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Sentinel Image to Estimate Industrial Tomato Leaf Area Index

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HIGHLIGHTS

- It's possible to estimate the Leaf Area Index (LAI) for industrial tomato from remote sensing.
- The estimated LAI was not completely homogeneous.
- The LAI estimated through orbital remote sensing shows good results.
- The orbital IAF validates the IAF results obtained by the destructive method for tomato.

Abstract: The Leaf Area Index (LAI) is one of the main physiological parameters of the plant related to transpiration, productivity and rainfall interception. Among the methods to determine the LAI, the use of remote sensing that estimates the LAI through image processing techniques stands out. Thus, the objective of this work was to estimate the LAI for industrial tomatoes from orbital remote sensing images and validate the results with the LAI obtained by the destructive method. The study was carried out in an area irrigated by a central pivot in the municipality of Vila Propício of Goiás. The leaf area was determined from georeferenced sampling in a regular grid of 60x60m, to calculate the SAVI and IAF vegetation index, 4 images obtained through the Sentinel satellite were used in the period from 07/01/2018 to 07/31/2018 where the culture is in the second phase of the vegetative cycle. The LAI estimated by the orbital remote sensing showed good results compared to the LAI obtained through the destructive method. The estimated leaf area index was not completely homogeneous, as part of the pivot showed better results, with a growth in the vegetative development phase and a decrease in the maturation phase of the crop. The values of the statistical analysis of the real LAI compared to the estimated LAI were very close, but the coefficient of variation showed a greater difference between them, indicating that there may be a greater variation in the estimate.

Keywords: digital agriculture; satellite monitoring; spectral index; technologies.

INTRODUCTION

The tomato crop (*Solanum Lycopersycum*) has social and economic importance due to its nutritional value, high levels of vitamins A and C, rich in lycopene and of good acceptability for fresh (table) and industrial consumption (sauces, extracts, ketchup, soups, juices, etc) [1].

The industrial tomato in the year 2018 had an estimated production of 160 million tons, in approximately 5 million hectares spread around the world. In Brazil, in the same year, the industrial tomato crop had a production of 4.5 million tons, with Goiás as the state responsible for the largest national production, with 32.4% of production, followed by São Paulo with 21.1 %, Minas Gerais with 16.7%, Bahia with 4.5% and Santa Catarina with 4.4% [2].

The tomato plant is perennial and shrubby, being considered annual. It can be developed in a creeping, semi-upright or erect form, it has two growth habits, the determined one, where they present a less vigorous vegetative growth, having plants with creeping development and the fruits destined for the agro-industry, and the indeterminate, which produce fruits intended for fresh consumption. The buds of these plants have a lower development due to the dominance of the apical bud, a vigorous vegetative growth together with the production of flowers and fruits, reaching 10 m in height in a year [3].

For the ideal cultivation of tomatoes, the water requirement is between 300 and 600mm and its altitude between 500 and 900m; preferably in sandy loam, deep and well-drained soils. The temperature for flowering is moderate (averages between 15ºC and 19ºC), but it flowers and bears fruit in different climatic conditions. Its average temperature during the cultivation period should be 21ºC, as it is sensitive to frost, and its growth is reduced when subjected to temperatures below 12ºC, whereas at temperatures above 28ºC, its fruits form with a yellowish color due to the reduction of synthesis. of lycopene and increased concentration of carotene [4].

The Leaf Area Index (LAI) is one of the main physiological parameters of the plant related to transpiration, productivity and rainfall interception. This parameter represents an important property of the vegetation canopy where the leaf area measured per unit area of land can also be used in biogeochemical and ecological studies of a crop, as well as in assessments of water interception and land cover and in the determination of gas exchange of water and carbon [5,6].

The LAI represents the total leaf area per unit of land area, functioning as an indicator of the surface available for interception and light absorption in order to carry out photosynthesis. Crop sowing should be programmed so that the maximum values of the leaf area index (LAI) coincide with the time when radiation is high, when net photosynthesis will be maximum [7,8].

From the correlation between the width and length of the leaves and through regression analysis, it is possible to obtain the mathematical models that estimate the leaf area. The LAI can be obtained directly (destructive method), where the leaves are removed, or indirectly (non-destructive method), where there is no need to remove the leaves, ensuring the integrity of the plant, obtaining the LAI through remote sensing. using image processing techniques [9].

