RELATING REMOTELY SENSED MULTI-TEMPORAL LANDSAT 7 ETM+ IMAGERY TO SUGARCANE CHARACTERISTICS

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Abstract

This paper explores the relationships between normalised multi-temporal Landsat Enhanced Thematic Mapper Plus satellite imagery and sugarcane age, variety and yield at Umfolozi. Five Landsat images were obtained for the Umfolozi mill supply area for the 2002-2003 growing season, as well as field boundary and agronomic information for large scale grower fields. The satellite images were normalised using the COST image-based atmospheric correction model, following which the spectral reflectance values for each field were extracted and stored in a relational database. The results show that thermal age groups of sugarcane can be identified from the at-satellite reflectances. Sugarcane varieties could not be distinguished by the at-satellite reflectances. No meaningful relationships between yield and the single-date at-satellite reflectances were found.

Keywords: sugarcane, spectral reflectance, at-satellite reflectance, COST correction, Landsat 7 ETM+, variety, cane age, yield

Introduction

The South African Sugar Association Experiment Station (SASEX) has investigated various applications of remote sensing in sugarcane agriculture, including precision agriculture (Schmidt *et al.,* 2000), cane area mapping, monitoring the timing of harvest (Gers and Schmidt, 2001) and yield forecasting (Schmidt *et al.,* 2001). These applications rely on the spectral characteristics of the sugarcane crop.

This paper investigates relationships that may exist between sugarcane varieties, crop age and yield and their spectral characteristics, which vary according to season and stage of crop development, using the multi-temporal Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite imagery at Umfolozi, in the KwaZulu-Natal province of South Africa. Vegetation indices are not considered in this paper. Research was conducted to clarify the practical applications and limitations of the Landsat 7 ETM+ sensor in sugarcane agriculture, given the lack of literature in this particular field.

The Umfolozi mill supply area (MSA), which extends from 27.85°S, 32.00°E to 28.57°S, 32.40°E, was selected as the study area because of its accurate field boundary and the field record information available for many of its large scale growers. This study forms part of a broader research programme in the Umfolozi MSA, which is investigating the use of remote sensing for cane area identification, yield forecasting and cane inventory assessment throughout the milling season.

Methods

The data and the methods outlined are the same as those presented by Gers (2003), which focused primarily on the phenological characteristics of sugarcane. The objectives of the research are nevertheless different. An abridged methodology is given below.

Field information

Accurate field boundary information for 10 large scale grower farms was obtained for the 2002-2003 season. (All 10 growers participated in the FieldWatch programme, a field record system designed to assist and improve agronomic management on a field scale.) Ninety-two fields covering an area of 564 hectares were sampled. Sugarcane yield, variety, starting date and harvest date information was obtained for these fields. Table 1 provides a summary of the fields sampled.

Table 1. Summary information for the fields sampled.

Variety	Fields sampled		
	Total area (ha)	Number of fields	Average area (ha)
N19	154.84	25	6.2
NCo376	78.49	12	6.5
N29	77.75	13	6.0
N22	67.14	12	5.6
N27	50.81	11	4.6
Mix	47.14	6	7.9
N17	45.70	7	6.5
N14	23.20	3	7.7
N12	11.60	2	5.8
N27/NCo376	7.96	1	8.0

Landsat 7 ETM+ satellite imagery

Five Landsat 7 ETM+ images were obtained, with a temporal resolution spanning from October 2001 to November 2002 (see Table 2). The intention was to select satellite images that were evenly spaced throughout the milling season (April to December), depending on factors such as cloud cover and constraints in conducting field work.

Table 2. Dates of Landsat 7 ETM+ image acquisition.

Date
30 October 2001
08 April 2002
13 July 2002
17 October 2002
18 November 2002

Image preparation and normalisation
All images were ortho-rectified using a 20-metre contour digital elevation model. The first image (30 October 2001) was geo-referenced using ground control points obtained from 1:20 000 digital orthophotography. All subsequent images were ortho-rectified to the first image.

