Australian Journal of Basic and Applied Sciences
2019 August; 13(8): pages 29-39
DOI: 10.22587/ajbas.2019.13.8.5
Original paper **AENSI Publications**
Journal home page: www.ajbasweb.com

Variation of Leaf Area Index by Remote Sensing and Surface Measurements for a Tropical Savanna

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Received date: 18 March 2019, Accepted date: 21 August 2019, Online date: 29 August 2019

Abstract

Studies of vegetation in parks within the urban perimeter are scarce, since the study of green area dynamics within a city requires high cost and mobility of collection. In this context, remote sensing appears as an ideal tool for the study of vegetation in contrast to anthropic areas. The ceptometer sensor are the most used in leaf area index in spatial analysis, so measurements with this type of sensor can be used to validate remote sensing products for this variable. Thus, the objective of this study was to measure leaf area index (LAI) obtained by orbital sensor in contrast to measurements in loco. Landsat 8 satellite reflectance measurements were used for validation with locally measured data at 30 sample points. The photosynthetically active radiation incident off and below the canopy, as well as the transmittance of the canopy, were measured at the site. The research was carried out in the tropical savanna fragment located in the *Mãe Bonifácia park*, in the Cuiabá city, Brazil, from October 2014 to September 2015. The leaf area index estimates presented a seasonal characteristic ranging from 6.5 m^2 m^{-2} in December 2014, rainy month, and 2.7 m^2 m^{-2} in September, dry month. For the data of orbital sensors, it is noticed that the highest values of LAI are observed in the year of 2015, with the highest median in April. The orbital sensor data averaged 21% of the data measured in loco, however the correlation coefficients and determination were considered satisfactory, modeling well the leaf area index dynamics, but indicating that adjustments should be made in the model for better fit.

Keywords: Photosynthetically active radiation; LAI; Urban park; Landsat 8

INTRODUCTION

Monitoring the dynamics of vegetation indices allows the diagnosis of natural and anthropogenic changes in the landscape of an ecosystem (Cunha et al., 2012). The calculation of these parameters, such as the leaf area index, (LAI), on a regional scale, would represent a large expenditure of material and human resources (Oliveira et al., 2012).

LAI is a dimensionless measure of the leaf cover that corresponds to the amount of leaf layers in m², by soil area also in m² (Larcher, 2006). LAI is one of the main physiological parameters measured in forests, being directly related to transpiration, productivity and interception of rainfall (Almeida et al., 2015). It is also one of the main outputs of the agricultural and forestry productivity estimation models (Stape et al., 2004; Landsberg & Sands, 2011).

Therefore, remote sensing appears as an option at no cost, allowing the mapping of vegetation and an indicator of the health of that ecosystem. (Barbosa et al., 2012; Rocchini, 2013; Jiang et al., 2013). Remote sensing has been one of the most powerful tools to detect, directly and indirectly, the properties of terrestrial biodiversity (Rocchini, 2013). With the increase in the number of sensors with high spatial and temporal resolution, the properties of forest biomass and vegetation phenology that are "invisible" in the field can be revealed (Jiang et al., 2013).

Different methodologies for identification and evaluation of changes in vegetation structure, physiognomy and dynamics are employed, such as the detection of change by vegetation indices. (Calera et al., 2004). So, LAI is essential for knowledge of phenomena at different scales, which provide valuable information for modeling, and for validation of production and plant cover data. (Barbosa et al., 2012).

The current literature on environmental, hydrological, and canopy structure variables and surface characteristics are limited by the lack of field data, especially long-term spatial data (Engman, 1996; Conly & Van Der Kamp, 2001; Mynemi et al., 2002; Mendoza et al., 2003; Price, 2005; Allen et al., 2007; Zheng & Moskal 2009; Biudes et al., 2013; Novais et al., 2015; Novais et al., 2016), in this way, spatialized data collection of canopy structure data is a complementary form of remote sensing.

In this context, the Brazilian savanna biome, locally known as cerrado, which in Mato Grosso cover about 300,000 km², being the second largest biome in the country, is constantly deforested and burned, and to the region of Cuiabá-MT, according to data from the National Institute for Space Research (INPE) (2016), in September 2015, 1584 fire outbreaks were recorded, emphasizing the need to monitor the leaf area index during the year.

Therefore, it is necessary to evaluate the dynamics of the leaf area index for the tropical Brazilian savanna forest, and to validate with spatial data measured in the field, since several studies for Brazilian tropical forests (Sanches et al., 2008; Pinto Junior et al., 2011, Biudes et al., 2013, Danelichen et al., 2014) found differences between LAI measured in the field and by remote sensing, mainly due to the seasonality and interannuality of LAI. The estimation of LAI by means of orbital sensor data cannot be generalized and requires validation of their estimates and products, considering local specificities and vegetation dynamics (Breda et al., 2003; Biudes et al., 2013; Danelichen et al., 2014).

