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Assessing the relationship between shire winter crop yield and seasonal variability of the MODIS NDVI and EVI images

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Abstract: Australian researchers have been developing robust yield estimation models, based mainly on the crop growth response to water availability during the crop season. However, knowledge of spatial distribution of yields within and across the production regions can be improved by the use of remote sensing techniques. Images of Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation indices, available since 1999, have the potential to contribute to crop yield estimation. The objective of this study was to analyse the relationship between winter crop yields and the spectral information available in 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 resolution, 16-day composite of MODIS Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) images were used during the winter crop season (April to November). Seasonal variability of the profiles of the vegetation index images for each crop season using different regions of interest (cropping mask) were displayed and analysed. Correlation analysis between wheat and barley yield data and MODIS image values were also conducted. The results showed high seasonal variability in the NDVI and EVI profiles, and the EVI values were consistently lower than those of the NDVI. The highest image values were observed in 2003 (in contrast to 2004), and were associated with rainfall amount and distribution. The seasonal variability of the profiles was similar in both shires, with minimum values in June and maximum values at the end of August. NDVI and EVI images showed sensitivity to seasonal variability of the vegetation and exhibited good association (e.g. r = 0.84, r = 0.77) with winter crop yields.

Key words: MODIS, wheat, barley, temporal profiles, correlation.

1. Introduction

Australia is one of the world's main grain crop producers. On average, Australia produces nearly 24 million tons of wheat and 6 million tons of barley per year. These two winter crops together occupy an area of nearly to 16.1 million hectares (ABARE, 2005). The mean national wheat and barley yields are 1.75 and 1.80 t/ha, respectively, which is considered lower compared to other big cereal producing countries. Some studies have pointed out that the high climate variability and the low fertility soils with poor water-holding capacities are the main limiting factors in achieving higher yield levels (Stephens & Lyons, 1998). Among climate elements, the dominant effect is caused by rainfall variability and water limitations, which is associated and amplified by the El Nino Southern Oscillation phenomena (Meinke & Hammer, 1997; Potgieter et al., 2002).

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 & Lyons, 1998; Potgieter et al., 2002).

However, considering the large extent of the area occupied by winter crops in the country, improvements on spatial yield representation are still a challenge for the crop yield modellers, 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, National Oceanic and Atmospheric Administration (NOAA) 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, NDVI images have been used assuming that these 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 high association with yield (Boken & Shaykewich, 2002; Manjunath et al., 2002; Dabrowska-Zielinska et al., 2002). However, some papers have pointed out the limitations of the NDVI NOAA product, associated mainly with atmospheric interference, canopy background contamination, and saturation problems (Huete et al., 2002).

To address these limitations, the Moderate Resolution Imaging spectroradiometer (MODIS) 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; Friedl et al., 2002). 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 of extending the AVHRR/NDVI/NOAA historical series, thereby 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 in MODIS vegetation index images. In this context, we conducted the following major tasks: a) test different crop masking approaches to extract vegetation index data, b) characterise seasonal variability of the winter crop profiles, c) compare NDVI and EVI, d) relate alterations in the vegetation index profiles to variability in rainfall, and e) relate seasonal variability of the profile statistics to observed winter crop yields.

2. Methods

2.1 The study region

The study was carried out in the Jondaryan and Pittsworth shires (191,030ha and 108,869ha, respectively), in the southern Queensland, Australia (Figure 1). These shires belong to a vast 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°C, and the monthly rainfall is below 50mm (Bureau of Meteorology, 2005). 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.

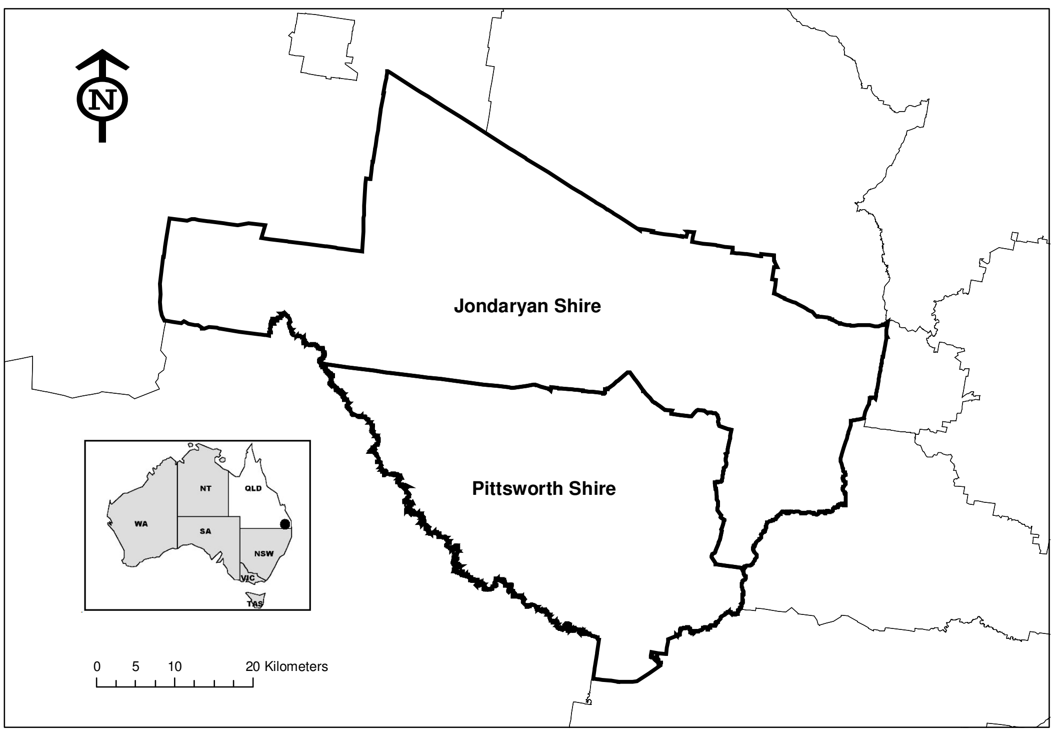

Figure 1- Study area: Jondaryan and Pittsworth shires, Queensland, Australia.

