USING SPOT 4 SATELLITE IMAGERY TO MONITOR AREA HARVESTED BY SMALL SCALE SUGARCANE FARMERS AT UMFOLOZI

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Abstract

This paper presents the use of time step Spot 4 satellite imagery to monitor sugarcane areas harvested by smallholder growers in a selected area within the Umfolozi mill supply area. This was achieved by manipulation of the four satellite-measured spectral bands and subsequent classification of sugarcane into harvested and non-harvested areas. Mixed results indicate that the satellite imagery classifications are able to clearly distinguish between standing sugarcane and harvested plots. Stressed cane was difficult to discriminate from harvested plots.

Introduction

There are many advantages to using satellite remote sensing in sugarcane agriculture, namely in-season crop observation, crop inventory, crop health monitoring, watershed management, damage assessment and land degradation (Sirvastva *et al.*, 1999). The advantages of using satellite remote sensed data are that it can be frequently collected for large areas and that the data are unbiased. It therefore lends itself well to agricultural applications (Sirvastva *et al.*, 1999; Krishna Rao *et al.*, 1999; Narciso and Schmidt, 1999; Noonan, 1999).

In an effort to determine the area under cane and the timing of harvest of the 5623 small growers supplying the Umfolozi mill, the Small Scale Grower Cane Development officers have made use of digital orthophotography and Differential Global Positioning Systems (DGPS) to accurately map and update their small grower cane plots. This has not, however, solved the problem of estimating the standing crop throughout the milling season, as the small-scale farmers sometimes submit insufficient and occasionally incorrect field information with their cane deliveries. As a result, cane delivery information captured at the mill was unable to indicate the field(s) from which the cane was harvested. Furthermore, rainfall in the study area, which lies on the northern boundary of the non-irrigated sugarcane areas, is highly variable. A good rainfall season can yield a large crop, while the drier years may result in under-utilisation of the milling capacity. These factors make estimation of area under sugarcane extremely difficult, and balancing mill capacity with cane supply can be confounded by lack of information in this regard.

Table 1. Statistics describing the small-scale grower canefields within the study area.

Statistic	Value
Sum of area (ha)	1642.513
Count of fields	1436
Mean area (ha)	1.1438
Maximum area (ha)	8.6436
Minimum area (ha)	0.1342
Range in area (ha)	8.5094

This research project investigated the use of Spot 4 satellite imagery for the monitoring of the status of the sugarcane crop, throughout the milling season, for small scale cane farmers in the Umfolozi mill supply area. The project was initiated in collaboration with the Umfolozi Small Grower Cane Development officers of Illovo Sugar, whose responsibility it is to monitor the standing sugarcane crop throughout the milling season in order to balance milling capacity with the estimated production. The use of satellite imagery was not seen as a means of replacing existing mapping and cane monitoring procedures, but rather to enhance the accuracy of current estimates by making use of existing mill data and field information.

The Spot 4 satellite was selected for its small spectral resolution (pixel size) of 20 metres. It was agreed that the smallest spectral resolution would best distinguish the small cane plots of average area 1.14 ha (Table 1). Secondly, the Spot 4 has a fourth shortwave infrared band, similar to the fifth band of Landsat Thematic Mapper, which is useful for determining vegetation and soil moisture content ([1] personal communication, Kiefer and Lillesand, 1994). The Spot image provider, Satellite Applications Centre (SAC), has used Spot imagery elsewhere within the sugar industry, and has provided a service whereby vegetation indices such as the NDVI (Normalised Differential Vegetation Index) have been sold to commercial sugarcane growers in Mpumulanga for visual interpretation of within-field variations throughout the milling season.

Multi-resolution merges of Spot 4 multispectral imagery (20 metre) and Spot 4 panchromatic (10 metre) to produce a simulated 10 metre spatial resolution was not considered, as this would double the cost of imagery.

Methodology

Broadly speaking the determination of the standing cane area throughout the milling season involved several steps:

- Selection of suitable satellite imagery
- Gathering ground-truth information
- Image processing
- Image classification
- Verification of classification accuracy.

Each of the above will be discussed.

