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MAPPING LAND USE AND LAND COVER CHANGES IN A REGION OF SUGARCANE EXPANSION USING TM AND MODIS DATA

Mapeamento de Mudanças de Uso e Cobertura da Terra em uma Região de Expansão de Cana-de-açúcar Utilizando TM e 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. Sugarcane expansion – a major LUCC process in Brazil - has been monitored by INPE's CANASAT project since 2003 (http://www.dsr.inpe.br/canasat/). In this study, an assessment of land use/cover conversion is presented in a region of important sugarcane expansion, the município of Barretos, in São Paulo State, in the 2003-2009 period. Detection of land use/cover changes is performed by classification of 2003 land use/cover and comparing 2003 classes with 2009 CANASAT maps. Land use/cover classification uses Landsat TM, and MODIS EVI2 time series, and two different techniques, segmentation followed by supervised classification, and object-based image analysis (OBIA) combining remotely sensed imagery and ancillary data. Results show that at least 40% of the increases in sugarcane area were due to conversion of pasture land; comparison of the two classification techniques shows better results by the OBIA technique, but both approaches agreed that most sugarcane expansion occurred on pastureland.

Keywords: Land Use/cover Change; TM Data, EVI2-MODIS, Sugarcane, Object-based Image Analysis.

RESUMO

As mudanças de uso e cobertura da terra (MUCT) constituem o objeto de um campo de pesquisa multidisciplinar em que as técnicas de sensoriamento remoto e sistemas de informação geográfica tem tido um papel importante. A expansão da cana-de-açúcar, um processo maior de MUCT no Brasil, tem sido monitorada pelo projeto CANASAT do INPE desde 2003 (http://www.dsr.inpe.br/canasat/). Este estudo avaliou a conversão de uso e cobertura da terra numa área de importante expansão da cana, o município de Barretos, Estado de São Paulo, no período 2003-2009. A detecção das mudanças de cobertura e uso da terra foi realizada através da classificação do uso e cobertura da terra em 2003 e comparação das classes de uso e cobertura em 2003 com o mapa do projeto CANASAT de 2009. A classificação do uso e cobertura da terra utilizou dados do sensor TM/Landsat e séries temporais MODIS EVI2, e duas técnicas distintas, segmentação seguida de classificação supervisionada e análise de imagens baseada em objetos (OBIA do nome em inglês “object-based image analysis”), combinando-se imagens de sensoriamento remoto e dados auxiliares. Os resultados mostraram que pelo menos 40% da expansão da área da cana decorreram da conversão de pastagens; a comparação das duas técnicas de classificação mostrou que a técnica OBIA produziu resultados melhores, mas ambas classificações concordaram que a maior parte da expansão da cana-de-açúcar ocorreu em pastagens.

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 for several applications, including forestry, water resources, urban-rural interface, and environmental impact studies. LUCC may have impacts at the local, regional and global scales, affecting the hydrologic and biogeochemical cycles, biological diversity, and greenhouse-gas emissions (TURNER; MEYER, 1994).

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

In Brazil, sugarcane production is concentrated in the State of São Paulo, which surpassed 50% of the entire national production in 2007 (IBGE, 2007), and reached 4.45 million ha in 2008/2009 (UNICA, 2009). Sugarcane 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 sugarcane expansion has motivated a number of monitoring and research initiatives (MELLO et al., 2013; ADAMI et al., 2012; VIEIRA et al., 2012; ADAMI et al., 2012), including the CANASAT program created 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 to map sugarcane areas starting from 2003 (Rudorff et al., 2010). The program results show that the area of sugarcane harvest in South-Central Brazil represented more than 6.5 million hectares in 2008/2009, increasing 15.7% in comparison to the preceding year (UNICA, 2009).

The present study presents an assessment of land use/cover changes due to the conversion of agricultural areas to sugarcane plantations in the 2003-2009 period in the município of Barretos (SP), a region of important sugarcane expansion in the State of São Paulo.

CANASAT sugarcane maps, agricultural statistics, Landsat TM and EVI2-MODIS images and EVI2 time series and two classification approaches - segmentation with supervised classification and object-based image analysis (OBIA) were used to classify 2003 pasture, perennial and annual crop areas and then these areas were compared to 2009 sugarcane areas mapped by CANASAT.

