CHARACTERIZING LAND USE AND COVER CHANGE AND SUGAR CANE EXPANSION USING TM DATA, EVI2-MODIS AND OBJECT-BASED IMAGE ANALYSIS

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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,whose expansion has been monitored since the early 2000 within the framework of INPE's CANASAT project. In this work, a methodology is proposed to investigate land use/cover changes in a region of sugar cane expansion based on integrating CANASAT maps, remote sensing data and agricultural statistics in a GIS, and assess, in particular, which land use/cover classes are converted to give place to sugar cane expansion in the 2003-2009 period. The area under study is the municipality of Barretos (São Paulo State), which suffered a strong expansion of sugar cane culture during the 2003-2009 period of study, accompanied by a 46% reduction in pasture areas, and a 40% increase in cattle. A land use/ cover map for the year of 2003 was produced based on Landsat Thematic Mapper (TM) , and MODIS EVI2 yearly maximum and time series; high spatial resolution images, available at Google Earth were also used. Two methods of classification were compared: a pixel-based automatic supervised classification using the SPRING software; and an object-based image analysis algorithm using Definiens software. The mapping evaluation was carried out by random points sampling verified by visual interpretation. The classifications using the object-based image analysis performed better than those executed by traditional pixel-based approach, and these methods resulted in Kappa indices of 0.68 and 0.47, respectively. Using the EVI2-MODIS time series was of fundamental importance for the discrimination among land use/cover classes.

1. INTRODUCTION

Land use/cover change (LUCC) studies are important for several applications on ,forestry , water resources concerns, urban-rural conflict analysis; environmental impact evaluations, as well as for updating information on land revenues for tributary purposes, planning and public policies. Changes in land use/cover and its consequences are not restricted to the surroundings of its occurrence. They can have implications at the regional and global scales, affecting the hydrologic and biogeochemical cycles, impacting biological diversity, and contributing to increases in greenhouse gas concentrations (e.g. TURNER; MEYER, 1994).

Changes in land cover/land use can have several origins. In this study, these changes associated with the expansion of sugar cane in the State of São Paulo are under scrutiny. In the last 30 years Brazil started a new chapter on the history of sugar cane production, stimulated by governmental policies directed to the promotion and production of bio-ethanol to improve the country´s energy self-sufficiency and reduce oil import (FISCHER et al. 2008).

São Paulo State dominates Brazilian sugar cane production, and its share is still growing: in the 70s it was already above 30% and since 1995 it surpassed 50% of the entire national production (IBGE, 2007). São Paulo has also put in place research efforts directed to the sugar-alcohol segment.

Data from CANASAT Project (http://www.dsr.inpe.br/canasat/) estimated 2008/2009 sugar cane harvest in South-Central Brazil at 6.53 million hectares, an increase of 15.7% from the previous harvest. From this amount, 4.45 million ha come from São Paulo State, which corresponds to 66% of the planted area. The impact caused by sugar cane plantation are being discussed by the scientific community, specially referring to environmental (Novaes et al. 2011) and social-economic (Camargo et al., 2008; Olivette et al., 2011; Olivette et al., 2010; Olivette e Camargo, 2009) issues.

The municipality of Barretos was chosen as the area of study because of the significant expansion of sugar cane plantation in the analyzed period (2003-2009) in that area. Its selection was based on analyzing data from the Cadastral Survey of Agro-Livestock Production Units – LUPA for all municipalities of São Paulo State.

1.1 Vegetation index

In remote sensing images, vegetation indices are obtained from the spectral response of the targets and, besides identifying the vegetated areas differentiating them from other targets, to characterize the states biophysical and biochemical processes of such areas (NASA, 2011). They are largely used for studies related to the identification and analysis of several cultures (D'Arco et al., 2005; Chen et al., 2006; Gusso et al., 2009; Picoli et al., 2009).

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/).

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

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.

