CANASAT PROJECT: MONITORING THE SUGARCANE HARVEST TYPE IN THE STATE OF SÃO PAULO, BRAZIL

Daniel Alves de Aguiar[1], Wagner Fernando da Silva[1], Bernardo Friedrich Theodor Rudorff[1], Marcos Adami[1]

[1]National Institute for Space Research (INPE), Remote Sensing Division (DSR),
São José dos Campos, 12227-010, São Paulo State, Brazil.
{daniel; wagner; bernardo, adami}@dsr.inpe.br

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ABSTRACT

In order to increase the sustainability the ethanol production process from sugarcane, it is necessary to reduce actions that harm the environment. One of these actions is the burning of sugarcane straw prior to harvest. In Brazil, agro-environmental protocols between the government and the sugar-ethanol sector have been signed. The agro-environmental protocol in the state of São Paulo requires the total termination of burning by 2017. To meet the objectives of the protocol, remote sensing satellite images are used to monitor and inspect the burning reduction each season. Using satellite images, the Canasat project has mapped the harvesting method (with or without burning) in the state of São Paulo since the 2006/07 season. The objective of this study is to present the methodology utilized and to evaluate the evolution of the harvesting method between the 2006/07 and 2008/09 seasons. The harvest type was also evaluated for each declivity class. Results demonstrated that the unburnt harvest increased from 50.9% in the 2006/07 season to 65.8% in the 2008/09 season. In the three seasons analyzed, approximately 97% of the total area available for harvest in the state is located in areas with a favorable declivity for harvesting without burning, i.e., mechanically. The western region of the state had the greatest expansion in sugarcane cultivated area and also the largest increases in areas of unburnt harvest.

1. INTRODUCTION

Brazil is the world's largest producer of sugarcane FAO (2009). Industrial-scale production occurs primarily in the states located in the Northeast and South-Central regions of the country. The state of São Paulo, in the South-Central region, is the largest producer in the country and was responsible for 61% of Brazil's sugarcane production in the 2008/09 season (UNICA, 2009).

The country is attempting to achieve sustainable ethanol production and to obtain its socio-environmental certification (Goldemberg, 2007; Goldemberg et al., 2008). One of the principle goals in this endeavor is to terminate the burning of sugarcane straw prior to harvest. Therefore, in 2007, São Paulo's State Secretary for the Environment (SMA) and representative in the sugar-energy sector signed the agro-environmental protocol for the sugar-ethanol sector. This protocol decrees, among other measures, ending the burning of sugarcane straw by 2014 in areas that are mechanically harvested (declivity less than or equal to 12%) and by 2017 in areas that are harvested non-mechanically (declivity greater than 12%; http://homologa.ambiente.sp.gov.br/etanolverde /english.asp). It is worth to mention that manual harvest of sugarcane can only be performed by burning the straw.

The implementation of this protocol has contributed to increasing the monitoring and inspection capacity of the sugar-energy sector. Using remote sensing satellite images, information can be obtained at multiple time-points, and therefore providing a monitoring system for the sugarcane production process. Furthermore, this crop is generally grown in large areas and possesses a long phenological cycle and a long harvest period, averaging 12 months and 8 months, respectively. These characteristics facilitate crop identification in the images (Abdel-Rahman and Ahmed, 2008).

In Brazil, 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 Queiroz Agricultural School (Esalq/USP) and the Center for Sugarcane Technology (CTC) have maintained the Canasat project (www.dsr.inpe.br/canasat/eng/). Using remote sensing imagery and geoprocessing techniques, the Canasat project monitors areas planted with sugarcane. Initially, mapping was performed only in the state of São Paulo (Rudorff et al., 2005), however since 2005, mapping has been extended to the other five states in the South-Central region of Brazil (Rudorff and Sugawara, 2007). These six states are responsible for 72.7% of Brazil's sugarcane production.

One of the project activities, in the state of São Paulo, is to monitor the type of harvest (with or without burning the sugarcane straw) performed since the 2006/07 crop season. Information provided by the project has been utilized by both the government and private groups. Beginning with the 2009/2010 crop season, maps depicting the type of harvest are generated monthly and sent to the SMA of São Paulo State. The SMA inspects these maps to determine if the straw burning has been authorized.

