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REAL-TIME SUGARCANE HARVEST MONITORING USING SPOT 4&5 SATELLITE DATA

By E. BAPPEL[1], A. BÉGUÉ[1], P. DEGENNE[1], V. LEBOURGEOIS[2], AND B. SIEGMUND[2]

[1]CIRAD, Maison de la Télédétection, 500 rue J.F. Breton, 34093 Montpellier Cedex 5, France.
[2]CIRAD, Station de la Bretagne, BP20, 97408 Saint Denis Messagerie Cedex 9, Ile de La Réunion, France.
bappel.teledetection@caramail.com

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Abstract

In the context of the SUCRETTE project, (Système de sUivi de la Canne à sucRE par TélédéTEction) the Centre International de Recherche Agronomique pour le Développement (CIRAD) has set up a sugarcane harvest monitoring program using satellite data on Reunion Island. The methodology was based on the study of the time series SPOT 4&5 reflectance images during the 2003 harvest season from June to December. By analysing SPOT 4&5 satellites images, harvested fields and standing cane were easily identified. A multi spectral classification of the scene was used to produce a harvest map. It was possible to generate a sugarcane harvest map and statistics ten days after image acquisition. The methodology allowed for the determination of the harvest advance rate during the six months of the harvesting campaign. In the study this was obtained by producing sugarcane harvest maps at four times (03/07/21, 03/08/21, 03/10/14 and 03/11/20). The overall classification accuracy of the harvested fields reached 98.8% using 82 ground control fields. The harvest advance rate estimated by remote sensing was close to the mill observation, with a maximum error of 8%. Furthermore, the mill records and the harvested area can be used to estimate sugarcane yield. These results indicated that remote sensing technology could be adapted to monitor harvest schedules in real-time, using SPOT 4&5 data. Information extracted from satellite images could be a decision support tool for mill opening and closing dates as well as for crushing rates, which could have a significant economic impact.

Introduction

The principal use of remote sensing for sugarcane monitoring is visual interpretation or image classification for sugarcane area mapping (McDonald and Routley, 1999; Narciso and Schmidt, 1999; Hadsarang and Sukmuang, 2000). The results are generally very acceptable

(accuracy of 90% or more) when high resolution satellite data (Landsat, SPOT) are acquired prior to the harvest season, when the crop canopy is fully developed. Literature references showed that remote sensing could be used to characterize sugarcane phenology, variety or water stress (Schmidt *et al.*, 2000; Gers, 2003).

In contrast, there are very few publications (Gers and Schmidt, 2001) on the use of remote sensing for cutting or planting surveys. This is because current satellite solutions are unable to provide the large number of image acquisitions during several consecutive months. In addition, due to cloudy tropical conditions, only satellites with a spatial resolution and programming capabilities adapted to the field-scale, like Spot satellites, offer an acquisition frequency high enough to monitor these dynamic processes.

On Reunion Island, two mills process the two millions tons of sugarcane produced annually. Each farmer has to harvest according to a quota of sugarcane per week. But sometimes, when rainy conditions are present farmers are not able to cut their weekly quotas. This is due to mechanization of the harvest process, and the soil compaction problems that could reduce future yields in the field.

Every year, some farmers are not able to harvest and deliver their whole quota due to the fixed mill opening and closing dates. In this context, CIRAD has conducted research to estimate the technical and economical feasibility of using remote sensing data for sugarcane harvest monitoring with SPOT 4&5 satellite data.

Methodology

A methodology has been developed to estimate areas of harvested sugarcane, bare soil and standing cane from the Spot 4&5 satellites images (10 metres ground resolution) within sugarcane production areas. The goal is to provide, in quasi real-time, information on sugarcane harvest rate. This information must be available quickly after image acquisition to be useful as a decision support tool for harvest management and monitoring.