2.2 Data sources and processing

The sets of wheat and barley yield data based on ground surveys were provided by the Australian Bureau of Statistics (ABS) for 2000 and 2001, and by the Australian Bureau of Agricultural Resource and Economics (ABARE) for the years 2003 and 2004. These datasets were considered sufficiently accurate and thus used to validate the results of MODIS-derived information. Yield data for 2002 was not available at the shire level, but only at the state level, and was therefore not included in the analyses. The monthly rainfall data at the shire level were provided by the Bureau of Meteorology (BoM) and were calculated by a weighted average technique using the meteorological stations network available. During the winter crop season, 16-day compositions of 250m resolution 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 freely from the Earth Observing System (EOS) Data Gateway - (http://edcimswww.cr.usgs.gov/pub/imswelcome).

2.3 Image processing

The downloaded vegetation index (VI) images had a range of -2,000 to 10,000 values to represent both NDVI and EVI values. Image processing was done in 4 steps. Firstly, the images were re-projected from ISIN (Integerized Sinusoidal) to UTM, Zone 56, and Datun WGS84, using the MRT (MODIS Reprojection Tools) software - (http://edcdaac.usgs.gov/landdaac/tools/modis/index.asp).

Secondly, 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 seasonal variability of the VI 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;
- *Minimum Image*: one band (minimum value from 9 June to 29 August), represents the lowest vegetation condition in the half first part of the crop season;
- *Difference Image*: one band (difference between the Maximum and Minimum images), used to build the cropping mask, as described in the next section.
- *Integrated Image*: one band (integration from the beginning to the end of the crop season), summarises all the cumulative VI behaviour during the crop season.

The third processing step was the definition of the cropping mask (CM), as described in the next section.

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 each CM. The last three steps were implemented using the ENVI software v. 4.1.

2.3 Definition of the cropping mask (CM)

Three CMs were analysed to find the best characterisation of the winter crop behaviour during the crop season, and referred to as *whole shire* mask, *cropping* mask, or *cropping threshold* mask. The *whole shire* mask was defined by the area within the boundaries of the Jondaryan and Pittsworth shires. The underlying hypothesis in using this mask was that the variation in the shire vegetation cover during the winter crop season resulted mainly from the development of the crops. The *cropping* mask was created by filtering just the area occupied by crops from a Land Use Map in 1:100,000 scale produced in another research project (Department of Natural Resources, 2001). In this mask, the idea was to limit the study just for areas suitable for cropping. Spectral data from other kinds of land cover was not considered.

As the winter crop area fluctuates from one year to another, a simple methodology was proposed to identify the winter cropping area, called *cropping threshold* mask. The hypothesis here was that VI can express the vegetation vigour and that during the cropping season, the crops show a temporal profile with very low values at the beginning of the period and change to higher ones later. For example, in Figure 2, the average EVI profiles for cropping areas and for the mean of non-cropping classes (e.g. soils, water, stubble, pastures, forestry, etc.) produced using the *cropping mask* was presented. Each displayed values representing the mean EVI value taken from all pixels of a given class in each image from April 6 to October 31.

