Ciencia e Investigación AGRARIA

Cien. Inv. Agr. 37(1):113-121. 2010
www.rcia.uc.cl

RESEARCH PAPER

# Temporal analysis of the reduction in gas emission in areas of mechanically-harvested sugarcane using satellite imagery

Christiano Luna Arraes[1], Jesús Camacho-Tamayo[2], Teresa Tarlé Pissarra[3], Célia P. Bueno[1], and Sergio Campos[4]

[1]Departamento de Suelos y Abonos and [3]Departamento de Ingeniería Rural, Facultad de Ciencias Agronómicas y Veterinarias, Universidad Estatal Paulista, Jaboticabal, SP, Brasil. [2]Programa de Ingeniería Agrícola, Universidad Nacional de Colombia, Sede Bogotá, Colombia. [4]Departamento de Ingeniería Rural Facultad de Ciencias Agronómicas y Veterinarias, Universidad Estatal Paulista, Botucatu, SP, Brasil.

**Abstract**

**C. Luna Arraes, J. Camacho-Tamayo, T. Tarlé Pissarra, C.P. Bueno, and S. Campos. 2010. Temporal analysis of the reduction in gas emission in areas of mechanically-harvested sugarcane using satellite imagery. Cien. Inv. Agr. 37(1):113-121.** The primary objective of this study was to estimate the amount of gas not emitted into the air in areas cultivated with sugarcane (*Saccharum officinarum*) that were mechanically harvested. Satellite images CBERS-2/CCD, from 08-13-2004, 08-14-2005, 08-15-2006 and 08-16-2007, of northwestern São Paulo State were processed using the Geographic Information System (GIS)-IDRISI 15.0. Areas of interest (the mechanically-harvested sugarcane fields) were identified and quantified based on the spectral response of the bands studied. Based on these data, the amount of gas that was not emitted was evaluated, according to the estimate equation proposed by the Intergovernmental Panel on Climate Change (IPCC). The results of 396.65 $km^2$ (5.91% for 2004); 447.56 $km^2$ (6.67% for 2005); 511.54 $km^2$ (7.62% in 2006); and 474.60 $km^2$ (7.07% for 2007), calculated from a total area of 6,710.89 $km^2$ with sugarcane, showed a significant increase of mechanical harvesting in the study area and a reduction of gas emissions of more than 300,000 t $yr^{-1}$.

**Key words:** Geographic information system, orbital image, remote sensing, *Saccharum officinarum*.

## Introduction

Sugarcane (*Saccharum officinarum* L.) is one of the main agricultural products of Latin America, with fields covering an area of 89,336 $km^2$. The main Latin American producers are Brazil (56,317 $km^2$), Mexico (6,400 $km^2$) and Colombia (4,317 $km^2$), with a mean yield of 73.91; 75.58 and 92.69 t $ha^{-1}$, respectively (FAO, 2008). Until a few years ago, the harvesting system for sugar and alcohol production included burning the foliage before the sugarcane was cut, with the consequent emission of ashes and combustion gases. These gases contribute to the greenhouse effect and global warming, due to the increase of the concentrations of carbon dioxide ($CO_2$), nitrous oxide ($N_2O$) and methane ($CH_4$).

In the agricultural sector, the emission of greenhouse gases can be reduced by avoiding the burning of foliage through the use of me-

Received 27 April 2009. Accepted 14 August 2009.
Corresponding author: christianoarraes@yahoo.com.br

chanical harvesters. This also contributes to improved soil properties by favoring carbon sequestration.

In Latin America, Brazil is one of the countries where policies have been implemented to abolish burnings in sugarcane plantations. Some regions have established specific standards to eliminate burnings, including the states of Mato Grosso do Sul, Goiás, Paraná and São Paulo. On September 19, 2002, Law 11.241 was enacted in the State of São Paulo, which created a gradual schedule for reducing sugarcane burning. This law, initiated in 2002, mandates that the practice of burning must be completely eliminated by 2021 in mechanizable areas, and by 2031 in non-mechanizable areas with slopes greater than 12% (Moraes, 2007).

Due to increasing and easy-to-access information from remote sensing, and the recent incorporation of new sensors with higher spatial, temporal and spectral resolutions, a better understanding of the anthropic processes acting on the terrestrial system are now possible. Remote sensing, along with geoprocessing techniques, has the potential to monitor agricultural activities and supply reliable and objective information on sowed areas and the productivity of crops (Terres *et al*., 1995; Ippoliti-Ramilo *et al*., 1999; Rizzi, 2004).