2. STUDY AREA

Barretos is located at the northern São Paulo State (Figure 1), geographical coordinates S20°33'26" and WGr 48°34'04". The average altitude is 530 m. Its population of 112,102 inhabitants is distributed at an area of 1,565 km^2 .

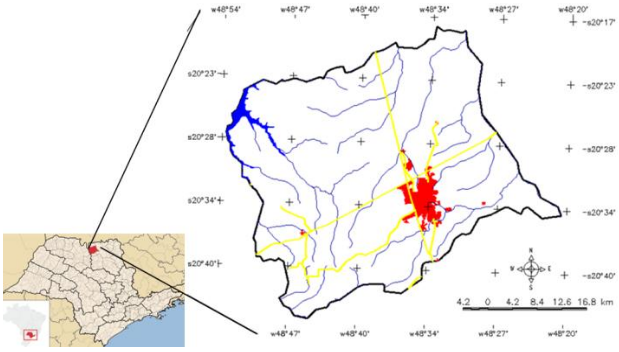

Figure 1 – Localization of the Barretos municipality.

The region surrounding Barretos is covered by *Cerrado* (Savanna) vegetation with some occurrence of Forest formations. Due mainly to livestock activities, the native vegetation, with a high biodiversity was changed, causing silting of rivers and soil erosion (IBGE, 2004).

According to data from the last agricultural and livestock census from IBGE, executed in 2006, sugar cane culture predominates with 44% of the municipal area, 32% with oranges, 7% soybeans and 6% pasture. The predominance of sugar cane is marked by six large ethanol plants installed in the region (IBGE, 2006).

3. MATERIAL AND METHODS

3.1 Material

Due to the availability of data from Project CANASAT and of high spatial resolution Google Earth images, LANDSAT-TM scenes of 2003 were used. Three datasets were selected from 2003, (March 4^{th}, June 16^{th} and August 19^{th}) 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 used.

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 made with softwares SPRING 5.1.7 and Definiens 7.

3.2. Methodology

The classification of the three Landsat-TM images from 2003 was done only in expansion areas of sugar cane during the period 2003-2009, because its aim was to verify on which type of land cover/land use the expansion of sugar cane was occurring in this timeframe.

The classification was made using and comparing two methods: automatic supervised pixel-based classification using SPRING software, and the object-based image analysis using Definiens software. Pasture, Temporary crops, Perennial crops and Forest classes were defined based on previous work (Alves et al, 2009 and 2010).

As for the object-based image analysis, scale, form and color parameters were utilized for image segmentation. Initially two levels of segmentation were considered:

- • 1^{st}-level (MRS8): multi-resolution segmentation algorithm, scale-8, form-0.1, 0.5, compactness, weight 2 for the bands 4 from April and July and weight 1 for the others bands;
- • 2^{nd} level (SDS4): spectral-difference segmentation algorithm, spectral distance -4.

A high degree of discrimination was obtained from the first level segmentation (MRS8). The decision rules for the classification of the 2003 thematic map were defined from the observation of the characteristics from the March image, followed by the June and August images, if necessary. After this procedure the thematic classes were linked. 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

<table>
<tr><th colspan="5">images of 2003</th><th colspan="2">August</th><th rowspan="2">Thematic Classes</th></tr>
<tr><th colspan="3">March</th><th colspan="2">June</th><th colspan="2"></th></tr>
<tr><td rowspan="2">BS</td><td colspan="2" rowspan="2">BS</td><td colspan="2">BS</td><td colspan="2">BS</td><td>Perennial crop1</td></tr>
<tr><td colspan="2">V</td><td colspan="2"></td><td>Temporary crop 1</td></tr>
<tr><td rowspan="8">VEGETATION</td><td rowspan="3">V</td><td rowspan="3">B</td><td>V</td><td>B</td><td colspan="2"></td><td>Temporary crop 2</td></tr>
<tr><td>V</td><td>NB</td><td colspan="2"></td><td>Pasture 1</td></tr>
<tr><td colspan="2">BS</td><td colspan="2"></td><td>Temporary crop 3</td></tr>
<tr><td rowspan="5">V</td><td rowspan="5">NB</td><td>V</td><td>B</td><td colspan="2"></td><td>Temporary crop 4</td></tr>
<tr><td colspan="2">BS</td><td colspan="2"></td><td>Pasture 2</td></tr>
<tr><td rowspan="2">V</td><td rowspan="2">NB</td><td colspan="2">V</td><td>Perennial crop 2</td></tr>
<tr><td colspan="2">BS</td><td>Pasture 3</td></tr>
</table>