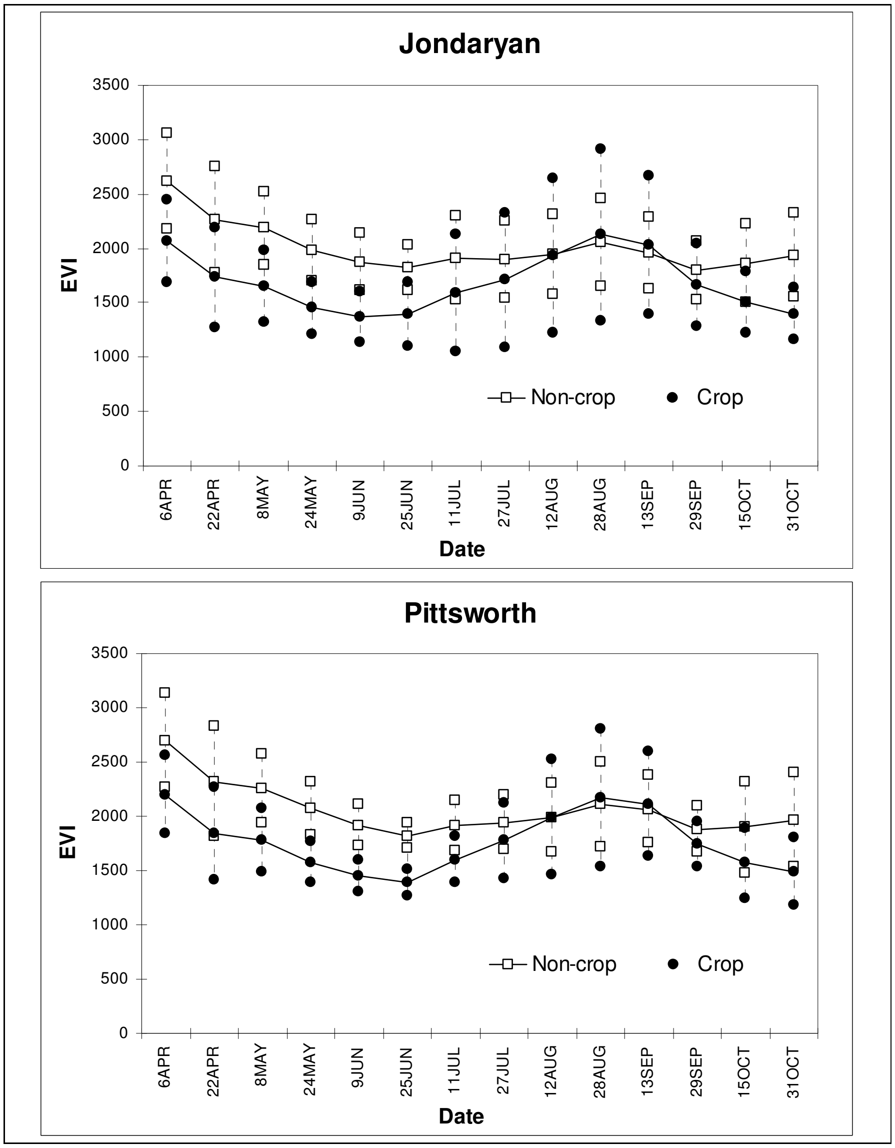

Figure 2 - Average temporal EVI profiles for cropping and non-cropping areas in the Jondaryan and Pittsworth shires, 2000 to 2004.

We assumed that pixels with higher values in the Difference Image are more likely to be cropped and healthy. The Difference Image was created to amplify the differences between the best and lowest vegetation condition during the crop season. The comparison between the actual winter cropping area planted (ABS and ABARE) and the estimated area using *cropping threshold* mask is presented in Figure 3. These arbitrary thresholds were used on the Difference Image to define the *cropping threshold* mask.

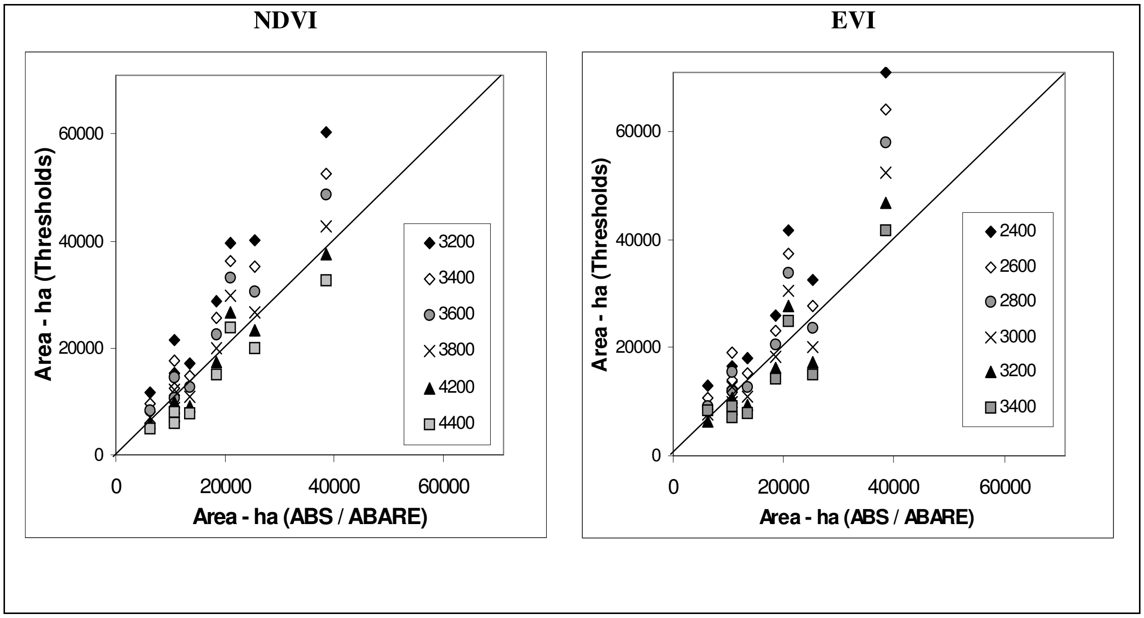

Figure 3 - Relationship between area planted with winter crops from ground survey (ABS and ABARE) and from different NDVI and EVI thresholds as defined by the *cropping threshold* mask in the Jondaryan and Pittsworth shires, 2000 to 2004.

For both VI, we formulated a criterion to choose the best threshold, i.e. the estimated area for all years and shires has to be bigger than those from estimated by ABS and ABARE with an increment of 25%. This increment is the relative standard error estimation declared by ABS and ABARE. This criterion was applied in order to reduce the area in each shire to be considered in the spectral analysis, but did not eliminate pixels that were associated with below normal development of crops. These pixels have to be taken into account to estimate a realistic mean shire yields. Six thresholds were tested for each index. The NDVI thresholds were 3200, 3400, 3600, 3800, 4000, 4200 and 4400. For EVI, the values 2400, 2600, 2800, 3000, 3200 and 3400 were tested. The established threshold was estimated at 3200 for NDVI and 2400 for EVI.

2.4 Analysis

Analysis tasks were performed for both the NDVI and EVI images, for the two shires (Jondaryan and Pittsworth), for the three CMs (*whole shire, cropping and cropping threshold*), and for the five years (2000 to 2004). Seasonal variability of the MODIS profiles were created and the differences among indices, shires, CMs and years were analysed. The seasonal variability of the MODIS profiles was associated with the variability of rainfall data. The correlation analysis was established using VI and rainfall on a monthly basis as well as using maximum VIs and rainfall accumulated in different periods during the crop season.

