MAPPING LAND USE AND LAND COVER CHANGE OF A SUGAR CANE EXPANSION AREA APPLYING OBJECT-BASED IMAGE ANALYSIS IN TM AND MODIS-EVI2 DATA

Mapeamento de mudanças de uso e cobertura da terra em area de expansão de cana-de-açúcar por meio de análise baseada em objetos em dados TM e EVI2-MODIS

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ABSTRACT

Land use/cover change (LUCC) is a cross-disciplinary research field in which remote sensing and geographic information systems (GIS) techniques have played an important role. Sugar cane expansion is one of the most important LUCC processes in Brazil, which has been monitored since the early 2000 within the framework of INPE's CANASAT project (http://www.dsr.inpe.br/canasat/). In this study, a methodology to detect land use/cover changes in a region of sugar cane expansion was proposed. It is based on integrating CANASAT sugar-cane maps, agricultural statistics, Landsat TM, MODIS EVI2 time series, pixel-based, and object-based image analysis (OBIA).This method was applied to an area of important sugar cane expansion in the 2003-2009 period – the São Paulo State, municipality of Barretos - to assess which land use/cover classes were converted to sugar cane plantations. Classification results obtained with both algorithms were evaluated indicating better results from the object-based approach. In any event, both algorithms showed that at least 40% of the sugar-cane expansion occurred in areas occupied by pastures at the beginning of the study period.

Keywords: land use/cover change; TM data; EVI2-MODIS; sugar cane; object-based image analysis.

RESUMO

O estudo das mudanças de cobertura e uso da terra é uma área de pesquisa multidisciplinar na qual o sensoriamento remoto e os sistemas de informação geográfica (SIG) têm uma relevante importância. A expansão da cultura da cana-de-açúcar é um dos mais importantes processos de mudança de uso e cobertura da terra que vem ocorrendo no Brasil e vem sendo monitorado, desde o início dos anos 2000, por meio de um projeto denominado CANASAT desenvolvido pelo INPE (http://www.dsr.inpe.br/canasat/). No presente trabalho foi proposta uma metodologia para identificar as mudanças de uso e cobertura da terra em áreas de expansão de cana-de-açúcar. Ela se baseia na integração dos mapas temáticos do projeto CANASAT, estatísticas agrícolas, imagens TM-Landsat e as séries temporais de EVI2-MODIS por meio de abordagens baseada em pixel e análise orientada a objetos (OBIA). A metodologia foi aplicada em uma área do Estado de São Paulo onde de grande importância para a expansão da cana-de-açúcar no período de 2003 a 2009, o município de Barretos, a fim de verificar quais foram os tipos de uso e cobertura da terra substituídos pela cana-de-açúcar. Os resultados obtidos nas classificações das imagens por meio de ambas as abordagens foram avaliados estatisticamente e indicaram maior acurácia para a abordagem por OBIA. Os resultados dos dois algoritmos indicaram que, no mínimo em 40% da área de estudo, a cana-de-açúcar substituiu áreas de pastagem neste período.

Palavras chaves: mudanças de uso e cobertura da terra, dados TM, EVI2-MODIS, cana-de-açúcar, análise baseada em objetos.

1. INTRODUCTION

Land use/cover change (LUCC) is an important research area in several fields, including forestry, water resources, urban-rural interface, and environmental impact studies. LUCC can have impacts at the local, regional and global scales, affecting the hydrologic and biogeochemical cycles, and biological diversity, and contributing to emissions of greenhouse gases (TURNER; MEYER, 1994).

Changes in land cover/land use can have a variety of origins. The present study focuses on the expansion of sugar cane plantations, one of the most important LUCC processes in Brazil in the last decades, due, in particular, to significant increases in ethanol production for automobile use (FISCHER et al. 2008).