In addition to these motives, this work corroborates the importance of the use of parks in large urban centers, since these places serve to practice physical activities, fun and for the population to come into contact with nature (Andrade et al., 2016; Novais et al., 2017), emphasizing the importance of more studies being done in urban parks.

Thus, the objective of this paper was to evaluate the variation of leaf area index (LAI) obtained by orbital sensor in contrast to measurements in loco to a tropical Brazilian savanna fragment.

MATERIALS AND METHODS

Sample points location

The experiment was carried out on savanna fragment, locally known as urban park Mãe Bonifácia, located in the western region of Cuiabá city, capital of the Mato Grosso state, midwest region of Brazil. Barros et al., (2010), affirm that the altitude variation is between 164 and 195 m and that the great floristic diversity is divided into three strata: the ciliary forest bordering the streams, the "cerradão" away from the watercourse and int the tigher regions the "cerrado stricto sensu".

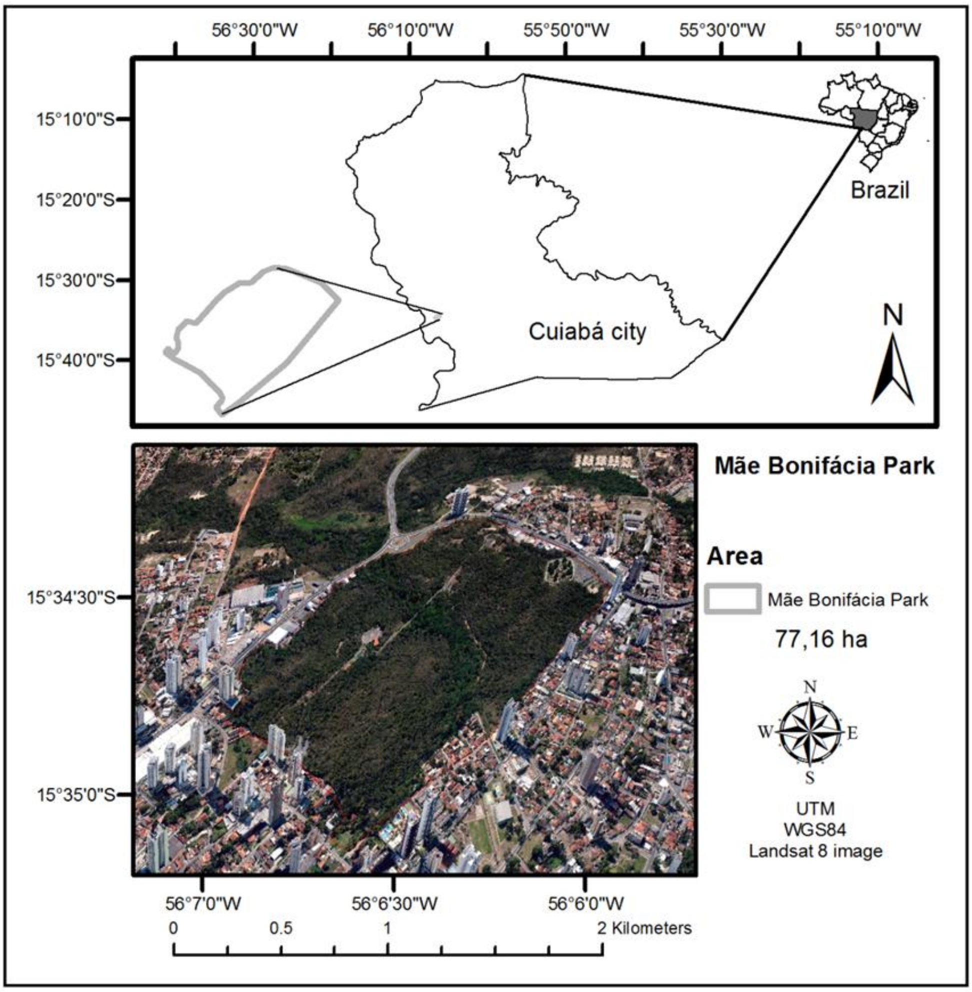

Figure 1: Study local, in a tropical savanna fragment in Brazilian Midwest.

According to Andrade et al. (2016), the Boniface Mother Park is a fragment of savanna that remains in its natural form and has not undergone relevant anthropic actions to alter its biophysical characteristics. Among the most abundant species are *Curatella americana, Albizia niopoides, Anadenanthera colubrina, Samanea Tubulosa, Stryphnodendron barbatimão, Inga Vera* and *Bowdichia virgilioides*, distributed in 76 hectares of area.

This urban park is important for the local population, because the presence of vegetation provides thermal comfort for the users of the park and for the region in its surroundings (Joaquim et al. 2018).