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

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

3. Results and Discussion

3.1 Cropping masks comparison

The differences in the area to be considered for spectral analysis for each cropping mask were large (Table 1). For both Jondaryan and Pittsworth shires, the estimated area using *cropping* mask represents nearly 70% of that using the *whole shire* mask. But the *cropping threshold* areas were much smaller than the *cropping* mask areas, with great variability during the five years. Based on this, we assumed that probably the spectral responses from *cropping mask* might be more similar to *whole shire* than to the *cropping threshold* areas. As a result, we expect that the best responses will be taken using the *cropping threshold* mask.

Shire / Cropping masks	Years				
	2000	2001	2002	2003	2004
Jondaryan					
Whole shire (ha)	191030				
Cropping (%)	68.7				
Cropping threshold (%)					
NDVI	21.0	11.3	23.8	31.5	7.9
EVI	17.0	6.6	20.8	37.2	8.7
ABS / ABARE	13.6	5.6		20.2	5.6
Pittsworth					
Whole shire (ha)	108869				
Cropping (%)	70.8				
Cropping threshold (%)					
NDVI	26.4	15.7	16.3	36.5	10.8
EVI	23.9	16.7	14.7	38.4	11.8
ABS / ABARE	17.1	12.4		19.2	5.8

Table 1 - Winter crop area estimated by ABS and ABARE and using the *whole shire*, *cropping* and *cropping threshold* masks for Jondaryan and Pittsworth shires, 2000 to 2004

The difficulty in the *cropping threshold* approach was to establish the VI difference values that best fit the winter cropping areas. Another thing is to define if there is a unique threshold that can be applied to all situations (years and shires). The results showed that it was not the case. The data variability was bigger for big areas (Figure 3), and that the threshold method tended to over estimate the area planted in bigger areas, especially for EVI. Therefore, further study is needed to define the winter crop area at a regional scale. Potgieter et al. (2005) have done some studies using different multivariate remote sensing analyses (e.g. Harmonic Analysis of Time Series and Principal Component Analysis) to have an accurate near real-time production forecast of wheat and barley crop area in Queensland using seasonal variability of the MODIS imagery. In this present study, we chose to use the simple *cropping threshold* methodology since the exact derivation of winter crop area is not our aim.

According to ABS and ABARE, the maximum values of cropping areas occurred in 2003 (20.2% in Jondaryan and 19.2% in Pittsworth) and minimum in 2004 (5.6% in Jondaryan and 5.8% in Pittsworth). The estimated areas using the *cropping threshold* mask for NDVI and EVI images have the same tendency, but the figures were always higher, as expected. For the minimum and maximum yield years, as discussed in the following sections, rainfall was the limiting element that defined area planted as well as yields in the region.

Figure 4 illustrates the seasonal variability of the profiles for NDVI and EVI in Jondaryan and Pittsworth as an average for the period from 2000 to 2004 obtained by the three CMs. Besides the differences between VI profiles, all CMs had the same general behaviour, following the characteristic pattern of the crop growth curve. In the beginning of the season, associated with low plant biomass, the average VI values were small. With the crop establishment, the values increased achieving a peak in August, consistent with the maximum crop development stage. When the crop matured, the plant biomass decreased and so did the corresponding VI values.

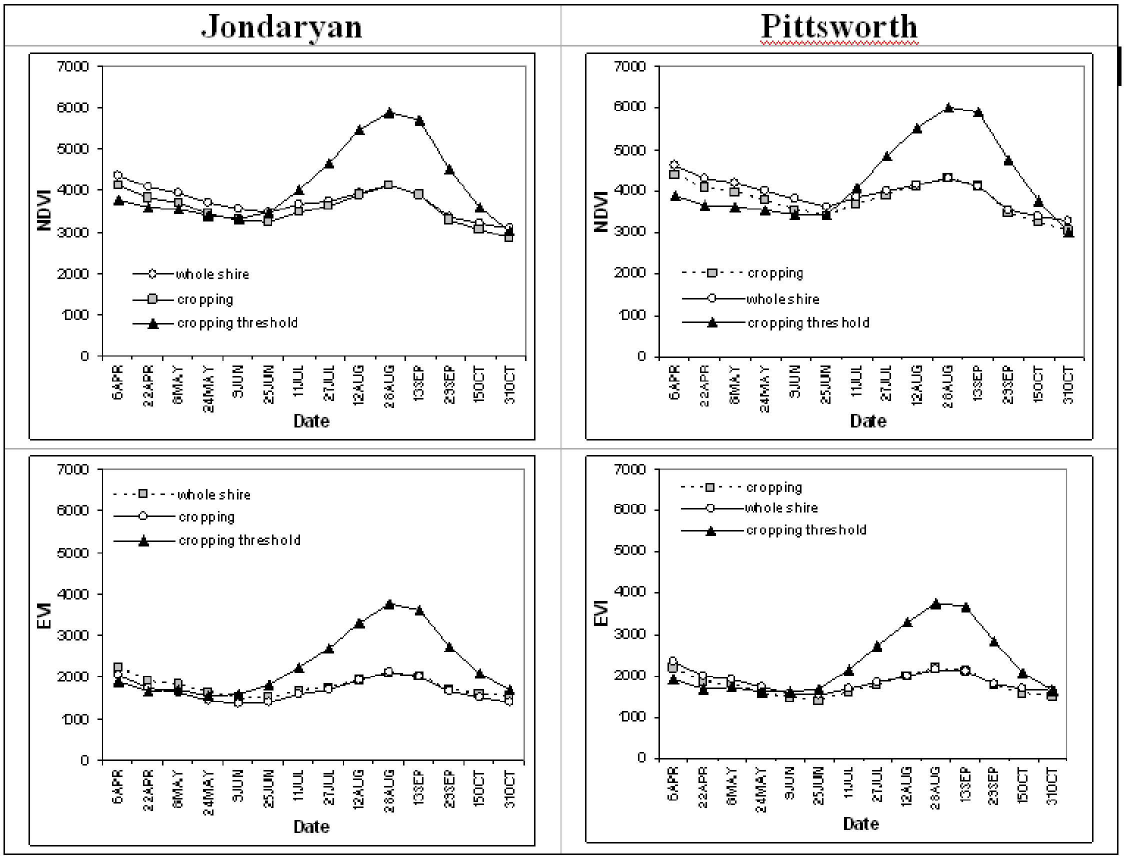

Figure 4 - Jondaryan and Pittsworth average temporal NDVI and EVI profiles, obtained by using *whole shire*, *cropping* and *cropping threshold* masks, 2000 to 2004

