CANASAT PROJECT: MONITORING OF THE SUGARCANE CULTIVATION AREA IN SOUTH CENTRAL BRAZIL

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ABSTRACT

Brazil is the world's largest producer of sugarcane and ethanol derived from this crop, which is grown in several Brazilian states. The Canasat project monitors the area under sugarcane cultivation using remote sensing satellite images. The project has collected data since 2003 for the state of São Paulo, which is the largest producer in the country, and since 2005 for five other states that altogether are responsible for 87% of the Brazilian sugarcane production. The data are available on the Canasat project website and are used by several public and private institutions connected to the sugar, ethanol and environmental sectors. The objective of this paper is to present the methodology of the Canasat project and to analyze the changes in the areas of sugarcane cultivation in south central Brazil from the 2005/06 crop year to the 2009/10 crop year. The total area available for harvest grew by 76.2% between 2005/06 and 2009/10, reaching 7.43 million ha in the most recent season. All six states showed growth in the area available for harvest each season. The state of Goiás had the highest total growth rate, while the state of Mato Grosso do Sul was the only state where the annual growth rate increased each season. The state of Mato Grosso possesses the smallest area available for annual harvest. The state of São Paulo showed the largest expansion in sugarcane cultivation area; the western portion of the state was responsible for 47% of this expansion.

1. INTRODUCTION

The production of ethanol from sugarcane in Brazil began in the 1970s with the National Ethanol Program, Proalcool. In the mid-1990s, production declined because of the low prices paid to producers and the international decline in the price of oil (Nass et al., 2007). Since 2003, however, the growing production of flex-fuel vehicles and the need to reduce production of greenhouse gases has rapidly promoted ethanol production. Currently, Brazil is the largest producer and exporter of sugarcane derivatives (Smeets et al., 2008).

Information on the production cycle of sugarcane is important for the construction of processing facilities and for the development of market strategies. Agricultural statistics are generally based on data obtained from direct interviews with the producers and technicians involved and on credit and financing information received from banks, among other sources. This process expends considerable time and money. On the other hand, time series images acquired through satellite-based remote sensing provide information that enables the operational monitoring of the production chains of diverse agricultural crops, including sugarcane, which has large areas of cultivation and an extended cultivation period (Abdell-Rahman and Ahmed, 2008).

Since 2003, the National Institute for Space Research (*Instituto Nacional de Pesquisas Espaciais* - INPE), the Industry Sugarcane Association (UNICA), the Center for Advanced Studies on Applied Economics (CEPEA) of the Luiz de Queiróz Agricultural School (Esalq/USP) and the Center for Sugarcane Technology (CTC), has maintained the Canasat project, which monitors areas under sugarcane cultivation using remote sensing satellite images and geospatial processing techniques. Initially, the state of São Paulo was mapped. In 2005, mapping was extended to five other sugarcane-producing states.

The data generated by the project are made available on the website <www.dsr.inpe.br/canasat/eng/> and have been used by private and governmental institutions to meet the demands of the sugar, ethanol and environmental sectors. Mapping of sugarcane producing areas serves as a basis for predicting and planning annual harvests and for indentifying environmental incompatibilities pertaining to the planting of sugarcane, e.g., crops located in permanent preservation areas as defined by the Forest Code.

The maps generated by the Canasat project are also used in other activities, such as monitoring harvest methods (with or without the burning of straw) and determining land use and occupation prior to sugarcane cultivation (Nassar et al., 2008; Rudorff et al., 2009). Availability of the maps at the beginning of the season enables users to plan activities related to the sector in advance. Images, maps of sugarcane production according to various classes and seasons, and locations of facilities are shown on the project website. Reports, tables and graphs can be obtained or searches performed by town, by state or by season.

The objective of this paper is to present the methodology used by the Canasat project and to analyze the changes in the areas of sugarcane cultivation in south central Brazil between 2005/06 and 2009/10. Analysis of changes in sugarcane cultivation during this period enabled the establishment of the spatial pattern of occupation and provided input data for dynamic spatial models and for the generation of future scenarios for the production of sugar and ethanol.

