of the variation of the estimated ETc through SEBAL are not explained by the variation in the observed ETc; therefore, the estimated ETc still shows high dispersion of values (Figure 2). ETc estimates for soybean through SEBAL tend to be higher than the observed ETc values, requiring calibration of the model (Figure 2B).

The ETc estimated through SEBAL as a function of the ETc observed in the field showed a R^2 of approximately 91%. Thus, 9% of the variation of ETc estimated through SEBAL are not explained by the variation of the observed ETc; therefore, the ETc estimates still present a significant variation. Considering this high variation, the estimation of evapotranspiration using the SEBAL algorithm for maize crops grown under the condition of the Cerrado biome in Brazil showed the need for calibration of this algorithm for the Cerrado region (Figure 2C).

ETc estimates through SEBAL tend to overestimate the observed ETc values. The ETc estimated through SEBAL overestimated the ETc observed in the field, however, the estimated and observed values presented a high correlation. Therefore, the method needs to be calibrated to allow more accurate estimations of common bean, soybean, and maize crop evapotranspiration.

Images collected by remote sensing allow interpretation of spatial crops patterns in large areas, however, spatial resolution incompatible with the temporal resolution may affect the applicability of the images, consequently remote sensing has emerged as an important source of data collected in the field in real time, with that has been used to monitor growth in annual crops (Mazzetto *et al.*, 2010; Pinto *et al.*, 2017; Junges *et al.*, 2017). The use of NDVI among different sensors and platforms it is very important for promoting the effectiveness of NDVI on crop assessment across space and over time (Grant, 2017).

The NDVI obtained by ground-based remote sensing is therefore of great importance because is a fast and nondestructive tool to monitor the canopy in real time, compiling into a single data several parameters related to crop growth and development, like meteorological conditions and agricultural management practices that are difficult to be quantified together (Junges *et al.*, 2017).

The common bean grain yield can be estimated as a function of the NDVI, additionally, general models present similar accuracy, demonstrating the feasibility of using the same model for several genotypes (Filla *et al.*, 2023). The temporal curves in regions with a high soybean grain yield present similar profile, reaching a high NDVI (Trindade *et al.*, 2019).

The NDVI is suitable tools for irrigated corn management and monitoring since they detect vegetation cover changes quickly and at low operational cost, however the NDVI showed better results during corn crop development, even though NDVI was less sensitive to high biomass amounts (Alvino *et al.*, 2020). Broadband indices (NDVI, RDVI, SAVI, OSAVI, GNDVI, and EVI) in general show strong positive correlations with all crop yield component variables (Sellami *et al.*, 2022).

This variability may be caused by variations in plant population, growth, and nutrition, incidence of diseases and pests, among others, which determine the production potential of crops (Vian *et al.*, 2018).

Molin (2002), Santi *et al.* (2012) defined critical limits for NDVI and determined classes that were used for dividing management zones of low (<90%), medium (90% to 110%), and high yields (>110%), based on the mean grain yield of the evaluated area.

The estimation of plant attributes in an indirect way favors the adoption of more specific management by rural producers, resulting in greater sustainability and crop yield (Filla *et al.*, 2023).

Assessment tools, such as SEBAL, have been widely used for estimating the evapotranspiration of crops, using orbital and surface information. Another application connected with estimation of evapotranspiration is the determination of crop coefficients (Kc), which promotes the periodic monitoring of the water status in crops (Allen; Tasumi; Trezza, 2007;

Teixeira, 2010; Araujo, 2016). Multiple linear regression, with an algorithm, used to estimate ETc and grain yield, is generally checked by R^2 values and its variations might be attributed to the high influence of collinearity of the predictors (Grossman *et al.*, 1996).

LST models like SEBAL can predict ETc particularly in semi-arid and arid regions where croplands are irrigated, nonetheless, they have limitations owing to the need for parameterization and calibration for each image, their degree of complexity, their sensitivity when defining the wet and dry conditions (cold and hot pixels) in each scene (Bastiaanssen *et al.*, 1998; Biggs *et al.*, 2015).

Static cropping areas resulted in the considerable underestimation of mean ETc (mm) and the overestimation of the total ET (km^3) due to the consideration of non-cultivated areas in ETc derivation over the years, furthermore, inappropriate NDVI threshold results in over- or underestimation (Abbasi *et al.*, 2021).

6 CONCLUSIONS

The Normalized Difference Vegetation Index (NDVI) of soybean crops presents stabilization between 32 and 80 days after planting (DAP), with a mean NDVI of 0.847.

NDVI of maize crop varies from 0.30 to 0.87 and the highest NDVI are found between 64 and 96 DAP.

The production potential of common bean, soybean, and maize crops based on NDVI can be classified as high (>110% of the mean yield).

The estimation of ETc for common bean, maize, and soybean crops using Surface Energy Balance Algorithms for Land (SEBAL) presents high dispersion, requiring calibration for a higher precision in the estimation of evapotranspiration under the conditions of the Cerrado biome in Brazil. However, the estimation of crop evapotranspiration using the SEBAL algorithm for common bean, maize, and soybean crops grown under the Cerrado conditions showed to be promising, mainly due to the easy monitoring of ETc over the crop development.

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