Remote Sensing Applications in Peanuts: the Assessment of Crop Maturity, Yield, Disease, Irrigation Efficency and Best Management Practices using Temporal Images

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ABSTRACT

The measurement of infrared reflectance from peanut crop canopies via multispectral satellite imagery has been shown to be an effective method for identifying the spatial variability in crop vigour, as well as producing high correlations with peanut yield (r= 0.91**) and pod maturity (r= 0.67**). For peanut growers this information is essential as less than optimum harvest timing can lead to lower quality produce, harvest losses, reduced grain filling and associated lowering of kernel grades, and high aflatoxin infection in years conducive to the contamination, all of which can substantially reduce grower returns. As well as the accurate yield prediction of individual crops, a significant correlation (r=0.82**) was identified between the pod yield of 115 dryland crop sample locations with that of the corresponding normalised difference vegetation index (NDVI) values calculated from satellite imagery for each site. This result is of major benefit to regional, state and even national marketers as currently there is no in-season method available for accurately forecasting the total production of Australian peanuts. This technology has also been effective in identifying irrigation deficiencies, crop disease and now with a four year library of images over intensive peanut cropping regions in south east Queensland, we are able to assess whether the spatial variability identified within any block is inherent or the result of an in-crop constraint.

Keywords: peanut, crop maturity, yield forecasting, multi-spectral satellite imagery, irrigation and disease monitoring.

INTRODUCTION

Within non-stressed vegetation, the spongy mesophyll and palisade tissue leaf structures reflect up to 60% of infrared (IR) light upward (reflected energy) or downwards (transmitted energy) and therefore any limiting factor that may reduce plant health and ultimately the turgidity of these tissue structures, will result in reduced levels of IR reflectance (Campbell, 1996). This variation in IR reflectance, or ultimately plant health, can be measured by a number of remote sensing technologies including multi-spectral satellite and aerial imagery. For peanut, multi-spectral imagery provided by the American owned QuickBird satellite has been used to accurately predict pod yield and maturity within both dryland and irrigated crops (Robson, 2007; Robson et al. 2006; Wright et al. 2005). This information has enabled growers to formulate better harvest regimes in order to maximise quality and yield, whilst minimising the risk of aflatoxin, a toxin produced by a naturally occurring soil- borne fungi *Aspergillus flavus* or *Aspergillus parasiticus* under end of season drought conditions.

As well as the prediction of yield and maturity of individual peanut crops, additional remote sensing applications are being investigated that include the determination of inherent spatial variability that may affect particular paddocks across years, irrespective of the crop grown. Most growers are aware of consistently under performing regions within individual paddocks, whether it is the result of poor soil type or nutrition etc. However, without a method of quantifying the actual area or the ability to form an accurate monetary estimate of the loss of production resulting from cropping within these areas, they still tend to be included in crop rotations. It is hypothesised that remote sensing can provide more accurate prediction of those areas that are inherently poor performing. In addition, with coordinated ground sampling, it is also possible to assess to what degree production is affected and the potential monetary loss of cropping these regions in high risk years. With this information a grower can potentially alter his cropping management to include the planting of more tolerant or short duration cultivars in those under performing regions, or alternatively if the regions are deemed totally unviable, accurately remove them from the cropping system. Another advantage of having a sound understanding of the inherent variability of a particular paddock, is that low vigour anomalies that may occur within a growing season can be easily identified, such as those arising from foliar or soil borne diseases or from less than optimum irrigation. It is further hypothesised that remote sensing, through in season satellite and aerial imagery, may be a viable option for the spatial monitoring of disease 'hotspots' or assessing direct plant response to irrigation efficiency.

Australian peanut processors currently estimate total peanut production via the amount of seed they distribute at the start of the season. Although in some years this may provide a reasonably accurate estimation it does not take into account yield and quality fluctuations that may arise from variations in seasonal conditions. It is therefore hypothesised that with the aid of satellite imagery an accurate prediction of total peanut cropping area, as well as an accurate prediction of peanut yield variability can be determined that would provide a more accurate estimate of total peanut yield within intensive cropping regions. This information supplied prior to harvest would be highly advantageous to regional and national marketers for planning decisions regarding end of season handling and forward marketing of product.