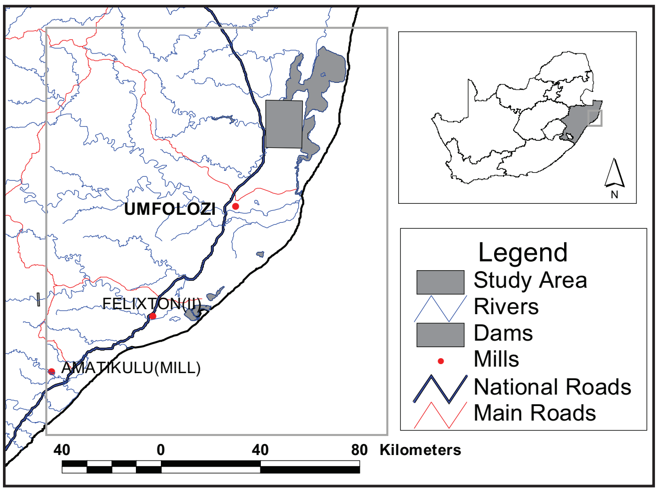

Figure 1. Map showing the location of the Umfolozi mill supply and study area.

Selection of suitable satellite imagery

Spot 4 is the latest multispectral satellite, launched by a French commercial company, Spot Image. This satellite is in a sun-synchronous orbit and has a circular period of 101 minutes. Spot 4 is phased in a 26 day cycle and passes the equator around 10h30 on its descending pass. The satellite measures the four bands described in Table 2.

SAC supplied the imagery in a co-ordinate system that would most accurately represent the small cane plots. (A Transverse Mercator projection with a central meridian of 33°E was selected to accurately represent field shapes and areas ([2] personal communication).) With the assistance of the Cane Development Officers, the Ntondweni location was chosen as the best target area, as it is isolated from the other small grower communities and is adjacent to commercial farms, which could be included in a future analysis.

The geographic location of the study area was between latitudes 28.05°S and 28.22°S and between longitudes 32.29°E and 32.42°E. The Greater St Lucia National Heritage Site falls within the northern extremity of the study area (Figure 1).

Table 2. The bands measured by the Spot 4 satellite and the wavelengths measured in each band (Spot Image Corporation, 2001).

Band	Wavelength and description
Band 1	0.50 to 0.59 µm (green)
Band 2	0.61 to 0.68 µm (red)
Band 3	0.79 to 0.89 µm (near infrared)
Band 4	1.58 to 1.75 µm (short wave infrared)

Table 3. Dates of satellite imagery. (Mill opening and closing dates were 15-04-2000 and 14-01-2001 respectively.)

Image number	Date
1	14 March 2000
2	26 May 2000
3	17 July 2000
4	13 October 2000

The dates of the satellite imagery were of critical importance. It was initially decided that five images should be acquired between the mill opening date (15-04-2000) and closure of the milling season (14-01-2001) at bi-monthly intervals. Theoretically this was possible since images can be acquired at 14 day intervals throughout the season, notwithstanding the 26 day cycle, as the satellite is able to take images from an oblique angle when the track of the satellite is not directly above the study area. While cloud cover posed problems throughout the year, a reasonable spread of images throughout the milling season was obtained (Table 3).

Many difficulties were encountered in acquiring satellite imagery relating to incorrect image scenes, co-ordinate systems, pixel size or resolution, level of geo-referencing, image formats and delays between image acquisition and processing of the data.

Ultimately these problems were overcome. The most cost and time efficient way of obtaining the imagery in the desired format in future would be to process the data in-house. The skill level was not, however, sufficiently developed at the onset of the project, nor was the software sufficient to complete these tasks in certain respects.

Gathering ground-truth information

Mill yield data was obtained to assist in classification and verification of the satellite imagery. That is, field numbers identified

Figure 2. False colour composite satellite image (17 July 2000) showing the extent of the study area and field boundaries.

on the mill delivery records would be joined to the map to identify harvested fields. These harvested fields would then be isolated and with a combination of green canefields, be used as either training sites for classifying the image or verification sites for determining the accuracy of the classification.

The Small Grower Cane Development officers provided mill delivery information which was not very useful, as it did not specify fully the field(s) from which the cane was harvested, since farmers possessing several fields used the same number for all deliveries. The mill yield data could therefore not be used to identify training sites for classification or verification of the classified images.

Small grower field maps were obtained from the Cane Development Officers who captured field boundaries by means of Differential Global Positioning Systems (DGPS) and digital orthophotographs. Once the data were obtained, topological, logical and structural errors were identified and corrected.