2. STUDY AREA

The study area corresponds to the município of Barretos, which is located in northern São Paulo State (Figure 1), covering 1,565 km^2 with a population of 112,102 inhabitants in 2000.

The original vegetation in the region was dominated by Cerrado (Savanna) including patches of the Brazilian Atlantic Forest. Throu-out the 20th century most of the native vegetation was converted into agricultural land and mostly used for livestock production (IBGE, 2004).

According to data from the last Agricultural Census (IBGE, 2006), sugarcane plantations was the predominant land use in Barretos representing 44% of the municipio area, followed by orange and soybean plantations (respectively 32% and 7%), and pastures (6%). The importance of sugarcane may be illustrated by the six large ethanol plants installed in the region (IBGE, 2006). Barretos also belongs to a region, which

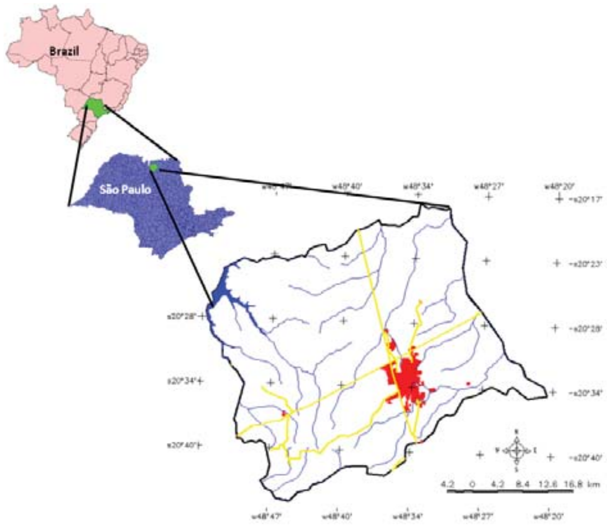

Fig. 1 – Município of Barretos (SP) with its approximate location in the State of São Paulo (SP) and in Brazil. Main urban area shown in red.

presented one of highest rates of sugarcane expansion according to data from the Cadastral Survey of Agro-Livestock Production Units – LUPA (São Paulo, 1997 & São Paulo, 2008).

3. DATA AND METHODS

3.1 Data

CANASAT Project sugarcane maps, available from 2003, LANDSAT-TM images for 2003 and 2009, and high spatial resolution Google Earth images were used in this study. Three LANDSAT-TM datasets were selected from 2003 (March 4, June 16 and August 19) to discriminate bare soil from annual crops. Time series of EVI2-MODIS products and monthly -accumulated rainfall data of TRMM (Tropical Rainfall Measuring Mission), were obtained from LAF, INPE's Remote Sensing Laboratory Applied to Agriculture and Forestry (https://www.dsr.inpe.br/laf/series/index.html), were also used.

The study used the well-known Normalized Difference Vegetation Index (NDVI) (TUCKER, 1978) together with the Enhanced Vegetation Index 2 (EVI2) (Equation 1) which allows to highlighting variations of land use/cover. The EVI2 index aggregates information to NDVI due to its frequency of 16 days For its calculation MOD13 from MODIS, collection 005 is used (spatial resolution of 250 m and 16 days composite) available at NASA's site (https://wist.echo.nasa.gov/api/).

$$EVI2 = 2.5 * \frac{NIR - Red}{NIR + 2.4 * Red + 1} \quad (1)$$

Variation of EVI2 was assessed by using the tool developed by Freitas et al. (2011) which allows to visualize MODIS temporal series of the entire South America. It was used to track the variation of EVI2 on a time series since 2000 for specific MODIS pixels, selected and localized with the aid of Google Earth mosaics.

After tracking changes in EVI2 values on the time series, the maximum annual EVI2 values of MODIS were spatially represented in a matrix, generating an image that was then 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.

3.2 Methods

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 sugarcane occurred during the 2003-2009 period of study by comparison with CANASAT 2009 sugarcane areas

TM image classification included two methods: segmentation followed by supervised classification using the SPRING software (Câmara, 1996), and the OBIA classification available in the Definiens software (Definiens, 2005 and 2006).