This methodology is based on the difference in spectral signatures between harvested sugarcane, bare soil and standing cane, allowing a maximum likelihood multi spectral classification. Prior classifications of bare soil were done to identify planted fields in 2003 before the beginning of the harvest season. These areas are not concerned by the next classification process. Training fields were selected by visual interpretation, and three classes were finally considered: bare soil, crop residues over bare soil and standing cane. The crop residues and bare soil classes were considered as harvested cane. The classified images and the vector layer of field boundaries are used to extract the percentage of harvested area for each geographical delivery unit.

The results are in statistical and cartographical form: harvest rate for each delivery centre and maps of harvested and standing cane on a field scale.

Results and validation

In the 2003 harvest season, harvesting was monitored four times using Spot 4&5 images as described in Figure 1.

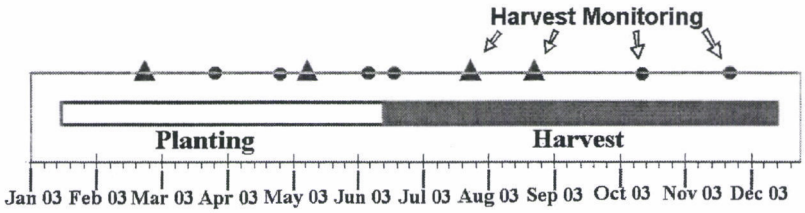

Fig 1. – Date and type of Spot Images recorded over Reunion Island in 2003. Triangle symbols represent Spot 5 and circle symbols are for Spot 4 image acquisition.

The trued harvest rate was calculated as the ratio of the tonnage accumulated on the date of interest to the final tonnage delivered at each delivery centre (data available from CTICS[1]). This value was compared to the harvest rate estimated by remote sensing.

Table 1- Results of the harvest monitoring done for the 2003 Reunion Island milling season, ground data (CTICS), estimated by remote sensing and RMSE.

Images acquisition	Monitored sugarcane area (ha)	Harvest rates Ground data (%)	Harvest rates Spot4&5 (%)	RMSE (%)
03/07/21	19591	8.9	10.9	2.8
03/08/21	11611	34.8	34.4	4.6
03/10/14	11449	62.3	63.9	6.1
03/11/20	7808	86.78	81.75	8.0

Validation of statistical and cartographical products by ground observations has been done on the four data sets .The results obtained for the harvest rate monitoring of the harvest season 2003 in Reunion Island and their comparisons with ground data are presented in Table 1.The Root Mean Square Error is expressed in harvest rate, i.e. for the 03/07/21, the harvest rate of each centre followed were estimated with an error more or less equal to 2.8%.

Validation of the harvest maps (Figure 2) is done with the Overall Accuracy Classification (the total precision of classification) which reaches 98.8%.

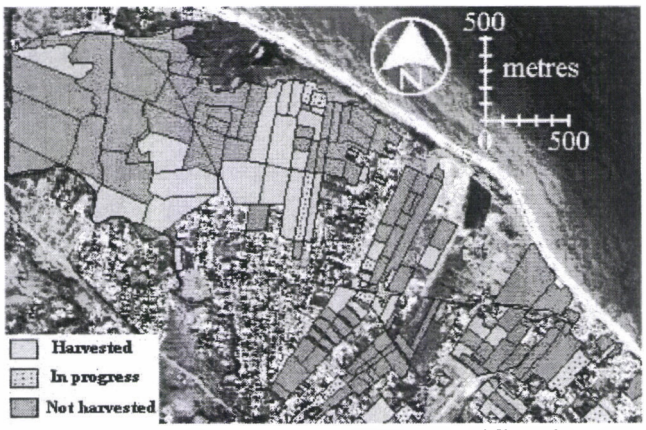

Fig 2. – Post processed image of harvested field classification overlapping a Spot 5 image, 2.5 metre ground resolution, real colour composite.

[1] CTICS: Centre Technique Interprofessionnelle de la Canne à Sucre, La Réunion.

