MULTISENSOR ANALYSIS IN A TEAK REFORESTATION AREA IN THE LEGAL AMAZON, BRAZIL

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Abstract: Image time series produced by remote sensing are crucial for monitoring land use and land cover assessments and transitions over space and time. In this context, the objective of this study was to analyze the temporal behavior of NDVI from multisensors during the years 2007, 2008, 2009, 2010 and 2011 in a commercial reforestation of *Tectona grandis* L. f., in the municipality of Cáceres – Mato Grosso (MT). To obtain the data, we used images from the TERRA satellite, MODIS sensor, product MOD13Q1, available with spatial resolution of 250 meters. The LANDSAT5/TM images were obtained from the U.S. Geological Survey (USGS) database, with the approximate possible dates from the MOD13Q1 images. We observed teak temporal behavior, highlighting the existence of two well-defined dry and rainy periods. Remote sensing can be useful to add spatial and spectral information related to teak reforestation monitoring.

Keywords: Vegetation index, Landsat, Modis, Remote sensing.

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INTRODUCTION

The use of data produced by orbital remote sensing, especially image time series, presents itself as an important tool for the systematic monitoring of land use and land cover and its transitions over time. According to Jackson and Huete (1991), vegetation indices aim to improve the signal from vegetation while decrease the effects of soil and solar irradiance. When observed over time with a certain regularity, from platforms with high temporal resolution, vegetation indices can represent the temporal signatures of each vegetation cover.

The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, under the responsibility of NASA (National Aeronautics and Space Administration), is on board the Terra and Aqua satellites, has 36 spectral bands and spatial resolutions ranging from 250, 500, and 1000 meters. Among the pre-processed MODIS products made available by LP-DAAC (Land Processes Distributed Active Archive Center), a NASA-linked center, is MOD13Q1, which has two vegetation indices, NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) (Rudorff, Shimabukuro and Ceballos, 2007).

The NDVI, proposed by Rouse et al. (1974), quantifies the presence of vegetation and its characteristic, varying between -1 and 1. The NDVI is obtained through the normalized difference between the near infrared and visible red bands. According to Huete, Justice and Liu (1994), although the calculation methods used for different vegetation indices present correct methodologies, different results for the same target are derived from them.

In view of the ease and availability of data and its broad utility in scientific work involving remote sensing, there is still an alternative, the exploration of data from the Landsat series of sensors. Developed by NASA, it was the first unmanned satellite specifically designed to acquire data from the Earth's surface in a synoptic, systematic and repetitive way. The Landsat 5 Thematic Mapper (TM) sensor is an Earth imaging sensor that was launched on March 1, 1984 and remained active until

November 2011, establishing itself as the Earth observation sensor with the longest period of operation: 28 years (NASA, 2023). Ponzoni, Junior and Lamparelli (2007) point out that the LANDSAT satellite images have been widely used in studies that include qualitative approaches, such as productivity estimates of some agricultural crops and the quantification of biophysical parameters of forest formations.

Teak (*Tectona grandis* L. f.), of Asian origin, more precisely from India, is a species that has spread throughout Oceania, Africa and America, and is one of the best known woods in the world. The main product of this species is a high quality wood, widely used in fine furniture and shipbuilding (Dupuy and Verhaegem, 1993). The species was introduced in Brazil in 1971, in the region of Cáceres, state of Mato Grosso. It was found to have excellent growing conditions and adaptation to local climatic conditions, besides producing wood with good prices on the international market (Caceres Florestal S.A., 1996).

Thus, with the constant concern to ensure the conservation of natural resources and biodiversity, ensuring production efficiency depends heavily on a well-managed plantation, which can offer a high-quality end product, it is essential to have information on the state of the forest over the years. In this context, the objective of this study was to analyze the temporal behavior of NDVI from MOD13Q1 and LANDSAT5/TM during the years 2007, 2008, 2009, 2010 and 2011 in a commercial reforestation of *Tectona grandis* L. f., in the Legal Amazon, state of Mato Grosso, Brazil.

