APPLICATION OF REMOTE SENSING TECHNOLOGY TO MONITOR SUGAR CANE CUTTING AND PLANTING IN GUADELOUPE (FRENCH WEST INDIES).

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Abstract

In the context of the SUCRETTE project, the CIRAD (Centre de coopération Internationale en Recherche Agronomique pour le Développement), in collaboration with Spot Image Company, conducts research activities to study the potentialities of remote sensing for sugarcane monitoring. Among different operational products that can be derived from satellite images, we present here how a time series of SPOT4 & 5 satellite data could be used as a decision support tool for planting survey and harvest monitoring of small-scale cane fields.
A pilot study was set up in Guadeloupe (French West Indies) where the individual sugarcane fields are progressively mapped in the framework of the AGRIGUA project. The objectives were to provide the fraction of harvested fields throughout the milling season and a summary map of ploughed fields at the end of the planting season. The spectral properties of the different cane field status - full covered green canopy, stressed canopy, crop residues and bare soil – showed that harvested and ploughed fields could be easily mapped with high accuracy (more then 90%) thanks to a field-base approach.
The resulting maps were then integrated within a decision support system devoted to sugarcane management. This on-shelf GIS permits to visualize maps and edit monthly statistics of the management practices in each administrative area.

1. Introduction

The SUCRETTE[1] research project (Ribbes, Bégué et al., 2002), investigated by CIRAD (Centre de coopération Internationale en Recherche Agronomique pour le Développement) and Spot Image Company, explores the potentialities of remote sensing to characterize sugarcane management practices (cutting, planting, fertilization, irrigation) and crop conditions (chlorophyll and moisture status of the crop), and to estimate sugarcane yield. The final product will be an operational management support tool for the sugarcane industry. The center of such a system is a field-based map coupled with a sugarcane production model and integrating thematic maps derived from high resolution satellite time series.

Previous remote sensing studies on sugar cane

In the literature, the principal use of remote sensing for sugarcane monitoring is visual interpretation or image classification for sugarcane area mapping (e.g. 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 the harvest season, when the crop canopy is fully developped. Literature references on the use of remote sensing for management practices or crop conditions mapping showed that remote sensing could be used to characterize cane phenology, variety or water-stress (Gers, 2003; Schmidt et al., 2000).

However, there are very few publications (Gers and Schmidt, 2001) on the use of remote sensing for cutting or planting surveys, mainly because satellite solutions are still insuffìcent to provide a large number of image acquisitions during several consecutive months. At this time, and for cloudy tropical conditions, only satellites with a spatial resolution in accordance to field-scale and presenting programmation capabilities, like Spot satellites, offer an acquisition frequency high enough to monitor these dynamic processes.

Objective

The objective of this paper is to present the potentialities of satellite remote sensing for sugarcane planting survey and harvest monitoring in small-scale fields areas under tropical cloud conditions.

Sugarcane planting is approched through mapping ploughed fields at the end of the planting season. We made the assessment that all the ploughed fields were going to be planted with sugarcane, which is not true and should be quantified. However, maps of ploughed fields should be highly correlated to sugarcane planting; the potential applications of such maps are a better knowledge of the sugarcane management practices and a contribution to the estimation of next year yield.

The harvest monitoring product is different as it is a statistical and dynamic product. Throughout the milling season, once a month, the fraction of harvested fields is calculated on sampled areas. This information could be used to improve efficiency in both factory and field, in particular by :

- a better estimation of the yield (the area harvested between two satellite scenes can be correlated with total tonnes cane delivered over the period to provide an estimate of the productivity) ;
- a better assessment of the standing cane area still to be harvested to optimize the cutters deployment and transport operations.

[1] SUivi de la Canne à sucRE par TélédéTEction

2. The study site

The study area takes place in Guadeloupe, island of the French West Indies. The sugarcane covers about 12 000 ha, representing about 30% of the total agricultural land (**Figure 1**). The mean size of the sugar cane fields is about 1 ha.

To test the methodology, we chose two test sites at different scales (**Figure 1**): a regional scale (Grande-Terre, 6880 ha of sugarcane encompassed by the coordinates 16°10'N to 16°30°N and 61°15'W to 61°35'W) with a majority of small-scale grower cane fields, and a farm scale (Gardel Farm, 16°17'N and 61°19'W) made of about 160 fields over 900 ha.