According to Sanches (2004), agricultural lifts obtained from remote sensing data are precise and objective, and along with a more detailed knowledge of the spectral behavior of the crops, allow for better data processing and analysis. Price (1999) showed that the combined use of these data can be used to explore areas of soil use and occupation.

The satellite, CBERS-2, features a synchronic orbit with the sun at 778 km, completing 14 revolutions a day around the Earth. This orbit allows the satellite to cross the Equator at 13:30 GMT (10:30 a.m., local time in Brazil), thus capturing the same conditions of sun illumination to enhance comparison of images acquired during different seasons (INPE, 2008).

A High Resolution Camera (Couple Charged Device-CCD) with a high spatial resolution (20 m) takes data from the same area every 26 days, in five spectral channels: the blue region B1 (450 to 520 nm), the green region B2 (520 to 590 nm), the red region B3 (630 to 690 nm), the infrared region B4 (770 to 890 nm) and the panchromatic region B5 (510 to 730 nm). Each image covers an area of 113 $km^2$. These images may be applied in agricultural studies to identify production zones, quantify areas of interest, monitor the behavior of agricultural expansion, quantify irrigation pivots, and estimate production (INPE, 2008).

It is fundamentally important to carry out a georeference of satellite images that is appropriate for the objective of a study, in order to determine the localization of an image or vector file in the space, as defined by a reference system of known coordinates (Eastman, 1998). An important figure to be considered is the root mean square (RMS) of the georeference for each image, as mistakes may lead to incorrect conclusions if studies are done using a temporary scale. According to the Brazilian Cartographic Pattern of Accuracy (PEC) decree 89.817/1984, the error can have a maximum of 25 m for a 1:50,000 scale.

Considering the importance of sugarcane production and the use of tools for monitoring agricultural production in the world, the objective of our study was to identify and quantify sugarcane areas with mechanical harvesting, as well as to estimate the amount of gases not emitted due to the absence of foliage burning. This study includes the years 2004 to 2007 and covers the northwest region of the State of São Paulo, Brazil.

## Materials and methods

### *Area of study*

The area of study covered 6,711 $km^2$, located in the Northwest region of the State of São Paulo (22º 43’ 38” to 22º 57’ 39” latitude S, and 48º

17' 34" to 48º 26' 28" longitude W). This area features a tropical climate, with an annual mean precipitation of 1,200 mm and a mean temperature of 22 ºC during the summer and 18ºC during the winter. The altitude is between 578 and 722 m. The main forms of soil use and occupation are as pastures and for the growth of sugarcane and citrus fruits.

*Image collection and processing*

To construct a cartographic base of the study area, images from satellite CBERS-2 in TIFF format were obtained and converted to GEOTIIF format using the geographic information system (SIG)-IDRISI-15.0. This geoprocessing tool was used to obtain a visual analysis of the areas where sugarcane is mechanically harvested. The data collected by the CCD sensor (CCD High Resolution Camera) of satellite CBERS-2, in the color bands 3 (red), 4 (near infrared) and 2 (green) were used to identify and quantify these areas.

The satellite images used were taken on August 13, 2004; August 14, 2005; August 15, 2006 and August 16, 2007, corresponding to orbit 156, point 127 of the satellite. These dates captured images of the zone of study under similar conditions, and because low or no cloudiness is characteristic in August, this guaranteed good quality images as well as the same level of comparison. The harvest zone of sugarcane, when collected mechanically, shows clear tones in the color composition (Figure 1), but when harvested manually, shows bluish tones (Figure 2).