2. METHODOLOGY

The study area includes the states in south central Brazil monitored by the Canasat project: São Paulo, Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais and Paraná. Although south central Brazil includes ten states, the South-Central region referred to in this article includes only the six states of major sugarcane production that have an area of 2.63 million km^2, approximately 31% of the Brazilian territory. These states are responsible for more than 87% of sugarcane production in the country (UNICA, 2009). Figure 1 illustrates the location of the Brazilian states covered by the Canasat project.

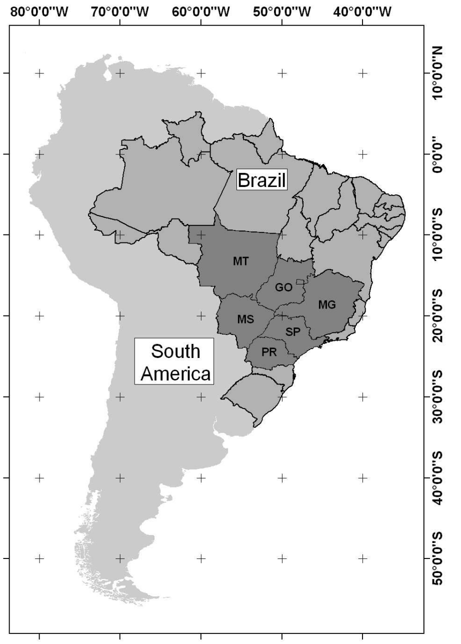

Figure 1. States monitored by the Canasat project: São Paulo - SP, Goiás - GO, Mato Grosso - MT, Mato Grosso do Sul - MS, Minas Gerais - MG and Paraná - PR.

Areas of sugarcane cultivation were identified in images from the TM/Landsat-5 sensor. As an alternative to the TM images that were obscured by cloud cover, images from the CCD (Charge Couple Device) sensor on board of the CBERS-2 and CBERS-2B satellites were used (Epiphânio et al., 2007). For each orbit/point of the TM/Landsat sensor, a database of images obtained by the two sensors on the dates of interest was created. All images were registered using first-order polynomials and nearest-neighbor interpolations based on orthorectified mosaics of TM/Landsat-7 images obtained from NASA (NASA,2007).

From the first maps generated by the Canasat project (Rudorff et al., 2005), which were produced by means of digital and visual classification of the satellite images, annual updates were made through visual interpretation of a temporal sequence of images for each crop year. In developing the map for the current season, the map from the last season was used as a basis. Two steps were followed: visual interpretation of the images and reclassification of isolated pixels. Although digital classification was used only in the first mapping, it is less relevant in updating maps for the current season because this procedure tends to commit many errors of omission and inclusion, making visual classification and editing necessary to obtain a satisfactory thematic map.

In the visual interpretation step, the matrix edit function within the SPRING program was used (Câmara et al., 1996). This function permits modification or correction of the classification results and definition of new class polygons. In this procedure, the interpreter used images from several dates contained in the database to confirm the appropriate class for each sugarcane stage. To homogenize the results, the resulting map from each database was revised by a more experienced interpreter and subsequently subjected to reclassification of isolated pixels. This technique enables the controlled and automatic correction of isolated pixels or groups of pixels that were incorrectly classified or unintentionally inserted by the interpreter.

To distinguish sugarcane from other targets, images from specific periods of the plant development were used, that is, images from dates when the sugarcane crop was well developed (January to March). Therefore, the mapping of areas to be harvested in the current season is based on images acquired prior to the beginning of the harvest season in April. However, it is more likely to acquire cloud free images from April on and, therefore, whenever necessary images from April and May were also used in the mapping procedure, especially during the revision part.

