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Assessing the relationship between shire winter crop yield and multi-temporal MODIS NDVI and EVI images

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ABSTRACT

Australian researchers have been developing robust yield simulation models, based mainly on the crop growth response to the rainfall amount and distribution during the crop season. However, better knowledge of spatial distribution of yields in the production regions can be estimated by the use of remote sensing techniques. The objective of this study was to analyse the relationship between winter crop yields and the spectral information available at MODIS vegetation index images at the shire level. The study was carried out in the Jondaryan and Pittsworth shires, Queensland, Australia. Five years (2000 to 2004) of 250m, 16-day composite of MODIS NDVI and EVI images were used during the winter crop season (April to November). For these shires, a mask of cropping area was applied by using a land use classification map derived from Landsat TM. Multi-temporal profiles of the NDVI and the EVI imagery for each crop season were displayed and analysed. Wheat and barley yields, provided by the Australian Bureau of Statistics, were correlated to the maximum and to the integrated crop season values for both NDVI and EVI at the shire level. The temporal VI profiles were quite similar in Jondaryan and Pittsworth, with minimum values in April, May and June, a peak in August, and decreasing until November. Bigger differences were found between years. The correlation analysis between the winter crop yields and VIs pointed out that EVI images were better than the NDVI ones. Most part of the coefficients was statistically significant when using EVI spectral information from the Integrated and Maximum results. The results presented in this paper showed that the VI images are a powerful tool to assess near real-time biomass status.

BIOGRAPHY OF PRESENTER

Andries Potgieter is a Research Scientist at the Queensland Department of Primary Industries & Fisheries. He is currently responsible for the Regional Commodity Forecasting project, with the primary goal of generating monthly wheat and sorghum crop outlooks at a shire, state and national level for Australia. He is currently enrolled in a PhD program that focuses on using remote sending to determine winter crop area planted at a regional scale and to discriminate among wheat, barley and chickpea crop signatures.

INTRODUCTION

Researchers in Australia have been developing crop yield estimation models that are focused on crop growth response to the water availability. Empirical agro-climatic and simulation approaches, considering water availability, showed adequate accuracy and precision for the Australian winter yield forecasting [Hammer et al., 1996]. These models have been also used to simulate long time series of yields, and supporting studies to allow better knowledge of the spatial and temporal yield patterns in Australia [Stephens, 1998; Potgieter et al., 2002].

However, considering the large extent of the area occupied by winter crops in the country, an improvement on spatial yield representation is still a challenge for the crop yield modelers, thus new approaches have to be tested and developed. Observations obtained through remote sensing techniques can provide that opportunity in monitoring, quantifying and investigating large scale vegetation alterations due to climate and human activities at different scales.

Since 1981, NOAA (National Oceanic and Atmospheric Administration) images have been used in various temporal and spatial land use change studies, and significant correlations were found between climate variables and vegetation parameters derived from remote sensing techniques [Markon & Peterson, 2002; Roerink et al., 2003]. In most of these studies, Normalized Difference Vegetation Indices (NDVI) images have been used, considering that NDVI images do not only map the presence of vegetation on a pixel basis, but also provide measures of the amount or condition of vegetation within a pixel. In the context of crop yield modeling, NDVI images have been used in many countries, and have showed significantly high association with yield [Boken & Shaykewich, 2002, Manjunath et al., 2002, Dabrowska-Zielinska et al., 2002]. Besides the good results, some papers have pointed out the limitations of NDVI/NOAA product, associated mainly to atmospheric interference, canopy background contamination, and saturation problems [Huete et al., 2002].

To address these limitations, the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor was launched in 1999, on board the Terra platform. This sensor was configured to obtain data on the dynamics of the terrestrial biosphere [Justice et al., 1998]. It is freely available in the form of different products, such as the vegetation indices like NDVI and EVI (Enhanced Vegetation Index). The NDVI images derived from MODIS images represent a possibility to extend the NDVI/NOAA historical series amplifying the availability of data to future monitoring studies. MODIS EVI imagery was specifically developed with improved sensitivity to high biomass condition and canopy structure through a de-coupling of the canopy background signal and a reduction in atmosphere influences [Huete et al., 2002].

The main objective of this study was to analyse the relationship between winter crop yields and the spectral information available at MODIS vegetation index images.