To make quantitative comparisons between multi-temporal imagery, the image-based atmospheric correction COST model described by Chavez (1996) was applied to the imagery. The COST model was applied to Bands 1, 2, 3, 4, 5 and 7 on all images to normalise seasonal effects (i.e. varying earth-sun and solar elevation angles) on the reflectance values. The resultant images represented at-satellite reflectance values for each band for each (multi-temporal) image (Tables 2 and 3). Only bands 1 to 5 and 7 were used in this study.

Table 3. The spectral bands for the Landsat 7 ETM+ satellite (modified from Irish, 2000 and Noonan, 1999).

	Band 1	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**Band 7**	**Band 8**
ETM+ spectral bandwidths (µm)	0.45 - 0.52	0.53 - 0.61	0.63 - 0.69	0.78 - 0.90	1.55 - 1.75	10.4 - 12.5	2.09 - 2.35	.52 - .90
Ground resolution (m)	30	30	30	30	30	60	30	15
Electromagnetic region	Visible Blue	Visible Green	Visible Red	Near Infrared	Middle Infrared	Thermal	Middle Infrared	Pan-chromatic
Generalised application details	Coastal water mapping, differentiation of vegetation from soils	Assess-ment of vegetation vigour	Chlorophyll absorption for vegetation differentiation	Biomass surveys and delineation of water bodies	Vegetation and soil moisture measurements		Hydrothermal mapping	Visual interpretation
Used for analysis in this study	Yes	Yes	Yes	Yes	Yes	No	Yes	No

Sugarcane phenology
Sugarcane phenological stages are pre-emergence, emergence, tiller emergence and flowering. Tiller emergence is of prime concern in the detection of sugarcane in remote sensing applications that rely on measurements of light reflected from the sugarcane canopy. Sugarcane flowering depends on favourable temperature, sunlight and daylength conditions, and does not always occur.

The development of the sugarcane ratoon canopy may be viewed as a process dependent on the emergence of tillers from the soil, and leaves from the whorl of each tiller. It was demonstrated by Inman-Bamber (1994) that the stalk population of sugarcane is highly correlated with thermal time when using a base temperature (T_b) of 16°C.

As can be seen from Figure 1, the tiller emergence phenological stage includes a tillering stage from 0 to 500°C days, at which the stalk population peaks, followed by tiller senescence, between 500 and 1000°C days, where tillers die off, followed by a relatively stable stalk population after about 1600°C days. Most of the sucrose accumulation occurs at these latter stages prior to harvesting.

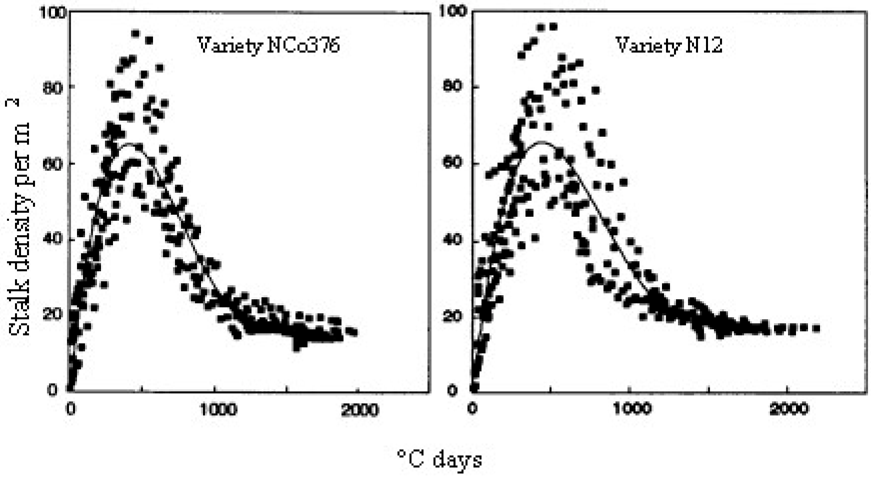

Figure 1. Thermal time for ratooning cane (T_b=16°C days) (source: Inman-Bamber, 1994).