Conclusion

The validation of these results indicates that it is possible to use Spot 4&5 satellites data to estimate the sugarcane harvest rate, during the harvest season, in near real-time. Maps deduced from the satellite images can be distributed to the sugar industry through a tailored GIS which is used to edit monthly spatial statistics of the sugarcane management practices. A small java mapping program is embedded in a HTML page, providing the possibility to distribute the interactive map to any final user without having to install a GIS software package on the final user's computer system. A web browser is the only requirement to view the maps dynamically. Information extracted from satellite images could be used as a decision support tool for mill closing dates as well as crushing rates, which could have a significant economic impact.

Acknowledgements

This research was supported by a "Région Réunion" Ph.D. Grant and was done in the context of the project ISLE_Reunion © CNES : a remote sensing reference database developed by CNES (Centre National d'Etudes Spatiales) for scientific and R&D studies, on "La Réunion" island. http://medias.obs-mip.fr/isle_reunion/

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ASSIMILATION OF A BIOPHYSICAL PARAMETER ESTIMATED BY REMOTE SENSING USING SPOT 4&5 DATA INTO A SUGARCANE YIELD FORECASTING MODEL

BY

E. BAPPEL[1], A. BÉGUÉ[1], J.F. MARTINÉ[2], A. PELLEGRINO[1], B. SIEGMUND[2]

[1] CIRAD, Maison de la Télédétection, 500 rue J.F. Breton, 34093 Montpellier Cedex 5, France.
[2] CIRAD, Station de la Bretagne, BP20, 97408 Saint Denis Messagerie Cedex 9, Ile de La Réunion, France.
Email : bappel.teledetection@caramail.com

KEYWORDS : SPOT satellite, NDVI, LAI, growth model

Abstract

In the context of the SUCRETTE project, (*Système de sUivi de la Canne à sucRE par TélédéTEction*) CIRAD (*Centre International de Recherche Agronomique pour le Développement*) has initiated a project to monitor growth of sugarcane in Reunion Island (55°60' E longitude, 20°90' S latitude). Ground measurements (Leaf Area Index) using a PCA Licor 2000 were taken from June 2002 to December 2002, coupled with SPOT 4&5 (Satellite Pour l'Observation de la Terre) images acquired during the same period. Yield estimates could be improved by combining remotely sensed data with growth models. The objective of this study was to determine a relationship between leaf area index (LAI) and the Normalized Difference Vegetation Index (NDVI) generated from SPOT 4&5 images, and to establish whether there is a benefit in using remotely estimated LAI instead of simulated LAI to estimate yield. A strong relationship between LAI and NDVI was obtained using an exponential function (R^2=0.86). A time series of 12 Spot images was used to produce NDVI profiles for each field. Gaps between dates were filled by fitting an empirical curve. LAI was estimated at a daily time step from the NDVI curve. The growth model Mosicas was forced using the estimated LAI. Actual yields were compared with yields simulated with and without LAI forcing. The coefficient of determination results indicate that R^2 between observed and simulated yields is equal to 0.42 and 0.66 for simulation without forcing and for simulation with LAI forcing, respectively. The root mean square error of 19.3 t/ha without LAI forcing decreased to 12.8 t/ha using LAI forcing.

Introduction

Remote sensing tools can provide information about vegetation in various wavelengths: the solar spectrum (Guyot, 1996), the active and passive microwave (for example, for radar: Prévot *et al.*, 1993) and the thermal range (Moran *et al.*, 1994). It appears that remotely sensed measurements can be related to instantaneous values of various canopy variables.

Rudorff and Batista (1990) showed that yield estimations by Landsat MSS data (linear model with vegetation index) based only on one date or only on agro-meteorological data were less accurate than those based on the combined agro-meteorological-spectral model. The combined model consisted of a multiple linear regression integrating vegetation index and simulated yield, with a standard error ranging between 10 and 14 t/ha for a mean yield of 75 t/ha.

The objective of this study was (1) to establish the relationship between the LAI of sugarcane and its radiometric response formalized by the NDVI, and (2) to establish whether yield estimations from a growth model could be improved by using these data.