In Brazil, sugar cane production is concentrated in the State of São Paulo, which surpassed 50% of the entire national production in 2007 (IBGE, 2007), Sugar-cane expansion has been reported to have several environmental and socio-economic effects, including the conversion of areas used for food production (Camargo et al., 2008; Novaes et al. 2011, Olivette et al., 2011; Olivette et al., 2010; Olivette e Camargo, 2009)

The importance of sugar cane expansion has motivated a number of studies and research initiatives (MELLO et al., 2013; ADAMI et al., 2012; VIEIRA et al., 2012; ADAMI et al., 2012), including the CANASAT monitoring program based at the Brazilian National Institute for Space Research (INPE) (http://www.dsr.inpe.br/canasat/). CANASAT monitoring has used Landsat TM, CBERS, MODIS and ResourceSat-I data, starting from 2003. The program results show that the area of sugar cane harvest in South-Central Brazil represented more than 6.5 million hectares in 2008/2009, increasing 15.7% in comparison to the preceding harvest. In 2008/2009, 4.45 million ha were observed in São Paulo State, corresponding to 66% of the total sugar cane area (UNICA, 2009).

The present study proposes a methodology aimed at discriminating the major land use/cover classes which are converted into areas of sugar cane production, testing it in the municipio of Barretos, an important area of sugar cane expansion.

The methodology uses CANASAT sugar-cane maps, agricultural statistics, Landsat TM and EVI2-MODIS images and EVI2 time series and two classification approaches: pixel-based classification and object-based image analysis (OBIA).

2. STUDY AREA

The study area corresponds to the municipio of Barretos which is located in northern São Paulo State (Figure 1), presenting an area of 1,565 km2 and a population of 112,102 inhabitants in 2000.

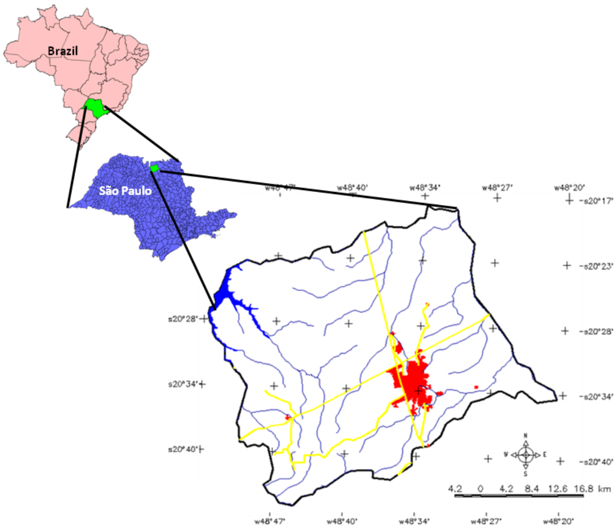

Fig. 1 – Localization of the Barretos municipality.

The original vegetation in the region was dominated by Cerrado (Savanna) including some patches of the Brazilian Atlantic Forest. At the end of the 20th century, most of the native vegetation had been converted into agricultural land and the area had been mostly used for livestock production, resulting in silting of rivers and soil erosion, and possible impacting biodiversity (IBGE, 2004).

According to data from the last Agricultural Census (IBGE, 2006), sugar cane culture was the predominant land use in Barretos representing 44% of its area, followed by orange and soybean plantations (respectively 32% and 7%), and pastures (6%). The importance of sugar cane may be illustrated by six large ethanol plants installed in the region (IBGE, 2006). Barretos also belongs to a region which presented one of highest rates of sugar cane expansion according to data from the Cadastral Survey of Agro-Livestock Production Units – LUPA (São Paulo, 1997 & São Paulo, 2008).

3. MATERIAL AND METHODS

3.1 Material

Due to the availability of data from Project CANASAT since 2003 and of high spatial resolution Google Earth images, LANDSAT-TM scenes of this period were used in this study. Three datasets were selected from 2003, (March 4th, June 16th and August 19th) aiming to detect bare soil which did not correspond to phases of growth from temporary cultures.

Maps from Project CANASAT; temporal series of EVI2-MODIS products and monthly accumulated rainfall data which uses the product 3B43 V6 of TRMM (Tropical Rainfall Measuring Mission), obtained from the Remote Sensing Laboratory Applied to Agriculture and Forestry at INPE- LAF (https://www.dsr.inpe.br/laf/series/index.html), were also used.