The climate of Cuiabá-MT is of type Aw, according to the classification of Köppen, identified primarily by the temperature, presenting two defined seasons, one dry, from May to October, and another rainy, from November to April, with averages between 28 °C e 32 °C (Alvares et. al., 2013).

In the park, thirty measuring points were chosen, being established in a random way, seeking to cover the diversity of the park. The thirty points were demarcated using stamping, labeling and georeferenced. The region bordering the park in the southeast / southwest surrounds has high occupancy by residences and buildings, in addition to the paved roads. The opposite region, northeast / northwest portion, is surrounded by the paving of a main road approximately 30 m wide.

Instrumentation and on-site measurement of leaf area index

Data were collected in the field: leaf area index (LAI), photosynthetically active radiation incident to the canopy (PAR_{inc}), photosynthetically active radiation transmitted by the canopy (PAR_{trans}), transmittance of the canopy, calculated by the division of PAR_{trans} by the PAR_{inc}. This data were collected by a ceptometer AccuPar - LP 80, which consists of a microprocessor datalogger that interprets the signals that arrive at the metal rod, called probe, where the sensors that detect the radiation are installed. The apparatus measures a photosynthetically active radiation in the wavelength range of 400 to 700 nm and converts to index of leaf area. The radiation values are expressed in micromoles per square meter per second ($\mu mol.m^{-2}s^{-1}$).

Leaf area index estimation by remote sensing

For the purpose of comparison with the measured leaf area index (LAI), surface reflections of the Landsat 8 satellite with 30 m spatial resolution (atmospheric corrections already performed by the USGS) were used, provided by the Center Science Processing Architecture (ESPA) (http: //earthexplorer.usgs.gov/) of the US Geological Survey (USGS). LAI was calculated using the model of Allen et al. (2002) described below. The Landsat 8 satellite was launched on February 11, 2013 and operates in equatorial orbit at 705 km altitude. The OLI (Operational Land Imager) onboard the satellite imagines the Earth's surface producing 185-km-wide images on the ground, 30-meter spatial resolution and 9 spectral bands. The satellite revisit time to image the same portion of the terrain is 16 days. All Landsat 8 image processing was performed using the ArcGIS 10.3 software and batch processing using Python 2.7 language through the Pythonwin compiler.

The leaf area index (LAI) was estimated by the ratio of leaf area of all vegetation per unit area projected by this vegetation. The LAI is an indicator of the biomass of each pixel of the image, calculated by (Allen et al., 2002):

$$LAI = -\frac{ln\left(\frac{0,69-IVAS}{0,59}\right)}{0,91} \qquad (1)$$

SAVI (vegetation index adjusted for soil effects) is the soil-adjusted vegetation index proposed for the purpose of reducing soil background effects, being calculated according to expression (Huete, 1988):

$$SAVI = \frac{(1+L)(\rho_{\lambda 5} - \rho_{\lambda 4})}{(L + \rho_{\lambda 5} + \rho_{\lambda 4})} \qquad (2)$$

The abbreviations $\rho_{\lambda 5}$ and $\rho_{\lambda 4}$ correspond to bands 5 and 4 of Landsat 8, respectively. The factor L is a function of vegetation density and its determination requires an a priori knowledge of the amount of vegetation. The value of this factor is critical in minimizing the effects of soil optical properties on vegetation reflectance. Huete (1988) suggested a value of L = 0.5 for first-order variations in the image, as being an optimized value of this reflectance.

Statistical analysis

The evaluation of the performance of the LAI estimation by remote sensing was performed using the following indicators: root mean square error "RMSE" (Equation 3) and absolute mean error "MAE" (Equation 4), both made in *Microsoft Excel* ® software.

The MAE indicates the absolute mean deviation of the estimated values from the measured values, which can be obtained by:

$$MAE = \sum \frac{|P_i - O_i|}{n} \qquad (3)$$

Where P_i is the estimated value, O_i is the observed value and O is the average of the observed values.

The RMSE indicates how much the model fails to estimate the variability of the measures around the mean and measures the variation of the estimated values around the measured values (Willmott & Matsuura, 2005). RMSE can be obtained by;

Citation: Novais, J. W. Z., *et al.*, Variation of Leaf Area Index by Remote Sensing and Surface Measurements for a Tropical Savanna. Australian Journal of Basic and Applied Sciences, 13(8: 29-39. DOI: 10.22587/ajbas.2019.13.8.5

$$RSME = \sqrt{\frac{\sum(P_i - O_i)^2}{n}} \quad (4)$$

The smallest limit of RSME is 0, which means that there is full adherence between model estimates and measures. Ideally, the MAE and RSME values should be close to zero (Willmott & Matsuura, 2005).