Analytical procedures

Thermal age identification

Gers (2003) showed by analysis of variance that each of the thermal age groups, described in Table 4, were significantly different in reflectance. However, a measure of group overlap, evident in Figure 2, was not provided. This paper presents a measure of overlap between the different thermal age groups in the form of a classification probability matrix.

Table 4. Groups of cumulative thermal time used to analyse field information.

Group	Phenological classes based on thermal age (T_b=16°C)	
	Cumulative thermal time range (°C days)	Description
1	0 – 70	Stalk emergence
2	400 – 600	Tillering
3	750 – 1000	Tiller senescence
4	>1500	Tiller stabilisation

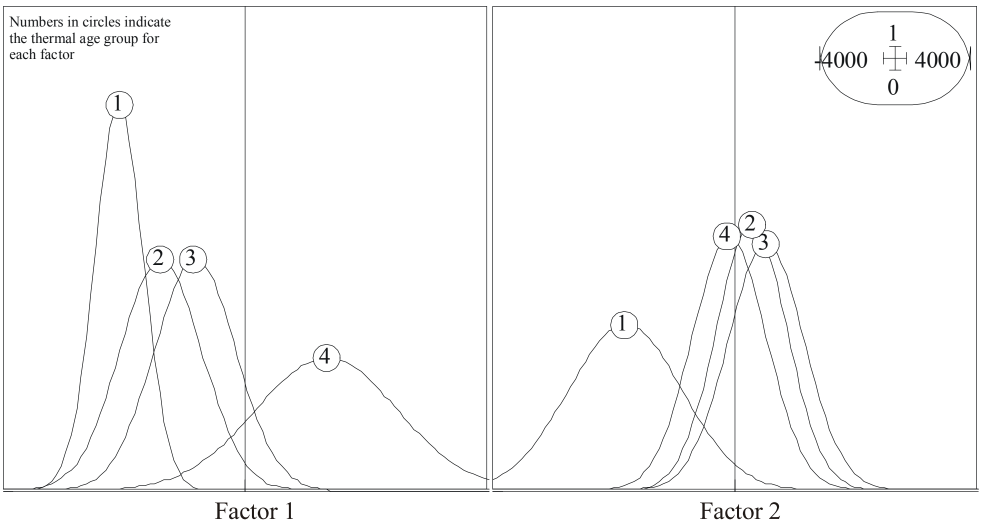

Figure 2. The four different thermal age groups against the first and second variance-covariance principal component factors (source: Gers, 2003).

Variety identification
Tests for variety identification for the five most abundant varieties, across all groups, and within each of thermal Groups 2, 3 and 4 was conducted. Group 1 was not considered because of the lack of a sugarcane canopy below 70°C days.

At-satellite reflectance data extraction
Given a root mean square error of less than one pixel in positional accuracy for the satellite imagery, an exclusion buffer of 30 m, or one pixel, was applied when extracting the at-satellite reflectance pixel values for each field to reduce edge effects.

Data preparation
Field information on variety, yield, cumulative thermal age at each image acquisition date, and at-satellite reflectance values for each field, was extracted and loaded into a relational database from whence data were extracted for analysis.

Multi-variate statistical procedures were applied to the data to evaluate the relationships between thermal age, variety and yield, and at-satellite reflectances, as presented below.

Results

Thermal age identification
The thermal age group misclassification probabilities provided in Table 5 were calculated from inter-group distances. (These inter-group Mahalanobis distances were computed from Canonical variate analysis of the first three variance-covariance principal component factors that accounted for more than 99% of the variability in the original data.)

Table 5. Thermal group classification probability matrix from which the probability of misclassifying a Group i (column) into Group j (row), can be obtained.