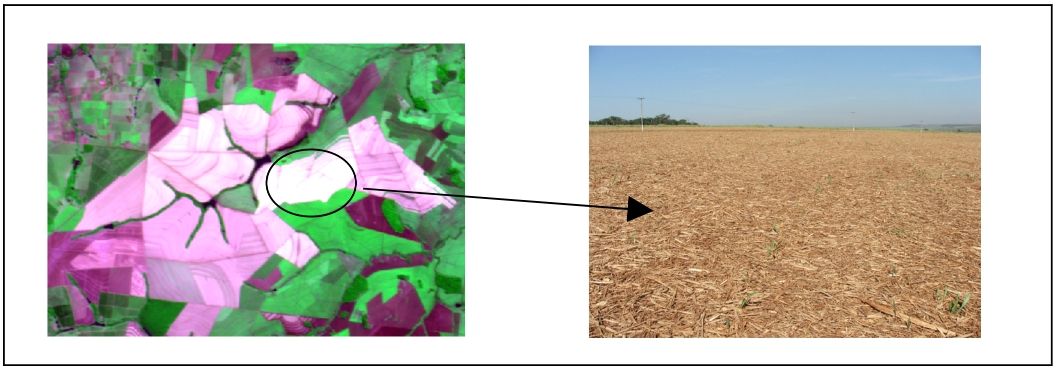

**Figure 1**. Spectral behavior of sugarcane areas with mechanical harvesting. Color composition 342 RGB (left) and image obtained in the field (right).

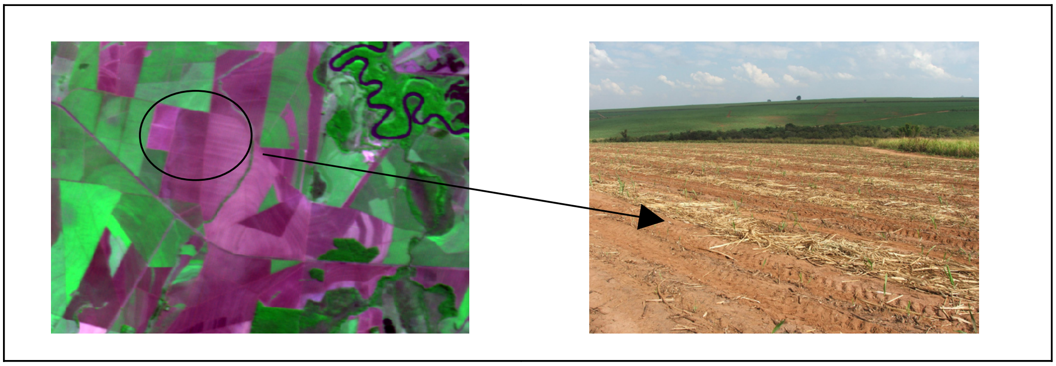

**Figure 2.** Spectral behavior of the sugarcane areas harvested manually. Color composition 342 RGB (left) and image obtained in the field (right).

This difference is due to the presence of harvest residues that are distributed uniformly in the soil during mechanical harvesting. In manual harvesting, the residues remaining at the surface do not cover the soil completely, and previous burning of sugarcane may reduce the amount of residues, increasing the proportion of exposed soil.

Therefore, before generating the tone composition for each year, a georeference of bands 2, 3 and 4 was elaborated separately using the "Reformat/Resample" module of the SIG-IDRISI-15.0. We used topographic maps scanned at 300 dpi of the municipalities of Jaboticabal (SF-22 -X-D-III-3), Taiúva (SF-22-X-D-III-1) and Ribeirão Preto (SF-23-V-C-I-I) in the State of São Paulo, at a 1:50.000 scale, and georeferenced the UTM projection (Universal Transversa de Mercator) with the horizontal Datum of the Corrego Alegre-22 Sur municipality.

In the process of geometric correction of the digital images, 150 points were identified, distributed over the image surface. These points must be perfectly visible in both the image and in the topographic maps to allow a good band georeference. The geometric correction was confirmed in field using the Navegación Garmin eTrex Vista Global Positioning System (GPS).

After the georeference was established, several points were used to outline the areas of study (mechanically-harvested sugarcane fields), in order to cover the maximum area possible on the colored georeferenced image.

Next, a spectral review was created using the "Makesig" module, and classification was made using the "Piped" module. In the classification, soil with harvest residues due to mechanical harvesting was identified and differentiated. The areas differentiated were outlined with polygons on the image, creating a reference file for each category of use and occupation of soil. Then, the images were classified based on these data. Uncertain areas were confirmed in the field, with the use of GPS.