The first method used for classification consisted of segmentation followed by supervised classification . Based on the knowledge of the interpreter, on the image pixel size, on the targets of interest and on the objective of classification, the segmentation parameters 10 and 30 were used respectively for similarity and minimum area. Similarity is based on the Euclidean distance between mean gray levels of each region, thus two regions are considered distinct if the distance between their averages is higher than the specified similarity threshold (CAMARA et al., 1996). The segment-based Bhattacharyya classification algorithm with a 99% threshold was used after segmentation.

The second method - OBIA classification - required more steps than the first, including, in particular, two levels of segmentation (Figure 2), and the possibility to incorporate more information in the procedure of image classification, such as texture, shape and context parameters. For the object-based image analysis, the interpreter must transfer his/her knowledge to the software, modeling the hierarchical network, and attempting to error reduction and an increase of classification precision.Training samples of Pasture, Annual crops, Perennial crops and Forest classes were defined using ground data collected on previous work (Alves et al, 2009 and 2010). Intra-annual EVI2 variability was also used 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 imagery were defined by tracking image changes observed on Landsat-5 acquisitions of March, June and August to identify bare soil and different types of vegetation signatures heuristically discriminated on the imagery, like smooth bright vegetation, smooth non-glossy vegetation, rough bright vegetation, and rough not-bright vegetation. These texture characteristics distinguished among smooth and rough classes, and brightness characteristics was inferred from to high TM4 values. Table 1 shows the land use/cover classes combinations and the sequences defined in each Landsat image.

The differentiation of thematic classes of land use showed in Table 1, such as between two annual crops, was considered only in regard to differentiation in processes of substitution on the land cover during one year. This was not aimed at establishing or grouping similar crops in the same classes.

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

The classification used a number of samples, for which a number of attributes were selected and defined (Table 2).

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 to help in this process.

Classification accuracy was assessed based on randomly selected sampling areas that were merged in a 43ha reference map. Kappa coefficients of agreement were estimated for the two thematic maps, obtained by supervised classification and OBIA. A z test was performed to compare them statistically.

Areas composing the reference map were classified based on the time series of EVI2-MODIS products and areas visited at a field survey. In this study pasture and annual crops – usually difficult to discriminate on Landsat imagery - were separated by analyzing the form, amplitude and the maximum and minimum