	Group 1	**Group 2**	**Group 3**	**Group 4**
Group 1	0.80	0.06	0.04	0.04
Group 2	0.09	0.51	0.32	0.14
Group 3	0.06	0.32	0.51	0.17
Group 4	0.05	0.11	0.13	0.65
Total	1.00	1.00	1.00	1.00

The probabilities provided in Table 5 should not be viewed as absolute values. The trends in the data are more important; in particular, Groups 1 and 4 are readily separable from Groups 2 and 3, which overlap with each other.

Variety identification
Analysis of the at-satellite reflectances across all thermal groups showed no significant differences between the top five sugarcane varieties (see Figure 3). The top five varieties constituted the five most abundant varieties by area for the sampled fields.

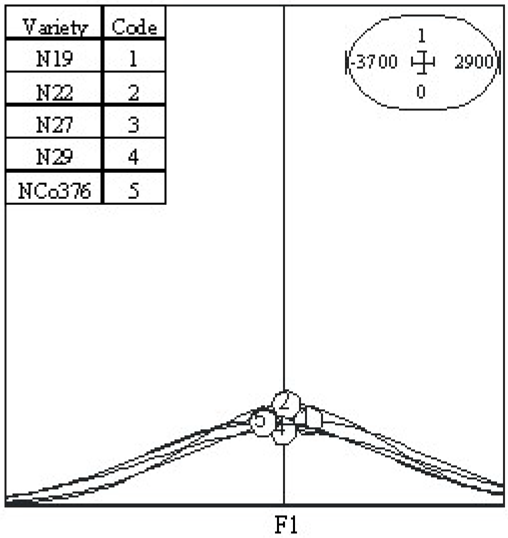

Figure 3. The five most abundant sugarcane varieties for all thermal groups against the first variance-covariance principal component factor that accounted for more than 74.8% of the variability.

This contrasts with the results obtained by Schmidt *et al.* (2000), who made use of high resolution Digital Multi-Spectral Video imagery to distinguish different sugarcane varieties using principal components. This would suggest that the spatial and/or spectral resolution of Landsat 7 ETM+ is unsuitable for variety identification, and that thermal age (i.e. growth stage) has a more profound influence on the spectral characteristics of the sugarcane canopy than the physical leaf characteristics associated with the different varieties.

Yield prediction

Correlation matrix principal component analyses were performed on the yield and at-satellite reflectance values in order to evaluate the relationships between the variables. Analyses were conducted across all thermal age groups (Groups 1 to 4) as well as for mature cane only (Group 4). As can be seen in Figure 4, a negative result was obtained. (A good positive result would show the yield arrow/vector extending close to the unity circumference line, preferably along the primary F1 axis or along the secondary F2 axis in either a positive or negative direction.) Correlation of yield and spectral bands was weak along the primary axes (F1) that accounted for about 56% of the variability for both analyses (i.e. for Groups 1-4 (A) and Group 4 only (B)). Although the at-satellite reflectances of mature cane indicated a better correlation with yield along the F2 axis (Figure 4B), this was not meaningful, given the weak correlation along F1 and the low percentage variability (27%) accounted for by the second factor. The scatter plot in Figure 5 confirmed these conclusions. No meaningful relationship between the spectral characteristics for mature cane and yield was evident.

It should be noted that all fields were harvested on a 12-month cycle. Given that the period for the satellite imagery was one year, the majority of mature sugarcane fields in thermal Group 4 were represented only once for a particular image. As a result, between-year comparisons of yield and at-satellite reflectances could not be made. Yield predictions for mature cane were therefore based on single-date comparisons of yield and at-satellite reflectances.