*Quantification of surfaces cultivated with sugarcane*

The sugarcane areas with mechanical harvesting were quantified for the years of study (2004, 2005, 2006 and 2007) using the "area" command in the "Database Query" module. Based on these data, the amount of gases not emitted was estimated, by the following the Equation, as proposed by the Intergovernmental Panel on Climate Change (IPCC, 2006).

$$G_E = A * M_Q * F_C * F_E * 10^{-3}$$

where, $G_E$: amount of gases emitted resulting from burning ($CO_2$, $CH_4$, $N_2O$); A: burned area, ha; $M_Q$: mass used for combustion, t ha$^{-1}$; $F_C$: combustion factor, and $F_E$: emission factor, g kg$^{-1}$ of burned dry matter.

For sugarcane, according to IPCC (2006), $M_Q$ is 6.5 t ha$^{-1}$, equivalent to the burned residues before harvest; $F_C$ is 0.80 for the gases emitted by combustion, and therefore, $F_E$ is 1,515 g kg$^{-1}$ for $CO_2$, 2.7 g kg$^{-1}$ for $CH_4$ and 0.07 g kg$^{-1}$ for $N_2O$.

## Results and discussion

Initially, a zone of study was identified using false color (Figure 3, A,C,D, and G). Zones where sugarcane is mechanically harvested have red tones (Figure 3, B,D,F,and H). These images allowed observation of the evolution of areas with mechanical harvesting of sugarcane, which increased during the period analyzed.

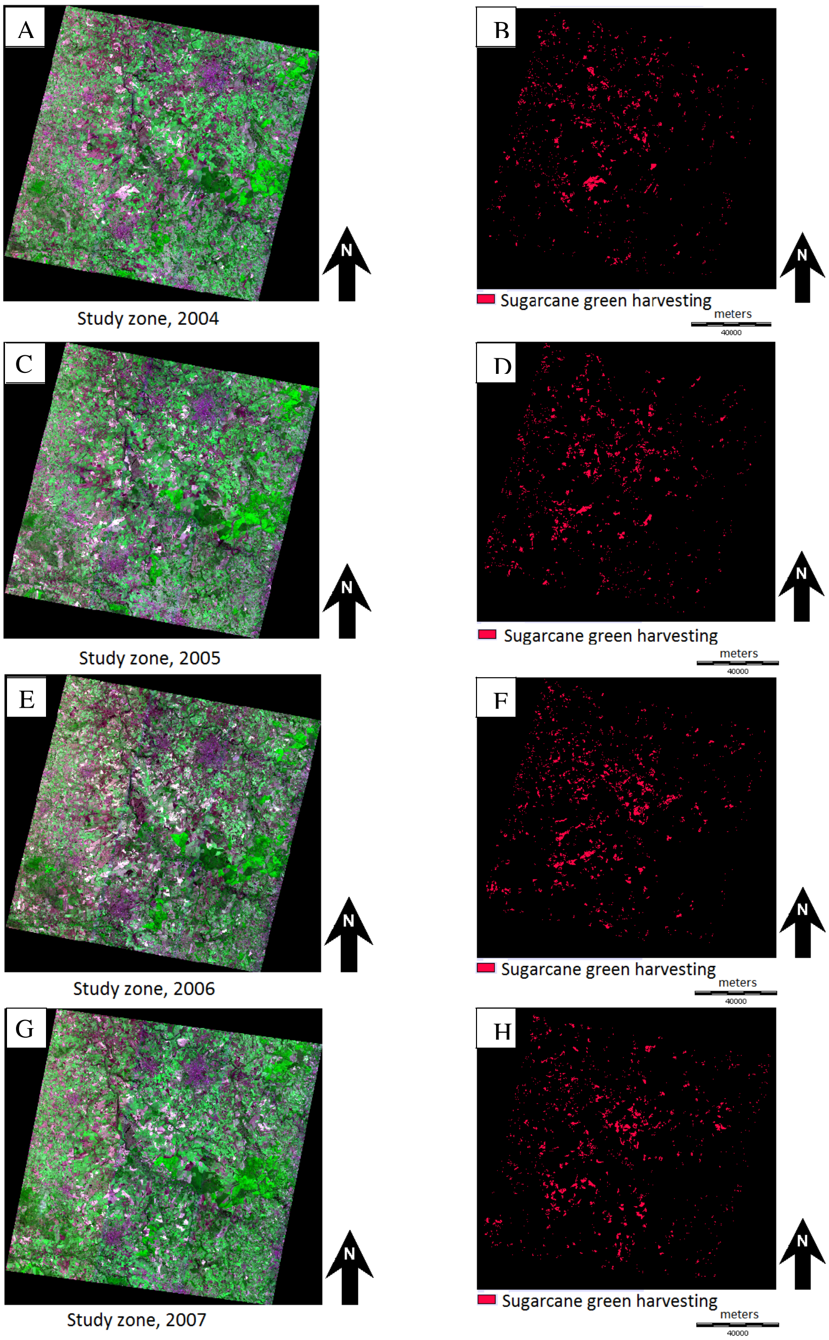


**Figure 3**. False color images (3R4G2B), captured in 2004 (A), 2005 (C), 2006 (E) and 2007 (G) and classifications for the same years: B, D, F and H, respectively.