Methodology

Several pre-processing steps were needed to use 12 Spot 4&5 multispectral images, ten metre resolution including: ortho-rectification, topographic normalization, numerical count to reflectance values, and finally, inter-calibration of the various sensors. This method involved establishing the relation between the LAI and corresponding NDVI values. NDVI values were calculated using the following equation according to Rouse *et al.* (1974):

$$\mathrm{NDVI} = \frac{(\mathrm{PIR} - \mathrm{R})}{(\mathrm{PIR} + \mathrm{R})}$$

where PIR and R are reflectance recorded by Spot 4&5 satellites in the near infra-red and red part of the solar spectrum, respectively. The relationship between LAI and NDVI was established by comparing 65 ground measurements of LAI with corresponding NDVI values. Each LAI observation was a field mean of three or four 20 m by 20 m sample areas within the field. Thirty LAI2000 measurements were taken on a diagonal line within each sample area.

A NDVI curve was fitted to 12 NDVI data points for each field by the square difference sum method with the R package used to fill gaps between dates. The resulting daily NDVI values were then used to estimate daily LAI values. These values were used as inputs for the Mosicas agro meteorological mechanistic growth model (Martiné, 2003).

Mosicas was used to simulate the final sugarcane yield obtained on 29 sugarcane fields, for both methods namely with and without LAI forcing (updating of LAI variable of the model derived from remote sensing). These fields were selected due to the availability of final NDVI and yield data and SPOT 4&5 images that were not restricted by cloud cover. The range of the field size is from 1.3 to 11 ha with a mean equal to 4.5 ha. The measured yields are from the mill records of sugarcane delivery for each field.

Results

Figure 1 shows the relationship between the NDVI calculated from Spot 4&5 reflectance and ground measured LAI.

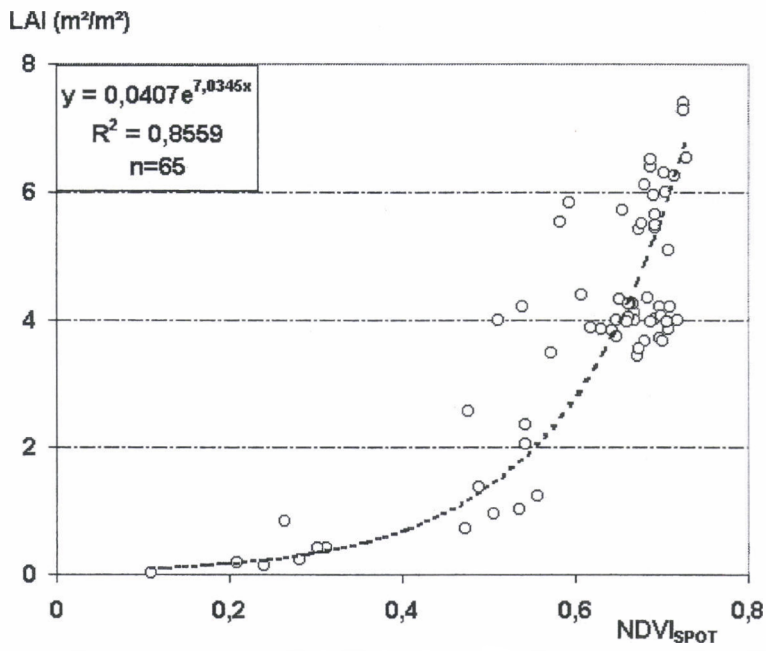

Fig. 1 – Relationship between sugarcane Leaf Area Index (LAI) and SPOT (Satellite Pour l'Observation de la Terre) Normalized Difference Vegetation Index (NDVI).

The coefficient of determination was equal to 0.86 and was significant at $P<0.001$ (n=65). The relationship is described by an exponential function with the following formula:

$$LAI = 0.0407 \times EXP(7.0345 \times NDVI_{SPOT})$$

Figure 2 shows an example of the fitted NDVI curve obtained for a field. A logistic equation gave the best fit.