MATERIAL AND METHODS

Study area

The present study was conducted in a *Tectona grandis* L. f. reforestation, located in Cáceres, south-central Mato Grosso, Legal Amazon state, in the geographic coordinates 16° 5′ 11.43′′ S and 58° 12′ 35.27′′ W (Figure 1). With an area of approximately 837.96 ha, the planting conducted in 2005 and presented some interventions in the population over the years of measurements, which began in 2007 until 2011.

The Legal Amazon is the territory comprising the states of Acre, Para, Amazonas, Roraima, Rondonia, Amapa and Mato Grosso and the regions located north of the 13° S parallel in the state of Tocantins, and west of the 44° W meridian in the state of Maranhao, totaling an area of 5,114,798.30 km². Where economic activities associated with deforestation have represented real threats to the protection of the Legal Amazon, especially in the state of Mato Grosso, located in agricultural frontier zones.

In the first years of measuring the area (2007 and 2008), the ants were combated, due to the young age of the population, in addition to maintenance such as weeding and trimming. In 2009, in addition to weeding and trimming, the first thinning was carried out in the stand, which was of the selective type, at an intensity of 50%, where individuals from the worst dominance classes are removed. This type of thinning was applied in young stands, with the aim of reducing the density of the stand, reducing intra-specific competition for light and nutrients, in order to favor the best individuals in the stand. For the following years of measurements (2010 and 2011), pruning, weeding, and mowing were performed in the study population.

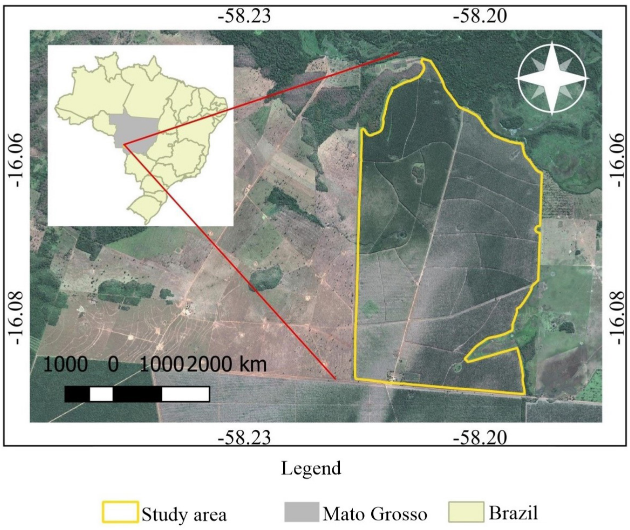

Figure 1: *Tectona grandis* L. F reforestation area, located in Cáceres, Mato Grosso.

The region's climate, according to the Köppen classification, is characterized as tropical savanna climate (Aw): tropical climate with average temperatures above 18 °C in all months. The dry season occurs in the fall/winter and the rainy season, in the spring/summer (Souza et al., 2013). The annual maximum temperature is 32 °C, and the minimum, 21 °C. However, daily maximums in spring can exceed 41 °C (Neves, Nunes and Neves, 2011). The predominant soil in the region is of the type Argiloso Vermelho-Amarelo dystrophic (RadamBrasil, 1982).

Data Collection

The local climate of the municipality presents two seasons well defined by the spatial and temporal distribution of rainfall. To analyze the dry and rainy periods in Cárceres - MT average annual precipitation data were obtained from the Series View portal of LAF-INPE (Laboratory of Remote Sensing Applied to Agriculture and Forestry of the National Institute for Space Research - INPE), which currently has monthly accumulated precipitation data from the TRMM sensor for any geographic coordinate in South America, from the year 2000. The data were obtained between the years 2007 and 2011, referring to the observation period of this study.

We used images from the TERRA satellite, MODIS sensor, product MOD13Q1, quadrant tile H13V10, available with spatial resolution of 250 meters and periodicity of 16 days, during the period from January 2007 to December 2011, available on the Application for Extracting and Exploring Analysis Ready Samples (AρρEEARS) platform of the USGS/Earth Resources Observation and Science (EROS) Center. This compositing process selects the best image pixel to compose the MOD13Q1 product, minimizing any spatial distortions and radiometric noise (Van Leeuwen, Huete and Laing, 1999).

The evaluation dates were selected by the QA condition of the MOD13Q1 images, whose value is 2112 on all pixels contained in the surrounding polygon. This value refers to a pixel with a low amount of aerosol, no detection of adjacent clouds and mixed clouds, with atmospheric correction, without the possibility of snow/ice and shadow, and is thus considered good quality.