RESULTS

It is observed in figure 2 the results of incident photosynthetically active radiation (PAR_{inc}), transmitted photosynthetically active radiation (PAR_{trans}), leaf area index (LAI) and transmittance.

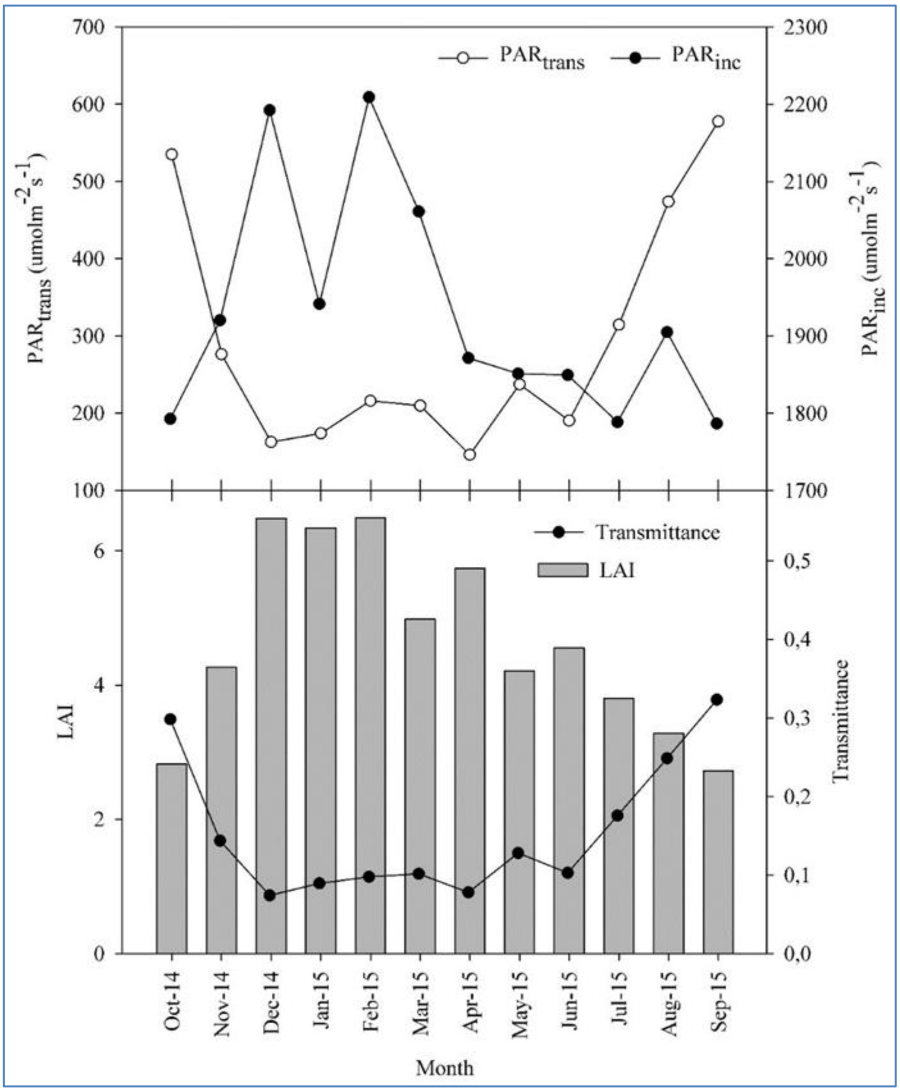

Figure 2. Monthly averages of incident photosynthetically active radiation (PAR_{inc}), transmitted photosynthetically active radiation (PAR_{trans}), leaf area index (LAI) and transmittance, from October 2014 to September 2015, for the tropical savanna fragment in Brazilian Midwest

According to the seasonal precipitation known for the region, a dry period, from April to October, and a rainy period, from November to March, there is a response in LAI with the beginning of the rainy season in November 2014, culminating in December of 2014 6.5 m^2m^{-2} of leaf area index. The LAI is determinant for the passage of the photosynthetically active radiation transmitted by the canopy, in which smaller LAI allow a greater passage of light (Danelichen et al., 2016). The lowest LAI value, 2.7 m^2m^{-2}, occurred in September 2015, in the dry period.

It is observed that from October to November 2014, beginning of the rainy season, LAI values increased by 33.8%, decreasing by 49.6% in PAR transmitted. As for the transmittance, the values decreased from 0.31 to 0.14, demonstrating a relation of inverse proportionality between LAI and transmittance.

With the increase of LAI in the rainy season, the lowest transmittancy value occurred in December 2014, 7%, contrasting with the 13% occurred in May 2015. The transmittance being the fraction of the incident light at a specific wavelength, which Passing through a sample, it is possible to occur a lower transmittance index in the period in which LAI occurs (Marques et al., 2017), since there is an increase in the plant leaf biomass volume, such as (Sallo et al., 2014), the greater the sample of the matter by which the light incidence will pass through.