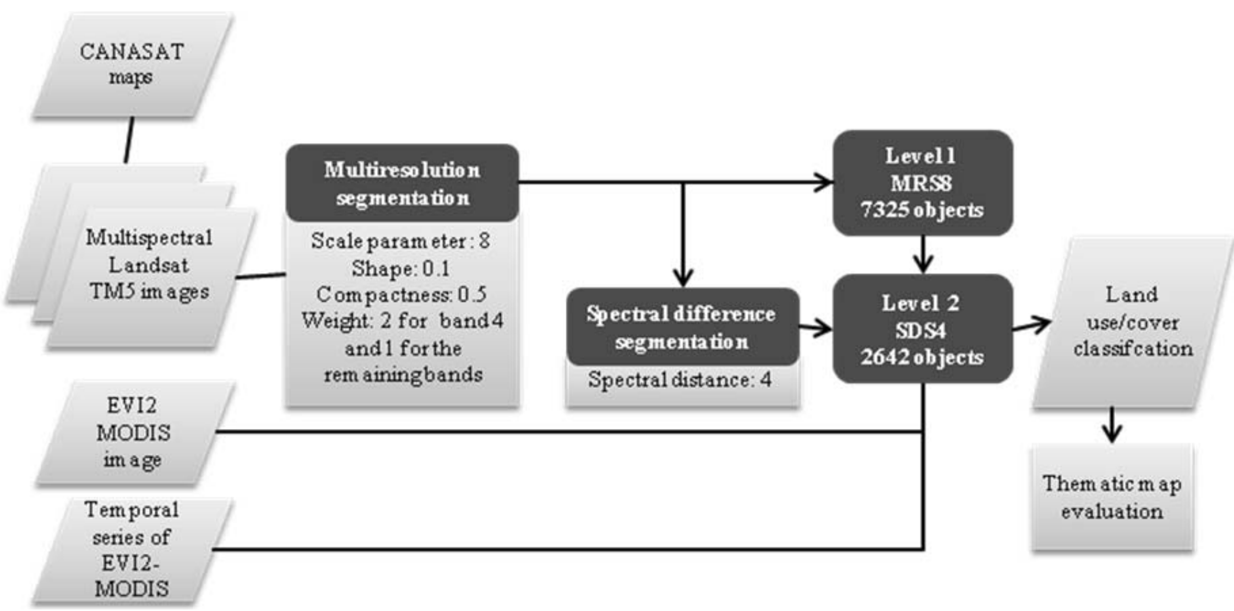

Fig. 2 - Flowchart of OBIA classification showing the Multi-resolution and Spectral Difference segmentation levels.

Table 1: Land cover classes sequence and land use classes according defined in multi-temporal LANDSAT TM-2003

<table>
<tr><th colspan="6">Images of 2003</th><th>Thematic Classes</th></tr>
<tr><th colspan="3">March</th><th colspan="2">June</th><th>August</th><th></th></tr>
<tr><td rowspan="2">BS</td><td rowspan="2" colspan="2">BS</td><td colspan="2">BS</td><td>BS</td><td>Perennial crop 1</td></tr>
<tr><td colspan="2">V</td><td></td><td>Annual crop 1</td></tr>
<tr><td rowspan="7">VEGETATION</td><td rowspan="3">V</td><td rowspan="3">B</td><td>V</td><td>B</td><td></td><td>Annual crop 2</td></tr>
<tr><td>V</td><td>NB</td><td></td><td>Pasture 1</td></tr>
<tr><td colspan="2">BS</td><td></td><td>Annual crop 3</td></tr>
<tr><td rowspan="4">V</td><td rowspan="4">NB</td><td>V</td><td>B</td><td></td><td>Annual crop 4</td></tr>
<tr><td colspan="2">BS</td><td></td><td>Pasture 2</td></tr>
<tr><td rowspan="2">V</td><td rowspan="2">NB</td><td>V</td><td>Perennial crop 2</td></tr>
<tr><td>BS</td><td>Pasture 3</td></tr>
</table>

BS	Bare Soil
V	Vegetation
B	Bright
NB	Not-Bright
	Not analyzed

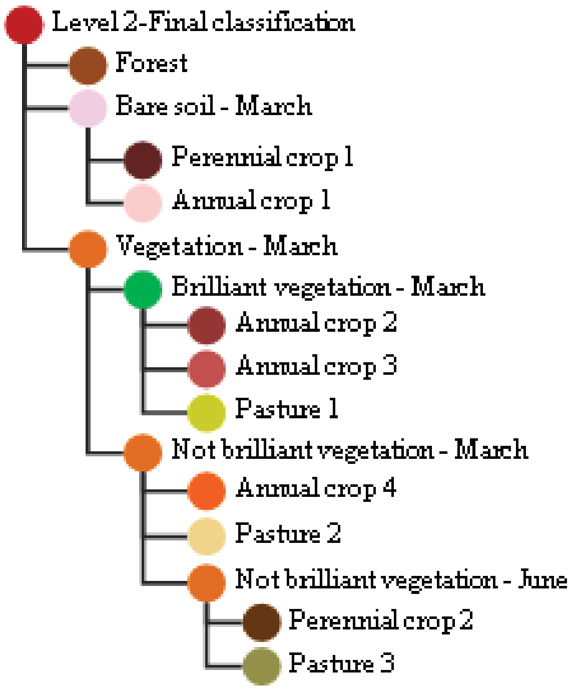

Fig. 3 – Hierarchical network used for Definiens-based classification of TM-Landsat.

values of the EV12 curves. Figures 4 and 5 show examples of the variation of pasture and annual crops areas on TM time series and on 2003 EVI2-MODIS multitemporal data. These figures present also examples of pasture and annual crops on Landsat images.