The objective of this study is to present the methodology of the Canasat project, including the monitoring of the harvesting method, and to analyze the evolution of the harvest areas with and without straw burning from the 2006/07 to the 2008/09 crop season. The maps generated by the project may serve as a basis for greenhouse gas emission models (Lara et al., 2005), carbon storage in silos (Galdos et. al., 2009), public health studies (Ribeiro, 2008) and as an aid to public policy in the agricultural sector (Moraes, 2007). These maps also allow evaluating the area of harvestable sugarcane that was not harvested due to weather or industry constrains which is essential information for accurate yield estimation.

2. METHODS

Identification of the harvesting method, either burning or not burning the sugarcane straw, is currently performed in the state of São Paulo, the largest producer of sugarcane in Brazil. São Paulo is located in Southeastern Brazil and has an area of 248,209 km^2. Figure 1 shows the location of São Paulo State and the area of sugarcane available for harvest in 2008/09.

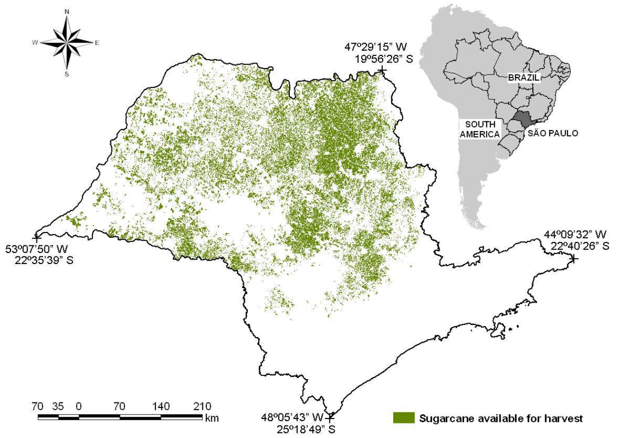

Figure 1. Location of the state of São Paulo within Brazil as well as the area containing harvestable sugarcane in the 2008/09 crop year.

The identification of the harvesting method was performed by a visual interpretation of TM (Thematic Mapper) sensor images taken from the Landsat-5 satellite. In the case of cloud cover on the TM images, CCD (Charge-Coupled Device) sensor images taken from the CBERS-2 and CBERS-2B satellites were used as an alternative (Epiphanio et al., 2007). For each orbit point of the TM and CCD sensors, a database was created with the data of interest from the images obtained by the two sensors. All images were registered based on the orthorectificated mosaics from TM/Landsat-7 images obtained by NASA (NASA,2007) utilizing a first degree polynomial and nearest neighbor interpolation.

Monitoring of the harvest type is only possible after producing a map of available sugarcane for harvest. This is then utilized as a mask for the remote sensing images and allows monitoring only the sugarcane areas that available for harvested in the current crop year. This map is prepared by the Canasat project at the beginning of each crop season.

In contrast with other agricultural crops, sugarcane has a long harvest season, lasting from April to December. The remote sensing images allow to identify the harvesting method, either burning or not burning the sugarcane straw, because the areas where sugarcane is harvested after burning present dark tones in response to soil exposure (Stoner and Baumgardner, 1981). Areas harvested without burning present bright tones because the ground is covered by dry leaves (Figure 2.1) (Aguiar et al., 2009). In Figures 2.5 and 2.6, field photos of recently harvested areas without straw burning and with straw burning, respectively, can be seen. Both the accumulation of straw after harvest and soil exposure from burnt straw may be observed in these figures.

Over time, the correct identification of the harvest method becomes less clear. Both weather and post-harvest agricultural practices such as the burning of straw in the field after harvest are the major factors that affect this identification (El-Hajj et al., 2009). Figure 2.2 illustrates an area with plots harvested on different dates. The difference in time and the use of different post-harvest agricultural practices create changes in the color and characterization of these plots, (which are differentiated in the image). However, all plots were harvested without burning.

Figure 2.3a shows an image acquired in July of 2008 in which it is possible to observe an area harvested without burning. This same area, in September of 2008, possesses dark tones due to either the straw being burnt following the harvest or due to the soil being exposed (Figure 2.3b). Therefore, the less time that has elapsed between the harvest time and the image acquisition, the more likely it is to correctly identify the harvesting method.