LANDSAT5/TM images were obtained from the U.S. Geological Survey (USGS) database (available at http://earthexplorer.usgs.gov/), Level 2 product, with atmospheric correction by the LaSRC method (Vermote et al., 2019). The closest possible dates being the MOD13Q1 images for the period January 2007 to December 2011 (Figure 2). A total of 66 MOD13Q1 images and 36 LANDSAT5/TM images were selected (Table 1).

Comparative analysis LANDSAT5/TM and MODIS13Q1

The Normalized Difference Vegetation Index (NDVI) defined by the normalized ratio between the wavelengths in the near infrared and red (Equation 1) was used. For the MOD13Q1 image this index was scaled in AppEEARS, being performed only its download, however, for the LANDSAT5/TM it was calculated using band 5 and 4 that correspond to the infrared and red respectively.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

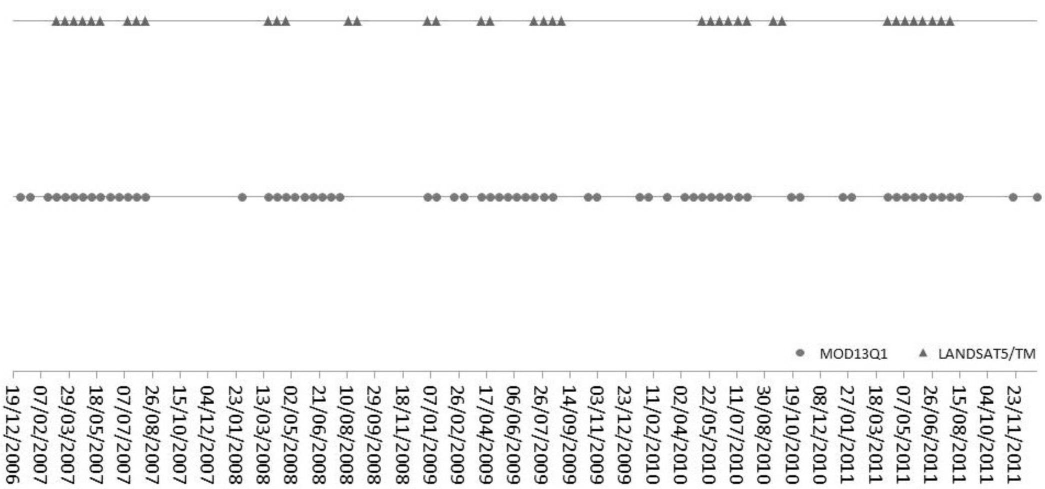

Figure 2: Dates of the images obtained with better QA for MOD13Q1 and LANDSAT5/TM, in the years 2007, 2008, 2009, 2010 and 2011.

where: ρ_{NIR} e ρ_{RED} are the two-way surface reflectance factors for the near infrared (NIR) and red (RED) bands.

In each image, the values of quartiles, minimum, maximum, average and median were extracted to make the boxplot. Then, the dry (May - September) and rainy (October - April) periods were established, period in which was defined by the analysis of precipitation over the years 2007 to 2011. To represent each dry and rainy period it was calculated average values of the images contained in each dry and rainy intervals. From the images, median, minimum, mean and maximum values were determined for LANDSAT5/TM and MOD13Q1 images.

RESULTS AND DISCUSSION

With the data obtained, it was possible to analyze the temporal behavior of the NDVI index for the years 2007 to 2011, for each selected image, through MOD13Q1 and LANDSAT5/TM (Figure 3).

Table 1: Number of images obtained for the periods (dry and rainy), 2007 to 2011.