Among the non-destructive methods, models that relate LAI values with vegetation indices (VIs) derived from remote sensors can be highlighted [9,10]. These indices are developed from the combination of spectral bands, and can help in the diagnosis of leaf mass index, biomass, absorbed photosynthetically active radiation, evaluation of plant cover and productivity estimation [11,12].

The vegetation index such as the Soil Adjusted Vegetation Index (SAVI), among others, performs combinations of values from different regions of the electromagnetic spectrum. The red and near infrared bands generate indices capable of referring to biophysical parameters of the vegetation cover and, when obtained from orbital remote sensing images, allow the monitoring of agricultural crops with great efficiency and low operational cost [11,12,13].

However, the LAI estimate from data obtained from remote sensing cannot be generalized and requires validations that take into account the specifics of the location and the dynamics of the vegetation. Therefore, the use of field data, integrated with data obtained by orbital sensors and vegetation indices, is very useful in the scientific area [6].

Thus, the objective of this work was to estimate the leaf area index (LAI) for industrial tomato from orbital remote sensing images and to validate the results with the LAI obtained by the destructive method.

MATERIAL AND METHODS

Characterization of the study area

The study was carried out in a central pivot irrigated area in the municipality of Vila Propício, Goiás, Brazil (Figure 1). Located at 15º27'31"S and 48º53'09"W with an average altitude of 722m, climate Aw, tropical climate with dry winter, rainy season in summer, from November to April, and clear dry season in winter, from May to October (July is the driest month), average annual temperature of 23.9ºC, average annual rainfall of 1474 mm (13).

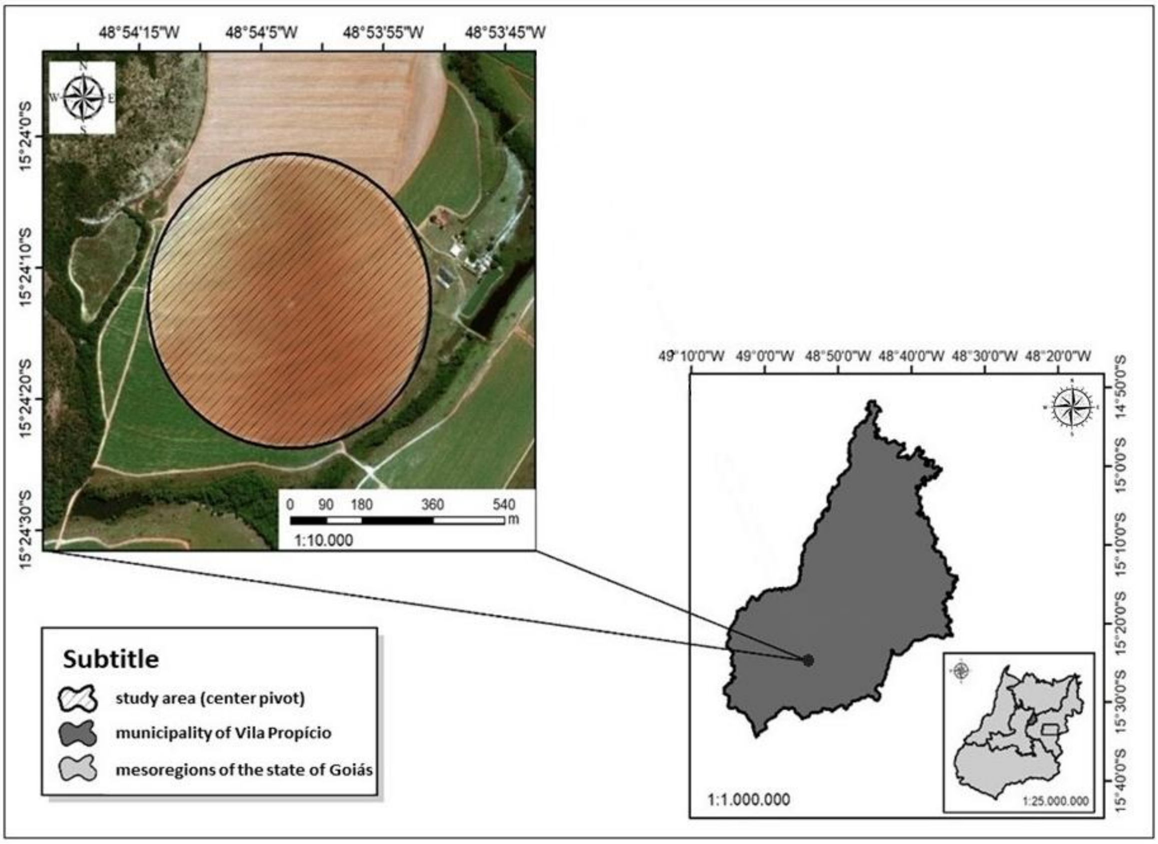

Figure 1. Geographic location of the central pivot in the municipality of Vila Propicio-GO. Source: The authors (2018).