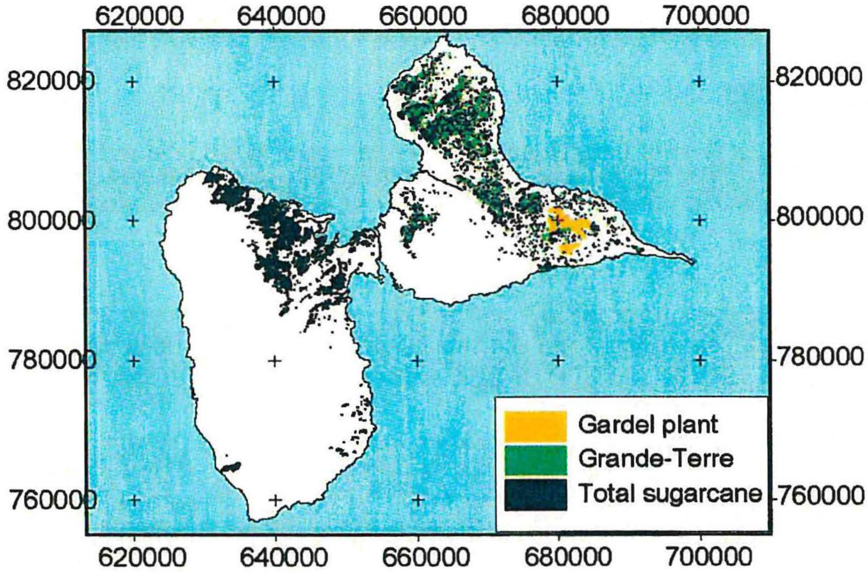

Figure 1 : Map of the 1999 sugarcane fields in Continental Guadeloupe (Lainé, 1999) ; Up-dates (AGRIGUA 2003) are in green+orange for the regional scale (Grande-Terre) and in orange for the farm scale (Gardel). Map projection is UTM Hayford.

In Guadeloupe, the milling season lasts about 4 months (between February and June), and growers plant during the rainy season, from July to October (**Figure 2**). In 2003 the mill opening and closing dates were March 12th and June 30th respectively.

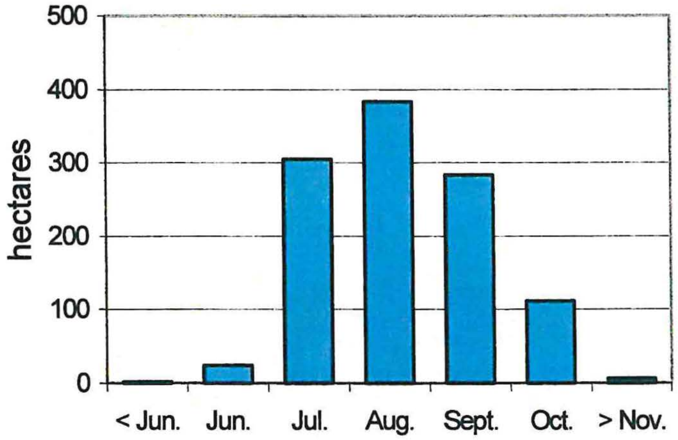

Figure 2: Time distribution of the planting areas in Grande-Terre area (AGRIGUA 2003).

3. The satellite images and the geographic data base

The AGRIGUA survey

The Guadeloupe cane field maps were obtained from the CIRAD-AGRIGUA[2] project. The AGRIGUA project consists in developping a Geographic Information System referencing all the agricultural fields of Guadeloupe. The sugarcane fields were first delineated in 1999 using digital orthophotographs (Lainé, 2001), and the field boundaries are progressively up-dated since 2002 by means of Differential Global Positioning Systems (DGPS) surveys. At the end of year 2003, planted cane fields were entirely mapped (1 113 ha) and about 1 100 ha of ratoon fields were up-dated in Grande-Terre.

The Gardel Farm data base

Gardel is one of the largest farm of Guadeloupe. For several years, agronomic and yield field data are recorded in a GIS which made a reliable and extensive data set available for this study.

The SPOT images

Satellite images were obtained from SPOT4 and SPOT5 sensors. The images are acquired in four spectral bands (green, red, near-infrared and shortwave-infrared) and the ground pixel resolution is 20 m and 10 m for SPOT4-HRVIR and SPOT5-HRG sensors respectively (except in the SWIR band, where the resolution is 20 m in all the cases) .

