METHODOLOGY FOR SYSTEMATICAL MAPPING OF ANNUAL CROPS IN MATO GROSSO DO SUL STATE (BRAZIL)

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Abstract

This paper presents the preliminary results of a methodology developed for the systematic mapping of annual crops, potentially applicable to the entire country. There are many interests and demands for information referring to agricultural activity worldwide. The execution of yearly crop harvests and its relation to the definition of future markets, the measurement of environmental impacts and, the formulation of public policies for agribusiness, are only some examples of the activities which would benefit from the data generation of cultures in the field. Mapping and monitoring the potential of daily images and of vegetation index from MODIS sensor system, in spite of its limitations due to the spatial resolution of 250m, has not yet been fully explored. The objective of this work is to develop and test a methodological approach based on the spectral/temporal characteristics of an annual series of images from this sensor and to identify and map annual crops in the State Mato Grosso do Sul, produced with images of medium and high spatial resolution during the year 2007.

Key-words: Agricultural monitoring. MODIS. Vegetation index. Temporal series.

Resumo

Metodologia para o mapeamento sistemático da agricultura anual no Mato Grosso do Sul

Este artigo apresenta os resultados preliminares de uma metodologia desenvolvida para a sistematização do mapeamento da agricultura anual, potencialmente aplicável em todo o território nacional. São vários os interesses das demandas pela geração de informações referentes à dinâmica da atividade agrícola no mundo. Exemplos, tais como a promoção de estimativas anuais de safras e a sua relação com a definição de preços dos mercados futuros, a mensuração de impactos ambientais e a formulação de políticas públicas para o agronegócio, são apenas algumas das atividades interessadas na geração de dados sobre as culturas no campo. O potencial de mapeamento e monitoramento das imagens diárias do índice de vegetação do sensor MODIS, apesar das limitações enfrentadas pela resolução espacial de 250m, ainda não foi completamente explorado e este trabalho teve o objetivo de desenvolver e testar uma abordagem metodológica, baseada no comportamento espectro-temporal de uma série anual dessas imagens, para identificação e mapeamento da agricultura anual no estado do Mato Grosso do Sul. Os resultados gerados obtiveram uma concordância de 82,2% quando comparados com o mapa oficial de cobertura vegetal e uso da terra do estado do Mato Grosso do Sul, do ano de 2007, produzido com o emprego de imagens de média e alta resolução espacial.

Palavras-chave: Monitoramento agrícola. MODIS. Índice de vegetação. Séries temporais.

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INTRODUCTION

Monitoring the space-time dynamics of the Brazilian agriculture has become a strategic question for the country, because agribusiness corresponds to approximately 25% of the Brazilian GDP (CEPEA, 2010). Furthermore, the dynamics of agriculture both in space and time, greatly interferes in questions related to the composition of the national agricultural production, with direct and indirect impacts on the environment, to the social and human development and to the formulation and execution of public policies. Perceiving the strategic importance of all these questions for the development of the Brazilian agribusiness, several national institutions have been active, for almost two decades, in the development of remote sensing and geo-processing methods and techniques to promote systematic mapping and monitoring of the agricultural activity.

Although some developed and tested methodologies have had a significant success in the use of remote sensing data for the estimation of harvests in agriculture, there are still important challenges to overcome. These challenges involve mainly the production of estimations with a significant time and cost reduction. Moreover, the use of conventional classification techniques both digital and analogical, of medium and high resolution images, nearly makes a synchronous information flow during the phenological development of cultures in the field impracticable, (FONTANA et al., 2000).

Despite the results published by Victoria et al. (2009) pointing to problems for mapping different physiognomies of Savanna adopting a procedure based on a Fourier analysis, the most potentially promising technological and methodological possibilities have been presented with the statistical analysis of time-series from vegetation index images. They are an alternative for the execution of systematic identification, mapping and monitoring of the phenologic development of the Brazilian vegetation, producing results with good precision and especially with a significant operational cost reduction, when compared to conventional techniques (FAO, 1998; BROWN et al., 2007, 2013; COUTINHO et al., 2011). This alternative allows the execution of systematic analysis, compatible with the regional and national scales and adequate for monitoring the dynamics of agriculture and specific demands of the national and international market.