Mapping and estimation of sugarcane cultivated area available for harvest incorporated three distinct classes:

Sugarcane available for harvest – This class included areas of sugarcane that could be harvested in the current season. This class included three groups:

a) *Ratoon Cane* – This term refers to areas of sugarcane available for harvest from sprouting after first or more cuts;

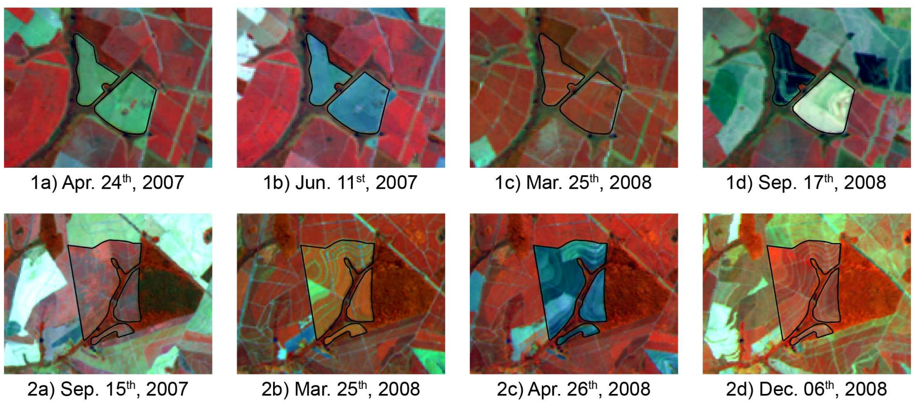

Figure 2. Temporal sequence of TM/Lansat-5 images [color composition 4(R)5(G)3(B)] illustrating the identification of areas of expansion (2.1) and under renovation (2.2).

b) *Renovated* – This term refers to areas of sugarcane that have undergone renovation during the previous crop year. In these areas, the less productive ratoons were replaced by sugarcane plants grown during a year-and-half and will be available for harvest in the current season;

c) *Expansion* – This term refers to areas that were under other land use and are now being cultivated with sugarcane and will be available for harvest for the first time.

Sugarcane under renovation – This class included areas that were cultivated with sugarcane during the previous crop season but no longer present a sugarcane patterns indicating that the area is being renewed or replaced by another land use. If theis area returns to sugarcane then it belongs to the renovation class; otherwise, it will be excluded. This class includes only sugarcane plants renewed with the year-and-half plant.

Total cultivated – This class encompassed the total area occupied by sugarcane, that is, the sum of the area of sugarcane available for harvest and the area of sugarcane under renovation.

Figure 2 illustrates a temporal sequence of TM images used in mapping of sugarcane cultivation in the various classes for the 2008/09 season. Figure 2.1 illustrates the identification procedure for areas of expansion. The region around the highlighted area was already cultivated and monitored by the project. Therefore, for this class, the map for the previous season was used as a mask, so that the interpreters analyzed only the region outside the mask. Based on the composition of the image (i.e., texture, tonality and shape), the area highlighted in Figure 2.1a shows a pattern characteristic of pasture, indicating that at the beginning of the 2007/08 season (April 2007) the area was not cultivated with sugarcane. In Figure 2.1b (June 2007), the same area shows a pattern characteristic of bare soil, indicating that it may be converted to sugarcane, available for harvest in the 2008/09 season. Figure 2.1c (March 2008) illustrates well-developed patterns characteristic of sugarcane, with tonality, texture and presence of access routes typical of this crop. In September 2008 (Figure 2.1d), the area was harvested, confirming that sugarcane was planted in 2007 and harvested in the 2008/09 season. After this area was identified as sugarcane, it was monitored in subsequent seasons, being denominated as ratoon after the first cut.

Figure 2.2 illustrates a temporal sequence of images in which the highlighted area was renovated during the 2008/09 season. In Figure 2.2a (September 2007), the area shows a pattern characteristic of sugarcane cultivation. However, it shows planting flaws and a pattern of plants with low productivity, which indicates that the sugarcane field should renewed. In Figure 2.2b, an image from March 2008, this area shows a pattern characteristic of soybean cultivation and in Figure 2.2c (April 2008) it shows a pattern of bare soil. With the image from December 2008 (Figure 2.2d) it can be confirmed that the field is again cultivated with sugarcane; however, it will be available for harvest only for the 2009/10 season.