The LAI by remote sensing of Landsat 8 satellite also presented variation throughout the studied period, in which the highest values are presented in lighter tones and smaller values in darker tones, gray level (Figure 3).

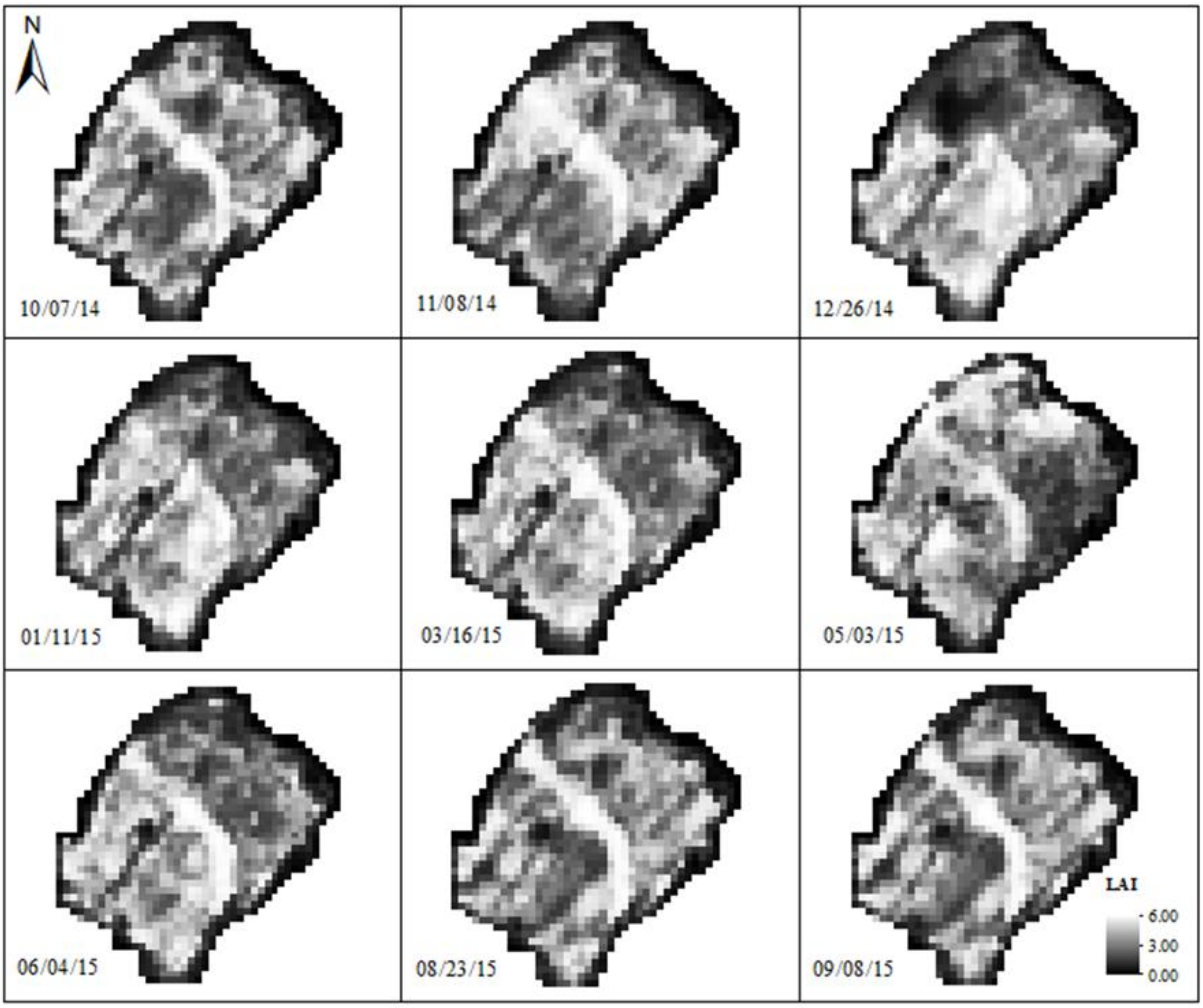

Figure 3. Leaf area index maps estimated using the Landsat 8 reflectance, from October 2014 to September 2015, for the tropical savanna fragment in Brazilian Midwest.

It is observed the rectangular strip that cuts the park in the middle, which demonstrates the presence of arboreal vegetation typical of the Brazilian savanna, having greater leaf area index during the months corresponding to the rainy season, decreasing during the months that correspond to the dry season, these areas of white belt reach the highest LAI values (above 5 m^2m^{-2}). This type of vegetation, in the highlighted range, occurs due to the presence of a small stream that cuts through the park, allowing denser trees.