In order to increase the probability to get cloud-free images, the SPOT satellites were intensively programmed over the area with a frequency of data acquisition of 2-3 days. The programming begins in September 2002 and will end in July 2004. Until now, an average of one image a month has been acquired for the SUCRETTE project. This study made use of the 2003 acquisitions, and the list of the images is given in **Figure 3**.

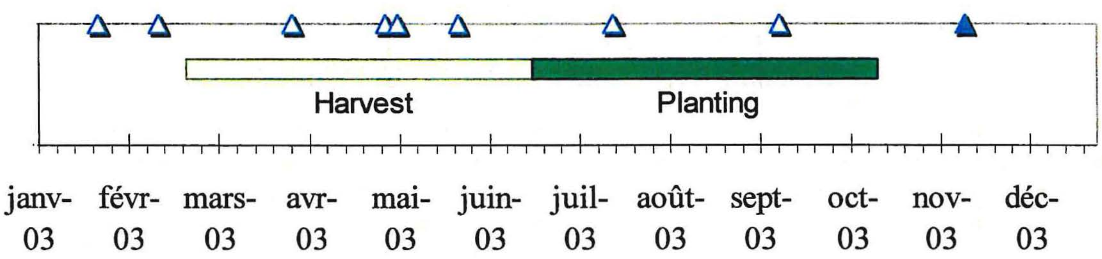

Figure 3 : Distribution of the SPOT images acquired over Guadeloupe in 2003. Open symbols are for SPOT5 and solid symbols are for SPOT4.

4. The methodology

Image pre-processing

The images were delivered in 2a level products. The geometrical correction is done in a standard cartographic projection (UTM WGS84) not tied to ground control points. Ground control points from the AGRIGUA field map were then used to process for a first order geometric correction and reproject in UTM Hayford (datum IGN S[te] Anne). All subsequent were rectified using the same image as reference. The total accuracy is bout 0.5 pixels (10 m).

[2] Association Guadeloupéenne de Recueil d'Information Géographique d'Utilité Agricole

A mask of the clouds and their shadow was drawn on the images by visual interpretation. The digital counts were converted to reflectances through SPOT calibration coefficients and solar elevation at the acquisition time.

Spectral signatures of the sugarcane main stages

For assessing what proportion of the crop has been harvested or planted, a good understanding of the spectral characteristics of the sugar cane crop over time is important for data identification and stratification. For this, four main stages of the crop were investigated : bare soil, fully developed green sugarcane crop, senescent crop and cane residues after cutting.

The spectral profiles on **Figure 4** indicate that the NIR band should permit to separate bare soil from the other classes, while the SWIR is very discriminant for cane residues. In other words, R and NIR based indices, such as the NDVI, will be helpful to monitor the vegetation growth and senescence but SWIR is necessary to correctly discriminate senescent vegetation from residues, and so to detect harvested crops.

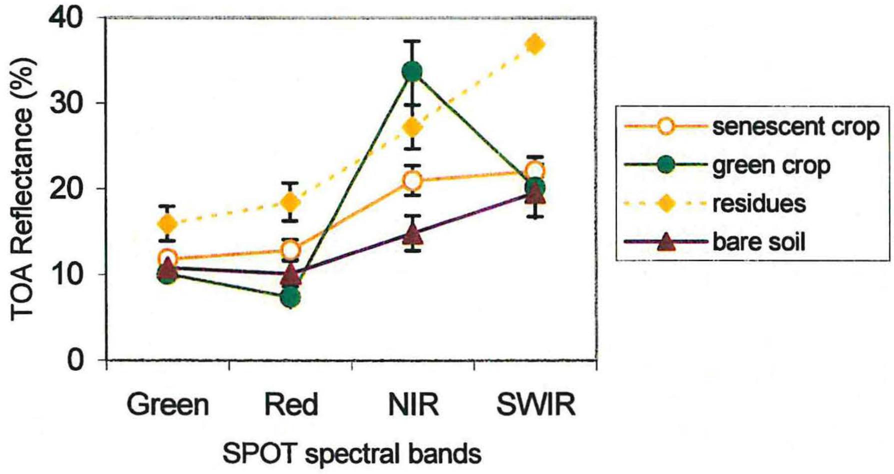

Figure 4 : Top Of the Atmosphere spectral reflectances of the main stages of a sugarcane crop. Bars represent +/- standard deviation.