One of the best known vegetation indices used in this study is the Normalized Difference Vegetation Index (NDVI), calculated from the ratio among images of red and infrared bands and the sum of these bands. Another vegetation index used in this study is the Enhanced Vegetation Index 2 (EVI2) (Equation 1) which allows to highlight variations of land use/cover. For its calculation MOD13 from MODIS, collection 005 is used (spatial resolution of 250 m and temporal resolution of 16 days) available at NASA's site (https://wist.echo.nasa.gov/api/).

$$\boldsymbol{EVI2} = \frac{\boldsymbol{2,5 \times NIR - Red}}{\boldsymbol{NIR + 2,4 \times Red + 1}} \quad (1)$$

Freitas et al. (2011) developed a tool which allows to visualize MODIS temporal series of the entire South America. Here we can observe the variation of EVI2 in a temporal series since 2000 for each MODIS pixel, selected and localized by the user at Google Earth mosaic. The EVI2 index aggregates information to NDVI due to its frequency of 16 days, but it lacks the spatial information.

After observations of EVI2 values at the temporal series, one observes the importance of the spatial representation of this information in a GIS. In this context, the maximum annual EVI2 values of MODIS were spatially represented in a matrix, generating an image, used for classification at the DEFINIENS software. Although the difference of pixel size of this EVI2 image (250 m) compared to Landsat-TM images is significant, it was very important for the classification task.

The classifications were carried out using SPRING 5.1.7 and Definiens 7 softwares.

3.2 Methodology

The three 2003 Landsat-TM images, corresponding to the first year of CANASAT monitoring, were used to determine original types of land cover/land use, which were then used to establish where the expansion of sugar cane occurred during the 2003-2009 period of study.

TM image classification included two methods: automatic supervised pixel-based classification using the SPRING software (Câmara, 1996), and the OBIA classification available in the Definiens software (Definiens, 2005 and 2006).

Regarding the pixel-based classification technique, in this work we chose to use the system supervised classification from segmented images. In the segmentation parameters were used 10 for the similarity and 30 to the area defined by empirical methods which are based on knowledge of the interpreter, the pixel size of the images, the size of the targets to be identified and the objectives of classification. The parameter *area* defines the smallest region, in pixels, to be bounded in the segmentation process. The parameter *similarity* is based on the Euclidean distance between the mean gray level of each region, thus two regions are considered distinct if the distance between their average is higher than the similarity threshold chosen (CAMARA et al., 1996). The classification algorithm used was Bhattacharyya, with a limier of acceptation of 99%.

OBIA classification required more steps than the supervised classification, including, in particular, two levels of segmentation (Figure 2), and the possibility to consider more information in the procedure of image classification, like texture, form and context parameters. So in the use of the object-based image analysis, the interpreter must transfer his/her knowledge to the software, modeling the hierarchical network, attempting to error reduction and an increase of classification precision.

