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"SPYING" ON THE WINTER WHEAT CROP – GENERATING OBJECTIVE PLANTED AREA AND CROP PRODUCTION ESTIMATES USING MODIS IMAGERY

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Abstract:
With world commodity markets becoming more competitive and the deregulation of the wheat industry in Australia during the nineties, advanced knowledge of likely production and its geographical distribution has become highly sought-after information. During the past 5 years, the Queensland Department of Primary Industries & Fisheries (DPI&F) has generated shire/state and national yield (t/ha) forecasts for wheat and sorghum crops on a monthly basis throughout the crop-growing season with appreciable success. However, to achieve an accurate near real-time production forecast, a real-time estimate of the crop area planted is required. Generating objective estimates of planted area will allow near real-time crop production estimates, which can then be used in updating supply chain information at the regional, state and national levels. While there are alternative methods (e.g. subjective opinions, surveys, censuses, etc.) to derive the required information, the use of remote sensing (RS) offers more objectivity, timeliness, repeatability and accuracy. Furthermore, the use of multi-temporal Moderate Resolution Imaging Spectroradiometer (MODIS) imagery (spanning an entire cropping season) is novel, and has been rarely used in determining crop area planted in targeted agricultural systems. In this paper, we provided a brief background of regional commodity forecasting in Queensland, and have reported some preliminary results on the use of digital image processing techniques to determine crop area planted. More specifically, different multivariate approaches to analysing remote sensing data [i.e. Harmonic Analysis of Time Series (HANTS) and Principal Component Analysis (PCA)] were compared in determining winter crop area planted from MODIS imagery for a specific case study in the Darling Downs region, Queensland. The methodology was validated for the 2003 and 2004 seasons at a shire level by contrasting aggregated shire total area planted with surveyed ABARE estimates. Finally, the ability of these methods to discriminate area planted for wheat, barley and chickpea at the shire level was determined. Preliminary results showed a significant potential to capture total crop area planted at a regional level and a good overall capability (>95% correct classification) in discriminating between these winter crops.

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

Accurate, objective and near real-time estimates of crop area planted are intrinsic to determining production figures for any crop. Currently, no accurate near real-time estimates of shire scale wheat area planted exist in the public domain in Australia. Even if such information is available in the private sector, it will be costly to the users, or it will be untimely, with accurate estimates available only 2 to 3 years after the event, as is the case with the Australian Bureau of Statistics (ABS) annual data.

Many within the grains industry (from the bulk handler to the policy maker), particularly in the recently deregulated marketing environment, seek advance information on likely production and its geographical distribution. Such information is also sought by government agencies (e.g. ABARE) in relation to policy interventions triggered by the degree of exceptional circumstances (e.g. drought, bumper crops, etc.). The current Regional Commodity Forecasting System (RCFS) of QDPI&F (www.dpi.qld.gov.au/fieldcrops) goes to some length to address this need through its monthly crop outlook report. However, this report only disseminates wheat yield per unit area (t/ha) at a shire scale and does not address the issue of area planted. This information can be sometimes misleading as was the case in 2004, for example, where an average wheat crop was forecast for most areas in the Darling Downs in July but no area was actually sown because of the lack of significant sowing rains.

This clearly illustrates the need for developing a system that can address the missing link: an accurate and objective way of determining winter crop area planted at a shire scale. The accessibility of up-to-date agricultural statistics is of utmost importance to assist government and industry in decision-making processes well before harvest. Moreover, the ceasing of the annual agricultural statistics census collated by the ABS has elevated the need for an objective regional commodity/crop production forecast to an even higher priority.

In this study we aim to examine the potential of remote sensing techniques to determine winter crop area planted through the use of multi-temporal MODIS satellite imagery.

METHODS

The case study area is located in the central Darling Downs region, approximately 150 km west of Brisbane, Queensland (Figure 1). For the purposes of this study, the Jondaryan and Pittsworth shires were selected. Seasonal cropping in these shires encompasses nearly half of the potential cropping area during winter or summer. Crop management practices are variable and paddock sizes can range from small (~ 20 ha) to very large (> 400 ha) fields. In addition, some larger paddocks might be divided into cropping strips. These strips can vary from 50 m to 180 m in some areas and are usually used in crop rotation practices. The practice of strip cropping was introduced as a preventative measure to mainly counteract the loss of topsoil and thus diminish water erosion during wet seasons. Soils in this region are generally deep and high in clay content, which have therefore very high potential soil water holding capacities.