The study from Victoria et al. (2012), whose estimation of planted area was executed by a statistical analysis of a vegetation index time-series, demonstrated that it is possible to detect seasonal variations related to phenology and to vegetation management, obtaining a high correlation, of the total planted area mapped, with official data published by IBGE (Brazilian Institute for Geography and Statistics), for the municipal base of Mato Grosso State.

Kastens et al. (2013), testing the performance of a statistical approach on the time-series of vegetation indices, to map specific cultures and their interactions with the main and the secondary harvest of Mato Grosso State, obtained very promising results with an algorithm based on the decision tree structure. In this work, the authors produced maps of some specific cultures and associations of cultures such as soybeans/fallow, cotton/fallow, soybean/maize, soybean/cotton and pasture, for the production of agricultural harvests from 2005 to 2009.

Seeking for new methodological advancements and for a further increase in the consistency and reliability of mapping from the agricultural activities in the Brazilian territory, the objective of this work is to develop and test the performance of a new methodology for the identification, mapping and systematical monitoring of the annual crop activity, based on the use of vegetation index images derived from MODIS (Moderate Resolution Imaging Spectroradiometer).

MATERIAL AND METHODS

The methodology proposed for the generation of maps from agricultural areas is based on the use of orbital remote sensing images, with high temporal resolution. Such methodology presents an analysis approach, gathering spectral and temporal characteristics once the detection considers the spectral behavior of cultures during their productive cycles, or during part of them. This new approach is different from conventional procedures for mapping land use/land cover, because it is not based on information obtained from the ground during just one date take, in just one moment of the phenologic development of cultures in the field.

The spectral-temporal approach has been appointed by various specialist groups as the most appropriate to monitor and map cultures (JÖNSSON; EKLUNGH, 2002; JAKUBAUSKAS et al., 2002; LU; WENG, 2007, WARDLOW et al., 2007; KASTENS et al., 2013).We are not considering several images with sequential dates independently, but are interpreting and characterizing the behavior of pixels along a time-series, emphasizing their spectral variations. Thereby, besides minimizing problems related to the cloud occurrence and to variations of atmospheric quality, it is possible to identify the dynamics of vegetation in specific temporal scales, including the characterization of phenologic cycles to follow questions related to plant sanity and variations of these cycles during several years, and to characterize, e.g., the dynamic of transitions between different land cover/land use types (BRADLEY et al., 2008).

In this study, the spectral variable adopted was the NDVI (Normalized Vegetation Difference Index). This index was proposed by Rouse et al, (1973) and it is the most frequently adopted for the characterization of vegetation, being used as a semi-quantitative measure of density and vegetative vigor. Several studies have testified its high correlation with the phytomass (JUSTICE; HIERNAUX, 1986) and the leaf area index (HOLBEN et al., 1980; PRICE, 1993). It is also one of the most recommended indices to promote agricultural monitoring.

The NDVI was obtained from maximum compositions of 16 days, generated from daily MODIS images, whose spatial resolution is 250 m. The original products are delivered free of charge from the Land Processes Distributed Active Archive Center, a NASA database. The product MOD13Q1, referring to vegetation indices, is also available at EMBRAPA Agricultural Informatics, for each Brazilian State in the most usual cartographic projections (ESQUERDO et al, 2011).

Different portions of the Earth surface, corresponding to pixels from MODIS images, present distinct spectral-temporal profiles (Figure 1), determined by factors such as the presence or absence of vegetation cover, volume, quality and phenologic development of phytomass, climatic seasonality, among others.

As for agricultural plantations, there is a typical temporal behavior of vegetation indices, which are low at the beginning of the cycle when the quantity of phytomass is scarce and the spectral response is influenced fundamentally by the soil. As the culture develops and the phytomass production increases, the vegetation indices respond positively with higher values, until they reach the vegetative peak. With the beginning senescence and harvest at annual crops, the values of the indices decrease, until they reach levels found at the beginning of the cultivation.