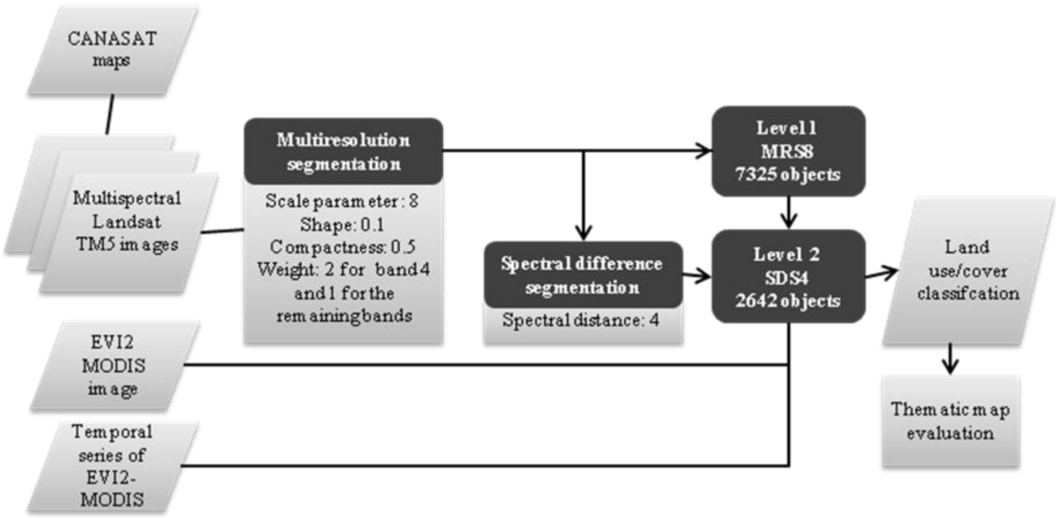

Fig. 2. Flowchart of OBIA classification, showing the Multiresolution and Spectral Difference segmentation levels.

Training samples of the Pasture, Temporary crops, Perennial crops and Forest classes were defined using data collected on previous work (Alves et al, 2009 and 2010). Intra-annual EVI2 variability was also instrumental to track land cover changes, and was based on the tool developed by Freitas et al (2011).

The decision rules for the classification of the 2003 thematic map were defined by tracking image changes in of March, June and August TM acquisitions which were differentiated bare soil, vegetation smooth bright; vegetation smooth non-glossy, vegetation rough bright, and vegetation rough not-bright. Observed texture characteristics distinguished the smooth and rough classes, and brightness characteristics corresponded to high TM4 values. Table 1 shows the land use/cover class combinations and the sequences defined in each Landsat image.

TABLE 1 - LAND COVER CLASSES SEQUENCE AND LAND USE CLASSES ACCORDING DEFINED IN MULTI-TEMPORAL LANDSAT TM-2003

images of 2003							Thematic Classes
March			June		August		
BS	BS		BS		BS		Perennial crop1
BS	BS		V				Temporary crop 1
VEGETATION	V	B	V	B			Temporary crop 2
VEGETATION	V	B	V	NB			Pasture 1
VEGETATION	V	B	BS				Temporary crop 3
VEGETATION	V	NB	V	B			Temporary crop 4
VEGETATION	V	NB	BS				Pasture 2
VEGETATION	V	NB	V	NB	V		Perennial crop 2
VEGETATION	V	NB	V	NB	BS		Pasture 3

BS	Bare Soil
V	Vegetation
B	bright
NB	Not-bright
(blank)	Not analyzed

The internal differentiation of each group of thematic classes of land use shown in Table 1, such as between one or two temporary cultures, was considered only in regard to differentiation in processes of substitution on the land cover during one year. This was not aim to establish or grouping similar cultivars in the same classes.

After the identification of the land cover change processes, a hierarchical network was defined in Definiens (Figure 3).

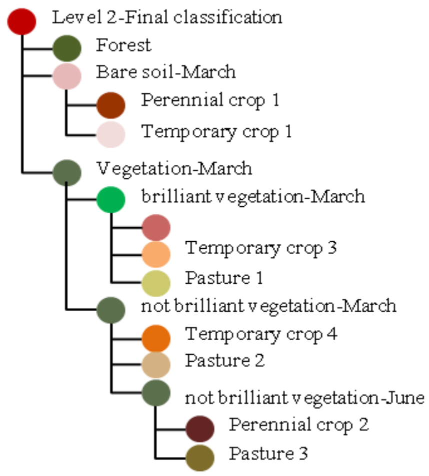

Fig. 3 – Hierarchical network classification used in Definiens for TM-Landsat image classification.

Following this procedure, samples and values of its attributes were selected, and its functions and thresholds defined. The number of samples and respective areas, as well as the attributes used for land use/cover classification of 2003 were clustered and presented in Table 2.