MATERIALS AND METHODS

Acquisition and analysis of satellite imagery

QuickBird satellite imagery was selected due to its high pixel resolution of 2.4m and its multi-spectral format (blue 450- 520nm, green 520- 600nm, red 630- 690nm and near infra-red (NIR) 760- 900nm), and was acquired over four years (11 April 2004, 19 Feb 2005, 17 Mar 2006, 2 Mar 2007) near the S.E. Queensland townships of Wooroolin (151 49'05E, –26 24'24S). For this study the images were not corrected for atmospheric variation, however this would be recommended if this application was to be adopted on a commercial scale. All multi-spectral imagery did have a Normalised Differential Vegetation Index (NDVI= (NIR- red)/ (NIR +red), where QuickBird band 4 correlated with NIR and band 3 with red) applied, so as to remove noise errors such as those associated with soil reflectance and shading.

For the determination of inherent variability within specific paddocks, selected blocks were sub-setted from each annual image and segregated into five classes of NDVI value using an unsupervised classification. The classes were then colour coded with Red indicating a high NDVI value and therefore larger crop vigour, followed by Yellow, Green, Blue and then Black indicating low vigour or bare soil. The classifications were then compared to identify if any consistent spatial trends occurred across years and crop types. The annual image data set of Wooroolin was also used for the regional prediction of total dryland cropping yield. Ground samples collected over the last 4 peanut seasons, including 115 samples from crops with 5 different varieties grown in eight separate dryland blocks, were correlated against the NDVI value at each sample location. A supervised angle mapper (SAM) classification was applied to a composite 5 band (red, green, blue, IR and NDVI) layer stack in an attempt to estimate the total peanut cropping area within the confines of the image. This technique extracted all pixels that displayed the same spectral values as those selected from known peanut crop training sites.

For the prediction of yield and maturity via satellite imagery a number of irrigated peanut crops were selected from an additional QuickBird image acquired near the township of Texas, Queensland (central point of image- 151 16’44E, -28 59’49S) (20 Feb 2007). This image was also transformed by NDVI before each individual irrigated crop was sub- setted, classified into the five regions of NDVI and ground sampled as described below.

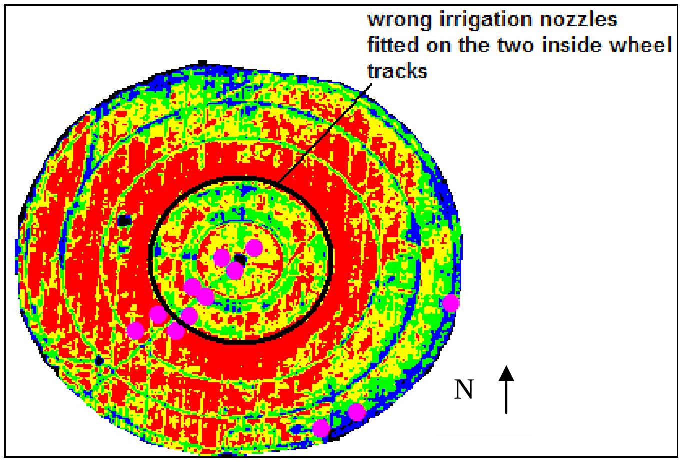
Field validation of QuickBird images

From the classified images, pod samples locations were selected to represent each colour class and located on the ground with a non- differential Garmin GPS (Geographics WGS-84). To compensate with the GPS accuracy of 5 metres, each sample location was selected within a > $20m^2$ area of homogenous colour zone. Three replicate samples were taken per colour zone and consisted of intact peanut bushes and pods from two adjacent 1m lengths of peanut row (i.e. $1.8m^2$). The samples were dried for three days at 40ºC, before pods were harvested using a stationary peanut thrasher. A 200g pod sub-sample was taken and shelled to measure the percentage of pods having a black (i.e. mature) pericarp using the ‘shell out’ method (Mackson et al. 2001), which was then used as an index of crop maturity. The maturity and yield values from each sample location were then correlated against the corresponding NDVI values to identify if any relationship existed.