	2007		2008		2009		2010		2011	
Images	dry	rainy.	dry	rainy	dry	rainy	dry	rainy	dry	rainy
LANDSAT5/TM	6	3	3	3	5	3	3	3	4	3
MOD13Q1	8	6	5	6	8	6	6	7	6	8

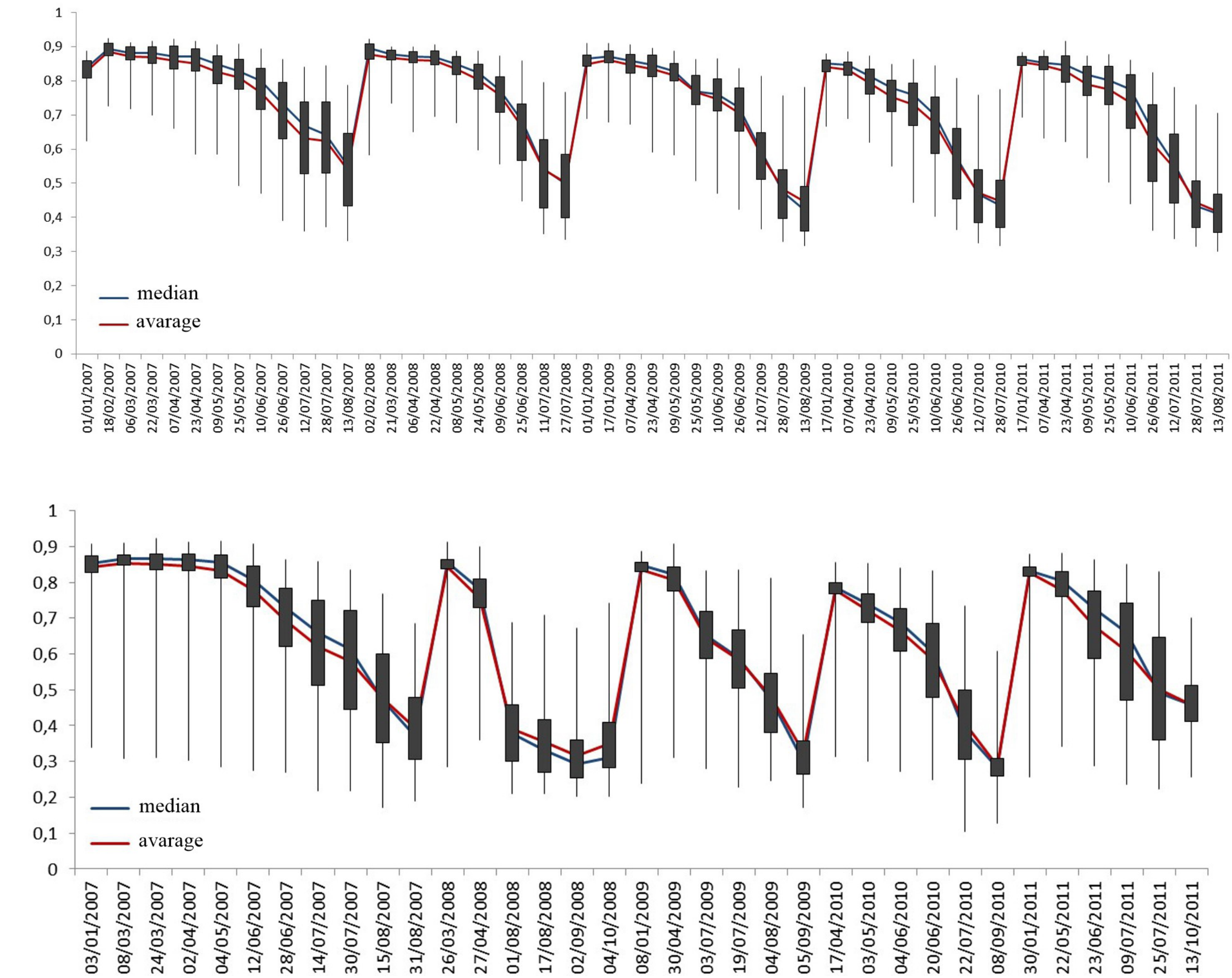

Figure 3: Boxplot of the temporal behavior of NDVI for MOD13Q1 and LANDSAT5/TM, in the years 2007, 2008, 2009, 2010 and 2011.

Note the evidence of two periods in both graphs, the first with higher NDVI index, during the months of October to April (rainy season) and the second period, with lower indices, referring to the months of May to September (dry season). This behavior can be proven from the analysis of the average annual precipitation of the municipality of Caceres, which shows a higher concentration of rainfall from October to April (Figure 4). Also, the frequency of occurrence shows that the rainiest month was January and that the period of greatest drought occurs between the months of May to September.