It was done boxplot for exploratory analysis of LAI data of Landsat 8, according to figure 4.

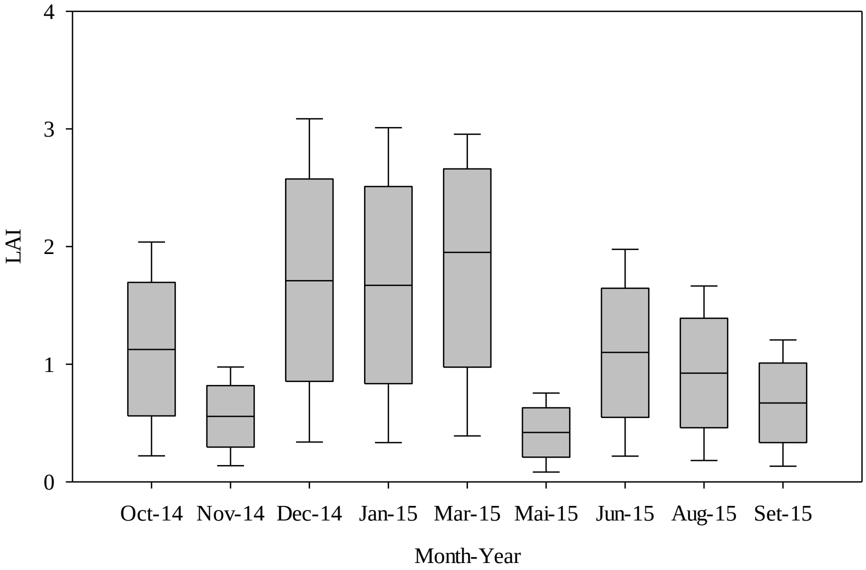

Figure 4. Box plot for leaf area index estimated by Landsat 8 reflectance, from October 2014 to September 2015, for the tropical savanna fragment in Brazilian Midwest

The exploratory evaluation of the data by the boxplot shows that the highest LAI values are observed in the year 2015, with the highest median in April, corresponding to the rainy season and lower values in the months corresponding to the dry season, with highlight the month of May 2015 (Figure 4).

The LAI measured in the field were contrasted with those estimated by the model of Allen et al. (2002), in order to observe possible patterns among the variables (Figure 5).