TABLE 2 - NUMBER OF SAMPLES AND RESPECTIVE AREAS, AND ATTRIBUTES USED FOR LAND USE/COVER CLASSIFICATION OF 2003

Thematic classes	Number of samples	Area (ha)	Area (%)	Attributes	Type of attribute
Forest	8	89.1	0.2	NDVI´s variance	spectral
				maximum annual EVI2	spectral
Perennial crops (1 and 2)	71	888.48	2.04	not brilliant vegetation- March	relational
				NDVI´s variance	spectral
				Band 4 average-June	spectral
				NDVI March and August	spectral
Temporary crops (1, 2, 3 and 4)	118	1517.49	3.49	NDVI March and June	relational
				maximum annual EVI2	spectral
				not brilliant vegetation-March	relational
				Band 4 average-March	spectral
				Band 4 average-June	spectral
Pasture (1, 2 and 3)	512	6538.14	15.01	NDVI March, June and August	spectral
				NDVI´s variance	spectral
				Band 4 average-March	spectral
				Band 4 average-June	spectral
				not brilliant vegetation- March	relational
				Not-perennial crop 2	relational
TOTAL	**709**	**9033.21**	**20.73**		

A land use/cover map for the year of 2003 was produced based on Landsat Thematic Mapper (TM) images, maximum annual EVI2-MODIS values and time series of EVI2. High spatial resolution images, available at Google Earth were also used.

Classification accuracy was assessed based on random sampling points verified in the reference map. The Kappa coefficients of agreement were estimated for both thematic maps, obtained by two different methods. The z test was performed to compare them statistically.

The reference thematic map was carried out using the temporal series of EVI2-MODIS products from land use/land cover of known sites. From Landsat images classification using traditional methods one usually verify the confusion between pasture and temporary crop classes. In this study these classes were separated using the form, amplitude and the maximum and minimum value of EV12 curves.

In Figures 4 and 5 two typical examples of the pasture and temporary crops curves can be observed on 2003 EVI2-MODIS multitemporal data. These figures present also examples of pasture and temporary crops represented on Landsat images.

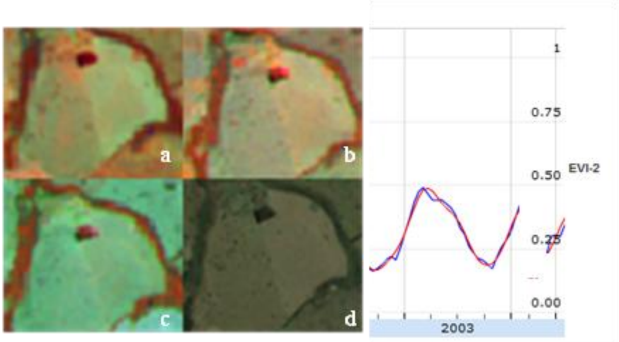

Fig. 4 – Pasture: Landsat images (March (a), June (b) and August (c)) and QuickBird image (d) and time series curves of EVI2-MODIS. (Freitas et al., 2011)

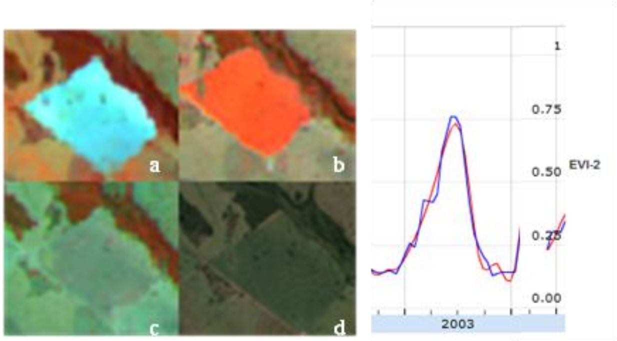

Fig. 5 – Temporary crops: Landsat images (March (a), June (b) and August (c)) and QuickBird image (d) and time series curves of EVI2-MODIS. (Freitas et al.,2011)

The analysis of the sampling points used to obtain the reference map show that the pasture curve has an amplitude value (minimum of 0.17 and maximum of 0.60) inferior than the temporary crops curves. In fact, temporary crops curves can present one or two curves peaks, corresponding to one or two crops in the area, and showed larger amplitude values (minimum between 0.08 and 0.10 and maximum between 0.70 and 0.90).