METHODS

The study region

The study was carried out in the Jondaryan and Pittsworth shires, in the southern Queensland, Australia. These shires are part of a big agricultural region called Darling Downs, where black and rich soils are predominant. The climate of the region is subtropical, with the annual rainfall ranges from 400 to 1,000mm. The winter is relatively cold and dry. The minimum temperature varies between 3 and 6^{o}C, and the monthly rainfall is below 50mm (http://www.bom.gov.au/). The winter crops, especially wheat and barley, are typically planted after the first rainfalls in April and then harvested in November. Most farmers in the area use minimum and zero tillage methods.

Data sources and processing

The actual wheat and barley yields data based on ground surveys were provided by the Australian Bureau of Statistics (ABS) for 2000 and 2001 and by Australian Bureau of Agricultural Resource and Economics (ABARE) for the years 2003 and 2004. Unfortunately, data for 2002 was not available at the shire level, but only at the state level and was therefore not included in the analyses.

During the winter crop season, 16-day composites of 250m NDVI and EVI MODIS images were selected for the first five years (2000 to 2004) of data availability. The 140 images (5 years, 14 images by year for NDVI and EVI) were downloaded from the Earth Observing System (EOS) Data Gateway [http://edcimswww.cr.usgs.gov/pub/imswelcome/].

Image processing

The downloaded vegetation index (VI) images use a range of -2000 to 10,000 values to represent both NDVI and EVI values. Image processing was done in three steps.

First, the images were re-projected from ISIN (Integerized Sinusoidal) to UTM, Zone -56, and Datun WGS84, using MRT (MODIS Reprojection Tools) software.

Second, for each year, the following five derived images were generated:
- Seasonal image: 14 bands (each 16-day composite image from 6 April to 31 October was associated with a band), represent the multi-temporal VI variation during the crop season;
- Maximum image: one band (maximum value from 9 June to 31 October), represents the best vegetation condition during the crop season;
- Integrated image: one band (integration from the beginning to the end of the crop season), summarizes all the historic VI behaviour during the crop season.

The last step in the image processing was the extraction of basic statistics data (histogram, mean and standard deviation) from the derived NDVI and EVI images using a cropping mask. The cropping mask was created by filtering just the area occupied by crops from a land use map in 1:100,000 scale [Department of Natural Resources, 2001]. The idea was to limit the study just for areas suitable for cropping. Spectral data from other kinds of land cover was not considered. The last three steps were preceded using ENVI software v. 4.1.

Analysis

All analysis were performance for both the NDVI and EVI images, for the two shires (Jondaryan and Pittsworth), and for the five years (2000 to 2004).

Multi-temporal MODIS profiles were created and the differences among indices, shires and years were analysed.

In order to assess the relationship between MODIS images and the winter crop yields, a simple correlation analysis was used. The following spectral parameters were tested:

- Mint, SDint - mean and standard deviation of the Integrated image;
- Mmax, SDmax - mean and standard deviation of the Maximum image;
- Mpeak, SDpeak - mean and standard deviation of the date with peak NDVI and EVI values;
- Cbest - correlation coefficient between each NDVI and EVI year and the best one.

The significance of the correlation coefficients was verified by using t-test.

RESULTS AND DISCUSSION

Multi-temporal variability

The multi-temporal variability of profiles was assessed by analysing the temporal VI differences among years. This approach has been used in many studies using NDVI from NOAA/AVHRR and MODIS images [Justice et al, 1991; Zhang et al., 2003]. In this study (Figures 1 and 2), the temporal profiles were quite similar in Jondaryan and Pittsworth, following the characteristic pattern of the crop growth curve. In the beginning of the season, associated with low biomass, the average VI values were small. With the crop establishment, the values increased achieving a peak in August, with the maximum crop development stage. After that, crop maturity makes biomass decrease and the same happened with the VI values.

The similarities in VI between shires are a consequence of the spatial proximity that determines climate, soils and agricultural practices. Figures 2 and 3 suggested that there were large differences between the years. In 2001 and 2004 VI values were considerably reduced by the presence of a big non-cropping area that were used to the calculation of the mean (Table 1).