The VI profiles were quite similar when using the *whole shire* and *cropping* masks. This was expected since the differences in the analysed areas in these two CMs were just 30% (Table 1). It was, however, in the *cropping threshold* mask that the differences in the profiles were pronounced, especially in the maximum crop development period. Compared with other CMs, the *cropping threshold* mask area had the temporal variability amplified, with smaller values from April to June and larger from June to October. For the *whole shire* and *cropping* masks a damped variability was due to mixed pixels in the region. Considering these results, we expect that the *cropping threshold* mask will be better in representing the crop behaviour and will probably have closer association to yield, mostly because the threshold was 'tuned' to real data. Then, the following analysis will consider just data from the *cropping threshold* mask.

3.2 Relationship between NDVI and EVI

During all years covered by this study, the EVI values were consistently lower than those of the NDVI. For the maximum and minimum yield years 2003 and 2004, Figure 5 presents the NDVI and EVI images for the date coincident of the maximum VI values, e.g. August 28 according to temporal average profiles showed in Figure 4. Green colors were associated with high VI, while brown colors to low values. In this data, the green colors were probably representing a map of the distribution of the crops areas in these two shires. It is evident the distinct behavior between indices, but also is possible to analyse the differences in the indices between years. According to ABS and ABARE, the crop area in 2003 was nearly four times higher than in 2004.

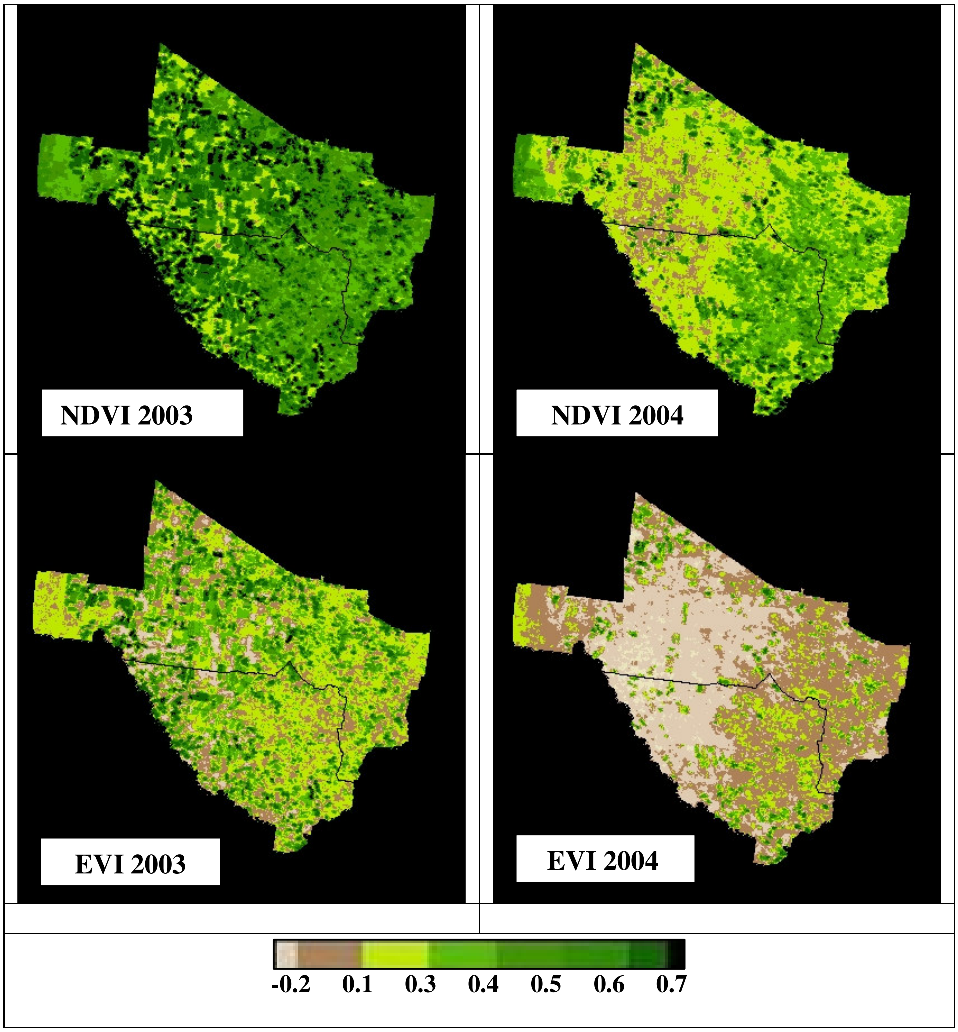

Figure 5 - NDVI and EVI images in August 28 for 2003 and 2004 in Jondaryan and Pittsworth shires

3.3 Seasonal variability

The seasonal variability of the profiles was assessed by analysing the temporal VI differences among years. This approach has been used in many researches using NDVI from NOAA AVHRR and MODIS images (Justice et al., 1991; Zhang et al., 2003). In this study, the temporal profiles were quite similar for both Jondaryan and Pittsworth shires, with minimum values in April, May and June, a peak in August, and decreasing until November.