The analysis of the EVI2-MODIS of the reference map show that the pasture curve has an amplitude value (minimum of 0.17 and maximum of 0.60) lower than the annual crops curves. In fact, annual 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 sugarcane expansion until 2009. The first map was obtained by supervised classification using the Bhattacharya algorithm in software SPRING, and the second one was obtained by OBIA classification using Definiens (Figure 6). In general, OBIA classification results showed more detail and allowed discrimination of up to nine different classes, that were not so well differentiated by supervised classification. Because of that, similar land use/land cover classes were grouped to compare the two maps (e.g. all annual crops were grouped into a single class). Figure 7 presents the area estimated for these classes for each map.

The distribution of land use/cover classes is similar in both maps, OBIA and supervised classification. Both maps show a relative predominance of large pasture areas in the western and central-western section and annual cultures in the central-western and eastern ones.

Comparing the results from the two methods we found that the differences in the classified areas were mainly due to a larger fraction of areas not classified in the segmentation/supervised classification map . The percentage of annual crops and pastures obtained by segmentation and supervised classification was similar (37% and 39%). In contrast, OBIA classification show a larger area of pasture in comparison with annual crops

Table 2: Number of samples and respective areas, and attributes used for land use/cover classification in 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
Annual 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**		

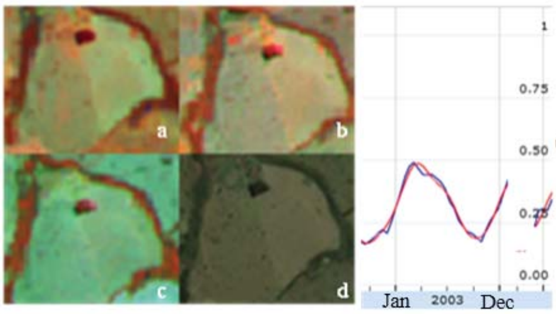

Fig. 4 – Variation of the response of pasture areas shown in: Landsat images (March 4th (a), June 16th (b) and August19th (c)) and QuickBird image (d) and time series curves of EVI2-MODIS. (Freitas et al., 2011)

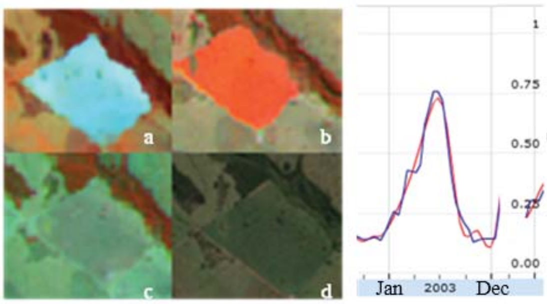

Fig. 5 – Annual crops: Landsat images (March 4th (a), June 16th (b) and August19th (c)) and QuickBird image (d) and time series curves of EVI2-MODIS. (Freitas et al.,2011)

similarly to the reference map. A similar problem occurred with the forest class whose area was overestimated by supervised classification. The perennial crop class presented similar percentage in both classifications, although they appear to have been overestimated in comparison to the reference map. The first level of segmentation performed in OBIA, produced a relatively large number of small objects MRS8 (Figure 2) This problem was corrected with the aid