Image classification and post-processing

Each SPOT image was classified using a maximum likehood algorithm within the sugarcane area. 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 class was considered as harvested cane, while the bare soil class was considered as planted cane between July and November. As seen in **Figure 5**, recently harvested plots can be easily identified on a PIR-SWIR-Red color composition. The main confusions are between standing crop and cane regrowth of fields harvested early in the season, and between bare soil and harvested fields with little crop residues.

The classifications were then simplified on a per-field basis, attributing to each field the majority class. This permitted to be less sensitive to the field border effect, to increase the sampled area by classifying the whole field even if it is partially masked, and to produce neat maps.

Three methods for thematic maps production and statistics have been tested:

- The first method consisted in processing the classifications individually. Because of missing data due to clouds and shadows, each image samples a different area which is supposed to be representative of the whole region.

- The second method consisted in considering only the intersection area of non missing data of a set of classifications. For each date, an harvested or planted field map is produced taking into account the previous classifications. For example, if a field has been classified previously once as harvested, it is definitely recorded as harvested. Here, the sampled area decreases as the number of classifications used in the calculation increases.
- The third method consisted in considering the union area of non missing data and apply the same decision rule as previously: for example, if a field is classified once as planted, it is definitely classified as planted. The number of missing dates for each field should inform on the accuracy of the final field classification.

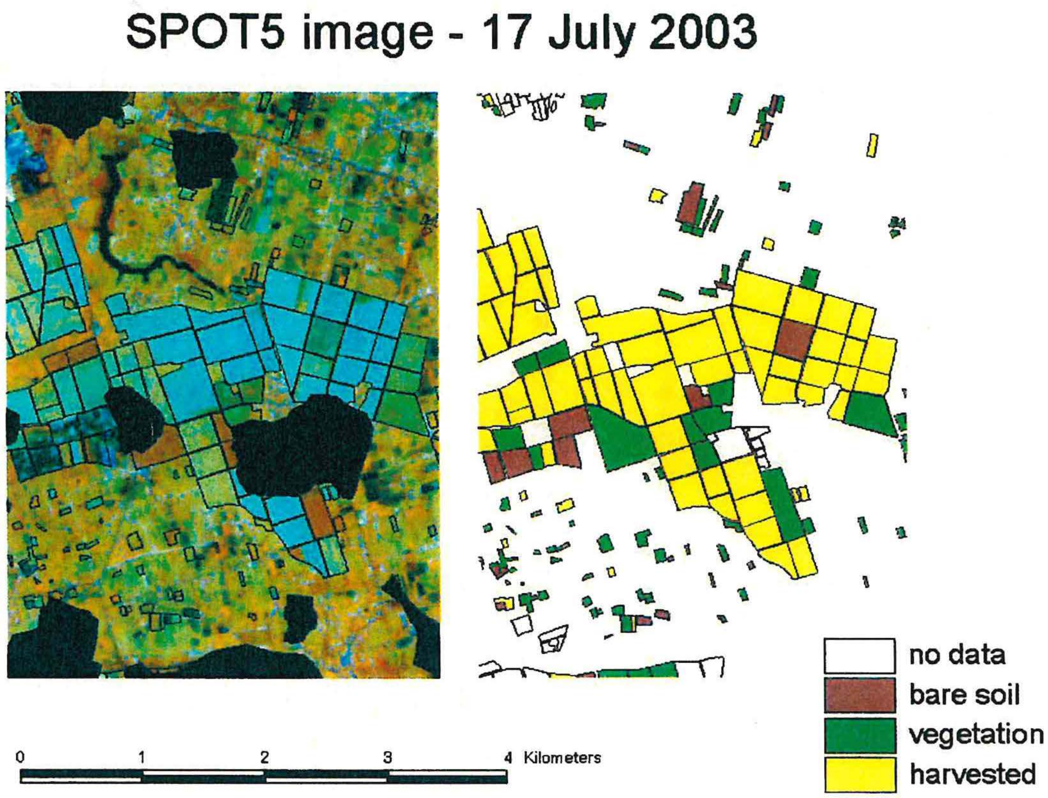

Figure 5 : On the left, a sample of a false colour composite satellite image (PIR, SWIR, Red) acquired just after the end of the milling season. Active vegetation appears in red on the image, recently harvested plot with residues appear in light blue and bare soil in dark blue. Black areas are masks of clouds. The AGRIGUA filed boundaries are on the top. On the right, the corresponding classified image post-processed on a field basis.