Declivity is a limiting factor for mechanical harvest. For this reason, in many crop fields, harvesting is performed using both methods. In the part of the field where the declivity is over 12%, burning is still used; however, in the part of the field with lower declivity the mechanical harvest is performed. Figures 2.4a and 2.4b illustrate this situation in a sequence of two dates; in the dark plots, with a high declivity, a manual harvest was performed (after burning), and in the light areas, with a declivity of less than 12%, the sugarcane was harvested mechanically (without burning). It should be noted that Figure 2.4b shows the presence of some clouds.

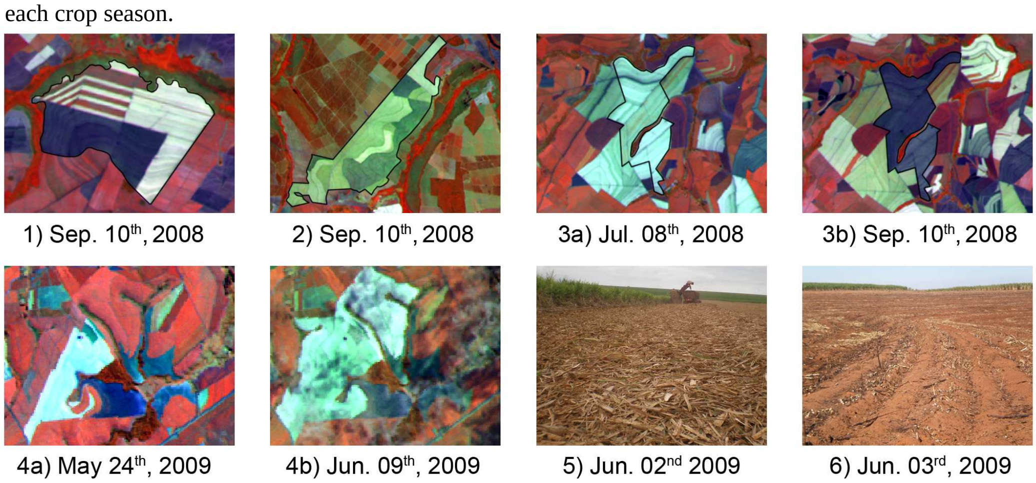

Figure 2. Temporal sequence of TM/Lansat-5 images, color composition 4(R)5(G)3(B), illustrating different harvest types (2.1 and 2.2), the change in harvest characteristics caused by post-harvest agricultural practices (2.3a and 2.3b), different harvest types due to declivity (2.4a and 2.4b), and field photos of recently harvested areas without straw burning and with straw burning (2.5 and 2.6).

A visual interpretation of the images was performed by trained interpreters in two stages: (i) the images were evaluated in chronological order, and at the moment in which an area was identified as harvested, it was assigned to the pertinent thematic class; (ii) after the visual interpretation was performed by the several interpreters, all the resultant maps were revised by a single interpreter (the reviser) to guarantee homogeneity of the interpretations.

Next, a mosaic (thematic map) was generated for the entire harvested sugarcane area in the state of São Paulo for the 2008/09 season. A declivity map, generated from the SRTM images, using the methodology described by Valeriano et al. (2006), was utilized to identify areas for mechanical harvest (≤12% declivity) and areas of non-mechanical harvest (>12% declivity). The intersection between the two maps permitted the evaluation of the different harvest modes by declivity.

3. RESULTS AND DISCUSSION

The total harvested area increased 20.9% (680 thousand ha) from crop year 2006/07 to 2008/09. This increase is a consequence of the expansion occurring in the state of São Paulo during this time period. Table 1 summarizes the total area harvested with and without burning, the unharvested areas for the three harvest years, and the harvest type for each declivity class. During the 2007/08 season, 5.6% of the total available area for harvest (220.871 ha) could not be evaluated due to cloud cover obscuring the images.