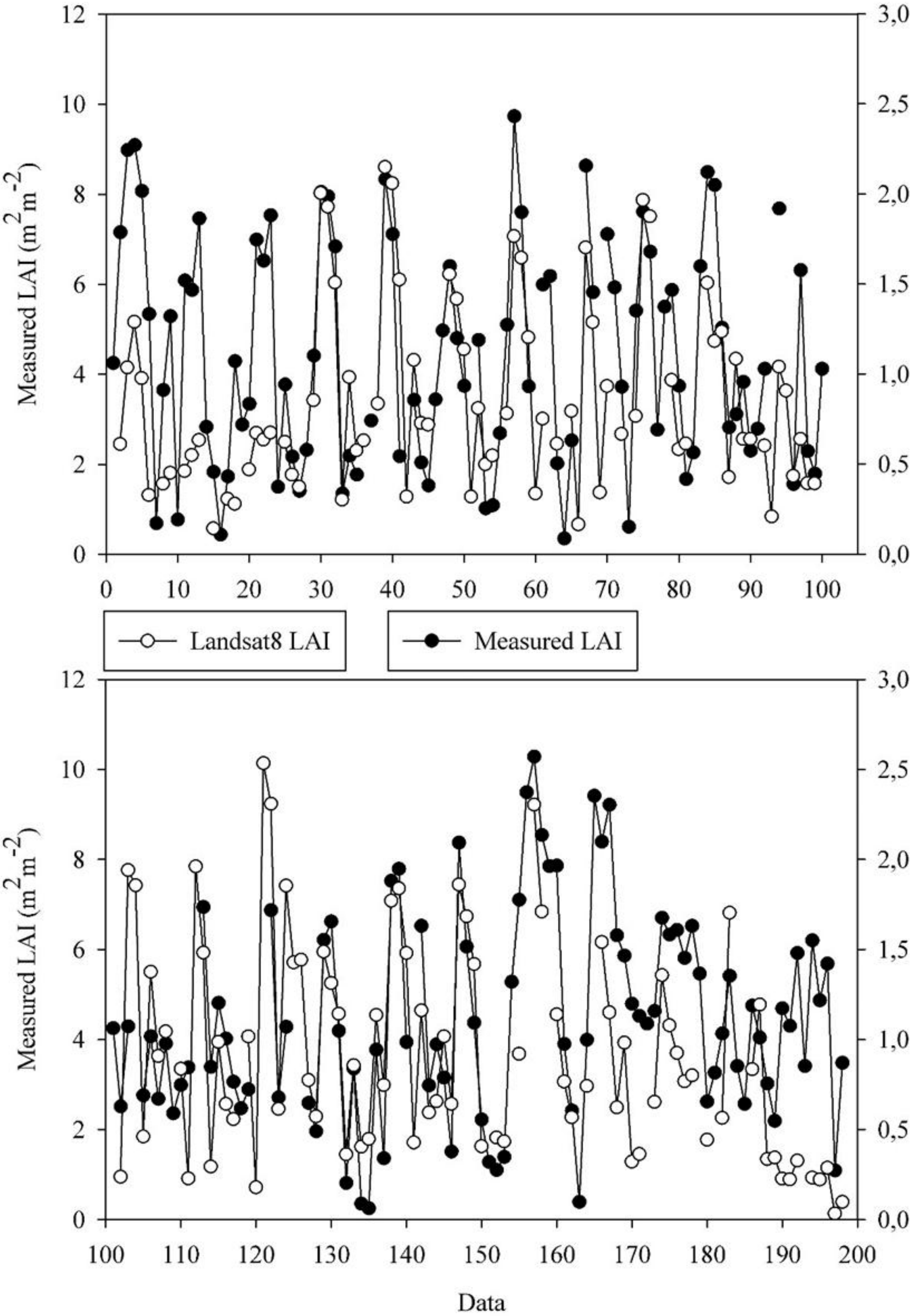

Figure 5. Leaf area index measured in the field and estimated by Landsat 8 reflectance, from October 2014 to September 2015, for the tropical savanna fragment in Brazilian Midwest.

Although the measurement scales are different, similarity is observed in the index curves patterns. The leaf area indexes estimated by Landsat 8 underestimate the values measured in the field, corresponding on average to approximately 21% of the data measured in the field.

In order to compare data measured in the field and by satellite, a correlation was made between the leaf area index measured in the field and estimated by the Landsat reflectance 8, table 1.

Table 1. Measurement points, geographical coordinates, mean absolute error (MAE), root mean square error (RMSE), Pearson correlation (r) and determination coefficient (R^2) for measured leaf area index values estimated by reflectance Of Landsat 8, from October 2014 to September 2015, for the tropical savanna fragment in Brazilian Midwest.

Points	Latitude	Longitude	MAE	RSME	R	R^2
1	8277337	596478	5,27	5,72	0,92	0,85
2	8277227	596383	3,21	3,89	0,90	0,81
3	8277100	596293	3,58	4,14	0,92	0,85
4	8277125	596179	2,90	3,71	0,95	0,91
5	8277220	596201	2,02	3,01	0,90	0,80
6	8277373	596142	2,66	3,24	0,89	0,78
7	8277373	596245	3,99	4,70	0,80	0,64
8	8277418	596278	3,13	4,14	0,81	0,66
9	8277539	596206	3,68	4,09	0,82	0,68
10	8277518	596345	3,97	4,49	0,79	0,63
11	8277589	595990	2,44	3,40	0,92	0,85
12	8277385	595887	2,31	2,85	0,89	0,79
13	8277267	595907	2,66	3,26	0,84	0,70
14	8277266	596048	0,87	2,39	0,93	0,87
15	8276972	595844	2,11	2,82	0,98	0,95
16	8276963	595602	3,11	3,75	0,81	0,65
17	8277230	595570	2,39	3,01	0,95	0,91
18	8277449	595801	6,15	6,55	0,89	0,79
19	8277683	595804	5,24	5,82	0,79	0,63
20	8277806	595877	4,76	4,87	0,81	0,65
21	8277832	596058	3,09	3,15	0,82	0,68
22	8277720	596211	4,22	4,45	0,92	0,84

There were correlation coefficients higher than 0.79 and coefficient of determination (R^2) above 0.63 (table 1), between the LAI estimated by Allen et al. (2002) and measured by the ceptometer, indicating agreement with the measurements of LAI performed in the urban park, confirming the patterns observed in figure 5.

DISCUSSION

The seasonality of the LAI was also observed in a study of transition forest Amazon/Savanna by Resende et al., (2010), finding averages of LAI of 5.5 m^2m^{-2} in the dry period and 8 $m^2m^{-2}$for rainy season.

There was a characteristic seasonality for the photosynthetically active radiation, with higher values in the summer, approximately 2200 $\mu molm^2s^{-1}$, same standard found by Novais (2015; 2016) for global radiation under study in the wetland, 200 km of the study region, and by Andrade et al. Al., (2014) in a study in the Atlantic forest in Alagoas, Brazil.

During the rainy season the plant reaches the maximum of its photosynthetic activity, since the highest values of difference between the PAR incident and the PAR transmitted were found in the months corresponding to the rainy season. From December 2014, rainy season, to September 2015, was observed the largest fall of photosynthetically active radiation, 1209.03 $\mu molm^2s^{-1}$.