5. Results and validation

Harvest mapping

The harvest monitoring was done using a set of five images (from March to July, **Figure 3**). The validation of the harvest monitoring classification procedures was performed on the area of the Gardel farm (900 ha) where all the agricultural operations are recorded in a data base (**Figure 6**).

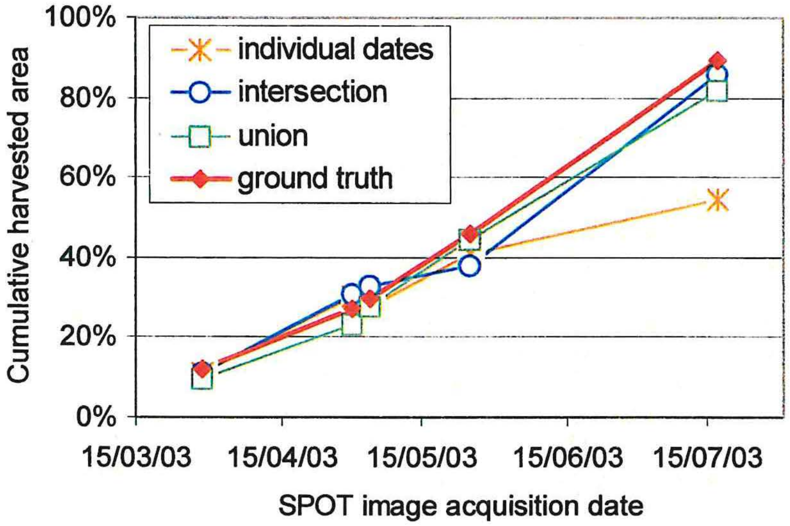

Figure 6 : Cumulative fraction of harvested area calculated on Gardel Farm using three different methods, and comparison with ground truth.

As expected, the first method in which the images were processed independantly, gives correct estimations at the beginning of the milling season, but under-estimates the harvested area at the end of the season. This under-estimation is due to the two-months cane regrowth that were classified as standing cane.
The second method, based on the intersected cloud-free area (48% of the total area in July), gives results that are very close to the ground truth with a maximum error of 8% of harvest fraction. A close examination of the classified image shows two sources of misclassification : confusion between harvest and bare soil when crop residues are taken from the field at the harvest, and confusion between vegetation and harvest when the delay between two images is too long.
The third method, based on the union of cloud-free area (98% of the total area) and attribution data decision rules in order to enlarge the sampled area, has a very good accuracy (maximum error of 8% of harvest fraction).

These results were then compared to the regional scale figures (**Table 1**). They are very similar.

In conclusion, even in unfavourable cloud conditions, one can extract with a good accuracy (more then 90%) the fraction of the cumulative harvested area on a monthly basis.

	AGRIGUA 2003		GARDEL PLANT	
Image acquisition date	Harvested area (ha)	Fraction of harvested area	Harvested area (ha)	Fraction of harvested area
29/03/03	121,2	11,2%	88,6	9,8%
30/04/03	276,3	25,5%	206,9	23,0%
04/05/03	335,1	31,0%	251,8	28,0%
25/05/03	505,3	46,7%	400,5	44,5%
17/07/03	855,2	79,0%	737,1	81,9%

Table 1: Cumulated harvested area at the regional (Grande-Terre) and farm (Gardel) scales, calculated on the union area of the cloud-free images.

Planting mapping

We do not try here to calculate step by step statistics of a dynamic process, but rather to have a assessment map of planted fields at the end of the planting season. We used the same procedure as for harvest monitoring, on a set of three images (from July to November, **Figure 3**).

The validation of the planting survey was performed against the AGRIGUA data base (1 100 ha planted in 2003 in Grande-Terre). The classification accuracy is given in **Figure 7** for the three methods.