Due to the availability of a digital map of land use/land cover from Mato Grosso do Sul State for the year 2007 (SILVA et al., 2011), the methodology for the classification of annual crops proposed in this study, considered the variation of amplitude obtained by the difference between maximum and minimum NDVI values, obtained along the productive cycle from harvest 2006/2007 and therefore the behavior of values situated between the months of September 2006 and October 2007 (Figure 2) was evaluated.

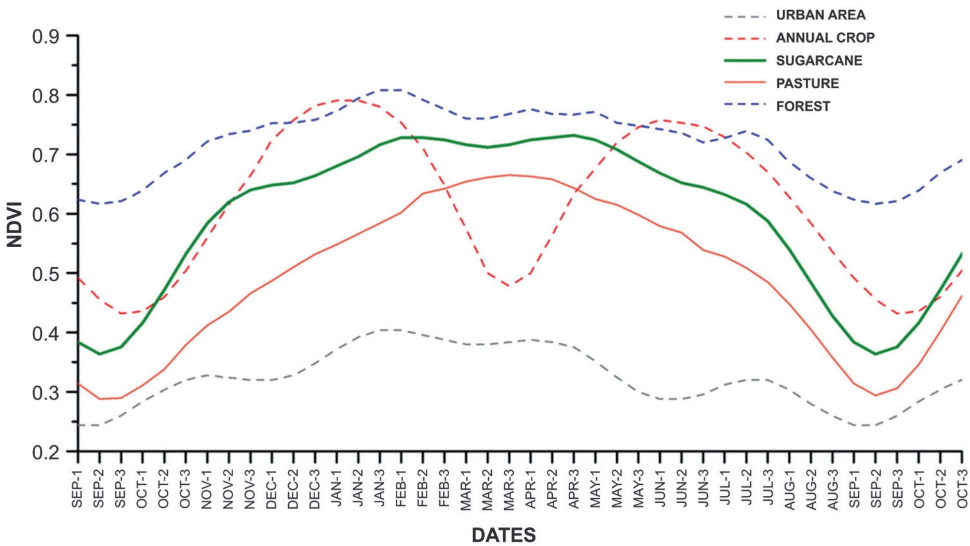

Figure 1 – Spectral-temporal profiles of the vegetation index from different targets

Source: Fernandes (2009).

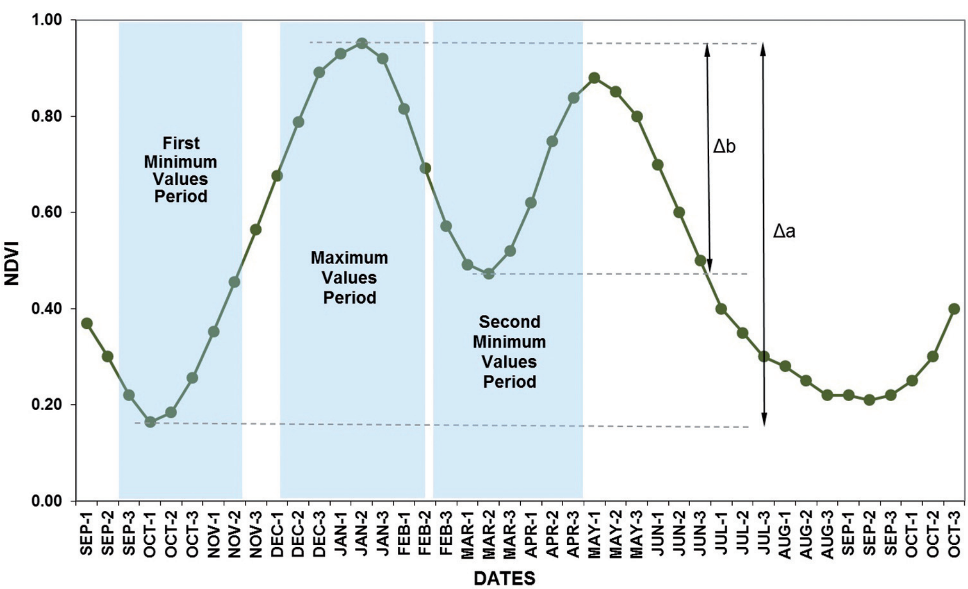

Figure 2 – Example of NDVI profile of a pixel with annual cultivation and two cycles of production, showing the differences (Δa and Δb) between the maximum and minimum values considered to classify this activity in MODIS images