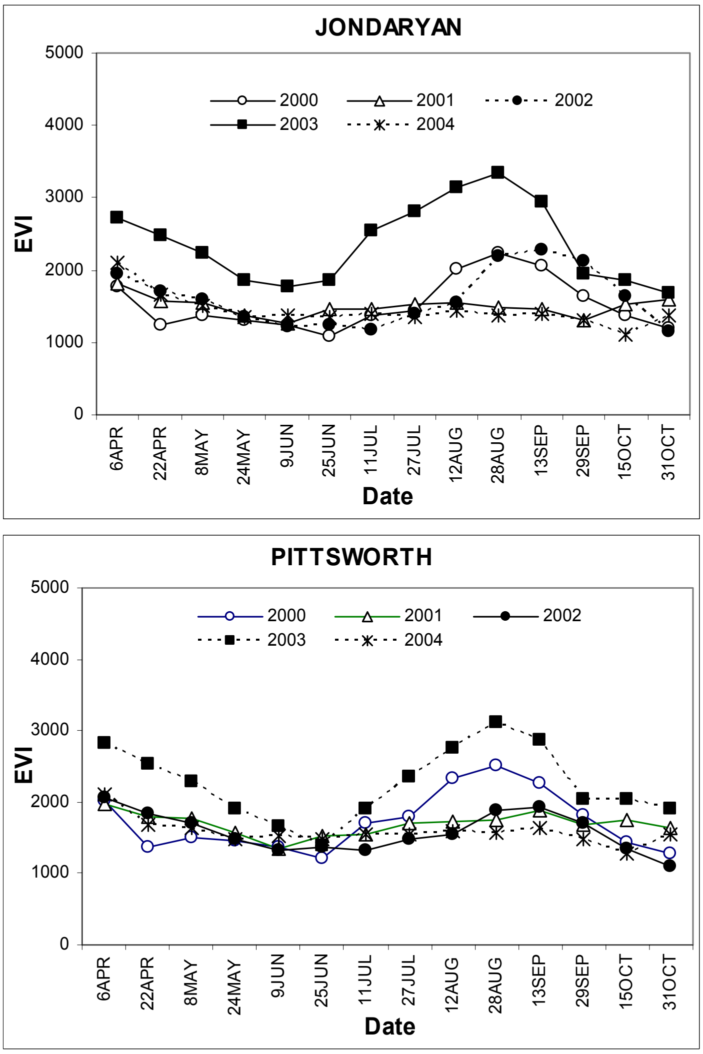

Figure 1: Multi-temporal EVI profiles from cropping areas in Jondaryan and Pittsworth shires, 2000 to 2004.

The biggest VI value in 2003 can be interpreted, as this was the year with the highest area planted (Table 1) as well as the year when the plants showed the best vigour.

For both Jondaryan and Pittsworth, the estimated area using a cropping mask represented 69% and 71% of the whole shire respectively (Table 1). Considering data from ABS and ABARE, the winter cropping areas were much smaller than this, with great variability during the four years, and will have an influence over the VI profiles.

Relationship between yields and VI data

According to actual yield data from ABS and ABARE (Table 2), the studied years had an adequate range of variability. Wheat yield varied from 1496 to 3350 Kg/ha and barley yield from 1191 to 2580 Kg/ha suggesting the higher yield to be nearly double that of the lowest yield.

During the crop season, the correlation coefficients between the winter crop yield from ABS and ABARE and the monthly VI values increased from April to July achieving coefficients above 0.8 for NDVI and EVI (Figure 3). After August, the correlation weakened. The smooth increase in coefficients is an evidence that the history of the plant vigour (inferred by VI) during the cropping season is well correlated to the final yield. It is important to emphasize that VIs express the biomass status since good association between VIs and leaf index area (LAI) and other biomass parameters have been found in many studies [Baret e Guyot, 1991; Gamon et al., 1995]. Yield, however, are a bit more complex phenomenon since they involve the transference of photosynthetic assimilates from leaves to grains. It means that it is possible to have a good amount of biomass but poor yield as a consequence of a severe drought during the period of grain filing. But in general, biomass and yield are well correlated and the same is expected for the relationship between yield and VI.