Determination of leaf area from the destructive method

Sampling was carried out in a regular grid of 60x60m (Figure 2) based on bibliographic surveys of related works [15,16]. The sample grid was constructed with the aid of the geographic information system (GIS) software Arcmap ®, create fishnet routine, Universal Transverse Mercartor (UTM) plane coordinate system, 22 S spindle, totaling 88 georeferenced points [17].

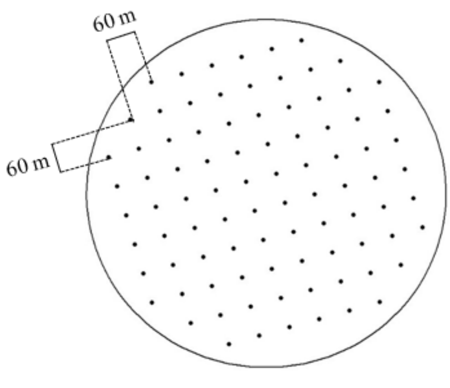

Figure 2. Sample grid of the experimental area. Source: The authors (2018).

To help identify the 88 sampling points, they were staked with the aid of a navigation GPS 30 days after transplanting (DAT). The evaluations of the Number of Plants (NP), Leaf Area (AF), and the Leaf Area Index

(LAI) were carried out at 76 DAT at each point of the sampling grid, according to the methodology proposed by Rocha [17].

Image acquisition

To estimate the IAF by remote sensing, Sentinel-2 images were used for the period from 07/01/2018 to 07/31/2018, made available free of charge by the United States Geological Survey (USGS - U.S. Geological Survey) (18). The use of Sentinel-2 satellite is applied for monitoring agriculture, forests, natural disasters, coastal zones. It has the ability to revisit every 5 days, it takes on board the MSI multispectral sensor that has 13 spectral bands, between 443 to 2190nm, with spatial resolution of 10, 20 and 60m for visible bands, infrared bands and aerial correction bands respectively (19).

IAF estimate

To determine the Leaf Area Index (LAI), the SAVI vegetation index was calculated for Sentinel images according to the methodologies proposed by related works [20,21].

The "Soil Adjusted Vegetation Index" (SAVI) was developed due to the influence that soils have on radiation from sparse plant canopies and, consequently, on the calculation of the vegetation index. As a result, it incorporated a soil adjustment constant to minimize its effects on the final result of the indices [21]. To obtain the SAVI, equation 1 will be used (Eq. 1).

$$SAVI = \left[\frac{(\rho_{ivp} - \rho_v)}{(\rho_{ivp} + \rho_v + L)}\right].(1 + L), \qquad (1)$$

Where, ρ_{ivp} reflectance in the near-infrared band, ρ_v the reflectance in the red band respectively, L the constant that minimizes the effects of the ground, and can vary from 0 to 1. For very low vegetation, it is suggested to use the factor L = 1, intermediate vegetation L = 0.5, for high densities L = 0.25. For the respective work, the value of L = 0.50 was used.

The LAI was calculated according to the methodology proposed by related works [21] according to equation 2 (Eq 2).

$$LAI = -\frac{ln*\left(\frac{0,69-SAVI}{0,59}\right)}{0,91}, \qquad (2)$$

The SAVI and IAF were obtained with the aid of the Arcmap® geographic information system software.

Validation of results

The results of leaf area and leaf area index were submitted to descriptive statistics through exploratory data analysis, allowing to know and visualize the trend, dispersion measures and distribution of the same. Descriptive measures were calculated: mean, median, variance, standard deviation, skewness, kurtosis and coefficient of variation.

To verify the accuracy between the LAI values measured in the field and those estimated by remote sensing, the Mean Square Error (MSE) and the Absolute Mean Error (AME) were calculated [6]. The MSE was calculated by equation (3) and measures the variation of estimated values around observed values.

$$MSE = \sqrt{\frac{\sum(o_i - e_i)^2}{N}}, \qquad (3)$$

Where, oi represents the values of leaf area observed in the field, ei the values of LAI estimated by remote sensing and N the number of observations performed.