After estimating the sugarcane area in each class, the changes in the area of cultivated sugarcane between the 2005/06 and 2009/10 seasons were analyzed for the states in the South-Central region.

3. RESULTS AND DISCUSSION

The total area of sugarcane cultivation in the South-Central Region during the most recent season analyzed (2009/10) was 7.91 million hectares (ha), of which 7.43 million ha (94%) were available for harvest. The remainder was in the process of renovation. Figure 3 illustrates the map visualization page of the Canasat website, which shows the spatial distribution of the various classes of sugarcane cultivation in the states included in the project. On this page, searches and visualizations of sugarcane area and density can be performed by municipality or by season. The boundaries of municipalities and remote sensing satellite image mosaics can also be viewed, and measurements of area and length can be performed. Figure 3 indicates a much greater concentration of sugarcane cultivation in the state of São Paulo when compared to the other states.

Figure 4a shows the change over time in the area of sugarcane available for harvest and the annual growth rate between the 2005/06 and 2009/10 seasons for the South-Central region and for each state. Between the 2005/06 and 2009/10 seasons, the area available for harvest in the South-Central region grew by 3.21 million ha, an increase of 76.2%.

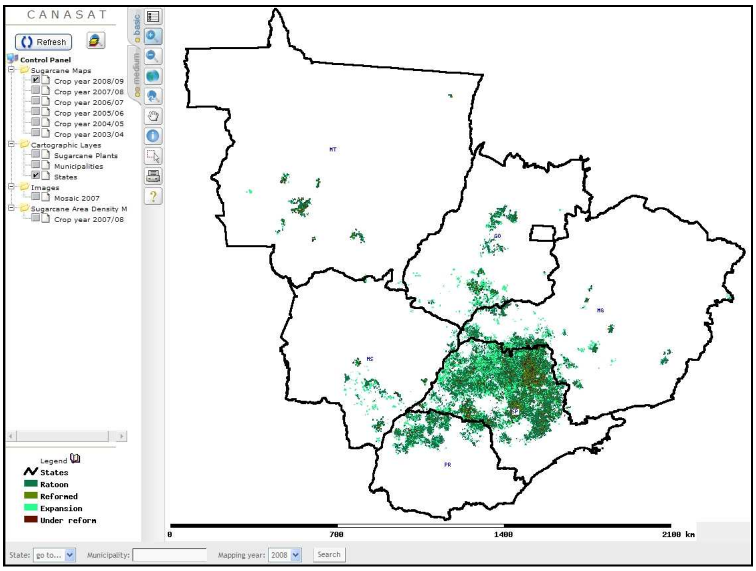

Figure 3. A sample map visualization page from the Canasat website.