4. RESULTS AND DISCUSSION

Two 2003 land use/cover maps were produced for the Barretos municipality, considering those areas of sugar cane expansion until 2009. The first map was obtained by a supervised classification using the Bhattacharya algorithm in software SPRING, and the second one was obtained by OBIA classification at Definiens (Figure 6).

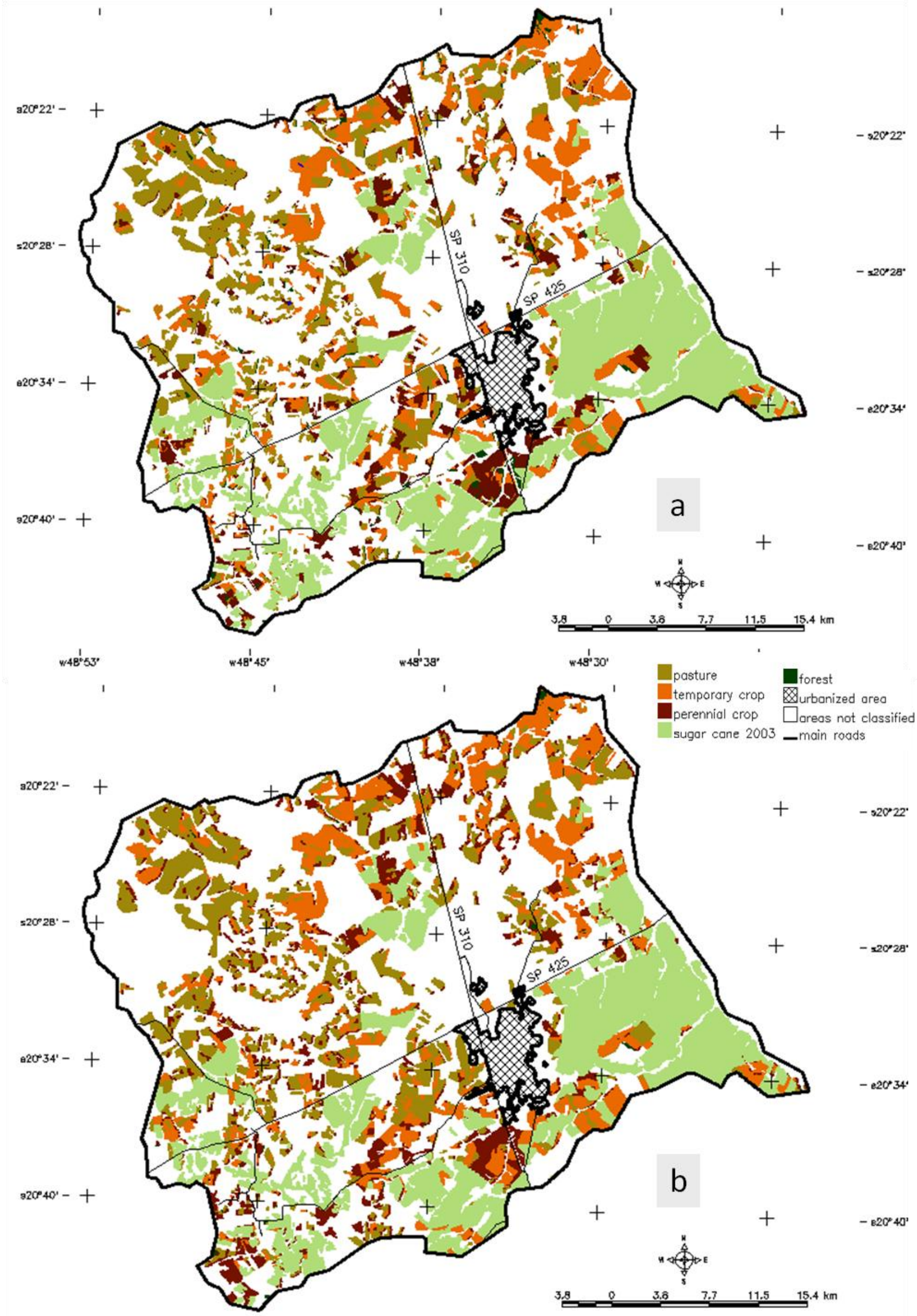

Fig. 6 – Land use/cover map of 2003 obtained by supervised classification/SPRING (a) and by object-based image analysis/DEFINIENS (b).