During the outlining of the sugarcane areas with mechanical harvesting, it was confirmed that the georeference of the topographic maps and the isolated bands conformed to the Brazilian Standard for Cartographic Accuracy (PEC) decree 89.817/1984, as observed in Tables 1 and 2.

The use of the images from satellite CBERS-2, in bands 3 (red), 4 (near infrared) and 2 (green), allowed the identification and differentiation of the patterns of spectral responses for the area of interest. The spatial and spectral resolutions of the CCD instrument demonstrate that the use of images is convenient for watching and monitoring agricultural and forest areas, as reported by other authors (Korontzi *et al*., 2008; McCarty *et al*., 2008; Puni *et al*., 2008), especially in accidental or controlled fires.

Alter analyzing the spectral bands, an increase in the size of areas where mechanical harvesting is carried out was observed, showing an increase during the period between 2004 and 2006 and a small reduction in 2007 (Table 3).

**Table 1.** Mean square error (EMS) for the satellite images, appropriate for the Brazilian Cartographic Accuracy Standard (PEC).

| Image, year/Band | Resolution m | RMS pixel | RMS, m* | (RMS) PEC, m |
|---|---|---|---|---|
| 2004/ (B2, B3, B4). | 20 | 0.595 | 14.87 | 25 |
| 2005/ (B2, B3, B4) | 20 | 0.583 | 14.65 | 25 |
| 2006/ (B2, B3, B4). | 20 | 0.575 | 14.37 | 25 |
| 2007/ (B2, B3, B4) | 20 | 0.602 | 15.05 | 25 |

*RMS (m) = [(RMS pixel)*(spatial resolution)]

**Table 2.** Mean square error (MSE) for topographic charts, appropriate to the Brazilian Standard for Cartographic Accuracy (PEC).

| Topographical card | Resolution m | RMS pixel | RMS, m* | RMS PEC, m |
|---|---|---|---|---|
| Jaboticabal | 5 | 0.582 | 2.91 | 25 |
| Taiúva | 5 | 0.600 | 3.00 | 25 |
| Ribeirão Preto | 5 | 0.590 | 2.95 | 25 |

*RMS (m) = [(RMS pixel)*(spatial resolution)]

**Table 3.** Area of mechanically-harvested sugarcane in the study area and gases retained by not burning the sugarcane before harvest. .

| | Area | | AI[1] | Greenhouse gases retained, t | | |
|---|---|---|---|---|---|---|
| Year | km$^2$ | % | % | $CO_2$ | $CH_4$ | $N_2O$ |
| 2004 | 396.65 | 5.91 | - | 312480.87 | 556.90 | 14.44 |
| 2005 | 447.56 | 6.67 | 12.83 | 352587.77 | 628.37 | 16.29 |
| 2006 | 511.54 | 7.62 | 28.96 | 402991.21 | 718.20 | 18.62 |
| 2007 | 474.6 | 7.07 | 19.65 | 373889.88 | 666.34 | 17.28 |

[1]AI: Area increased during the year 2004.

Additional climate sources show that the small reduction between 2006 and 2007 was due to higher pluviometric precipitation in April (54 mm), May (106 mm) and July (88 mm) of 2007, delaying the period of mechanical harvesting, as sugarcane refineries commonly suspend mechanical harvesting if precipitation is higher than 40 or 50 mm, due to excess humidity. According to Aguiar *et al.* (2007), rain is the main inconvenience for harvesting, as rain directly affects the machinery.

A progressive increase of mechanically-harvested areas was observed during the years studied, demonstrating an observance of the state law and, consequently, a reduction of the annual emission of combustion gases caused by the foliage burning (Table 3). The levels were 7,878 kg $ha^{-1}$ for $CO_2$, 14.04 kg $ha^{-1}$ for $CH_4$ and 0.36 kg $ha^{-1}$ for $N_2O$.