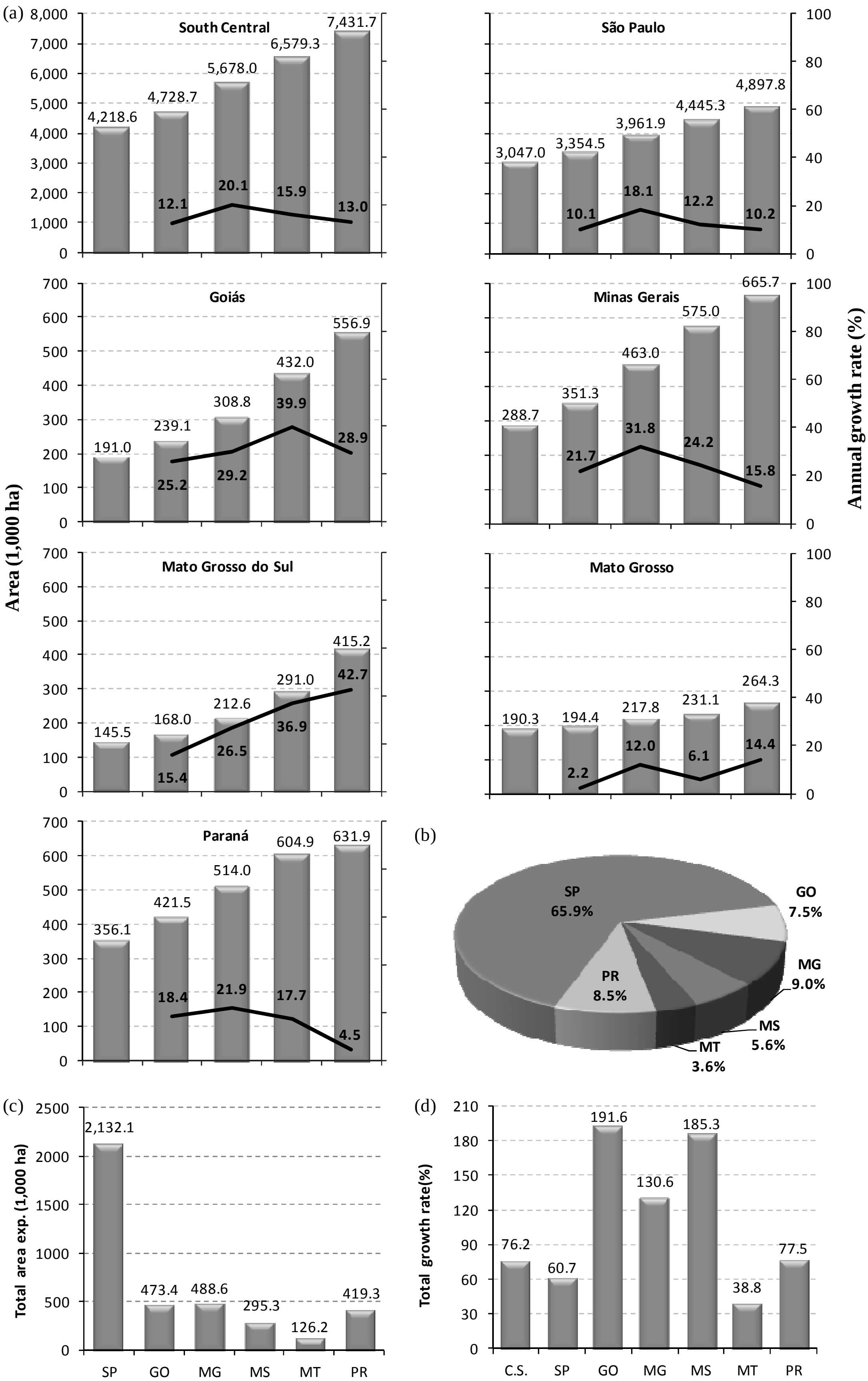

Figure 4. (a) Change over time in the area available for harvest between the 2005/06 and 2009/10 seasons for the South-Central region and for the states monitored by the Canasat project. (b) Percentage of the total area available for harvest in the South-Central region found within each state during the 2009/10 season. (c) Total area of expansion from the 2005/06 season to the 2009/10 season. (d) Total growth rate from the 2005/06 season to the 2009/10 season. S.C. = South-Central region; SP = São Paulo; GO = Goiás; MG = Minas Gerais; MS = Mato Grosso do Sul; MT = Mato Grosso; PR = Paraná.

In all states, the area of sugarcane cultivation increased in every season. São Paulo was the state with the largest area, which reached approximately 4.9 million ha during the most recent season, representing 65.9% of the total area of sugarcane cultivation in the South-Central region (Figures 4a and 4b).

The state of Mato Grosso had the smallest cultivated area and, consequently, the smallest area available for harvest, which reached 264.3 thousand ha during the most recent season, representing 3.6% of the available area in the South-Central region. Compared with the 2008/09 season, the annual growth rate declined in the 2009/10 season in all states except Mato Grosso and Mato Grosso do Sul. The latter was the only state where the annual growth rate increased in every season. Furthermore, it was the state with the greatest growth rate in the most recent season (42.7%).