Both LUCC thematic maps show a concentration of large pasture areas in the western and central-western section and temporary cultures in the central-western and eastern ones. Result produced by the OBIA classification (nine land use/land cover classes) show a higher degree of detail when compared to the traditional supervised classification method (four land use/land cover classes). Because of that, similar land use/land cover classes were grouped to compare the two maps (e.g. all temporary crops were grouped into a single class). A summary of the area of land use/land cover classes obtained from both classification methods is presented at Figure 7.

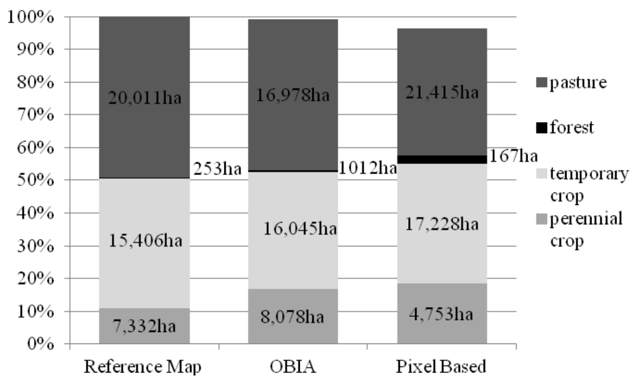

Fig. 7 – Areas in hectares and percentage of land use/land cover classes obtained from OBIA and traditional method.

By comparing the results from the two methods we found that the difference in the total classified area was mainly due by SPRING pixel-based classification producing a relatively large number of unclassified pixels. The percentage of temporary crops and pastures obtained by the SPRING were similar (37% and 39%). This was not verified in the OBIA classification, in which the area of pasture was greater than that of temporary crops and is similar that the one from the reference map. A similar problem occurred with the forest class whose area was overestimated in the SPRING classification. Perennial crops represented similar percentage in both classifications, being, however, overestimated when compared to the reference map.

OBIA first level of segmentation, MRS8 (Figure 2), presented a relatively large number of small objects, whose correct interpretation was based on using TM channel 4 to highlight the differences of vegetation response in the near infrared, and distinguish crop areas, forest and other vegetation areas.

The spectral difference algorithm segmentation was used to assemble contiguous objects with similar spectral characteristics. The algorithm's parameter considered up to 4 levels of gray. Thus, the small objects generated in the MRS8 level were preserved. This algorithm allowed to reduce the number of segmented objects, reducing the processing time of classification and minimizing the internal details of non-desirable thematic classes. The final classification was done in the level SDS4 (Figure 2).

During the OBIA procedure to select samples, attributes and algorithm thresholds for segmentation, using the large difference in EVI2 values to discriminate temporary crops (higher maximum annual EVI2 values) from pasture areas (lower maximum annual EVI2 values) was adequate for most areas. However two problems were identified: the first, which is specific for this study, is related to the fact that those sections presenting new pastures showed high EVI2 values, similar to those of temporary cultures, leading to the adoption of other attributes to discriminate among these classes. The second one is the difficulty of using the maximum annual EVI2 image, due to the difference of Landsat TM and MODIS pixel sizes, resulting in difficulties for the delimitation of the borders from the mapped areas.

Image classification suggests a certain degree of spatial correlation for the substitution of pasture areas and temporary crops for sugar cane in the period 2003-2009. Results from both classification methods estimated that at least 40% of the new sugar cane area appeared in areas of pasture; temporary crops accounted for more than a third of the classified area. The remaining area occupied by sugar cane in this period occurred on areas previously covered by perennial crops and by Forest.

Map evaluation was based on the confusion matrices generated from the sample points and thematic maps obtained with SPRING (Table 3) and DEFINIENS (Table 4), which reflect the main problems occurring during the classification procedure.