In the 2006/07 season, the area harvested by burning was 1.02 million hectares greater than the area harvested without burning. In the 2008/09 season this difference was 73.6 thousand hectares, which represents an increase of 73.1% in the harvested area without burning between these two seasons (Table 1a). Therefore, the percentage of the total area harvested with burning decreased each season, from 65.8% in 2006/07 to 50.9% in 2008/09. Despite the fact that the overall harvested area without burning increased considerably, the area harvested with burning did not show a considerable reduction. This indicates that, the majority of newly cultivated areas are harvested without burning. The limiting factor for the conversion of the harvest method is that the plots must be prepared for the harvesting machines. This requires adequate planting lines, and in addition, many areas have a declivity greater than 12%. Also, the vegetative cycle of sugarcane is approximately 6 to 7 years, and farmers do not reform the plots until the end of this period. Therefore, the plots currently harvested with the burning method should be gradually converted to non-burning plots or eliminated for sugarcane production if declivity is >12%.

The total unharvested area increased each season, reaching 11.6% of the total available area for harvest in the 2008/09 season (Table 1a). The principle reason for this fact is that the ethanol plants under construction presented significant delays to enter in operational activity. Also, unfavorable weather conditions during the harvest season reduced the harvesting capacity (Aguiar et al., 2007).

When considering the declivity classes, in the entire state, approximately 97% of the available area for harvest during the three seasons was located at a declivity of ≤12% (which allows for mechanical harvesting) (Table 1b). However, harvesting with burning was predominant, especially in the areas with a declivity >12%. In this declivity class, harvesting is performed manually; therefore, the straw has to be burned to easy the harvest.

Table 1. Total area of sugarcane harvested (a) per declivity class (b and c) without and with burning and the unharvested area, for the seasons of 2006/07 to 2008/09. The percentages in relation to without and with burning refer to the total harvested area while the percentage of unharvested sugarcane refers to the total available area for harvest at the beginning of each season.

(a)

Year Season	Harvest type					
	Without burning		With burning		Unharvested	
	(ha)	%	(ha)	%	(ha)	%
2008/09	1,928,561	49.1	2,002,215	50.9	514,502	11.6
2007/08*	1,667,502	46.6	1,909,235	53.4	164,321	4.1
2006/07	1,113,855	34.2	2,138,408	65.8	102,208	3.0

(b)

Year Season	Declivity ≤12%					
	Without burning		With burning		Unharvested	
	(ha)	%	(ha)	%	(ha)	%
2008/09	1,891,845	49.7	1,917,719	50.3	494,307	11.5
2007/08*	1,630,825	47.0	1,835,907	53.0	158,960	4.1
2006/07	1,089,812	34.7	2,055,017	65.3	98,877	3.0

(c)

Year Season	Declivity >12%					
	Without burning		With burning		Unharvested	
	(ha)	%	(ha)	%	(ha)	%
2008/09	36,715	30.3	84,496	69.7	20,195	14.3
2007/08*	37,132	33.8	72,763	66.2	5,367	4.2
2006/07	24,043	22.4	83,392	77.6	3,331	3.0

* For the season 2007/08, a total of 220,871 ha, 5.6% of the total area available for harvest could not be evaluated because of cloud cover obscuring the images.

On the other hand, an analysis of the three seasons indicates that the percentage of the area harvested without burning increased each season. The areas harvested without burning reached 49.7% in the 2008/09 season in areas with a declivity ≤12%. The same was not true in sugarcane areas with a declivity >12%. In these areas, the harvest without burning was greater in the 2007/08 season than in 2008/09 and harvesting with burning increased in the last analyzed season (Table 1c). A total of 11,993 ha could not be evaluated in areas with a declivity >12% in the 2007/08 season. If we postulate that this area was harvested with burning, the percentages of the harvesting method for the 2007/08 season at a declivity of >12% would be modified to 69.5% with burning and 30.5% without. Therefore, even in this situation, the percentage of the area harvested with burning increased slightly in the 2008/09 season in relation to the 2007/08 season, and the percentage of the area harvested without burning decreased.

Despite the fact that the percentage of sugarcane cultivated in declivities >12% is low (3%), the percentage of unharvested sugarcane in this class for the 2008/09 season was greater than in declivities ≤12%.