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

After the identifications of the land cover change processes, a hierarchical network was defined at Definiens (Figure 2).

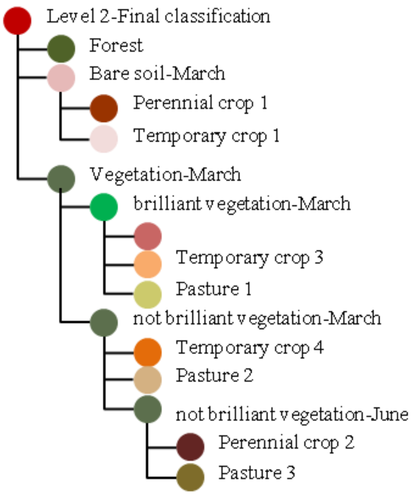

Figure 2 – Hierarchical network classification used in Definiens for TM-Landsat image classification of 2003.

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 are 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	89.10	0.20	NDVI´s variance	spectral
				average maximum EVI2	spectral
Perennial crop 1	9	51.39	0.12	NDVI march	spectral
				NDVI june	spectral
				NDVI august	spectral
Perennial crop 2	62	837.09	1.92	not brilliant vegetation- march	relational
				NDVI´s variance	spectral
				b4 average-june	spectral
				NDVI march	spectral
				NDVI august	spectral
Temporary crop 1	50	612.72	1.41	NDVI march	spectral
				average maximum EVI2	spectral
				NDVI june	spectral
Temporary crop 2	33	431.82	0.99	NDVI march	spectral
				b4 average-march	spectral
				average maximum EVI2	spectral
				b4 average-june	spectral
Temporary crop 3	21	291.42	0.67	NDVI march	spectral
				b4 average-march	spectral
				average maximum EVI2	spectral
				NDVI june	spectral
Temporary crop 4	14	181.53	0.42	not brilliant vegetation--march	relational
				NDVI march	spectral
				average maximum EVI2	spectral
				b4 average-june	spectral
Pasture 1	427	5423.40	12.45	NDVI march	spectral
				b4 average-march	spectral
				b4 average-june	spectral
				NDVI´s variance	spectral
Pasture 2	46	619.11	1.42	not brilliant vegetation- march	relational
				NDVI march	spectral
				NDVI june	spectral
				NDVI´s variance	spectral
Pasture 3	39	495.63	1.14	not brilliant vegetation- march	relational
				NDVI´s variance	spectral
				b4 average-june	spectral
				NDVI march	spectral
				NDVI august	spectral
				Not-perennial crop 2	relational
TOTAL	**709**	**9033.21**	**20.73**		

The map evaluation was carried by random sampling points verified in a reference map obtained by visual interpretation. Kappa indexes were calculated from both thematic maps, obtained by different methods. The z test was performed to compare them statistically.

4. RESULTS AND DISCUSSION

Following the described procedures, 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 at SPRING (Figure 3), and the second one obtained by object-based image analysis at Definiens (Figure 4).

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. The amount of class sub-divisions indicates a higher degree of detail, which can be obtained by an object-based image classification (Figure 3) when compared to the traditional classification method (Figure 4). Because of that, similar land cover/land use classes were grouped to compare quantitatively the two maps (e.g. all temporary crops were grouped into a single class). The land cover/land use areas obtained from both classification methods are presented at Figure 5.