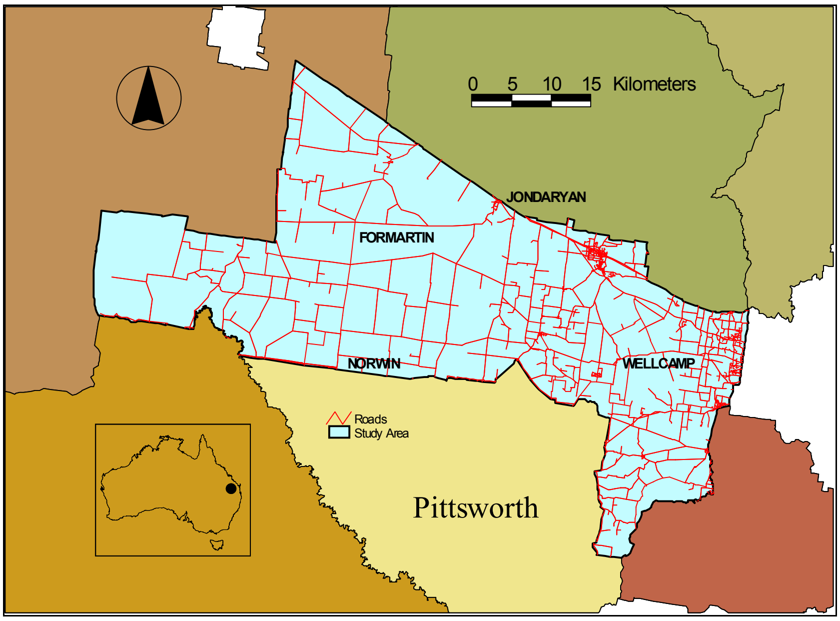


Figure 1: Location of the Jondaryan and Pittsworth shires within the northeastern region of Australia.

The 16-day aggregated MODIS Enhanced Vegetation Index (EVI) imagery, which is derived from combinations of the MODIS red, near infra-red and blue spectral bands, was used to form a time series of data that represented the crop growth curve for each pixel. Standard and advanced image processing techniques were applied to the multi-date EVI imagery. These methods included geometric and radiometric corrections, image enhancement and transformation, supervised classification and accuracy assessment. Temporal classification methodology and multi-temporal algorithms were adapted, developed and tested at the shire level in order to determine crop area planted for different crop types (e.g. wheat, barley and chickpea) during the winter growing season.

The efficiency of three multi-temporal approaches i.e. (i) the Harmonic Analysis of Time-series (HANTS) [Jakubauskas *et al*., 2001; Jakubauskas *et al*., 2002], (ii) Principal Component Analysis (PCA) and (iii) Curve fitting procedures, were investigated and validated based on their association with observed ABS shire scale data over a period of 2 years (2003 and 2004). For this paper we only focused on the first two approaches, i.e. HANTS and PCA. Contrasting these former approaches to a single date EVI MODIS classification (acquired around average maximum EVI values for all winter crops) and a multi-date MODIS EVI (day of year (DOY) 97 to DOY 305) determined the best multi-temporal approach to be used. Figure 2 depicts the steps involve in determining which approach has the highest accuracy in total area planted and the best discriminative ability between different crop species within a specific season. This process was repeated for each season.