The similarities between shires are a consequence of the spatial proximity that determines similar climate, soils and agricultural practices. Figure 6 shows that there were larger differences from one year to another than between the shires. For each shire, the profiles differences among the years were bigger during the crop cycle, after June until the beginning of September.

The VIs values in 2003 were the highest, achieving VIs near to 7000 for NDVI and near 5000 for EVI. In the other years the pattern was different. VIs in 2001 and 2004 showed smaller amplitude (difference between maximum and minimum) with bigger values at the beginning of the crop season and smaller values at the end of it comparing to 2000 and 2002. These differences were probably a consequence of the weather conditions during the crop season. The seasonal variability of the VI profiles has been associated with the variability of plant vigour (Huete et al., 1997) and therefore it can be used in crop yield modelling, as discussed in the last section of this paper.

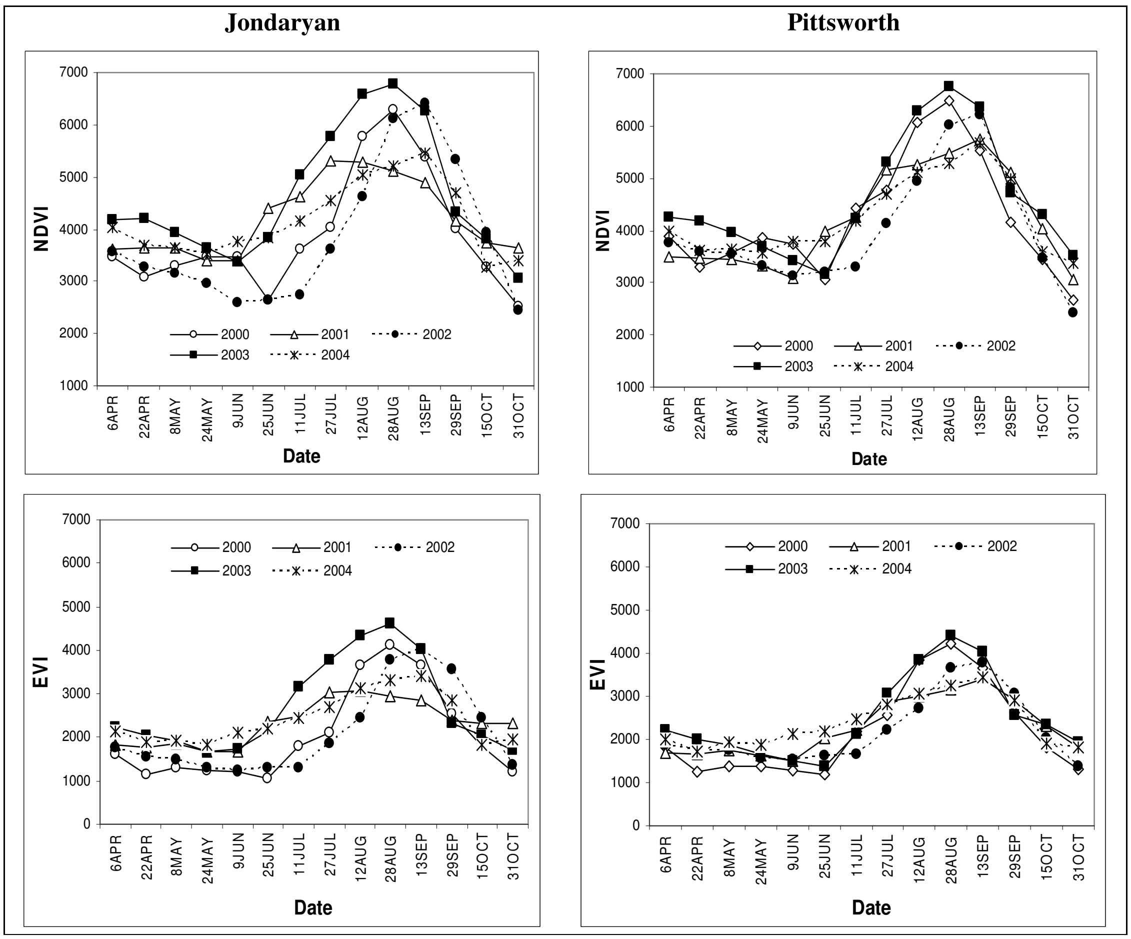

Figure 6 - Seasonal variability of the NDVI and EVI profiles in Jondaryan and Pittsworth from *cropping threshold* masks

3.4 Relationship between rainfall and VI data

The seasonal variability in the plant vigour at a regional scale is caused by an interaction of several complex factors, especially those deriving from climate and management variability. But rainfall amount and distribution has been pointed out as one of the most important factors determining agricultural production in the study region (Hammer et al., 1996). Jondaryan and Pittsworth presented similar rainfall totals (from April to September) during the four analysed years (Table 2).

Shire	**Months**						
Year	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
Jondaryan							
2000	7	24	39	9	4	3	84
2001	50	8	0	25	9	19	112
2002	1	10	36	0	49	9	105
2003	52	23	73	16	13	6	183
2004	33	10	2	10	23	23	101
Pittsworth							
2000	9	31	34	9	4	1	88
2001	43	17	1	28	11	25	126
2002	0	11	38	0	34	7	89
2003	38	16	56	26	16	5	158
2004	49	6	6	8	24	35	128

Table 2 - Rainfall in the period from April to September in Jondaryan and Pittsworth shires

Both shires are located in the same rainfall region and the mechanisms causing rainfall are likely to be the same. In 2003, the rainfall was bigger than in the other years, but above to normal for this period (the climatologic normal 1961-90 are 225mm and 233mm for Jondaryan and Pittsworth, respectively). The other four years were characterised as very dry ones. Figure 7 illustrates that part of the variability in the EVI profiles which were associated to inter-annual differences in rainfall amount and distribution, specially in the beginning of the crop season.