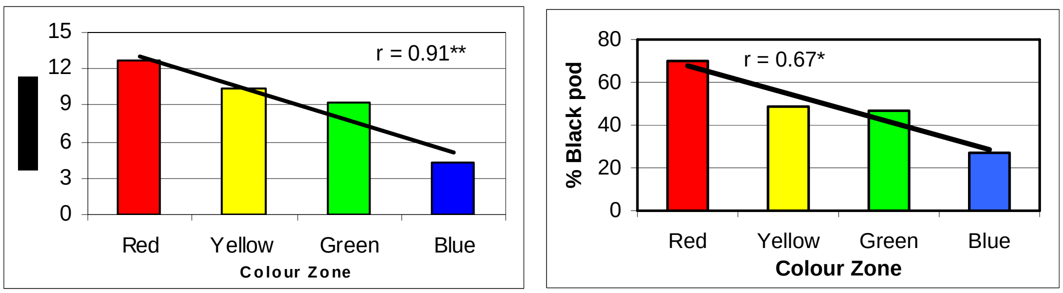
RESULTS AND DISCUSSION

Maturity and yield prediction, and monitoring of irrigation efficiency from individual peanut crops

The ground sampling of an irrigated peanut crop (cv. Holt) (Figure 1a) produced a highly significant correlation between yield and the NDVI value corresponding with sample each site (r= 0.91**, P = 0.000) (Figure 1b). The regions of the crop displaying higher IR reflectance or crop vigour (Red zones) produced a higher yield, in this case over 12t/ha compared to 4t/ha in the Blue zones, a result that is consistent with those previously reported by Robson (2007). For pod maturity, a significant correlation (r=0.67*, P=0.015) (Figure 1c) was also identified with a greater percentage of mature (Black) pods in the Red zone (70%) compared to the Blue zone (27%), a finding that contradicts results previously reported by Robson et al. (2007). Robson et al. (2007) hypothesised that peanut pods growing in low vigour (Black and Blue) areas within dryland and partially irrigated crops matured faster as canopies within these regions provided less shading, allowed more solar radiation to heat the soil resulting in a more rapid accumulation of heat units by the maturing pods. This hypothesis may however be negated in a fully irrigated system due to increased soil water availability and larger overall canopies minimising any variations in the amount of solar radiation heating the soil and hence nullifying the resultant thermal time accumulation effect.



a. Area = 21.9 ha (cv. Holt)



c.

Figure 1. (a) Unsupervised classification of a NDVI derived image of a fully irrigated peanut crop (cv. Holt), Red indicates a high NDVI value or high crop vigour, followed by Yellow, Green and Blue representing a low NDVI value and low crop vigour. The pink dots indicate the sample locations while the black circle encompasses the region where the wrong irrigator nozzles where installed, resulting in reduced crop reflectance. Correlation between measured pod yield (t/ha) (b) and pod maturity (% Black) (c) measured at each sample point against corresponding NDVI value. (* =P≤ 0.05, ** = P≤ 0.01).

By calculating the area encompassed by each classified region as well as the corresponding yield values as determined by the replicated hand samples, then an estimate of total production for each zone as well as for the entire crop can be made (Table 1).

Table 1. Average pod yield (t/ha) measured from the replicated hand samples, the area encompassed by each colour zone and the calculated yield (t/ha) produced by each colour zone. (Black zones weren't sampled as these mainly represented irrigator wheel tracks).

	Red	Yellow	Green	Blue	Black	Total
area (%) of pivot of each zone	38.8	31.5	20.5	7.8	0.3	100.0
area (ha) encompased by each zone	8.5	6.9	4.5	1.7	1.4	21.9
Yld (t/ha) (calc. from hand samples)	12.68	10.31	9.18	4.31	n/a	
Total Yld (t) per zone (area of each zone* hand sample yld)	107.79	71.17	41.33	7.34	n/a	227.64

Table 1 shows that nearly 39% of the crop within this irrigated pivot grew at an optimum level (Red zones) which had an estimated yield of 12.68 t/ha and equated to 107.8 tonnes produced by this zone alone. This production nearly equalled the sum of the other three zones, in which 61% of the pivot only produced 139.8 t. This variation when expressed in monetary terms emphasises the potential loss in production from those regions with less than optimal growth (Table 2).

Table 2. Cost estimate on the potential loss of production by those zones showing less than optimum growth

Total Area of Pivot	21.9 (ha)
Total predicted yield from all colour classes	227.64 (t)
Average yield for all colour classes	10.4 (t/ha)
Average yield for Red colour class	12.68 (t/ha)
Total predicted yield if pivot all Red	277.7 (t)
Yield Difference	50.1 (t)

From Table 2, it can be seen that if the entire crop had optimum growth (Red) then the predicted total pivot yield would have been 278 tonnes, or more than 50 tonnes more than the total predicted yield based on the measured variation within each colour zone. In monetary terms, this represents a potential loss of $50,000 (at $1000 per tonne) from under performing regions within the crop. The predominantly Green areas located at the northern and south- eastern areas of the pivot (Figure 1a) are likely to be associated with a poorer soil type, and with the aide of this image to coordinate soil sampling, an agronomist could easily identify the deficiency and offer remedial action. This technology also offers a grower the opportunity to quantify the potential losses experienced by the incorrect fitting of the two irrigation nozzles located closest to the centre of the pivot (Figure 1a), and if appropriate, pursue those responsible for the monetary losses.