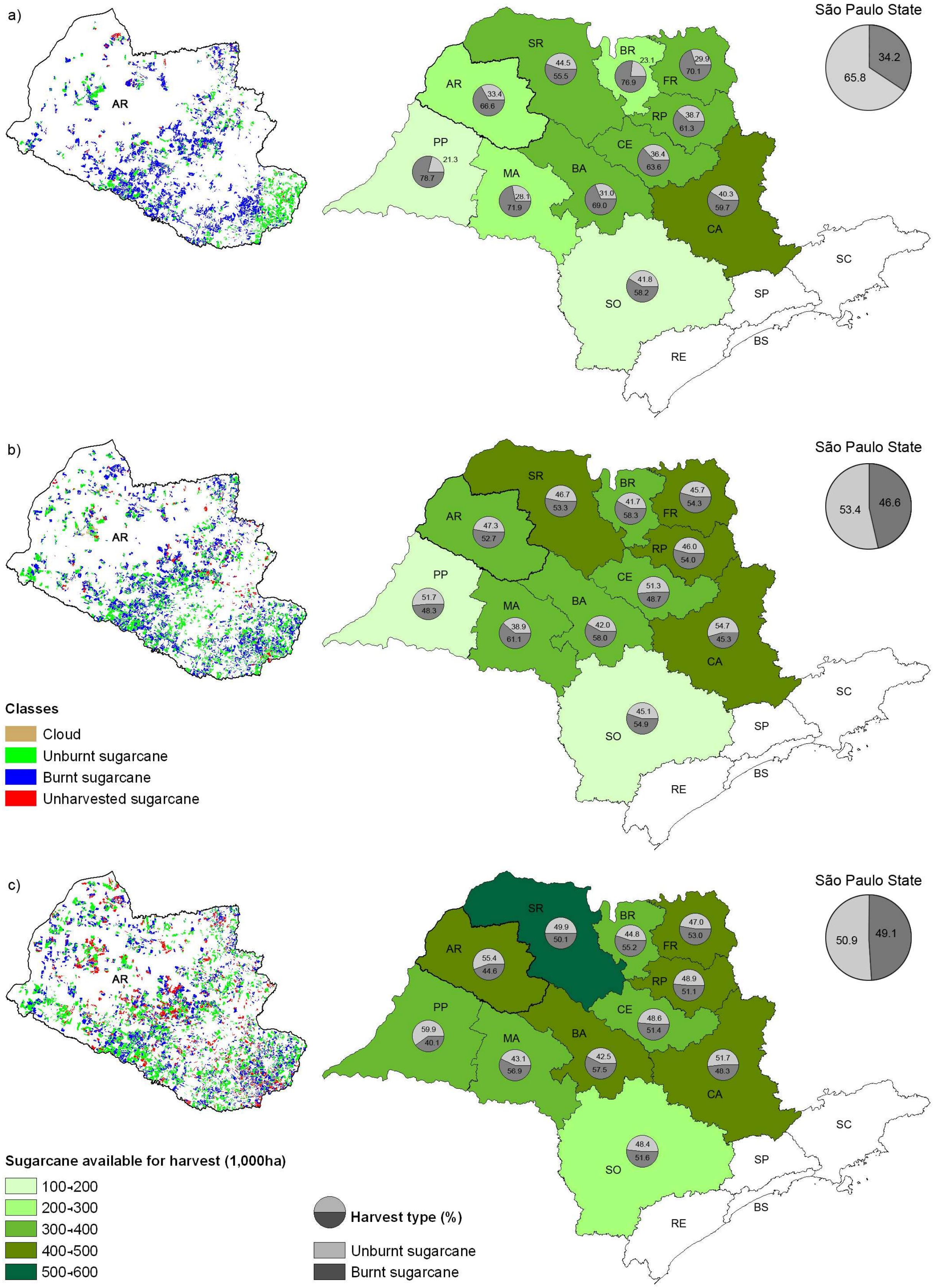

Figure 3. Area available for sugarcane harvest, the percentage of each harvest type (with or without burning) for the Administrative Regions (RA) of the state of São Paulo for the seasons of (a) 2006/07, (b) 2007/08 and (c) 2008/09 and localization of the harvest areas (with and without burning) and the unharvested areas for the RA of Araçatuba (AR). RAs: 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).