The AME was calculated by equation (4), it indicates the absolute mean deviation (deviation) of the estimated values in relation to the measured values.

$$AME = \sum\frac{|o_i - e_i|}{N}, \qquad (4)$$

RESULTS AND DISCUSSION

Observing the images, it can be seen that between 69 and 84 DAT there was an increase in the leaf area (Figure 3) but it was not completely homogeneous. Part of the pivot showed a better leaf area, probably due to the larger size of the crop, soil conditions, higher incidence of solar radiation, among other edaphoclimatic factors that can interfere with the growth and development of the crop.

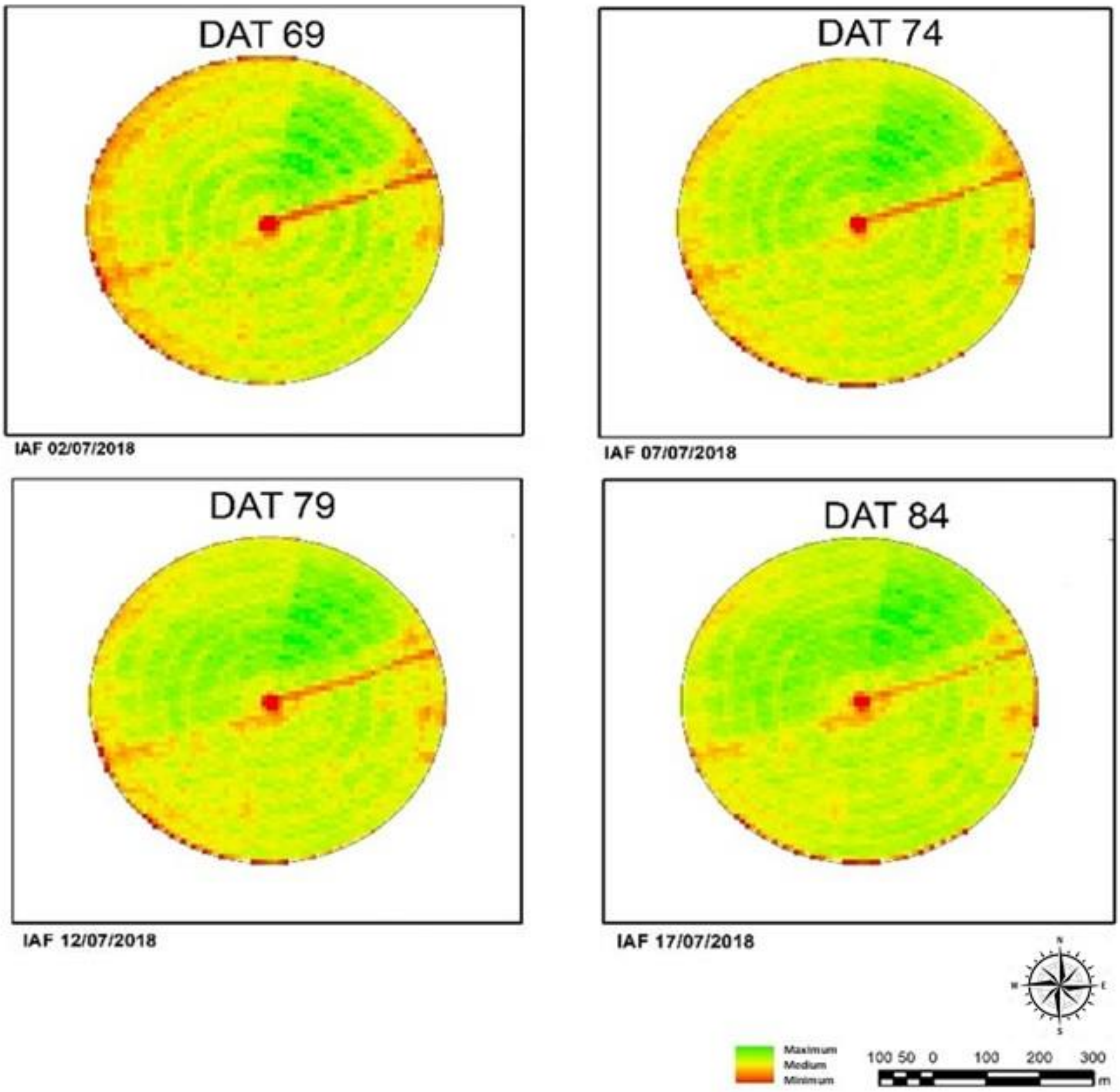

Figure 3. Development of the LAI. Source: The authors (2018).