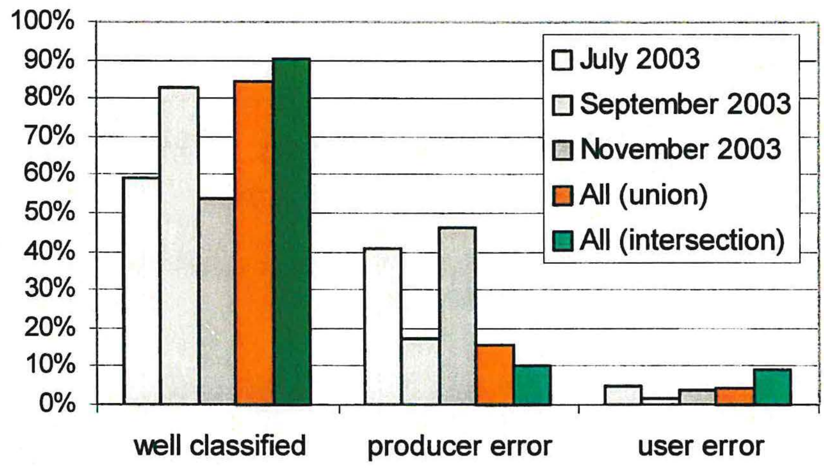

Figure 7 : Planted fields classification accuracy and errors in Grande-Terre (reference : AGRIGUA 2003) using different sets of SPOT images.

For the single date image processing, September image gives the best results in terms of planting classification accuracy (83% of well classified planted area), with 17% of lacking attribution (producer error) and 2% of excessive attribution (user error). As expected, July and November have a low classification accuracy ; in July, planting and so ploughing is not advanced enough to be identified by remote sensing, while in November the fields that were planted early in the season exhibit cane regrowth and are confounded with the ratoons regrowth.

On the cloud-free intersected area, the planting classification accuracy is very high (90%) with small producer (10%) and user (9%) errors. The user error can be explained by a fraction of classified ploughed field not devoted to cane growing.

6. An on-shelf GIS tool for management support

To demonstrate how the results of this research could relate with the management processes of the sugar cane agricultural sector, we are developing a geographic information system (GIS) that integrates the analysis results presented above with a capacity to produce lightweight interactive maps to distribute the results to different kinds of final users at a low cost.

Our system is designed with three different kinds of users in mind :
. Experts of remote sensing image analysis and spatial data analysis
. GIS administrators
. Final users who only need to browse interactive maps

The results of remote sensing image and spatial data analysis are provided by the experts who actually make the analysis work. The spatial data and attributes are imported into the database of our GIS, commonly in shapefile format.

The data model of that GIS is designed to represent data at different levels of spatial objects aggregation. At the lowest level is the field, with its geographical boundaries and a set of attributes. One level above we define groups of fields. Such group can represent a farm for example, or any other type of management unit. A set of attributes can be attached to those groups. Again one level above we can define groups of farms and associated attributes. And it is possible to define more aggregation levels as needed.