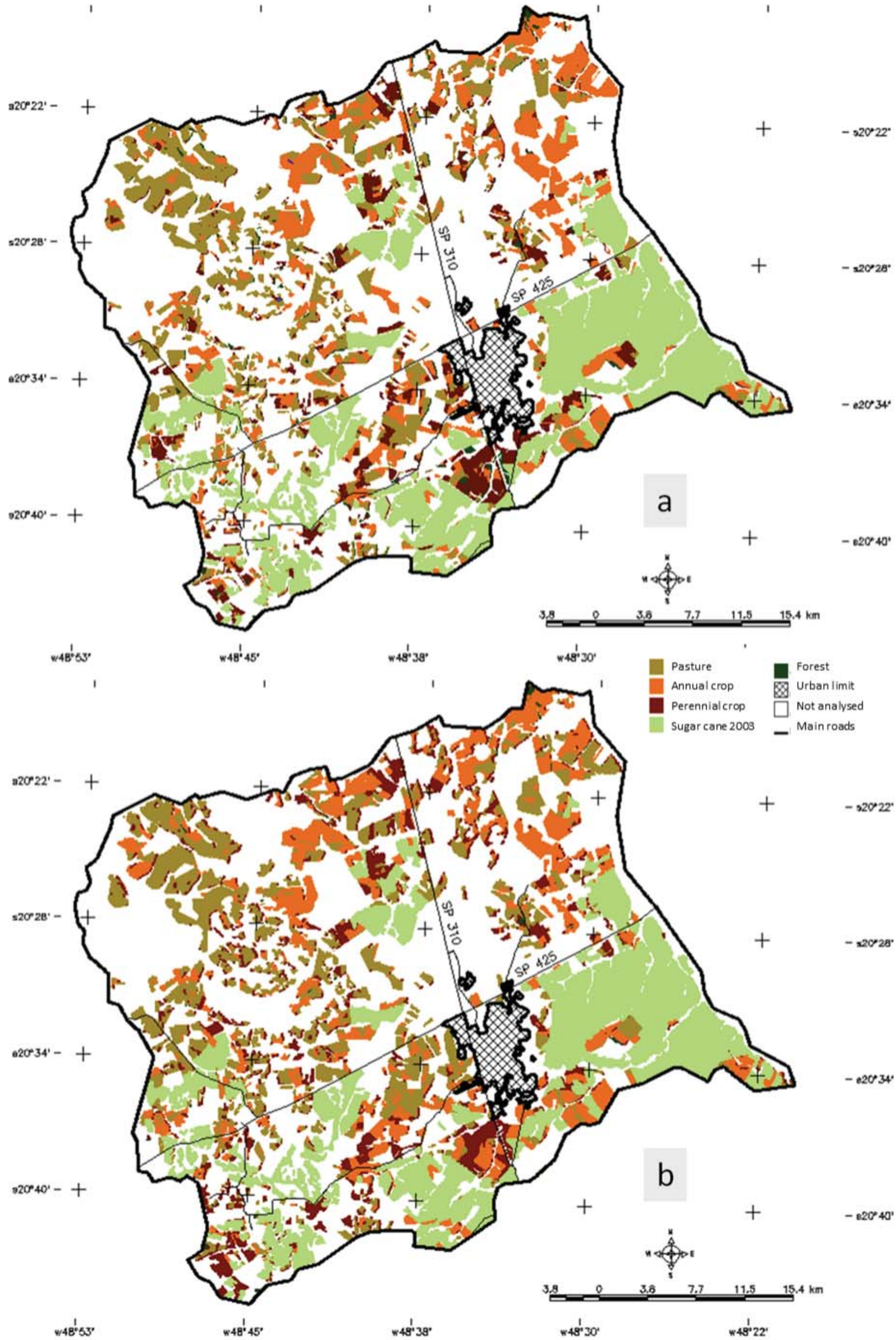

Fig. 6 – Barretos' 2003 land use/cover map produced by supervised classification (a) and by object-based image analysis (b). SP 310 and 425 are the two main roads crossing the município.

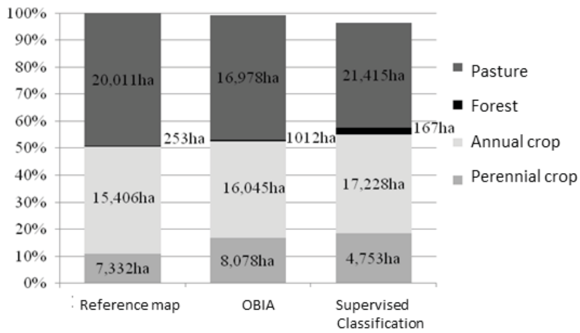

Fig. 7 – Comparison of OBIA and supervised classification results with the reference map.

of image interpretation of the near infrared TM channel 4 that highlight the differences of vegetation response and allow distinguishing 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, small objects generated in the MRS8 level were preserved. This algorithm allowed to diminish the number of segmented objects, reducing the overall classification time and minimizing excessive details of undesirable land use/cover classes. The final classification was done in the level SDS4 (Figure 2). For sample, attribute and algorithm selection to segmentation, using the large difference in EVI2 values to discriminate annual crops (higher maximum annual EVI2 values) from pastures (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 areas presenting newly cultivated pastures showed high EVI2 values, similar to those of annual cultures, leading to the inclusion of additional attributes to discriminate among these classes. The second one is the difficulty to delimit the borders classes, using EVI2 image due to the difference of Landsat TM and MODIS pixel sizes. Image classification results suggested a certain degree of spatial correlation for the substitution of pasture areas and annual crops for sugarcane in the period 2003-2009.