Campos (2003), found that mechanical harvesting reduced the emission of greenhouse effect gases by about 5 t $ha^{-1}$ $yr^{-1}$. Harvest residues remain in the harvest system, and microbial activity and the decomposition process retain gases in the soil. Luca *et al.* (2008) found that carbon fixation varied from 5,750 to 7,695 kg $ha^{-1}$ $yr^{-1}$ of $CO_2$, in the first 20 cm below ground, 3 years after the beginning of mechanical harvesting.

Another aspect to be considered is the balance of emitted greenhouse effect gases in the process of sugarcane production, including all aspects involved in the system (Möllersten *et al.,* 2009), especially the use of supplies (seeds, pesticides and fertilizers) and the use of agricultural machinery, which varies according to different crop activities (Withtreras *et al.*, 2009). Based on different requirements for sugarcane production, Cerri *et al.* (2007) reported that with mechanical harvesting, compared to burning, around 1,275 kg $ha^{-1}$ $yr^{-1}$ of $CO_2$ is not emitted.

This systematic method provides coherent, quantitative, spatial and temporally explicit measurements, differentiating areas harvested mechanically from areas where sugarcane foliage is burned. The results found here reflect only a three-month period of harvesting time, as once the harvest has been made, sugarcane begins its natural regeneration. Areas that have been renewed recently are not identified in the images, as the soil remains uncovered. This process is carried out by farmers every 4 or 5 years using conventional farming methods. Therefore, in order to make an estimation of the mechanically-harvested areas during all the harvesting periods, it is advisable to take images over time and make period field visits, allowing consolidation of the information obtained.

From the results obtained in this study, it is possible to conclude that the SIG IDRISI-2.0 allowed fast and adequate results, and stored, processed, transformed and analyzed information to achieve the proposed objective.

Bands 2, 3 and 4 of satellite CBERS-2/CCD allowed differentiation and quantification of the zones of interest, demonstrating this to be a useful tool for the differentiation of soil use and occupation. Therefore, it is feasible to use satellite images to estimate the amount of undesired gases which are not expelled in areas where sugarcane is mechanically harvested.

## Resumen

**C. Luna Arraes, J. Camacho-Tamayo, T. Tarlé Pissarra, C.P. Bueno y S. Campos. 2010. Análisis temporal de reducción de emisión de gases en áreas de caña de azúcar cosechadas mecánicamente utilizando imágenes satelitales. Cien. Inv. Agr. 37(1):113-121.** Este trabajo tuvo por objetivo estimar temporalmente la cantidad de gases que dejaron de ser emitidos al aire, en áreas cultivadas con caña de azúcar (*Saccharum officinarum*), cosechadas mecánicamente, en el noroeste del Estado de São Paulo utilizando imágenes orbitales. Se utilizaron cuatro imágenes del satélite CBERS-2/CCD, con recepción los días 13/08/2004; 14/08/2005; 15/08/2006 e 16/08/2007, donde se procesó por medio del Sistema de Información Geográfica (SIG) IDRISI 15.0. Fue posible, por medio de la clasificación supervisada, identificar y cuantificar las áreas de interés (caña cosechada mecánicamente) debido a las respuestas espectrales de las bandas estudiadas. Con base en estos datos, se valoró la cantidad de gases dejados de emitir, de acuerdo a la estimación propuesta por la Intergovernmental Panel on Climate Change (IPCC)**.** Estas áreas calculadas corresponden a 396,65 $km^2$ (5,91% para el 2004), 447,56 $km^2$ (6,67% para el 2005); 511,54 $km^2$ (7,62% para el 2006) y 474,60 $km^2$ (7,07% para el 2007), de un total de 6710,89 $km^2$ con caña de azúcar, presentando un aumento significativo de la cosecha mecanizada y reducción de emisión de gases de efecto invernadero, superior a 300.000 t $año^{-1}$, para la zona de estudio.


**Palabras clave:** Imágenes orbitales, *Saccharum officinarum*, sensoriamiento remoto, sistema de información geográfica.

## References


Aguiar, D.A., W.F. Silva, F.F. Feitosa, F.G Gonçalves, R. Rizzi, and B.F.T. Rudorff. 2007. Análise Espacial da Colheita da Cana-de-Açúcar no Estado de São Paulo: A Influência da Precipitação. Pages 2231-2238. In: Memórias, XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, Instituto Nacional de Pesquisas Espaciais - INPE, 2007.