The state of Goiás had the greatest total growth rate (191.6%) between the 2005/06 and 2009/10 seasons (Figure 4d), followed by the states of Mato Grosso do Sul (185.3%) and Minas Gerais (130.6%). This fact can be explained by Goiás having shown the highest growth rates in every season except the most recent, in which it had the second highest rate. The primary reason for the strong growth of the area of sugarcane cultivation in these three states was the construction of new processing facilities in these locations.

The lowest growth rate in the 2009/10 season was obtained for the state of Paraná (4.5%). This state was the second largest producer of sugarcane in the country until the 2008/09 season (Figure 4a and UNICA, 2009). However, after the 2009/10 season, Paraná lost its position to Minas Gerais, which showed a higher growth rate (15.8%). The state of Paraná is the second largest producer of soybeans in Brazil, and this crop competes with the expansion of sugarcane in the state. When the area of soybean cultivation in Paraná declined during the 2005/06 and 2007/08 seasons (CONAB, 2009), the area of sugarcane cultivation showed greater growth rates (Figure 4a). When the area of soybean cultivation increased again during the 2008/09 and 2009/10 seasons, the expansion rate of the area of sugarcane cultivation declined again. In the 2009/10 season, the area of soybean cultivation in Paraná showed its highest growth rate among recent seasons (6.0%; CONAB, 2009). This may be one of the reasons why this state showed the lowest growth rate for sugarcane cultivation in the 2009/10 season.

Although the state of São Paulo showed only the fifth highest total growth rate between the 2005/06 and 2009/10 seasons (60.7%; Figure 4d), the total area of expansion in that state was 2.13 million ha. This area is 4.4 times greater than that of the state with the second greatest expansion, Minas Gerais, where sugarcane cultivation expanded by 488.6 thousand ha. São Paulo has a much larger total cultivated area than the other states; therefore, even a low growth rate will result in a large area of expansion. Notably, the total area of expansion is the sum of the new areas of sugarcane cultivation between the 2005/06 and 2009/10 seasons. This area differs from the increase in the area available for harvest between the two seasons because it considers the variation in the areas under renovation, renovated areas, and areas that were no longer planted with sugarcane during each season.

Figure 5 illustrates the total area of expansion between the 2005/06 and 2009/10 seasons and the concentration of sugarcane in each Administrative Region (AR) of the state of São Paulo. The RAs were created by the Geographic and Cartographic Institute (IGC) of the state of São Paulo for governmental planning purposes. Each RA is made up of several municipalities within a given geographical area with economic and social similarities (http://www.igc.sp.gov.br/mapasRas.htm).

The four RAs located in the southeastern part of the state (São José dos Campos - SC, São Paulo - SP, Baixada Santista - BS and Registro- RE) do not cultivate sugarcane for agro-industrial purposes because they possess less extensive cultivated areas. These RAs present less favorable environmental conditions for the cultivation of this crop, such as high rainfall and rugged terrain (Alfonsi et al., 1987). Therefore, these RAs are not monitored by the project.