Ground-truth work was conducted to establish accurate field information, which could be used to classify and verify the satellite images. Ideally, ground-truth should have been conducted prior to each image acquisition. Ground-truth work was unfortunately only conducted for the third image. There were many reasons for this including:

- Inception of the project after the first image acquisition
- Time and distance constraints
- Delays in identifying the use of mill data as insufficient for use as training or verification sites
- Lack of practical and technical experience in planning and executing remotely sensed projects.

With assistance from the Umfolozi mill Small Grower Cane Development staff, a field visit was made on 21 July 2000 to establish the crop status of a series of fields. Cane and harvested plots of land were identified and annotated onto a map of the area.

Image processing

Using image-processing software, each image was imported and cropped to a common geographical area. The minimum and maximum reflectance values for each band were determined from the pixel values within the (cane) field boundaries. Each band was then linearly stretched between the minimum and maximum reflectance values (see Figure 3) to increase discrimination of cane and harvested plot reflectance values. The stretched bands were then used for classification purposes.

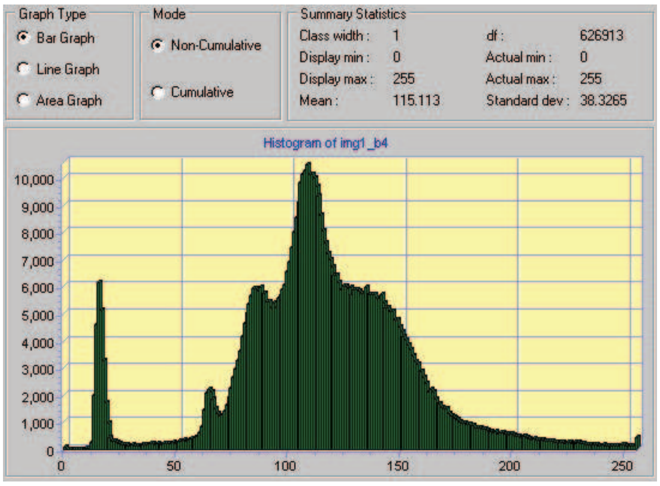

Figure 3. Histogram of the spectral reflectance values for the entire image for the fourth band (shortwave infrared) on 26 May 2000.

Image classification and verification

Supervised classifications were performed on the stretched bands of all four images. Since ground-truth work was not conduced for the 14 March, 26 May and 13 October images, for reasons previously given, classification and verification sites were selected from visual interpretation of the images. For the most part, fields with standing and harvested cane were readily distinguished when identifying training and verification sites. Fields in which the crop status was unclear were not selected as training or verification sites. The classification results for these images were assumed to be as accurate as those for which ground-truth information was available.

It was thought that all the fields in the first image would have full canopy, considering the long time delay between the mill closing date in 1999 and the date of the first image, taken prior to the mill opening in 2000. This was not, however, the case as several fields were harvested or fallow throughout all the images. These fields were considered abandoned and removed from the sample of fields. Abandoned fields were defined as having more than 80% area fallow in all four images.

Once the images were classified into standing cane and harvested pixels, harvested areas were determined for each image. Applying simple pixel logic between successive images allowed the cumulative harvested areas to be determined. The percentage of cane correctly classified was determined using error matrices.

Table 4. Examples of the mill yield information. The 'Field no#' field represents the farmer's grower code, which in most cases does not relate directly to the mapped plot of land from which the cane was harvested.

Date	Field no#	Name	Zone	Section	Cane (tons)
16 June 00	123456	Msweli E	Nkundusi C	N	31.8
02 July 00	123456	Msweli E	Nkundusi C	N	31.9
25 July 00	123456	Msweli E	Nkundusi C	N	31.8
30 July 00	123456	Msweli E	Nkundusi C	N	27.5

Results

Project results are presented below in two main sections:

- Verification of the accuracy of the classifications
- Regional application to determine harvested areas.

Verification of the accuracy of the classifications

The use of error matrices on each classified image allowed for the determination of the percentage cane incorrectly classified. The key results from the error matrices are listed in Table 5.

Regional application to determine harvested areas

The harvested areas in each image were obtained from supervised classifications of each image using the Maximum Likelihood method ([3] personal communication, Eastman (1999)). Comparing the changes in harvested areas between successive classified images, allowed for determination of the cumulative harvested areas (Table 6).

Discussion

According to Sirvasta *et al.* (1999) and Krinsha *et al.* (1999) sugarcane can be detected 120 days after planting or harvest. Furthermore active growth of the crop increases its discrimination from other land covers. Table 5 illustrates how standing cane discrimination, for the classifications of the first, second and last image was best. This coincided with preceding periods of high rainfall (Table 7), temperature and active growth.