Campos, D.C de. 2003. Potencialidade do Sistema de Colheita Sem Queima da Cana-de-Açúcar Para o Seqüestro de Carbono. Tesis de Doctorado en Agronomía (Microbiología Agrícola), Escuela Superior de Agricultura Luiz de Queiroz, Universidad de São Paulo, Piracicaba, Brasil. 103 pp.

Cerri, C.E.P., G. Sparovek, M. Bernoux, W.E. Easterling, J.M. Melillo, and C.C. Cerri. 2007. Tropical agriculture and global warming: impacts and mitigation options. Scientia Agricola 64:83-99.

Contreras, A.M., E. Rosa, M. Pérez, H. Van Langenhove, and J. Dewulf. 2009. Comparative life cycle assessment of four alternatives for using by-products of cane sugar production. Journal of Cleaner Production 17:772–779.

Eastman, J.R. 1998. Idrisi for windows: Introdução e exercícios tutoriais. J. Ronald Eastman (eds.). Heinrich Hasenack and Eliseu Weber. UFRGS Centro de Recursos Idrisi, Porto Alegre, Brasil. 109 pp.

FAO. 2008. Faostat Agriculture. Food and Agriculture Organization of the United Nations (FAO). 2008. http://faostat.fao.org/site/601/default.aspx (Accessed: April, 2008).

INPE. 2008. Catálogo de imagens CBERS. Instituto Nacional de Pesquisas Espaciais (INPE). São José dos Campos. Brasil. http://www.cbers.inpe.br. (Accessed: March, 2008).

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories: Agriculture, forestry and others land use. v. 4. Intergovernmental Panel on Climate Change (IPCC).

Ippoliti-Ramilo, G.A. 1999. Imagens tm/ Landsat-5. da época de pré-plantio para a previsão de área de culturas de verão. Tesis de Maestría (Sensoriamento Remoto) – Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brasil. 183 pp.

Korontzi, S., J. McCarty, and C. Justice. 2008. Monitoring agricultural burning in the Mississippi River Valley Region from the Moderate Resolution Imaging Spectroradiometer (MODIS). Journal of the Air and Waste Management Association 58:1235-1239.

Luca, E.F. de, C. Feller, C.C. Cerri, B. Barthès, V. Chaplot, D.C. Campos, and C. Manechini. 2008. Avaliação de atributos físicos e estoques de carbono e nitrogênio em solos com queima e sem queima de canavial. Revista Brasileira de Ciência do Solo 32:789-800.

McCarty, J.L., T. Loboda, and S. Trigg S. 2008. A hybrid remote sensing approach to quantifying crop residue burning in the United States. Applied Engineering in Agriculture 24:515–527.

Möllersten, K., J. Yan, and J.R. Moreira. 2009. Potential market niches for biomass energy with CO2 capture and storage-Opportunities for energy supply with negative CO2 emissions. Biomass and Bioenergy 25: 273-285.

Moraes, M.A.F.D. 2007. O mercado de trabalho da agroindústria canavieira: desafios e oportunidades. Economia Aplicada 11:605-619.

Price, J.J. 1999. Combining Multispectral Data of Different Spatial Resolution. IEEE Transactions on Geoscience and Remote Sensing 37:1199-1203.

Punia, M, V.P. Nautiyal, and Y. Kant. 2008. Identifying biomass burned area patches of agriculture residue using satellite remote sensing data. Current Science (India) 94:1185-1190.

Rizzi, R. 2004. Geotecnologias em um Sistema de Estimativa de Produção de Soja: Estudo de Caso no Rio Grande do Sul. Tesis de Doctorado (Sensoriamiento Remoto). Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brasil. 214 pp.

Sanches, I.A. 2004. Sensoriamento Remoto para Levantamento Espectro-Temporal e Estimativa de Area de Culturas Agrícolas. Tesis de Maestría en Sensoriamiento Remoto (INPE-10290-TDI/909), Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brasil. 172 pp.

Terres, J.M., J. Delince, M. Van de Steene, and A. Hawkins. 1995. The use of remote sensing and GIS capabilities to support the reform of the common agricultural policy of the European Community. Remoto Sensing Reviews 12:53-60.