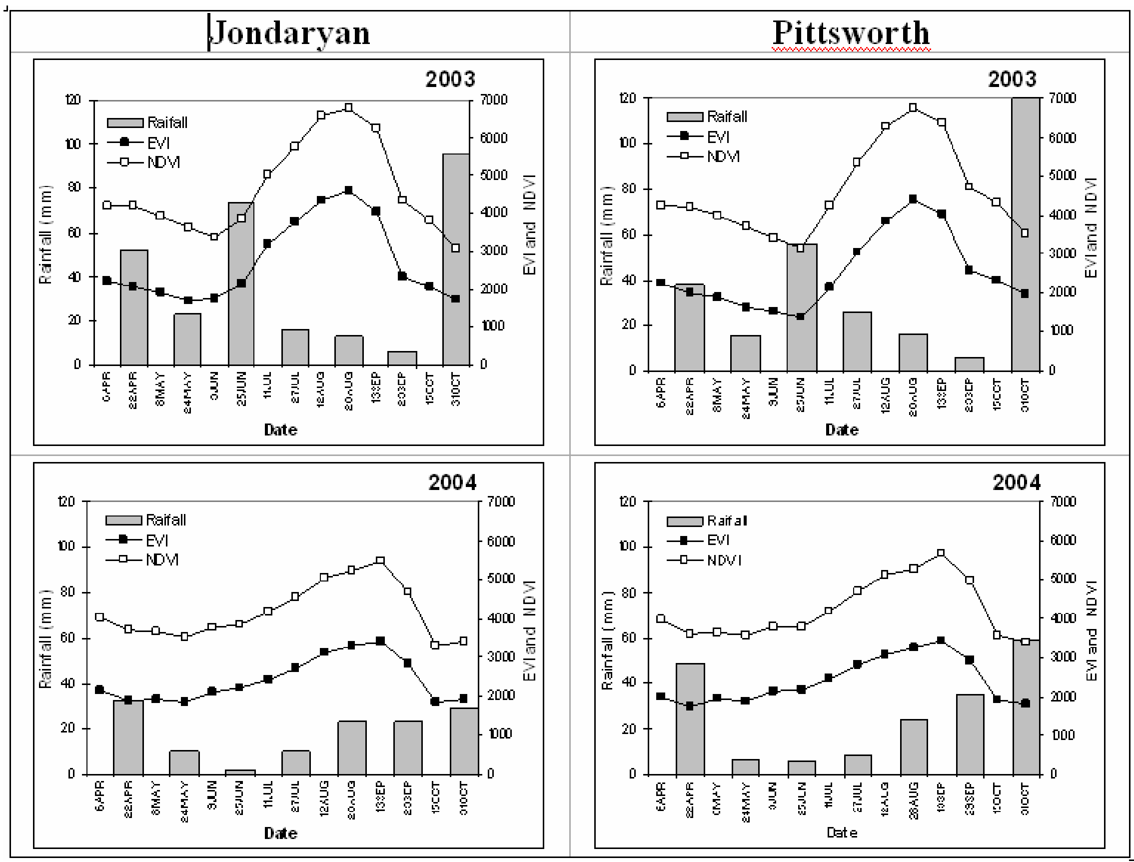

Figure 7 - Monthly rainfall, NDVI and EVI profile (*cropping threshold* CMs) from April to November, in Jondaryan and Pittsworth shires, 2003 and 2004.

Most of the monthly correlations analysis between VIs and rainfall (Table 3) were not significant during the studied period. But the maximum EVI and NDVI were very well correlated with the accumulated rainfall during the crop growing season. This is an interesting result, since many studies showed that spatial and temporal variability in wheat production in Australia is dominated by rainfall occurrence (Potgieter et al., 2002). Then, taking into account the good association between rainfall and VIs, one can infer that both NDVI and EVI are likely to be good indicators of near real-time winter wheat vigour. Remote sensing technology in this case can introduce the advantage of increasing the spatial detailing of the information, defined by the spatial resolution of the sensor ($1km^2$ for MODIS). Besides that, these techniques represent another source of information about the crop vigour that can be used in crop monitoring programs. The next section expounds more on this relationship.

Period	EVI	NDVI
Monthly[1]		
APR	0.65	0.64
MAY	-0.57	0.54
JUN	-0.49	-0.50
JUL	0.67	0.81**
AUG	-0.16	-0.11
SEP	0.17	0.46
Accumulated[2]		
APR-MAY	0.71*	0.77**
APR-JUN	0.84**	0.82**
APR-JUL	0.82**	0.86**
APR-AUG	0.84**	0.78**

[1] Monthly rainfall and VI correlation; [2] Accumulated rainfall and maximum VI correlation;
* P<0.01 - ** P<0.05 (number of samples = 10).

Table 3 - Correlation coefficients between rainfall and NDVI and EVI for Jondaryan and Pittsworth shires, 2000 to 2004

3.5 Relationship between yields and VI data

According to the actual yield data from ABS and ABARE (Table 4), the studied years had an adequate range of variability. Wheat yields varied from 1496 to 3350 kg/ha and barley yields from 1191 to 2580 kg/ha, e.g. the higher yield was nearly double that of the lowest yield.