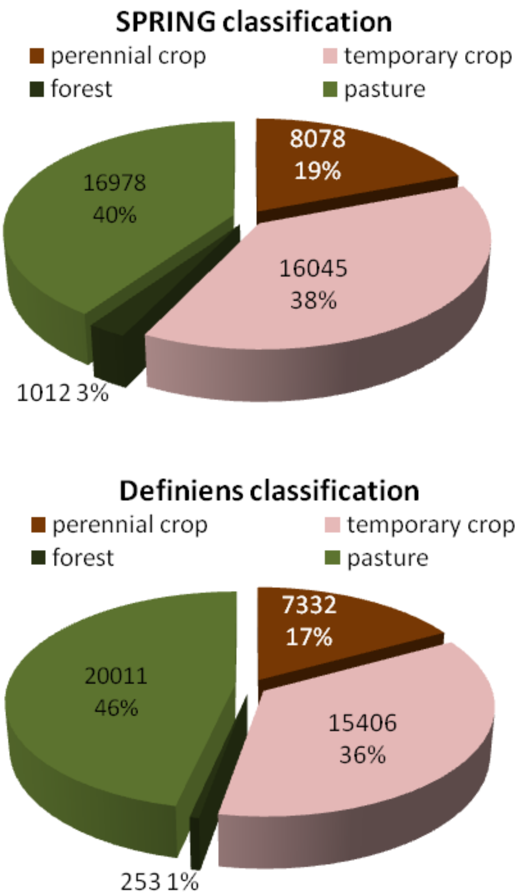

Figure 5 – Areas in hectares and percentage of land cover/land use classes at the thematic maps.