Neves, Nunes and Neves (2011). evaluating the characterization of the climatic conditions of Cáceres, between 1971 and 2009, found that the highest average temperatures occur in the humid period and the lowest in the dry, configuring the local climate in two seasons defined by the spatial and temporal distribution of rainfall. According to the authors, there is a variability of rainfall within the analyzed period, concluding that the rainfall in this region is higher in the months associated with the entry of greater solar radiation in the Southern Hemisphere, i.e. the action of mesoscale convective systems, in this case the South Atlantic Convergence Zone (SACZ), which causes convective rains in much of Brazil, also affecting this area.

For agricultural activities, temperature can be decisive to decide the type of crop to be adopted. The conditions of high luminosity associated with high temperatures, depending on the type of culture, influence the development cycle of the plant, and there may be a reduction of the cycle and anticipation of the reproductive phase, causing a decrease in production during certain times of the year (Neves, Nunes and Neves, 2011). This is the case of Teca, widely cultivated in the state of Mato Grosso, due to its favorable soil and climate conditions. Teca shows better growth in places with a well-defined dry season, rainfall between 1270 and 2540 mm, minimum temperature between 13° and 17°C and maximum between 39 and 43° C (Pandey and Brown, 2000; Krishnapillay, 2000).

As it is a deciduous species, there is a progressive loss of mass with increasing time and heating temperature (Hakkou et al., 2005;

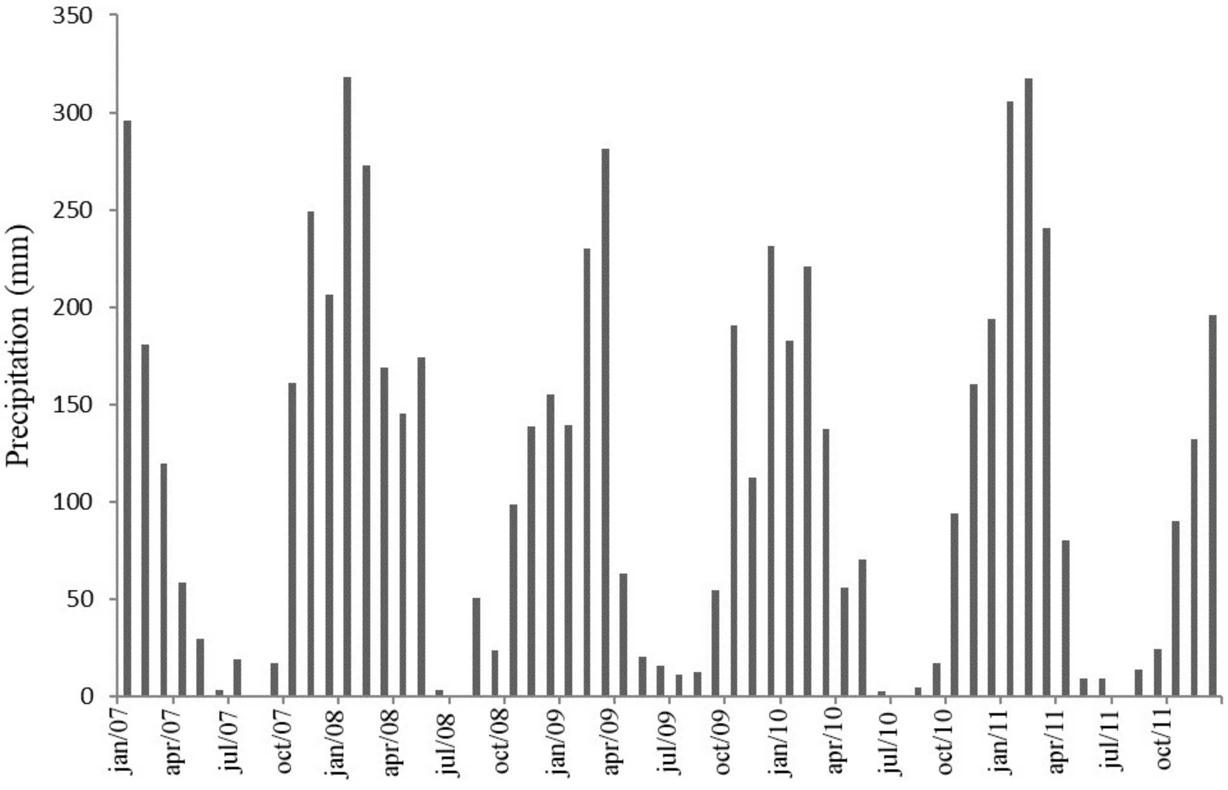

Figure 4: Average annual precipitation for the city of Cáceres/MT (2007-2011).