According to Lara et al. (2005), approximately 20 tons of dry sugarcane material is burnt per hectare, contributing to approximately 0.48 Tg of carbon per year in global emissions. Soares et al. (2009) stated that sugarcane harvested without burning eliminates methane (CH_4) and nitrous oxide (N_2O) emissions totaling 1.72 tons in carbon dioxide equivalent per hectare. This diminishes the total greenhouse gas emissions produced during sugarcane harvest by approximately 80%. Therefore, a reduction of 136,193 ha harvested with burning reduced carbon dioxide equivalent emissions by 234.2 thousand tons. Postulating that by 2014 all areas that are mechanically harvested will have attained the goals stipulated by the agro-environmental protocol, the harvests will be performed without burning and the newly planted areas will also be harvested without burning, a minimum of 3.29 million tons of carbon dioxide equivalent per year will not released into the atmosphere. By 2017, when no sugarcane areas will burnt for harvest this figure will be even greater (3.44 million tons of carbon dioxide equivalent per year).

Figure 3 shows the area available for sugarcane harvest and the percentage of each harvest type for the Administrative Regions (AR) of the state of São Paulo for the 2006/07 to 2008/09 seasons. It also illustrates the location of the areas of each harvest type for the AR of Araçatuba. The ARs were created by the Geographic and Cartographic Institute of São Paulo (IGC) for governmental planning. Each AR is composed of several municipalities within a specific geographic area with economic and social similarities (http://www.igc.sp.gov.br/mapasRas.htm).

The four ARs located in the southeast region of the state (São José dos Campos, São Paulo, Baixada Santista and Registro) possesses less extensive cultivated areas and therefore do not produce sugarcane for the agroindustrial sector. This is because they possess less favorable environmental conditions for the cultivation of sugarcane, such as greater rates of rainfall or unfavorable for mechanization (Alfonsi et al., 1987). Therefore, these ARs are not monitored by the Canasat Project.

All of the ARs showed an increase in area available for sugarcane between the 2006/07 and 2008/09 seasons. This can be verified by the change in class in Figures 3a, 3b and 3c, with the exception of the Central AR in which there was an increase in area without a change in class. The ARs of São José do Rio Preto and Araçatuba were the only ARs that changed class each season, demonstrating a large expansion in cultivated sugarcane area between the analyzed seasons. São José do Rio Preto had the greatest area available for harvest in the 2008/09 season, representing 12.8% of the total area available in the state.

All ARs had increases in the percentage of unburnt harvested area between the seasons of 2006/07 and 2008/09 except for Campinas and Central. These two ARs significantly increased their percentages in the 2008/09 season in relation to that of 2007/08 (Figure 3). The largest change in harvest type occurred in the AR of Presidente Prudent where 21.3% of the harvested areas in the 2006/07 season were harvested without burning and this percentage increased to 59.9% in the 2008/09 season. This AR had the greatest percentage of burnt harvest in the 2006/07 season (78.8%) and in the 2008/09 season it was the AR with the lowest percentage of burnt harvest (40.1%). In contrast, Bauru was the AR with the greatest percentage of burnt harvest (57.5%)

Araçatuba also showed a large change in the percentage of unburnt harvest, increasing from 33.4% in the 2006/07 season to 55.4% in the 2008/09 season (and was the AR with the second largest percentage of unburnt harvest in the last season). This change can be seen in Figure 3, in which this AR is highlighted with the localization of burnt and unburnt harvests. In the 2006/07 season the high percentage of burnt harvest (blue) can be seen, while in the 2008/09 season the majority of harvested areas are unburnt (green; there is also an increase in unharvested sugarcane).

4. FINAL CONSIDERATIONS

The use of remote sensing satellite images allowed evaluate the sugarcane harvest type, burnt and unburnt, in the state of São Paulo over the course of three seasons. Data generated by the Canasat Project demonstrated that the harvest type in the state has changed over the seasons due to governmental pressure to increased sugarcane harvest mechanization. In the 2006/07 season, 50.9% of the state's sugarcane harvest was unburnt, and this percentage increased to 65.8% in the 2008/09 season. All of the Administrative Regions in the state, except for two, showed reductions in the percentage of burnt areas. The two exceptions showed a small increase in the 2008/09 season compared to that of 2007/08. Western São Paulo is confirmed as the region with greatest expansion and also the region with the greatest increases in unburnt harvest.

For the three analyzed seasons, approximately 97% of the total area available for harvest in the state of São Paulo was located in declivities <12%; therefore, allowing mechanical harvest. The spatial analysis of the harvest type allows to establish local and regional monitoring and inspection to evaluate the effectiveness of the agro-environmental protocol to reduce and ultimately cease the pre-harvest burnt practice of sugarcane fields.

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