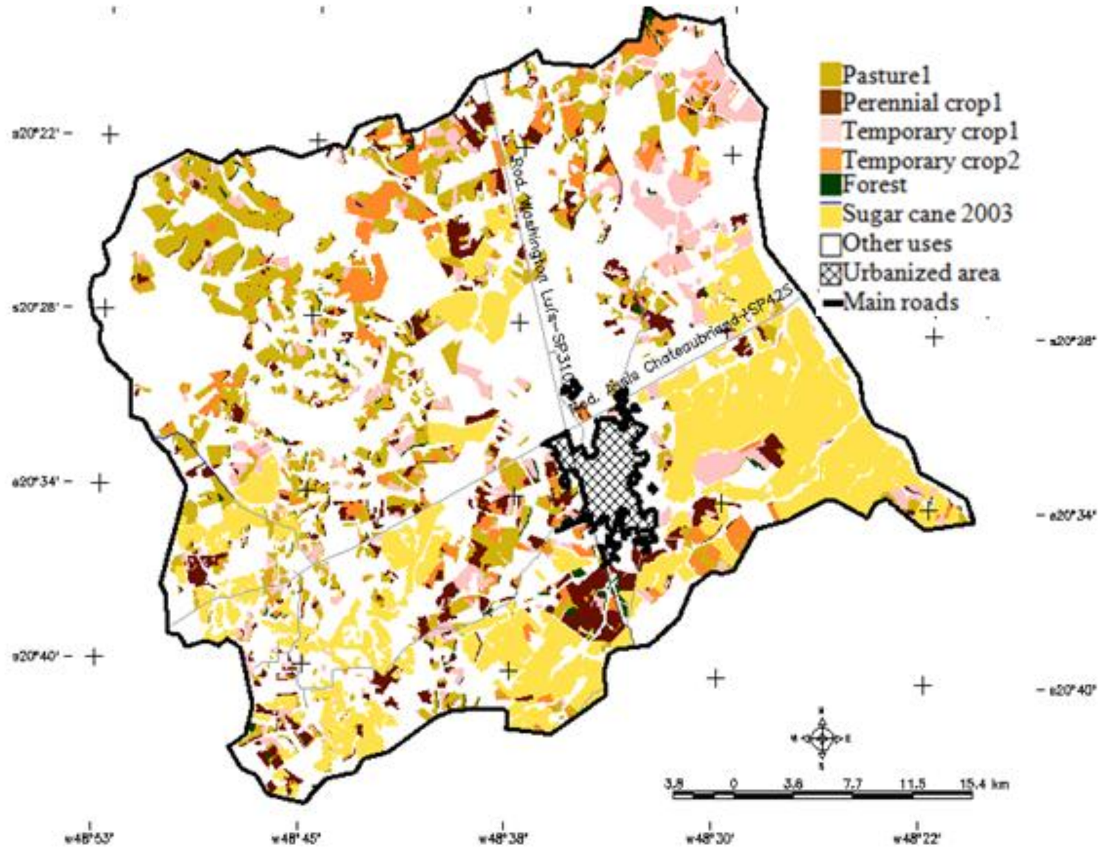

Figure 3 – Land use/cover map of 2003 obtained by supervised classification (SPRING).

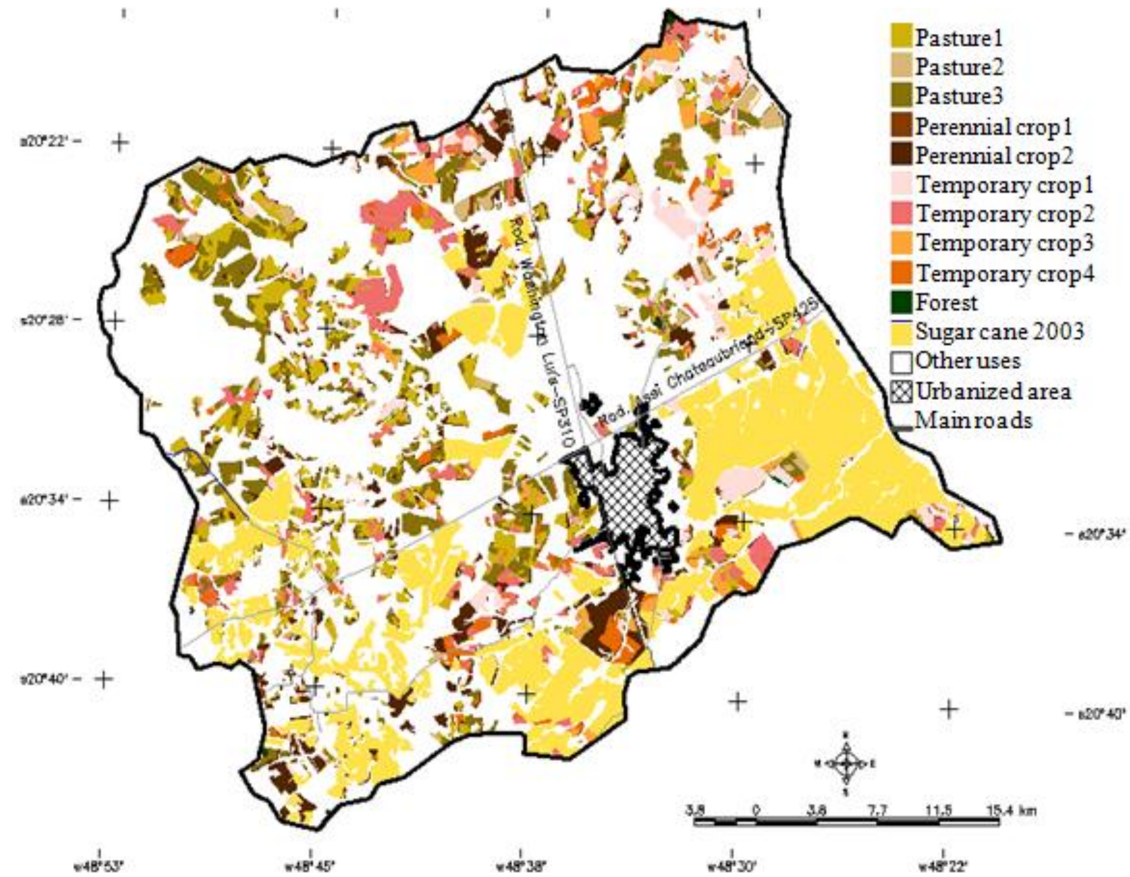

Figure 4 – Land use/cover map of 2003 obtained by object-based image analysis (DEFINIENS).