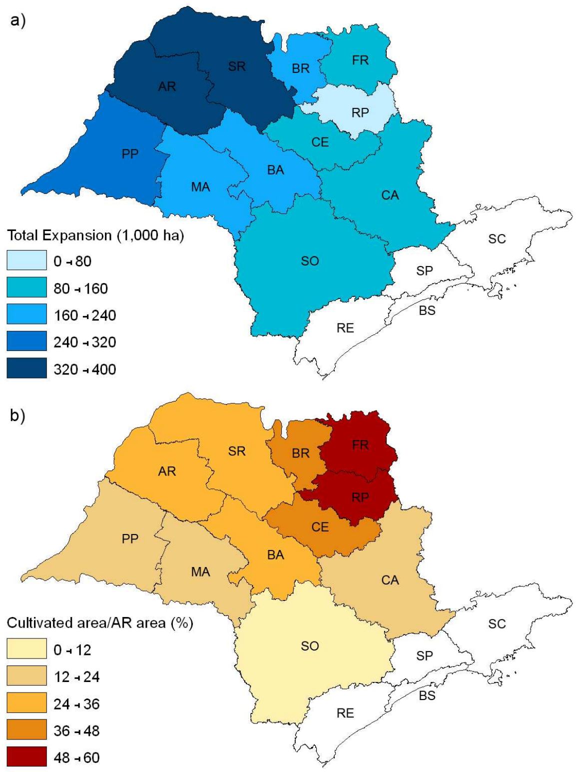

Figure 5. Total area of expansion between the 2005/06 and 2009/10 seasons (a); concentration of sugarcane (total cultivated area/RA area) for the 2009/10 season (b) in the Administrative Regions of Araçatuba (AR), Baixada Santista (BS), Barretos (BR), Bauru (BA), Campinas (CA), Central (CE), Franca (FR), Marília (MA), Presidente Prudente (PP), Registro (RE), Ribeirão Preto (RP), São José do Rio Preto (SR), São José dos Campos (SC), São Paulo (SP) and Sorocaba (SO).

The greatest expansions occurred in RAs located in the western part of the state (Figure 5a). The RA of São José do Rio Preto (SR) showed the greatest expansion (398 thousand ha) between the 2005/06 and 2009/10 seasons, followed by the RAs of Araçatuba (AR) and Presidente Prudente (PP), which showed expansions of 326 thousand ha and 282 thousand ha, respectively. These RAs were responsible for 47.2% of the expansion in the state during the analyzed period. According to Canasat data, SR and AR have been the RAs with the largest areas of sugarcane cultivation in the state since the 2008/09 season. However, the concentration of sugarcane in these RAs is not high, remaining between 24% and 36% (Figure 5b). Thus, these RAs have potential for further expansion of sugarcane cultivation. Furthermore, Western São Paulo state has a tradition of extensive cattle farming, but many cattle farmers have been changing their production and management strategies, restoring degraded pastures and adopting confinement systems. These changes make new areas available for the cultivation of sugarcane (Torres et al., 2009). Nassar et al. (2008) have also demonstrated that in the state of São Paulo, new areas of sugarcane cultivation mostly occupy areas that were previously occupied by pastures.

The north central part of the state has a stronger tradition of sugarcane cultivation and ARs of small territorial extent. For this reason, concentrations of sugarcane are high, especially in the ARs of Ribeirão Preto (RP) and Franca (FR) (Figure 5b). This explains the low expansion observed in these ARs. For example, RP provided only 2.7% of the total area of expansion for the state during the analyzed period.
The AR of Sorocaba has the lowest concentration of sugarcane cultivation because, in addition to being the AR with the largest territorial extent, it has the smallest cultivated sugarcane area.

4. FINAL CONSIDERATIONS

The methodology used by the Canasat project allowed to monitoring the cultivated sugarcane area in south central Brazil, making it possible to determine, by means of remote sensing satellite images, newly cultivated areas, areas under renovation and areas available for harvest during each season. The south center region represents almost one third of the Brazilian territory and has by far the greatest potential for sugarcane cultivation expansion and the use of remote sensing techniques to monitor this expansion and the land use cover change is very relevant for a sustainable ethanol production as an alternative to reduce green house gas emissions.

A total of 7.91 million hectares are currently under sugarcane cultivation in the South-Central region, of which 7.49 million hectares are available for harvest during the 2009/10 season. Between the 2005/06 and 2009/10 seasons, the area of sugarcane cultivation increased in all states monitored by the project. The state of Mato Grosso do Sul showed an increase in annual growth rate in every season analyzed and the highest rate in the most recent season. However, the state of Goiás had the highest total growth rate.

The state of São Paulo showed the largest area of expansion in across the seasons analyzed, with the western part of the state being responsible for most of this expansion. The north central part of the state, with a longer tradition of sugarcane cultivation, had the highest concentrations of this crop and the smallest areas of expansion.

Data generated by the Canasat project are available on its website and are relevant to several sectors that require specialized information about the area of sugarcane cultivation according to the various classes.

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