In order to obtain these values, graphs from the temporal profiles of the vegetation index were generated, based on annual crops mapped by Silva et al., (2011), to describe the temporal behavior of phytomass during the productive cycle and to conduct analysis and preliminary inferences related to different phenologic phases of vegetation in each one of them. From the spectral variations described in these graphs, the best periods to obtain the maximum and minimum values of vegetation indices were determined, to calculate their differences.

Figure 1, shows that the greatest problem to promote the discrimination among classes, considering only the differences among maximum and minimum values of the vegetative cycle, was the discrimination between annual crop, pasture and sugar cane classes.

Although these three thematic classes present significant similar difference values between the maximum and minimum for the entire period analyzed, it was possible to identify and separate them through the delimitation of specific periods when these values were obtained (Figure 2).

Thereby the compositions between September and November were considered for the determination of minimum values-1, period foreseen for the implementation of annual crops in the field; February and April for the determination of minimum values-2, period foreseen for the harvest of the annual summer crops and the compositions between December and February for the determination of maximum values, period of apex occurrence of the phenologic development of cultures in the field.

The main objective for the inclusion of two minimum values in the analysis of the time-series (minimum-1 and minimum-2) was to improve the discrimination of sugar cane and pasture classes from the thematic class annual crop, since the time of phenologic development of these two cultures is longer than the period delimitated by the occurrence of the two minima required (Figures 1 and 2). In this protocol, the values of thresholds Δa and Δb, defined to promote the identification of annual crops were 0.50 and 0.45 respectively.

Evidently the periods of maximum and minimum values vary annually in each region, depending on changes in climatic seasonality, types of cultivars, etc., demanding a previous and detailed analysis of sample areas in several points of the region under study. The entire process for the generation of a mask from the annual crop was executed from routines developed on IDL (Interactive Data Language).

Finally, for the validation of results obtained, the official map of land use/land cover from Mato Grosso do Sul State, referring to the year 2007 (SILVA et al., 2011) was used. In this document, the classification discriminated the annual crop thematic classes, semi-perennial agriculture (sugar cane) and cattle raising (planted pasture). On the total area of annual crop, corresponding to the 11,626 polygons defined by the union of the annual crop map generated, and from the thematic class compiled from the official map of the State (Silva et al., 2011), 360 points were distributed randomly, to perform a validation with a confidence level of 95% and an interval of 5%.

At each one of the 360 points selected, an agreement was observed between the annual crop class in the mask generated and the official land use/land cover map. In cases of disagreement between both maps, NDVI profiles were made, obtained during the productive cycle from the harvest 2006/2007 and also from CBERS-2B/CCD images acquired during the same period analyzed, to classify the mistake. This protocol was used to calculate the similarity frequencies of mappings, as well as to estimate omission and inclusion errors.

RESULTS AND DISCUSSIONS

The result of the validation process from the random raffle of 360 points was the confirmation of the annual crop class in 296 (82.2%) of them. Besides that, omission errors were found in 34 points (9.4%) where the methodology adopted was unable to identify the presence of annual crop, visually confirmed by NDVI curves and by satellite images with a higher spatial resolution. Inclusion errors occurred at 30 (9.4%) other points, where the classification of annual crop was not confirmed either by MODIS images, or by the land use/ land cover map and or by satellite images with higher spatial resolution, considered in the validation protocol.

The omission errors were especially observed in polygons with smaller dimensions, where the pixel contamination produced by different land use/land cover of adjacent areas, caused a mixture of spectral values and consequently a de-characterization of the typical spectral-temporal behavior of the annual crop. This has been the biggest problem when mapping land use/land cover with vegetation index images from MODIS, especially in regions where the agrarian structure and the pattern of spatial partition of the agricultural activities, defined a very heterogeneous and sub-divided occupation mosaic.