It should be noted that the error matrices, which determined fraction of area incorrectly classified, were calculated on a pixel and not a field level basis. Edge effects occur when standing cane situated adjacent to harvested cane, mask the true value or status of the pixels along the (adjacent) edges of the harvested field. The small size of many fields, resulted in increased contributions of edge effect inaccuracies in the error matrix determination. Moreover classification of small fields to harvested or green cane were further complicated by unclassified pixels within fields. In view of these factors it can be said that general classification accuracies of standing cane were good.

The fraction of area incorrectly classified for harvested cane was higher than that for standing cane in all four images. The fraction 0.38 of area incorrectly classified as harvested cane, in the first image, was extremely high. Closer inspection of the composition of this error revealed that 0.305 of 0.38 was accounted for by pixels that were unclassified (i.e. the classifying algorithm could not decide to which class (standing or har-

Table 5. Verification results per land cover for each image classification.

Date	Land cover	Fraction of area incorrectly classified	Confidence interval at the 95% level
14 March 2000	Harvested cane	0.3809	0.0406
	Standing cane	0.0276	0.0084
	Standing and harvested cane	0.0829	0.0096
26 May 2000	Harvested cane	0.1106	0.0308
	Standing cane	0.0246	0.0065
	Standing and harvested cane	0.0378	0.0073
17 July 2000	Harvested cane	0.1457	0.0203
	Standing cane	0.1032	0.0503
	Standing and harvested cane	0.1116	0.0198
13 October 2000	Harvested cane	0.1434	0.0249
	Standing cane	0.0285	0.0138
	Standing and harvested cane	0.0946	0.0158

Table 6. Harvested and cumulative harvested areas from each image obtained from supervised classification of all four spectral bands.

	Image 1 14 March	Image 2 26 May	Image 3 17 July	Image 4 13 October
Harvested area as per classification (ha)	283.1	262.1	323.2	599.0
Standing cane area as per classification (ha)	1166.4	1187.4	1126.3	850.6
Total area (ha)	*1449.5*	*1449.5*	*1449.5*	*1449.5*
Cumulative harvested area results				
Harvested cane since previous image (ha)*	283.1	146.1	180.8	436.5
Standing cane area (ha)	1166.4	1303.4	1268.7	1013.0
Cumulative harvested area (ha)	283.1	429.2	610.0	1046.6
Cumulative harvested area (%)	19.5%	29.6%	42.1%	72.2%
Total area (ha)	*1449.5*	*1449.5*	*1449.5*	*1449.5*

* The reason why the harvested cane since the previous image was lower than the corresponding harvested area for that image was that certain harvested areas did not develop full canopy, resulting in them being classified twice as harvested.

vested cane) the pixels should be assigned). Only 0.075 of the 0.38 fraction of area incorrectly classified were sugarcane pixels. A possible explanation could be that the area received 595 mm rainfall in the first three months. This unusually wet period (Table 7) may have resulted in excessive weed growth making discrimination of the harvested plots difficult, hence the high composition of unclassified pixels.

It would appear that the higher inaccuracies in classifying harvested cane, compared to standing cane, was due to the lack of discrimination of sugarcane trash, weed growth and flowering cane that was prolific during 2000. The ground-truth work conducted on 21 July 2000 did not adequately account for these factors. Furthermore the use of visual interpretation to identify the training and verification sites, in the remaining images, was inadequate to accurately discriminate the land cover of these fields. The accuracies in classifying harvested cane fields would have increased, had a more comprehensive ground-truthing exercise been conducted, for all four images.

It should be noted that the verification methods employed in terms of obtaining field information for the error matrix evaluation were not strictly correct. This had to be done however, as no actual field information was available for the first, second and fourth images. Mill data were not sufficiently detailed for meaningful verifications to be made. Despite the biased sampling method employed, the results are nonetheless believed to be representative of the accuracy of the classification.

The overall accuracies in discriminating cane status were worst for the July image. Several factors are believed to be responsible for this:

- Drier conditions resulted in poorer land cover discrimination.
- The total sampling area was smaller compared to the first two images.
- The cane was flowering heavily.