At the end of the rainy season the foliar senescence phenomenon begins, a metabolic process caused by the redirection of the nutrients to other zones of the plant, that in the savanna occurs only in the aerial part of the plant culminating in foliar abscision (Maillard, 2015). This foliar abscission allows considerable savings in water loss in the transpiration process and in the availability of nutrients to maintain a leaf surface with low photosynthetic productivity due to the severe water deficit in the dry season (Dalmagro et al., 2013).

To the transmittance, Januário et al. (1992) estimated a transmittance of radiation of 4.7% for rainforest in the Amazon forest. However, studies by Leitão (1999) and Senna et al. (2005) presented transmittance values of 1.3% and 3%, respectively. Novais et al. (2018) observed transmittance values in the Brazilian wetland ranging from 1% in moist periods to 16% in the driest. The lowest mean value of transmittance, 0.1, occurred in June 2015. Lower values of transmittance generally occur for the highest values of the zenith solar angle, because for greater zenith angles, the path traveled by radiation within the canopy will also be larger, Increasing the absorption by leaves and branches (Senna et al., 2005; Spolador et al., 2006).

The savanna, due to its sparse vegetation, allowed transmittances from 32% in the driest period to 7% in the wetter periods. This differentiated behavior is explained by the occurrence or not of clearings, which significantly modify the PAR regime within the forest (Sansevero et al., 2006).

As for the comparisons between field measurements and measurements made by Landsat 8, ground measurements of LAI are able to measure radiation that is transmitted integrally by gaps in the canopy leaves. Such a level of measurement is not achieved by the orbital sensor, which has the measure of a larger area than the ceptometer measures, and is perhaps the cause of the observed differences. Thus, the canopy structural pattern and stratification seems to be the main factor causing the differences in absorption that lead to imprecise and biased LAI estimates (Bréda 2003), This difference between the LAI estimated based on the images of the Landsat 8 satellite using the model proposed by Allen et al. (2002) and the measurement is probably related to influences, such as noise effects (atmospheric radiance path), asymptotic (saturated) signal exposure on high biomass conditions, and the sensitivity of this method to variations in the background Canopy (Aragão et al., 2005).

The interface between ecosystems and the atmosphere is difficult to compute due to spatial variability and temporal variability: variations of annual and interannual cycles that interact with structural patterns and homogeneity (Bréda, 2003). Factors such as differences in absorption are also considered. While the Allen et al. (2002) determines the LAI of the radiation absorption by the leaves only, the LAI measured by the sensor takes into account the fraction of radiation that is transmitted and absorbed by the canopy (Senna et al., 2005).

The results obtained in this work differed from those obtained by Allen et al. (2007) and Fideles et al. (2005). Possibly it resides in the fact that these authors parametrize the model with agricultural species, with defined canopy pattern and a spatial variability of the geometry of the canopy inferior to the one found in urban parks. Although there was a difference between the measured and estimated values, it was possible to identify the spatial variability of the leaf area index, as was observed in figure 5. The results found are similar to other validation studies of sensing products by field measurements, such as Castrignano et al. (2015), which found quality index for comparisons relatively low, 40-50%, being the poor results are probably due to the too coarse sampling, with large areas without any ground-truth data of LAI.

The high values of the coefficient of determination (R^2) found, table 1, are in accordance with a similar study performed by Almeida et al. (2015) in eucalyptus plantation (*grandis x urophylla*) also for Brazilian savanna, which found coefficients of determination greater than 0.6.

Presumably, the higher spatial resolution of surface reflectance would provide more detailed information about the land surface, and hence, a better estimate of LAI (Wang & Liang 2008).

CONCLUSION

The terrestrial measures of leaf area index presented seasonality, ranging from 6.5 m^2m^{-2} in December, rainy month, and 2.7 m^2m^2 in September, dry month. For data from orbital sensors, the highest LAI values are observed in the year 2015, with the highest median in the month of April, the month corresponding to the rainy season and lower values in the months corresponding to the dry season, with emphasis on the month of May 2015.

The orbital sensor data corresponded on average to 21% of the data measured in loco with the ceptometer, however the coefficients of correlation and determination were considered satisfactory, indicating that adjustments should be made in the model. Thus, care should be taken when using remote sensing data for leaf area index estimates for tropical savanna area.

ACKNOWLEDGEMENT

The authors thank the National Foundation for the Development of Private Higher Education (Fundação Nacional de Desenvolvimento do Ensino Superior Particular) - FUNADESP.

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Citation: Novais, J. W. Z., *et al.*, Variation of Leaf Area Index by Remote Sensing and Surface Measurements for a Tropical Savanna. Australian Journal of Basic and Applied Sciences, 13(8: 29-39. DOI: 10.22587/ajbas.2019.13.8.5

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