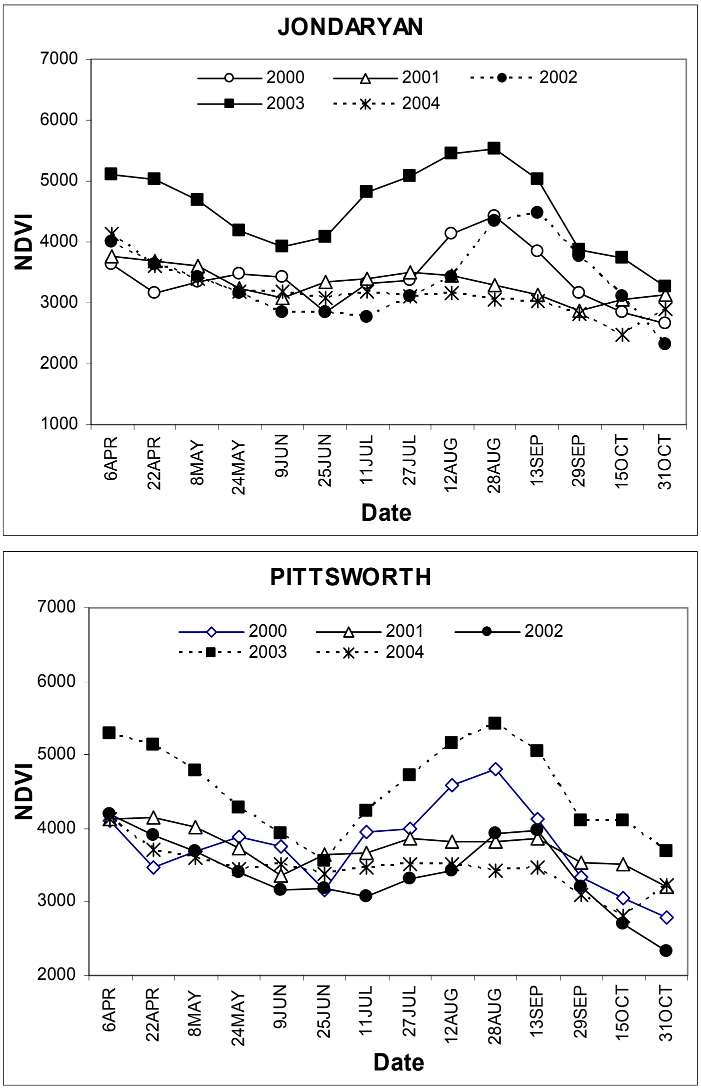

Figure 2: Multi-temporal NDVI profiles from cropping areas in Jondaryan and Pittsworth shires, 2000 to 2004.

Besides the quite good association found between monthly VI values and yield, it is more consistent to establish correlation using spectral parameters that consider more than one month of the spectral information. In this analysis we tested some spectral parameters that have been proposed by remote sensing studies which focussed on yield. The results are presented in Table 3. The magnitude of the coefficients found in this analysis was quite similar to other studies carried out in different regions using NDVI from AVHRR/NOAA [Boken & Shaykewich, 2002; Labus et al., 2002].

Shire	**2000**	**2001**	**2003**	**2004**
Jondaryan				
Whole shire (ha)	191,030			
Cropping (%)	68.7			
ABS / ABARE (%)	13.3	5.6	20.2	5.6
Pittsworth				
Whole shire (ha)	108,869			
Cropping (%)	70.8			
ABS / ABARE (%)	17.1	12.4	19.2	5.8

Table 1: Winter crop area estimated by ABS and ABARE, shire and cropping area for Jondaryan and Pittsworth shires, 2000 to 2004.

Generally, more significant correlations were found for the EVI than NDVI imagery. Using EVI, five coefficients were significant, whereby just two were significant for NDVI images. This is expected, since EVI was developed to improve the sensitivity to high biomass condition that is observed during the maximum development, e.g. during the main period of yield definition.

All coefficients were statistically significant when using EVI spectral information from the mean and the standard deviation of the Integrated (MInt) and the Maximum (MMax) images. For the NDVI analysis, all correlation coefficients using standard deviation parameters were not significant.

Shire	**Wheat**	**Barley**	**Winter crops**
Jondaryan			
2000	1502	1191	1353
2001	1496	1271	1389
2003	3350	2580	3126
2004	2165	1710	1961
Pittsworth			
2000	1614	1426	1536
2001	2557	1766	2167
2003	2565	2013	2427
2004	2132	1225	1689

Table 2: Actual wheat, barley and winter crop yields (Kg/ha) for Jondaryan and Pittsworth, 2000 to 2004 (Data Source: ABS and ABARE).