Garcia et al., 2012). In addition, factors such as the adoption of spacing between trees during planting, leaving the soil exposed during mass loss, coupled with thinning or the entry of trees in the stand, may have generated a greater variation in the vegetation index for this period. This explains the greater amplitude of the quartiles in the dry period, with NDVI averages ranging from 0.4 to 0.7, corresponding to the months of October to April.

On the other hand, the rainy season show quartile values approximate each other, with averages ranging from 0.8 to 0.9, which may be related to the swelling of the crop and the greater vegetation cover during this season. In its native habitat, Teca is a pioneer, with opposite, leathery leaves, rough to the touch, with short or absent petioles, with acute apex and base. Adult individuals have leaves that average 30 to 40 cm long and 25 cm wide. In younger individuals, up to three years old, the leaves can reach twice these dimensions, flowering is intense and begins about a month after the first rains, extending for more than 60 days (Vieira et al., 2002).

The intensity of the NDVI vegetation index changes that occurred during the study interval was indicated by a scale where values ranged from 0 to 1 (Figure 5).

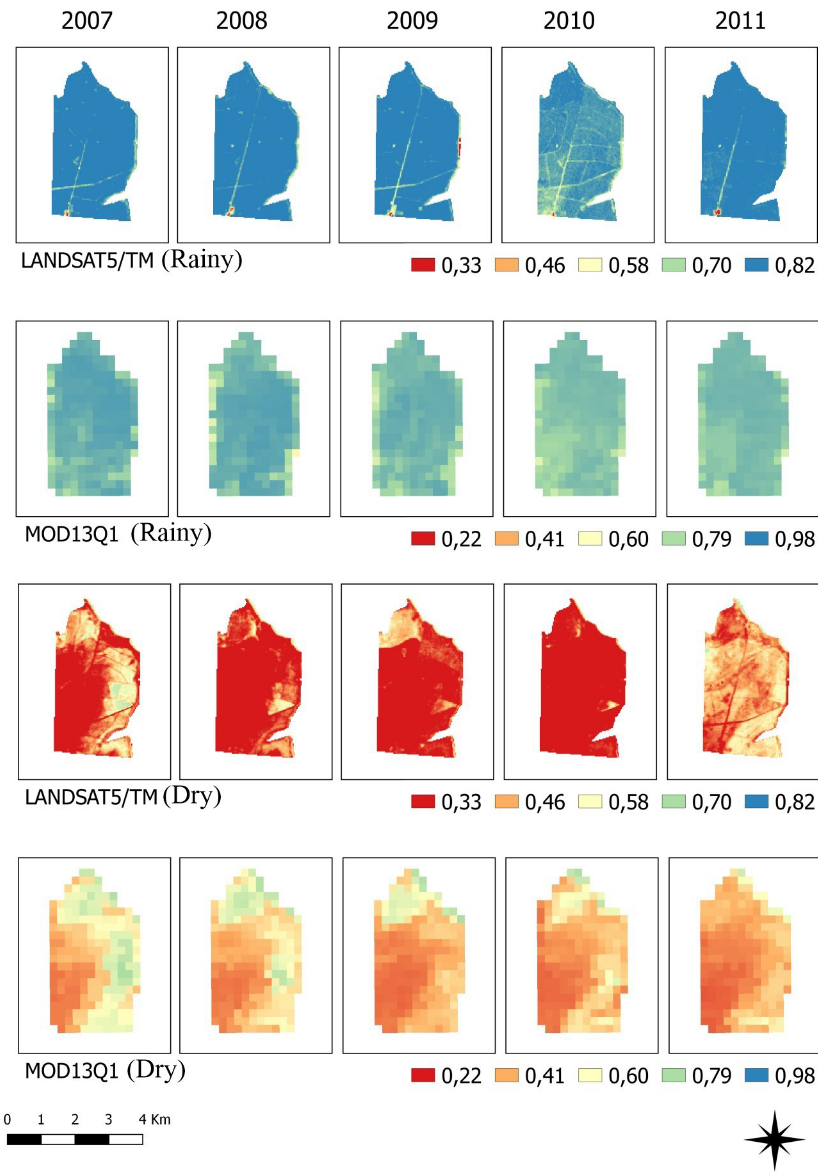

Figure 5: Mean NDVI space-time values in teak field monitored by LANDSAT5/TM and MOD13Q1 products, during dry and rainy seasons from 2007 to 2011.

During the rainy season, few variations of the vegetation index was observed, concentrating its lower amplitude, in dominance in the south and central region of the area, and greater amplitude in the north, with values ranging from 0.33 to 0.82 for LANDSAT5/TM and 0.22 to 0.98 for MOD13Q1. In 2007 and 2008, there was little variation in NDVI, with values close to each other. In 2009 there was selective thinning of 50% of the individuals, but it was the following year (2010), that the area suffered the greatest effect of thinning, showing a pattern different from the others, with a greater deficit in a band from the northeast to the southwest of the area.