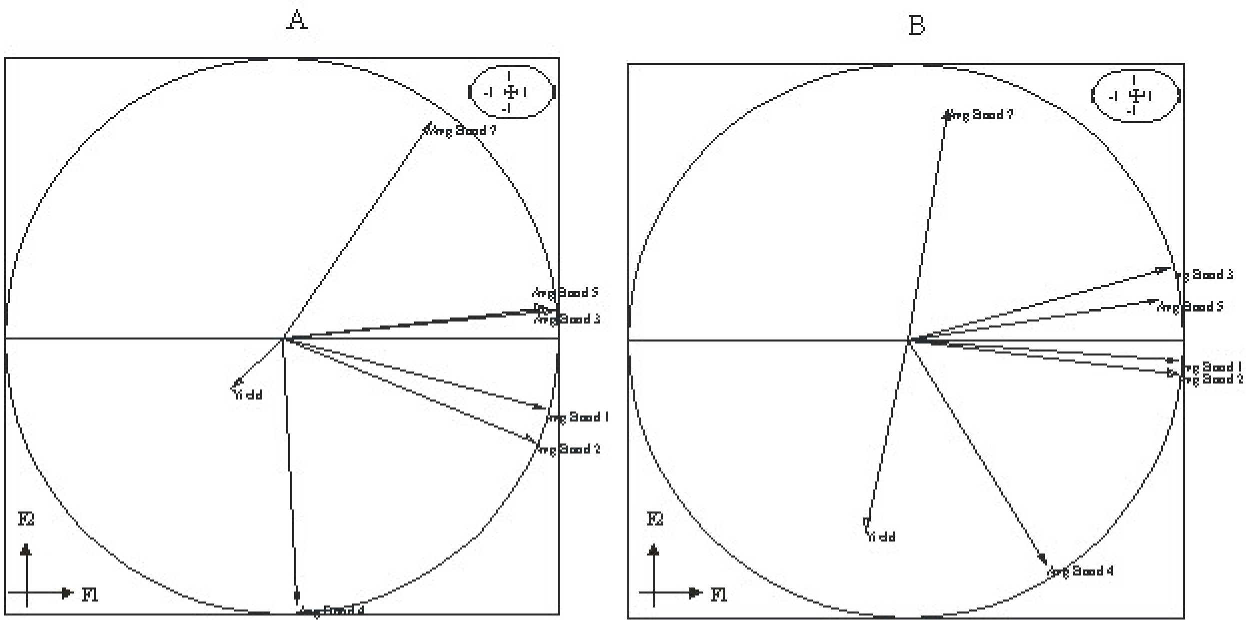

Figure 4. Correlation circles for the first two principal components of the average at-satellite reflectance and yield values for the five most abundant sugarcane varieties. Correlation circle A represents all thermal age groups (1 to 4), and correlation circle B represents mature cane fields (Group 4 only).