The images containing the highest EVI2 values were used in order to enhance the difference among areas with temporary cultures and pastures, since the first ones usually present higher maximum annual values, as observed in isolated pixels during the elaboration of the reference map. During the procedure of selection of samples, attributes and its thresholds at DEFINIENS, this approach was adequate for most areas. However two problems were identified: the first, which is specific for this study, is due to the fact that those sections presenting new pastures showed extreme EVI2 values, similar to those of temporary cultures, leading to the adoption of other attributes to discriminate among the different land uses. The second one is the difficulty for the use of the yearly maximum EVI2 image, due to the difference of Landsat TM and MODIS pixel sizes, resulting in difficulties for the delimitation of the borders from the areas mapped.

The maps derived from satellite imagery suggest a certain degree of spatial correlation for the substitution of pasture areas and temporary crops for sugar cane in the period 2003-2009. The results of both classification methods estimate that at least 40% of the planted sugar cane occurred in areas of pasture in the Barretos municipality; temporary crop apprehend both nearly a third of the classified area. The remaining area occupied by sugar cane in this period was occupied by Perennial crop and Forest areas.

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 allow to 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 SPRING classification
SPRING 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**

Table 4 – Confusion matrix of Landsat-TM classification in 2003, using DEFINIENS.

		Sample points				
		pasture	forest	Temporary crop	Perennial crop	Total Definiens classification
Definiens 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**

The analysis of confusion matrices shows that the main problem at both classifications are commission errors at class ”Perennial crop” associated to classes “Pasture” and “Temporary crops”. At the classification with SPRING (Table 3) this problem became more evident because the summation of commission errors from this class (55) surpasses the amount of agreement pixels (52). Referring to Temporary crops, this can 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 with young “Perennial crops”. As for orange cultures, the texture aspects of some sections undergoing improvements or substitution by other plants is similar to pasture. Another quite evident problem observed on Tables 3 and 4, and especially at the first one, is related to classes Temporary crops and Pasture, concerning its commission and omission errors. Confusions among both classes are quite frequent due to the similarities of them on the image, especially for well conserved pastures. This occurred even during the identification by visual interpretation at Landsat-TM and high resolution images. To settle this question it was necessary to use other data, such as the analysis of EVI2 data, used in this study. So the use of the object-based image analysis paradigm, where the interpreter must transfer its knowledge to the software, modeling the hierarchical network, in spite of error reduction and an increase of classification precision, does not eliminate totally the confusion for the identification of these types of land use.

The test *z* applied to image classifications of 2003, indicated that the null hypothesis was denied, i.e. the classifications are not similar to a random classification. This is because the Kappa 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%)
SPRING classification	0.65	0.47	14.43	4.91
Definiens classification	0.79	0.68	24.85	

At Table 5 one observes that both the global accuracy indices and the Kappa coefficient of agreement estimated for the classification made at DEFINIENS was superior that obtained for the SPRING classification (respectively, 0.68, 0.47). The *z* test applied to compare the results of both classifications also reveals the same behavior, showing that the performance of the traditional method at SPRING was inferior to that of the object-based classification, at a significance level of 1%.

5. CONCLUSION

At both dates analyzed, classifications using object-based image analysis at DEFINIENS delivered better results when compared to those ones using the traditional SPRING method. This difference is due mainly to the use of spectral attributes, such as the relational ones.

The EVI2 image of yearly maximum for 2003 was important for the classification, special for temporary crops, allowing discriminating them directly from most pastures. In some sections of new pasture areas 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.

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