The use of vegetation indices such as the Normalised Differential Vegetation Index (NDVI) and the Infrared Index were explored as the means of determining the crop biomass and areas. Several single farmer fields were identified for which yield data were available. This was unsuccessful as many of the records indicated that fields had been harvested while visual interpretation of the imagery contradicted this. Secondly the small number of fields for which yield data were available, had an insufficient range in cane yields to obtain a meaningful calibration curve for extrapolation purposes. Furthermore, many different classification techniques and methods were applied to the NDVIs in an effort to determine area under cane. These were largely unsuccessful.

This lengthy study concludes the first pilot project using Spot 4 multi-spectral resolution satellite imagery, for the monitoring of cane areas within the South African sugar industry. The project has identified key areas requiring more in-depth research, highlighted in the recommendations, as well as potential problem areas. Valuable insights have been gained that will improve the accuracy, reliability and timely delivery of future remote sensing projects.

Recommendations

It should be noted that the aim of this pilot project was not to use satellite remote sensing as a means of replacing existing mapping and cane monitoring system procedures of the Umfolozi mill. The focus was rather to combine the existing information sources where possible, to improve the accuracy in determining the harvested cane areas throughout the milling season. Secondly, this pilot project has not operationalised this methodology, but rather has identified key areas that will facilitate practical implementation and improvement of results.

Key areas that should be addressed in greater detail in follow-up projects include:

- Gathering ground-truth information
- Image processing
- Image classification.

Each of the above will be briefly discussed.

Table 7. Monthly and long term mean rainfall for Glen Park, Hluhluwe (28.13°S, 32.28°E) (source: [4]personal communication).

Year	Month	Rainfall (mm)	Long term mean (mm)	Image No. and date
2000	Jan	183	112	
2000	Feb	200	127	
2000	Mar	212	84	1, 14 March
2000	Apr	76	52	
2000	May	81	36	2, 26 May
2000	Jun	34	23	
2000	Jul	9	26	3, 17 July
2000	Aug	0	29	
2000	Sep	46	55	
2000	Oct	51	85	4, 13 October
2000	Nov	276	96	
2000	Dec	65	89	
2000	Totals	1233	813	

Gathering of ground-truth information

Once the calendar cycle dates of image acquisition have been obtained, ground truth work should identify the following land covers on a representative sample of fields that include:

- Harvested and standing cane fields representing a full range of harvested and growing conditions respectively.
- Fields harvested shortly after image acquisition. (The yield information for these fields should ideally represent a broad range in yields.)

Image processing

It is imperative that the level of geo-referencing is as accurate as possible, since an inaccuracy of a pixel or two will have serious implications when overlaying field boundaries and comparing successive images. The small area of the cane fields further magnifies this need.

Image classification

While the results presented in this paper presented only the Maximum Likelihood method of classification, investigations into other techniques were made. Notably classification procedures should model the classified results on a field basis, to determine the overall status of the field. These models must take cognisance of unclassified pixels.

Furthermore, sub-pixel classifications should be investigated. A pixel may have combinations of both harvested and standing cane spectral signatures in which case the dominant spectral signature should dominate.

A more sophisticated iterative unsupervised classification procedure that minimises the overall classification error with each iteration, should be tested.

Conclusions

In the Umfolozi area extensive use has been made of accurately mapped small scale grower field information to monitor cane areas harvested during the milling season. Field management by the small-scale grower varies, ranging from poorly weeded fields with large trees and fallow portions within the field to agronomically well managed fields. Furthermore, the harvesting of the fields is inconsistent at times, with certain fields being partially harvested while others are abandoned. These factors make assessments of the global standing crop by means of field surveys extremely difficult.

The use of satellite imagery in this project has shown that remotely sensed data can to a large extent work around the complications inherent in the estimation of global areas of standing cane, while harvested cane areas proved more difficult to identify. An improved ground truth information gathering strategy would have improved the accuracy in determining both standing and harvested cane areas.

This study did not include yield estimates based on the crop signatures or vegetation indices, due to a lack of accurate field information. Given accurate field information, estimates based on satellite data could have been verified. Future studies will focus attention on yield forecasting using crop spectral signatures and vegetation indexes. Commercial estates within the study area, not included in this in this project, will also be investigated.

Ultimately if the South African sugar industry is to remain a cost competitive global sugar producer, accurate and timely information delivery must be harnessed to improve production, efficiency and sustainability. Remotely sensed information may be able to assist in determination of crop estimates and hence play an integral role in competitive, sustainable sugarcane production.

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