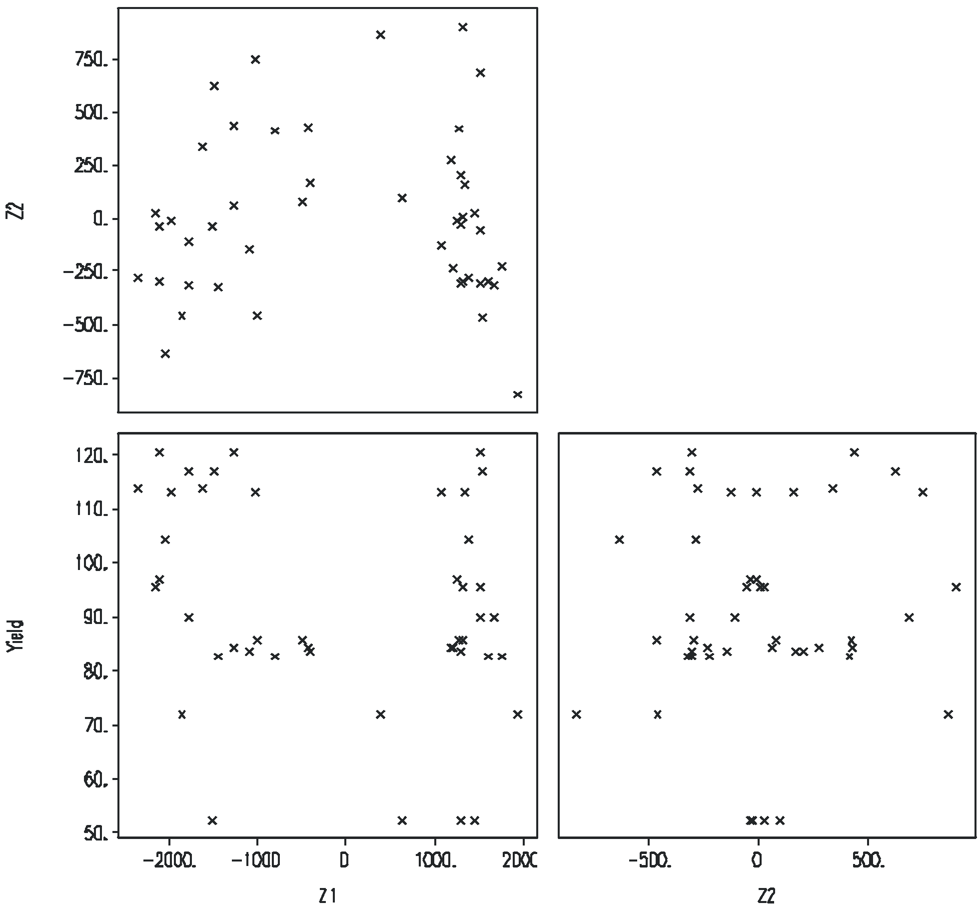

Figure 5. Plot of the first two variance-covariance principal component scores (Z1, Z2) against yield for mature sugarcane (>1500°C days, base temperature = 16°C).

General Remarks

Surprisingly, scientific studies and papers relating remote sensing to crop phenology or characteristics (other than yield) for crops such as sugarcane, maize, tobacco, millet and sorghum are scarce. However, literature searches in these focus areas will continue, in order to place this research in a broader context. The lack of scientific papers in this specific area would suggest that this type of research is relatively new, particularly with regard to sugarcane and the use of the Landsat 7 ETM+ sensor.

It should be noted that while Group 1 was readily identifiable, this was not likely to have been as a result of the sugarcane emerging, but rather the reflectance of the bare ground. In sugarcane fields, bare soil rather than emerging tillers is identified.

When applying this methodology of thermal age identification to other agricultural sectors, the following should be taken into consideration:

- Only large fields with an average area of 5.99 hectares were sampled.
- The impacts of water availability and the effects of crop moisture stress on the spectral signatures were not considered, since the majority of fields sampled were fully irrigated or received supplementary irrigation.
- The effects of management factors and field size on the results have not been quantified and may require further investigation.

Conclusion

Results from the reported study show that the Landsat 7 ETM+ at-satellite reflectances can be used to measure thermal age groups for large sugarcane fields. Mature sugarcane and emerging cane were well separated in spectral reflectances, whereas tillering and tiller senescing fields were similar in appearance.

Variety identification results from the reported study show that the spatial resolution and/or spectral resolution of the Landsat 7 ETM+ at-satellite reflectances were not sufficient to distinguish between different sugarcane varieties, at any thermal age, for fully canopied sugarcane fields.

Yield forecast results from the reported study show that sugarcane yield cannot be predicted from single-date Landsat 7 ETM+ at-satellite reflectances. These results remained negative for comparisons across fields with different thermal ages and mature sugarcane fields.

A potential application for this research is in conjunction with cane inventory assessments at regular intervals throughout the milling season to provide area-based estimates of the standing crop, as well as for predicting how long the crop is likely to remain in the field before being harvested. This information is particularly important in the South African context, where climatic variability has large impacts on cane supply. This information could assist mill and cane supply managers to optimise sugar production through improved cane supply scheduling, given a yield estimate and the age distribution of the standing crop.

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