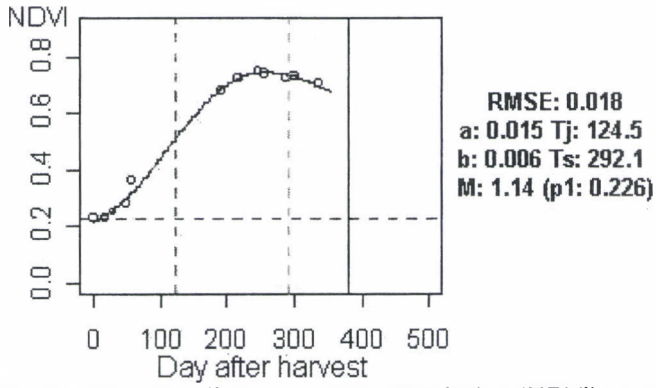

Fig. 2 – Empirically fitted Normalized Difference Vegetation Index (NDVI) curve and NDVI data points for a field grown in the 2002-2003 season.

Yields estimated with and without the LAI forcing strategy are compared with measured yields. Results are presented in Figure 3.

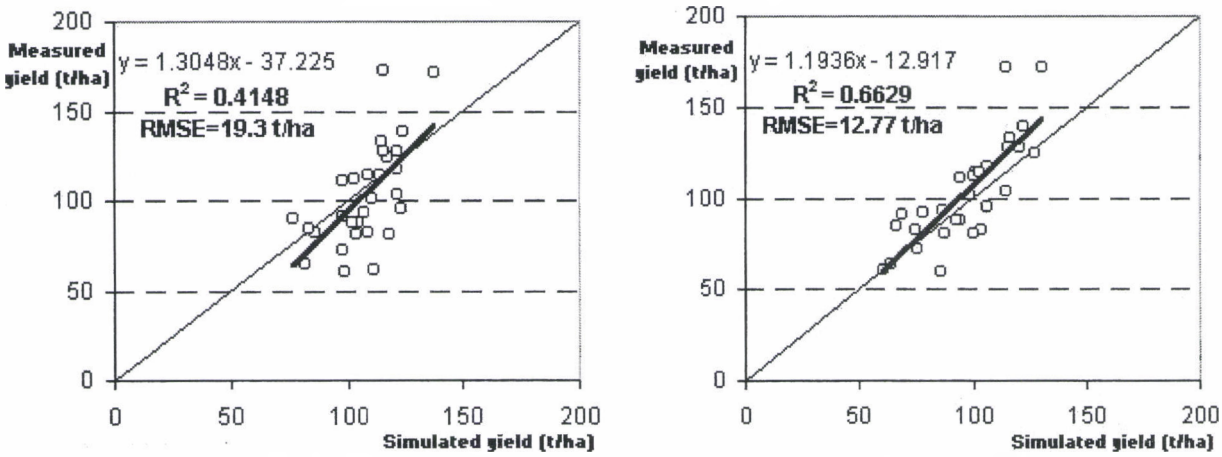

Fig. 3 – Comparison of Mosicas (agro meteorological mechanistic growth model) simulated to observed sugarcane yield with and without leaf area index (LAI) forcing.

The root mean square error of 19.3 t/ha for simulations without forcing decreased to 12.8 t/ha for simulations with LAI forcing (Figure 3). Moreover, the coefficient of determination increased considerably to reach the value of 0.67 with LAI forcing compared to 0.42 without LAI forcing.

Conclusion

A strong relationship was established between sugarcane LAI and the NDVI generated from SPOT 4&5 data. In addition, we could calculate the adjusted NDVI for each field, necessary for obtaining the NDVI values at a daily time step. The root mean square error obtained between the observed NDVI and the NDVI logistic functions was at maximum equal to 0.03 for a mean NDVI of 0.45. Finally, sugarcane yield estimated using growth models like Mosicas could be improved significantly by forcing the model with LAI values estimated from NDVI data from SPOT data. Our research turns to the study of the relationship which can exist between the maximum of NDVI and the final yields of sugarcane. If the relationship between the maximum of NDVI and the final yields is significant, it will be possible to estimate final yields only from the radiometric SPOT data, using fewer images.

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