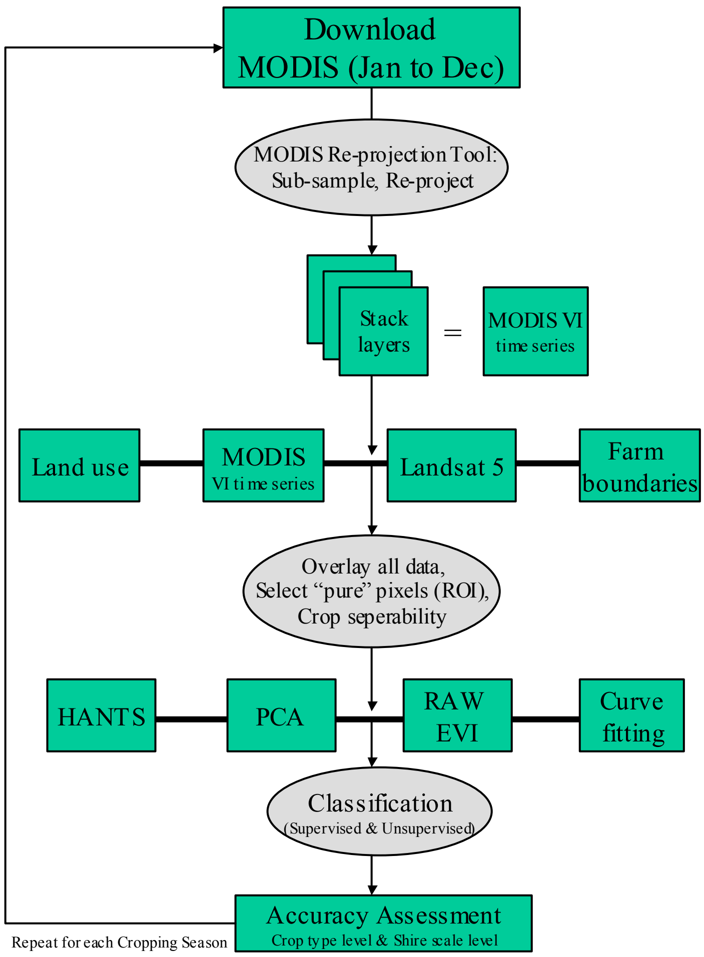


Figure 2: Diagram depicting the processes involved in determining the best approach for predicting shire scale winter crop area discrimination.

The EVI spectral vegetation index was used to generate supervised classifications. The final supervised classification image was subjected to rigorous accuracy assessment using the error matrix through ground truthing - obtained from a region of interest (ROI) - and the use of ancillary information from farmers or extension officers. Aggregated shire level area estimates were contrasted against actual shire scale area data obtained from relevant sources (ABS and ABARE). The process was repeated for the 2003 and 2004 winter crop-growing season to validate the methodology.

RESULTS AND DISCUSSION

Figure 3 shows the average spectral crop growth profiles for wheat, barley and chickpea. The profiles represent the crop response based on soil, plant and water regime combination within the study area for each season (Figure 3, 2003 on the left and 2004 on the right). On average, barley and wheat had higher EVI values during the 2003 season than the 2004 season. Conversely, chickpea had much higher EVI values in the 2004 season than the 2003 season. Although there is some overlap in the spectral profile distributions between crops, the differences in the shape of the profiles between wheat, barley and chickpea are clear in both years. The much lower EVI peaks for wheat and barley during the 2004 season were mainly due to the very much below average rainfall recorded during 2004 and as a result caused a reduction in biomass and crop growth and thus lower EVI values.

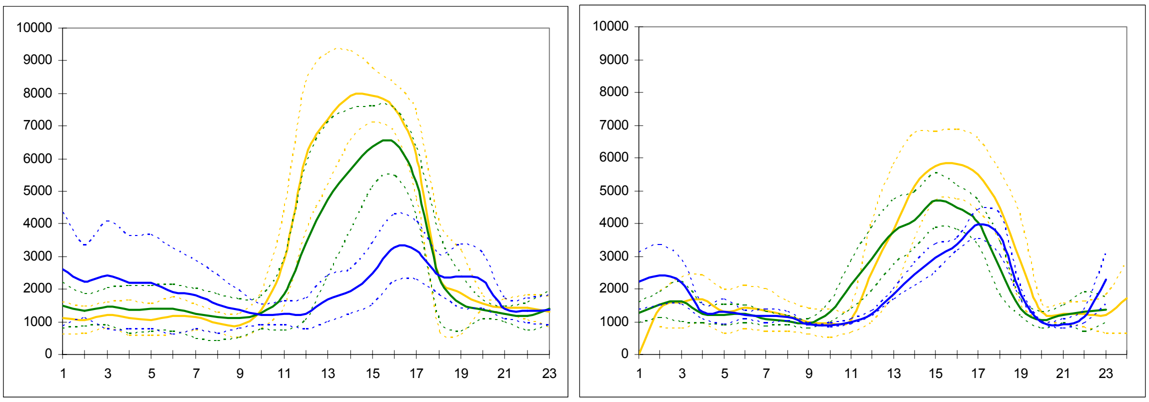
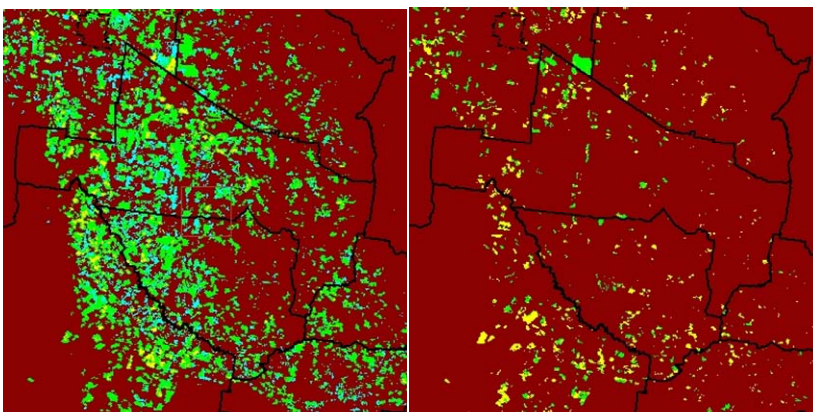


Figure 3: Average spectral profile throughout the growing season for wheat (green), barley (yellow) and chickpea (blue) for 2003 (left) and 2004 (right). The dotted lines represent one standard deviation range around the mean (solid lines).