Figure 3 illustrates another component of the problem associated to the spatial resolution of MODIS images, which is the polygon delimitation of annual crop, where this activity was correctly detected. It is possible to observe, again, an incompatible generalization with the execution of approaches in more detailed scales than 1:250,000.

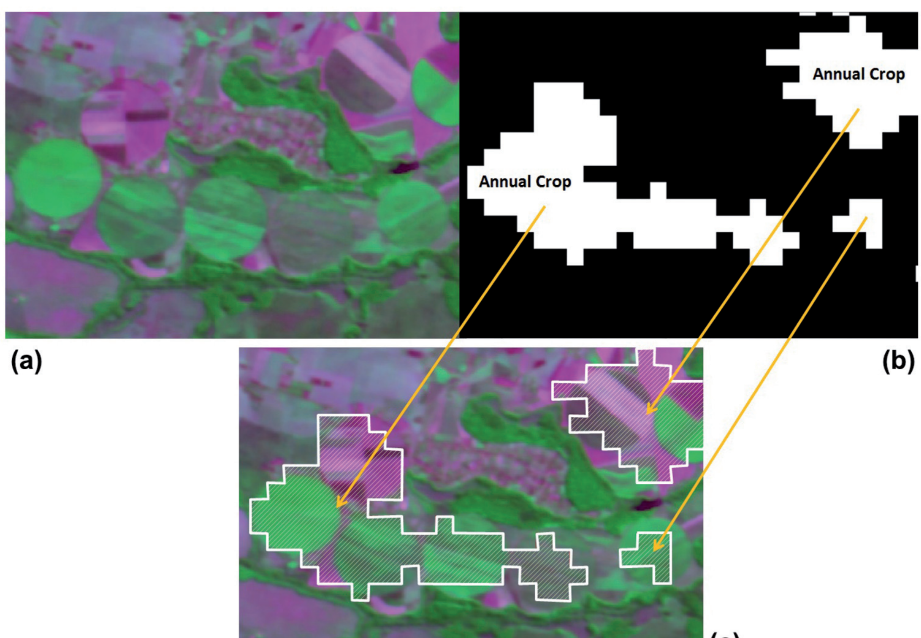

Figure 3 – CBERS image showing some types of land use/land cover (a); mask of agriculture generated with MODIS images (b); superposition of the mask on CBERS image which allowed the execution of validation (c)

Figure 4 presents the map of annual crop in the Mato Grosso do Sul State, obtained by the proposed methodology, where it can be observed that this activity is concentrated on four regions of the State. The largest one is located in the micro-region Dourados, in the Central-Southern part of the State, predominantly in the area inserted in the basin of Paraná River. In the central region of the State, the agriculture is concentrated around the municipality of São Gabriel d'Oeste on the Paraguai River basin. To the north, the agricultural activity is concentrated on the municipalities of Sonora (to the West) and Chapadão do Sul (to the East).

Considering the borders of the main river basins from Mato Grosso do Sul State, the relative frequency of annual crop occurrence in the region, delimited by the Alto Paraguai River basin was of approximately 20%, and less than 1% for the area of Pantanal floodplain, while on the Paraná river basin it was of 80%, as shown in figure 4.