The same was observed in the correlation using the VI values of the month with maximum mean value (Peak). Correlations were not significant for the mean (MPeak) or for the standard deviation (SDPeak) in both VI.

The correlation with the best year (Cbest) can be considered as a measure of deviation from the maximum yield. We found significant values for NDVI and EVI images.

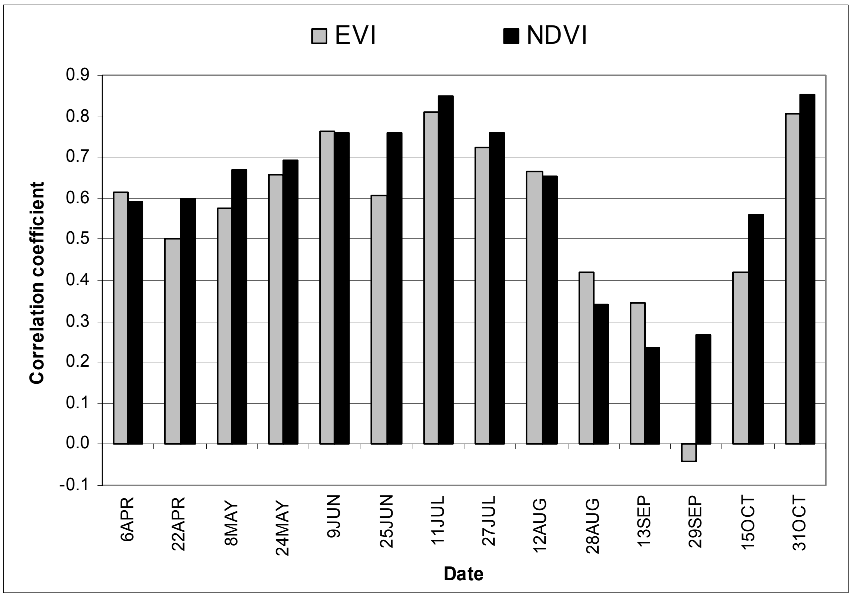

Figure 3: Correlation coefficients between yield and monthly NDVI and EVI data for Jondaryan and Pittsworth, 2000, 2001, 2003 and 2004.

Taking into account the consistency in the results (Table 3), EVI extracted from the standard deviation image seems to be the best yield indicator. Based on previous studies [Boden and Shaykewich, 2002; Manjunath et al., 2002] we expect that the EVI data introduced in agro-climatic models can improve the model performance, mainly in terms of spatial representation. In this case the spectral data to be incorporated to the yield modelling is related to the period from the beginning of June to the beginning of November, which means that it is possible to build a predictive model. However, it needs to be investigated.

Vegetation index	Mint[1]	MMax[2]	MPeak[3]	SDInt[1]	SDMax[2]	SDPeak[3]	Cbest[4]
EVI	0.78**	0.72*	0.67	0.85**	0.79**	0.63	0.80**
NDVI	0.72*	0.66	0.58	0.50	0.32	0.29	0.79**

Table 3: Correlation coefficients between winter crop yields and VI parameters derived from NDVI and EVI images for Jondaryan and Pittsworth, 2000, 2001, 2003 and 2004 (Mean and standard deviation for: [1] Integrated value from June 9 to August 29; [2] Maximum value from June 9 to August 29; [3] Value for the month with maximum mean value; [4] Correlation coefficient between actual and the best year; * P<0.01; ** P<0.05 (no of samples = 10).

CONCLUSIONS

Several correlation analyses were carried out to better understand the relationship between winter crop yields at the shire level and the spectral information available at five years of MODIS vegetation index images (2000 to 2004). The temporal VI profiles were quite similar in Jondaryan and Pittsworth, with minimum values in April, May and June, a peak in August, and decreasing until November. The similarities between shires were a consequence of relatively similar climate, soils and agricultural practices. Bigger differences were found between years. The correlation analysis between the winter crop yields and VIs pointed out that EVI images were better than the NDVI ones. Most part of the coefficients was statistically significant when using EVI spectral information from the Integrated and Maximum imagery approaches. The results presented in this paper showed that MODIS EVI imagery is a powerful tool to assess near real-time biomass status. In future studies, we recommend the following: increase the data set, aggregate more years and shires, use a more accurate cropping mask, and develop an agricultural-spectral model for winter yield forecast using MODIS EVI images.

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