Figure 4 shows the classified images for the 2003 and the 2004 seasons using the HANTS approach. This classification was done by training the maximum likelihood classifier using the ground truth data captured for each crop class for each season. The ground truth data is unique to each season. Overall the two seasons differ significantly in the amount of winter crops planted. The final crop classes used in the classification were wheat, barley, chickpea and other (e.g. natural/production forest, vegetation, soil, etc.). From the results, it is obvious that more winter crop was planted during the 2003 season than the 2004 season. As previously mentioned, this related to the very poor rainfall recorded and, therefore, the lack of consequent sowing opportunities during the winter crop planting window (i.e. April to June) in the 2004 season.



2003 Season **2004 Season**

Figure 4: Classified images for the 2003 and the 2004 seasons. Wheat is coloured in green, barley in brown, chickpea in cyan and other (e.g. natural and production forest, vegetation, stubble, bare soil etc.) in red.

Table 1 gives the ground truth accuracy (classified to reference pixels) for all four methods. These accuracies represent the percentage of correctly classified pixels when contrasted against an independent ground truth data (IGTD) set for each crop class for the Jondaryan shire.

	ACCURACY (%)				
METHOD	**Overall**	**Wheat**	**Barley**	**Chickpea**	**Other**
Single date EVI	60	57	85	46	59
Multi - date EVI	87	75	76	93	100
HANTS	95	67	95	93	100
PCA	92	60	80	93	100

Table 1: Ground Truth accuracy (%) across all classes (Wheat, Barley, Chickpea and Other) and within each class for each method. This was generated by contrasting randomly chosen ROI groundtruth samples with the final classified image for each method.

The overall accuracy among these methods ranged from 60% to 95%. The single-date method had the worst overall accuracy with only 60% of the ground truth samples correctly classified. Multi-date and PCA methods produced higher accuracies with 87% and 92% of the IGTD correctly classified. The HANTS method achieved the highest overall pixel accuracy and had very high within crop accuracies.

When comparing the total winter crop area estimates (i.e. wheat, barley and chickpea) to actual shire scale data as derived from the ABARE survey, the HANTS method produced the smallest average deviation across shires and seasons with an average mean absolute deviation of 29% (AMAD). The single-date method had the smallest deviation for total wheat area estimated (i.e. 16%) across shires and seasons. However, this result is fortuitous because of the very poor overall and within class pixel accuracies (Table 1) derived when using a single-date approach. This appreciably high accuracy for the single-date wheat classification at a shire level is therefore spurious because of compensating errors when aggregating to a shire scale. Furthermore, the single-date approach is further compounded by the question of “which is the best date to use?” and can therefore not be recommended as an acceptable method in determining winter crop area at a regional scale.

The HANTS approach had the best overall ground truth and shire scale accuracy across both seasons and is thus more robust than any of the other approaches used in this study. The shire scale accuracy of HANTS can be further increased by including ground truth data on areas that have been double cropped with barley (areas that had a summer as well as a winter crop; data not shown). The degree of discrimination between wheat and barley relates to how similar/dissimilar the spectral profile trajectories are (Figure 3) within the cropping window. The spectral profile trajectory represents the crop life cycle (e.g. emergence, anthesis, maturity, etc.) at a specific location, which incorporates the plant’s response to its immediate environment (i.e. temperature, soil, moisture, light, etc.). Thus, applying the HANTS methodology to other geographical regions with soils and climate regimes not captured within the study area needs further investigation.

CONCLUSION

This study showed that the use of multi-temporal MODIS enhanced vegetation index imagery achieved significantly high accuracy in determining total winter crop area at a pixel and regional scale. The best approach was the harmonic analysis method, which decomposed the MODIS EVI time series into functions. Using 3-harmonics plus the harmonic mean resulted in the best approach to classify crop area estimates for wheat, barley and chickpea. Although use of single-date data produced high shire scale accuracy for wheat, this result contradicted the poor pixel scale accuracy of this approach, indicating fortuitous compensating errors. Further studies are needed to extrapolate the HANTS approach to other geographical areas

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