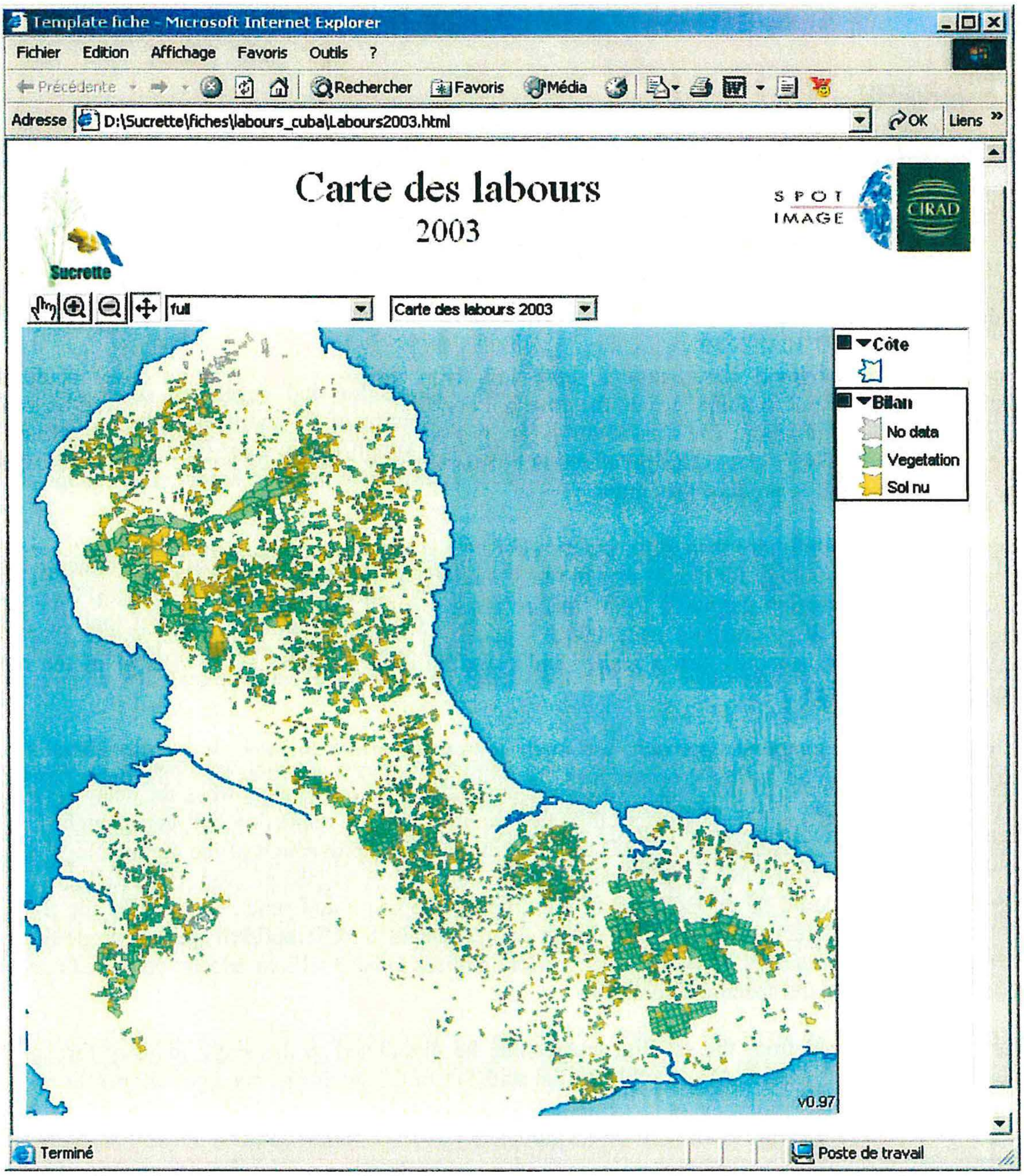

Figure 8 : Example of a screen of the sugarcane GIS tool.

The GIS is typically managed by a "GIS administrator" who has the capability to update the content of the database, view layers and perform complex requests as needed.

One original capability of that tool though is to generate lightweight interactive maps on demand. The GIS administrator selects a set of pre-defined forms to generate, like the "Sugar cane ploughing survey form" for example, and the software generates a directory with several data files and a HTML page (**Figure 8**). A light java mapping program is embedded in that 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 enough to browse the maps dynamically. Please note that what our system generates is not a web site, but we do use web mapping technologies.

7. Conclusions

Despite difficult experimental conditions, small size of the fields and high cloudiness, we demonstrated in this preliminary study that SPOT images could be used to map ploughed fields and calculate harvest progress throughout the milling season. The main constraint is to have previously established the field map boundaries. In this study we used the field geographic data base from an existing GPS and aerial photographs project, but recent studies (Lainé, 2004) show that the field boundaries could be mapped from very high spatial resolution satellite images such as Ikonos, QuickBird or SPOT5-HRS.

From maximum likehood classifications, bare soil, crop residue and vegetation cover could be distinguished. We want to point here on the essential contribution of the shortwave infra-red band for crop residues discrimination. The classification results were simplified on a per-field basis, attributing to each field the majority class. This permitted to be less sensitive to the field border effect, to increase the sampled area and to produce neat maps.

The validation results (more than 90% accuracy for both harvest and planting mapping) indicate that remote sensing technology for monitoring in real time harvest schedules is possible using SPOT4 and SPOT5 data. Information extracted from satellite images could be a decision support tool for mill closing dates as well as crushing rates which could have a significant economic impact. Planting surveys from space becomes also a reality and could be used for a better knowledge of the crop management practices.

In our spatial and temporal approach, the main sources of errors include the misclassification of harvested fields with no or little crop residues, the omission of harvested plots when the delay between two cloud-free images is too long (more then two months) and the confusion between ploughed and planted fields. Current research at CIRAD are focusing on the improvement of the methodology. One solution could be to model the temporal spectral signatures of the sugarcane crop. Both Red and NIR vegetation indices could be an indicator of the crop development and senescence, while the SWIR band could help to detect sudden changes due to harvest thanks to differentiated spectral properties of vegetation and crop residues. However, such modeling needs to have radiometrically corrected images in order to normalize the spectral signatures.

Finally, maps derived 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.

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