Studies carried out with Eucalyptus showed the same development in an area, where the LAI varied, which may be influenced by local climatic conditions, showing a greater growth at the beginning of the development cycle and after this period a decrease [5].

Another study carried out with cherry tomatoes under protected cultivation conditions showed a higher LAI at 85 DAT, starting from the slope. This maximum LAI was influenced by the increase in irradiance, increasing the production of photoassimilates in the culture during this period [8].

The LAI of the study area was obtained in the second phase of the vegetative cycle of the tomato crop, ranging from 69 to 84 DAT, between these days the crop was in the post-flowering stage, leaving for the maturation of the fruits, which is the period from its IAF apex, heading for its slope [17].

The vegetative cycle of tomato plants is divided into 3 distinct phases, namely: the first, which begins with the transplanting of the seedlings and ends at the beginning of flowering and lasts an average of four to five weeks; the second lasts from five to six weeks and is marked by the time of flowering, ending at the beginning of the fruit harvest; and the third phase means the whole harvesting process [23].

In a study carried out in the municipality of Rio Largo in Alagoas, to determine the relationship between LAI and productivity during the vegetative cycle of the tomato crop grown in a protected environment, it was observed that the crop showed maximum productivity from 85 DAT. After this period IAF had a decline, associated with abscission of old leaves, radiation, soil conditions and edaphoclimatic factors [8].

In order to compare the real LAI and LAI estimated by the remote sensing images, it is observed by the descriptive statistics that the mean and median values presented very close results (Table 1), not suffering many variations, thus indicating the presence of a normal distribution of data.

Table 1. Descriptive statistics of the leaf area index obtained by remote sensing (estimated LAI) and leaf area obtained in the field (real LAI).

	Estimated LAI	*Real LAI*
Mean	2,167	2,664
Median	2,156	2,733
Standard deviation	0,237	0,650
Sample variance	0,056	0,422
Kurtosis	2,123	3,643
Asymmetry	1,136	0,793
Coefficient of variation	10,951	24,386

The asymmetry coefficient is sensitive to extreme values than the mean, median and standard deviation, since the asymmetry coefficient can be strongly influenced by a single value, since the deviations that occur between the mean and each value are raised to the third potency [24]. According to Person's asymmetry coefficient (AS), the asymmetry will be considered moderate if 0.15 <|AS|< 1, and considered strong if |AS|>1 [25]. The asymmetry coefficient values found indicate that the data distribution has strong asymmetry for the real LAI with a value of 1.136, and moderate asymmetry for the estimated LAI, having a value of 0.793.

The variables showed a positive kurtosis coefficient (C) with values of 2.123 and 3.643 for estimated LAI and real LAI, respectively, thus characterizing a distribution frequency with fewer deviations from the mean; presenting platykurtic curve C > 0.263, according to the percentile kurtosis coefficient [25].

The assessment of variability for the classification of soil attributes considered: low variability (CV < 12%); mean (12% < CV < 60 %); and high (CV > 60%) [26]. The coefficient of variation presented results between medium and high, for the estimated LAI of 0.951 and the real LAI of 24.386, respectively, which may indicate heterogeneity in the data.

The MSE and AME are appropriate methods to verify the accuracy of estimated data. The lowest limit in MSE is zero, which is ideal, but the result found was an MSE of 0.798 and an AME of 0.629, which indicates good agreement.

In a study carried out in several locations in São Paulo, monthly rainfall data obtained by the TRMM satellite and temperature data obtained by the Aqua/MODIS satellite were evaluated and compared. For the validation of thermopluviometric data by remote sensing, the MSE and the AME were also slightly above the ideal value, but this did not interfere with the result, thus demonstrating that there was a good agreement and the satellite is able to offer good estimates for such a study [27].

In another study with the objective of evaluating LAI estimates in a pasture area, the MSE and AME showed a low correlation, verifying that these estimates should be used with care, as they did not show a good agreement [6].

The leaf area index (LAI) estimated through orbital remote sensing showed good results compared to the LAI obtained through the destructive method.

The estimated leaf area index was not completely homogeneous, as part of the pivot showed better results, with a growth in the vegetative development phase and a decrease in the maturation phase of the crop.

This heterogeneity is related to the size of the crop, soil conditions, higher incidence of radiation and crop development.

The values of the statistical analysis of the real LAI compared to the estimated LAI were very close, but the coefficient of variation showed a greater difference between them, indicating that there may be a greater variation in the estimate, making it more careful when use this type of estimate.

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