Comparison of the 2003 maps (Figure 6.a, b) with the 2009 CANASAT map revealed that results from both classification methods show at least 40% of the area of sugarcane expansion between 2003 and 2009 occurred in areas of 2003 pasture, while annual crops accounted for a third of sugarcane expansion The remaining area of sugarcane expansion during the period of study occurred on areas previously covered by perennial crops (17% and 19%) and by Forest (1% and 3%) (FIGURE 7).

Confusion matrices obtained by superimposing the reference map and and the classification results are shown on Tables 3 and 4, respectively, for the OBIA and segmentation/ supervised classification methods.

In case of confusion with annual crops, the great diversity of patterns found in the image 2003 representing diverse cultures, can justify this

The analysis of the confusion matrices shows that commission errors for class "Perennial crops" associated to classes "Pasture" and "Annual crops" were high for both methods. In the supervised classification (Table 3) this problem became more evident because the summation of commission errors from "Perennial crops" (29+4+22=55) exceeded the amount of agreement pixels (52). In the case of the confusion with annual crops, a larger diversity of the 2003 image patterns, representing diverse cultures, could justify this. Regarding the confusion between "Pasture" areas and "Perennial crops" (in early stages of growth), one can observe the similarity among the spectral patterns observed in the images. Another quite evident problem observed on Tables 3 and 4, and especially on the second one, is concerning commission and omission errors related to classes "Annual crops" and "Pasture". Confusion

Table 3: Confusion matrix for the object-based image analysis (OBIA) method

	Pasture	Forest	Annual crops	Perennial crops	**Total OBIA classification**
Pasture	**178**	2	31	5	216
Forest	1	**12**	2	0	15
Anual crops	19	0	**142**	6	167
Perennial crops	15	3	19	**64**	101
Total Reference	213	17	194	75	**499**

Table 4: Confusion matrix method for the supervised classification

	Sample points				
	Pasture	Forest	Annual crops	Perennial crops	**Total supervised classification**
Pasture	**120**	0	37	9	166
Forest	2	**12**	0	5	19
Anual crops	51	1	**125**	7	184
Perennial crops	29	4	22	**52**	107
Total Reference	202	17	184	73	**476**

between both classes is quite frequent due to their spectral similarities on the image, especially for well conserved pastures. This confusion occurred even during visual interpretation of Landsat-TM and high resolution Google-Earth images. In this work the annual EVI2 images were utilized to settle this question. The use of these images decreased the errors in the classification process, reducing the confusion between pastures and annual crops.

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 shows that both the global accuracy indices and the Kappa coefficient of agreement estimated for OBIA was superior than that obtained for supervised 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 OBIA classification was superior at the significance level of 1%.

5. CONCLUSION

Classification produced by the object-based image analysis (OBIA) method showed better results when compared to those of the supervised classification method. It is suggested that this difference can be attributed to the use of spectral attributes, such as vegetation indices and other types of attributes, such as the relational ones.

Results indicate that using the 2003 maximum annual EVI2 image improved classification performance, particularly in the case of annual crops, allowing to differentiate them from the most pasture areas. At the same time, the use of this attribute in the case of newly cultivated pastures does not seem to be as efficient, because they tended to present maximum EVI2 values similar to those ones of some annual crops. These images seem to have produced better results for the classification of forests.

Table 5: Kappa and z tests of global accuracy obtained for 2003 images and z test comparing both methods presented

	Overall accuracy	Kappa	test z (α =1%)	comparative test z (α =1%)
Supervised Classification	0.65	0.47	14.43	
OBIA Classification	0.79	0.68	24.85	4.91

Both classification methods confirmed that pastures were the primary source for sugarcane expansion (40% and 46%) in the município of Barretos, followed by annual crops (38% and 36%). The remaining new sugarcane areas occupied areas of perennial crops (19% and 17%) and forest (3% and 1%).

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 annual crops for cane sugar in the period from 2003 to 2009.

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