TABLE 3 – CONFUSION MATRIX OF LANDSAT-TM CLASSIFICATION IN 2003, USING SPRING

		Sample points				
		pasture	forest	Temporary crop	Perennial crop	Total OBIA classification
OBIA classification	pasture	**178**	2	31	5	216
	forest	1	**12**	2	0	15
	Temporary crops	19	0	**142**	6	167
	Perennial crops	15	3	19	**64**	101
	Total Reference	213	17	194	75	**499**

TABLE 4 – CONFUSION MATRIX OF LANDSAT-TM CLASSIFICATION IN 2003, USING DEFINIENS

		Sample points				
		pasture	forest	Temporary crop	Perennial crop	Total Pixel Based classification
Pixel based classification	pasture	**120**	0	37	9	166
	forest	2	**12**	0	5	19
	Temporary crops	51	1	**125**	7	184
	Perennial crops	29	4	22	**52**	107
	Total Reference	202	17	184	73	**476**

The analysis of confusion matrices shows that the main problem at both classifications are commission errors at class "Perennial crops" associated to classes "Pasture" and "Temporary crops". In the SPRING classification (Table 3) this problem became more evident because the summation of commission errors from this class (55) exceeded the amount of agreement pixels (52). In relation to Temporary crops, this could be explained by the diversity of the 2003 image patterns. Regarding the confusion at “Pasture” areas, one observes a similarity of the color patterns of this land use and “Perennial crops” at early growing stages. As for orange plantations, the texture aspects of some parcels undergoing improvements or substitution by other plants is similar to pasture. Another quite evident problem observed on Tables 3 and 4, and especially on the first one, is related to classes Temporary crops and Pasture, concerning their commission and omission errors. Confusion between both classes is quite frequent due to their similarities on the image, especially for well conserved pastures. This occurred even during visual interpretation of Landsat-TM and high resolution images, such as those available on Google Earth, for instance. To settle this question it seemed necessary to use other imagery, such as maximum annual EVI2 image used in this study. In spite of the gain using these image in classification process, does not eliminate totally the confusion for the identification of these types of land use.

The z test applied to the 2003 image classifications indicated that the classification results could not be considered similar to a random classification. This is because the z values obtained are much higher than zero, at 1% significance level (Table 5).

TABLE 5 – KAPPA AND Z TESTS OF GLOBAL ACCURACY OBTAINED FOR 2003 IMAGES AND Z TEST COMPARING BOTH METHODS PRESENTED

	Overall accuracy	Kappa	teste z (α=1%)	comparative teste z (α=1%)
Pixel Based classification	0.65	0.47	14.43	4.91
OBIA classification	0.79	0.68	24.85	

Table 5 shows that both the global accuracy indices and the Kappa coefficient of agreement estimated for the object-based image analysis made at DEFINIENS was superior than that obtained for the pixel-based SPRING classification (respectively, 0.68, 0.47). The z test comparing the results of both classifications also suggests the same condition, showing that the performance of the pixel-based method was inferior to that of the object-based classification, at a significance level of 1%.

5. CONCLUSION

The results obtained using object-based image analysis at DEFINIENS showed better results when compared to those ones using the pixel-based SPRING method. This difference is due mainly to the use of spectral attributes, such as vegetation indices and other types of attributes, such as the relational ones.

The maximum annual EVI2 image for 2003 was important for the classification, specially for temporary crops, allowing to differentiate them from the most areas of pasture. In the case of some areas of new pastures this attribute was not efficient, because they presented maximum EVI2 values similar to those ones of some temporary crops. These images were used efficiently for the classification of forests.

Both classification methods confirmed that pastures were the primary source for sugar cane expansion in the municipio of Barretos, followed by temporary crops. The rest of the new sugar cane areas occupied areas of perennial crops and forest.

Census data can provide statistics information about LUCC, but only the mappings obtained from the classification of remote sensing images provide spatial dimension to the trend of replacing pasture and temporary crops for cane sugar in the period from 2003 to 2009.

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