In 2011, the site under study showed few variabilities, one noticed an almost uniform plantation increase represented by the predominantly blue color. Considering that this is a forest plantation, it can be stated that the plantation presented equity.

For the dry period, the year 2007 showed an index of 0.3 to 0.70, with higher indices in the eastern extremities of the area. The years 2008, 2009, and 2010 showed lower vegetation indices (0.33), the last two due to the thinning that the area sustained in 2009, noting the uniformity of the area represented by the predominantly red color. Thus, the NDVI proved to be susceptible to the interventions suffered by the plantation as selective thinning and pruning in the years 2010 and 2011, due to its greater sensitivity to the presence of chlorophyll and other pigments responsible for absorbing solar radiation in the red band.

It was possible to observe that there is an overall difference in the image when refined by LANDSAT5/TM and MOD13Q1, especially when compared to the minimum value of the area. This difference is related to the spatial resolution between LANDSAT5/TM and MOD13Q1. The 30-meter resolution pixel tends to cover an area where the target in question has little spectral mixing, and this condition is less likely to occur when a 250-meter resolution is used. In this case, the minimum value can be inserted in a region of higher concentration of exposed soil, such as the carriers that can only be seen in the LANDSAT5/TM images. The greater vegetation cover of teak with relatively high NDVI values throughout the area in the rainy season influenced the little difference between the images in maximum, average and median values (Figure 6).

The expectation of having a difference between LANDSAT and MOD13Q1 was expected due to the factors that refer to the composition of the