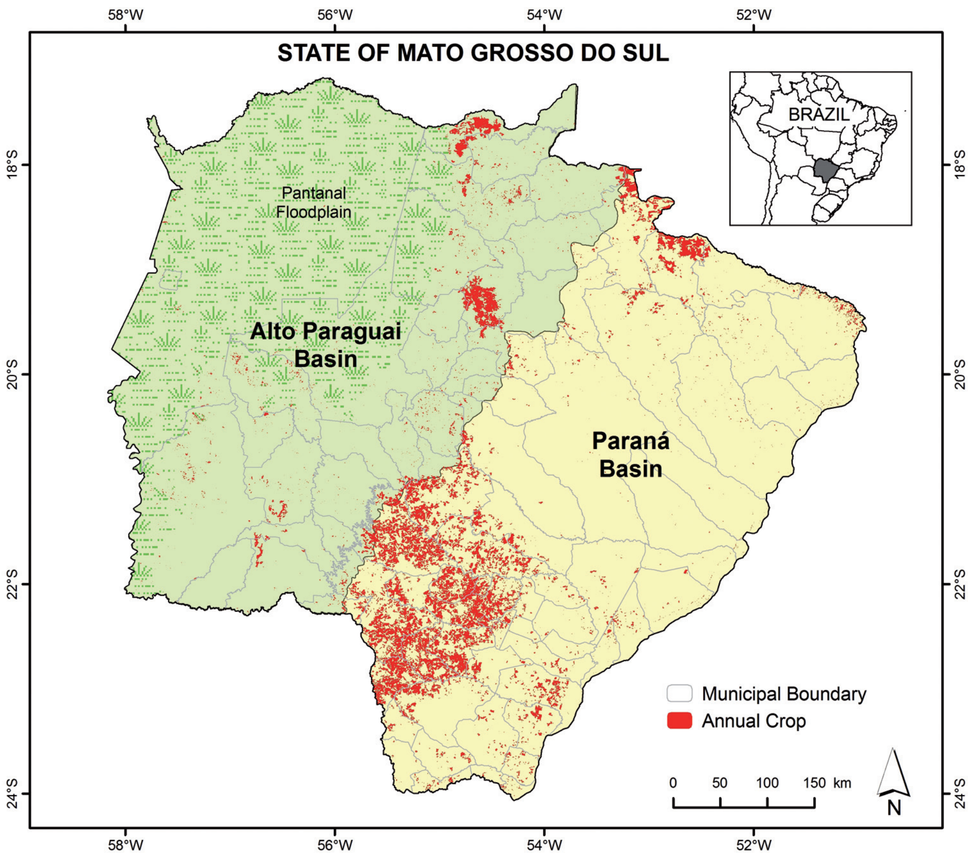

Figure 4 – Map of MatoGrosso do Sul State, showing the spatial distribution of the area used for annual agriculture for the production 2006/2007 harvest

In spite of the limitation from the spatial resolution, shown in figure 3, the numeric results obtained by the validation and a more contextual evaluation, suggest that the method of mapping the annual crops, based on vegetation indexes of MODIS images, presents some important advantages for its execution in large extensions of the Brazilian territory, such as reduction of data volume, costs, and processing time. This applies especially when one compares the methodology used with the conventional methods, based on high spatial resolution images. Furthermore, for State or National approaches (Figure 4), the spatial resolution of MODIS images is compatible with the cartographic scale required.

The possibility to execute systematic mapping for the detection of tendencies and the execution of models from the spatial dynamics of annual crops, offers new perspectives to support the operation of private institutions and governmental agencies related to agriculture and agribusiness, especially in questions related to monitoring and formulating public policies and market variables.

CONCLUSIONS AND SUGGESTIONS

In spite of limitations imposed by the spatial resolution of 250m of MODIS images, it has great potential although not fully exploited, to systematically map and monitor activities of land use/land cover of large territorial extensions.

The varied heterogeneity of territorial expression from the Brazilian agriculture, associated to its accelerated dynamics, both in space and time, are good examples for the development and testing of new methodological approaches and tools for the analysis of spatially explicit objects.

Requiring comparatively modest financial and operational resources, especially if one considers conventional methods for the analysis of medium to high spatial resolution satellite images, the methodology developed and tested, presents a promising performance, especially for the development of analysis in regional and national scales.

In spite of recent methodological advancements obtained with the execution and validation of protocols based on time-series of vegetation index images obtained from MODIS data, there are still challenges to overcome, especially those related to the noise suppression or interferences in the historical series and to the spatial image resolution.

In this discussion among the potentials and limitations on the use of temporal series of vegetation indices derived from MODIS data to map the national agriculture, some important challenges are related to the discrimination, delimitation, systematic mapping and monitoring of the main cultures in the entire country.

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