Shire		Crop	
Year	Wheat	Barley	Winter crops
Jondaryan			
2000	1499	1191	1355
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

Data Source: ABS and ABARE

Table 4 - Actual wheat, barley and winter crop yields (kg/ha) for Jondaryan and Pittsworth

We tested the correlation between yield and some spectral parameters that have been proposed by remote sensing studies that focused on yield, and the results are presented in Table 5. The magnitude of the coefficients found in this analysis was quite similar to the other studies carried out in different regions using NDVI from AVHRR NOAA (Boken & Shaykewich, 2002; Labus et al., 2002).

Index / VI Parameter	**Mean**		**Standard Correlation**			**Cor**
	Int[1]	**Max[2]**	**Int[1]**	**Max[2]**	**Peak[3]**	**best[4]**
EVI	0.84**	0.84**	0.35	0.69	0.18	0.68
NDVI	0.60	0.77**	-0.06	-0.46	-0.52	0.71*

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 in the temporal profile; [4] Correlation coefficient between actual and the best year (2003); * P<0.01; ** P<0.05 (no. of samples = 10)

Table 5 - Correlation coefficients between winter crop yields and VI parameters derived from NDVI and EVI images using *cropping threshold* mask for Jondaryan and Pittsworth shires, 2000, 2001, 2003 and 2004

The best coefficients were found for EVI spectral information from the mean of the Integrated and the mean of the Maximum images (r=0.84). These parameters showed smaller correlation coefficients for the NDVI images than those observed for the EVI images, just Mmax was significant (r=0.77). This is expected, since EVI was developed to improve the sensitivity to high biomass condition (Huete et al., 2002) observed during the maximum development stage, e.g. during the main period of yield definition.

These results showed that the vegetation vigour, represented by the cumulative VI behaviour (Mint) and the best vegetation condition (Mmax) during the crop season images, are very well correlated with yields. Similar results has been found by many researchers (Labus et al., 2002; Dabrowska-Zielinsda et al., 2002). The relationship between vegetation vigour and yield works in the sense that high yields are only attained when high biomass have occurred; however, the inverse is not always true, since high biomasses are not a guarantee of high yields, if special conditions happen, in critical periods, like water deficit in the reproductive phase. A connection linking biomass and yield can be worked out; this was suggested, for instance by Zhong-hu and Rajaram (1993).

No correlation coefficient was significant for the mean (MPeak) or for the standard deviation parameters (SInt, SMax and Speak) 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 value in NDVI images (Corbest=0.71), but in EVI images the coefficient was not significant. Taking into account these results (Table 5), EVI extracted from *cropping threshold* mask of the mean Integrated and Maximum images seems to be the best yield indicator. As an example, Figure 8 illustrates the association between the mean Integrated parameter (MInt) during the crop season from EVI images and the yield estimated by ABS and ABARE, especially for the Pittsworth shire.

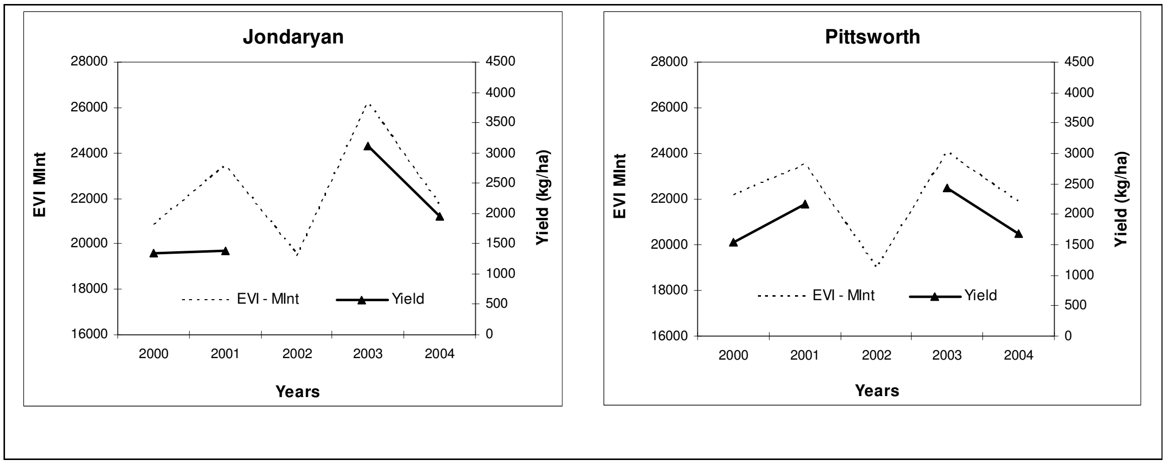

Figure 8 - Estimated yields (kg/ha) from ABS and ABARE and the mean EVI integrated (MInt) during the crop season in the Jondaryan shire for *cropping threshold* mask, 2000 to 2004

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 the ability to map crops. In this case, the spectral data to be incorporated to the yield modeling is related to the period from the beginning of June to the beginning of November, which means that is possible to build a predictive model, eg: the estimation is produced before the crop harvest. However, it needs to be tested.

4. 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 from five years of MODIS vegetation index images (2000 to 2004). Comparing the VI profiles from the three cropping masks, it was the *cropping threshold* mask that better represented the crop behaviour during the season. During the analysed period, EVI values were consistently lower than those of the NDVI. The seasonal VI profiles were quite similar for both Jondaryan and Pittsworth shires, 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 and the rainfall variability is the most important factor. More than 80% of the VI variability is explained by rainfall.

The correlation analysis between the winter crop yields and VIs pointed out that EVI images were better than the NDVI ones. Coefficients were statistically significant when using EVI spectral information from the mean of the Integrated and Maximum images. EVI extracted from the *cropping threshold* mask was the best yield indicator that could be used for crop yield modeling. The results presented in this paper showed that the VI images are a powerful tool to assess near real-time biomass status. For future studies, we recommend the following aspects: increase the data set by aggregating 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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