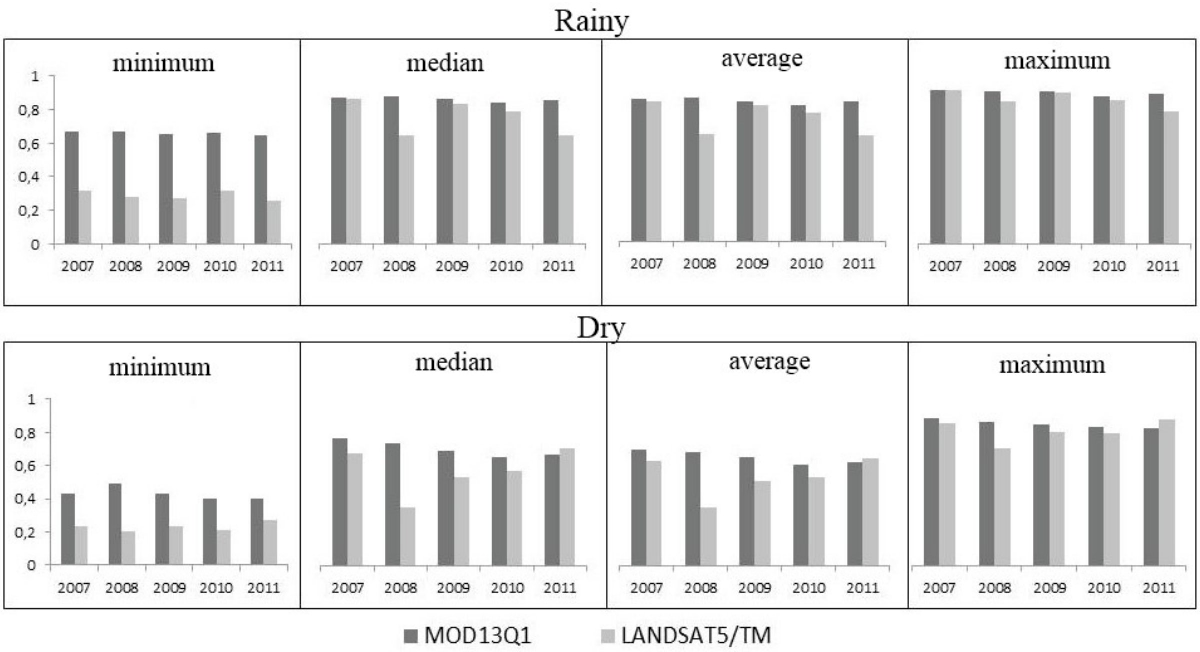

Figure 6: Period averages (dry and rainy) for LANDSAT5/TM and MOD13Q1, in the years 2007, 2008, 2009, 2010 and 2011.

images. Because the dates are not properly on the same day, there is assurance that the LANDSAT images are under full atmospheric interference, because their acquisition was made based on the QA values of MOD13Q1. It is important to note, that this product refers to a better quality pixel at the 16-day interval, i.e., there is greater reliability than the MOD13Q1 NDVI values in relation to the LANDSAT images.

When using different resolutions, one must take into consideration the classification and interpretation errors that can be made. An analysis with LANDSAT may be recommended since it may be able to individualize a target of a lower spectral mixture and thus monitor it. In this sense, it may indicate its use if the object under study refers to the location of a planting fault or even areas that need management due to low development. The MOD13Q1 images, however, are able to perform a general survey of the area and can indicate the harvest time and thus be used as a tool for crop management planning. The images from the Modis sensor on board the Terra satellite present low resolution, however, they provide high periodicity information on a global scale. Therefore, the use of this instrument to periodically map environmental attributes is increasing, with particular emphasis on the monitoring of vegetation cover (Rudorff, Shimabukuro and Ceballos, 2007; Liesenberg, Ponzoni and Galvão, 2007; Carvalho et al., 2008; Couto Junior et al., 2011).

Each sensor has different spatial resolution and variations in radiometric responses, and the environment also interferes in the detection results due to atmospheric absorption and scattering, amount of molecules dispersed in the atmosphere, presence of clouds and their shadows, variation in irradiance and solar angle, variations in plant phenology and soil components according to seasonal changes (Anderson et al., 2003). These facts demonstrate that the use of a particular sensor may have advantages for a specific application.

Rizzi and Rudorff (2007), through soybean sowing mapping, made a comparison between Modis/Terra and LANDSAT and concluded the classification performed using MODIS images, presented, in absolute terms, good results, but, relatively, was inferior to the result found with TM images. Still, according to the authors, there was no difference in quality in the crop identification evaluated between the two sensors.

Few studies compare MOD13Q1 and LANSAT5/TM imagery for land surface monitoring. One example is the study comparing LANDSAT imagery and MOD13Q1 imagery to estimate vegetation abundance, which revealed that these images generate compatible estimates (Price, 2003).

CONCLUSIONS

It was possible to monitor Teak temporal behavior, highlighting the existence of two well-defined periods (dry and rainy), with a progressive loss of mass during the dry season, due to low rainfall and increased temperature.

NDVI vegetation index presented values near to 0.33 in dry period, with highest values near 0.82 in the rainy period for LANDSAT5/TM. Considering MODIS monitoring, NDVI values ranged from 0.22 (dry period) to 0.98 (rainy period) using MOD13Q1 product data.

The different image values observed when measured by LANDSAT5/TM and MOD13Q1 are related to the sensors resolution variation.

Remote sensing can be useful to add spatial and spectral information related to teak reforestation monitoring. Vegetation indices variation can be appropriate tool for management and monitoring reforestation and native teak, detecting changes in vegetation cover quickly and free for the end user.

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