Temporal assessment of the inherent spatial variability of paddocks

The acquisition of four years of multi-spectral satellite imagery over the intensive peanut growing region of Wooroolin has enabled across season image analysis to be undertaken on specific paddocks for the identification of inherent spatial variability. The left hand side (pink circle) (Figure 2) of the following rainfed block is shown to be consistently underperforming (Blue- Black), most likely a result of poorer soil type, irrespective of whether the crop being grown was peanuts or maize. This information could enable the grower to modify their farming practices by possibly planting a short duration variety in the region more prone to stress, to reduce the amount of time that the crop is exposed to potential yield limiting conditions, or alternatively removing this area from the cropping system altogether if yields are extremely poor. Also, poor performing regions such as that displayed in Figure 2, have been shown to more prone to aflatoxin contamination (Robson, 2007, Robson et al. 2006), so in years where the risk of infection is high, a grower can opt to segregate the harvest, delivering those peanuts that are of a higher risk of being infected and likely to attract a financial penalty, separately to those that may be aflatoxin free.

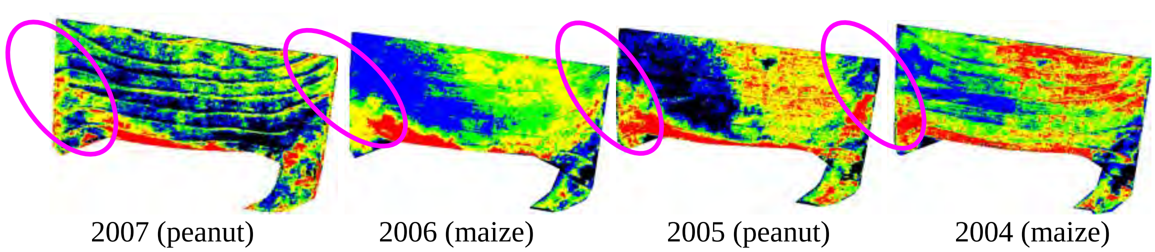


Figure 2. A four year (2004-2007) classified NDVI comparison of a rainfed paddock near the South Burnett township of Wooroolin. The pink circles indicate a consistently underperforming region of the paddock that occurs in both peanut and maize rotations.

By having a firm understanding of the spatial variability displayed by a particular paddock, a grower or agronomist, with the aid of in- season imagery, can easily identify any additional stress that may occur within a specific crop during a growing season. This is demonstrated in Figure 3, where the classified image of the 2006 maize crop displays a large area of low vigour (pink circle around Black area) that is not apparent in the images of the same paddock across other years. Following further investigation it was identified that this region of very low vigour was associated with an area of severe erosion brought on by a heavy rainfall event that had washed away germinating plants.

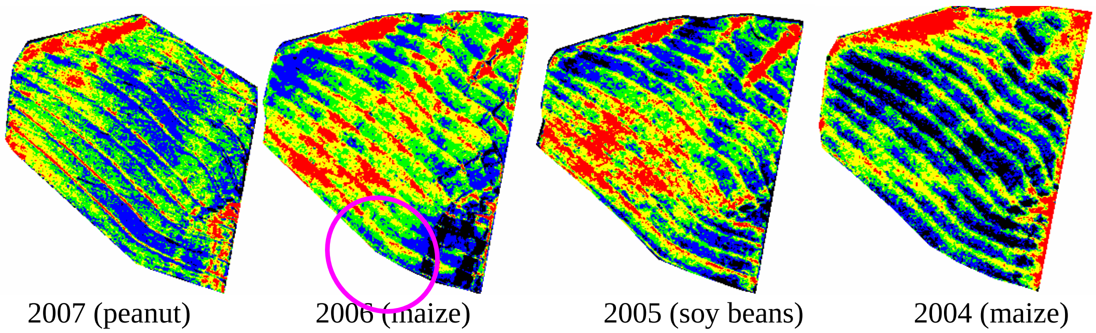
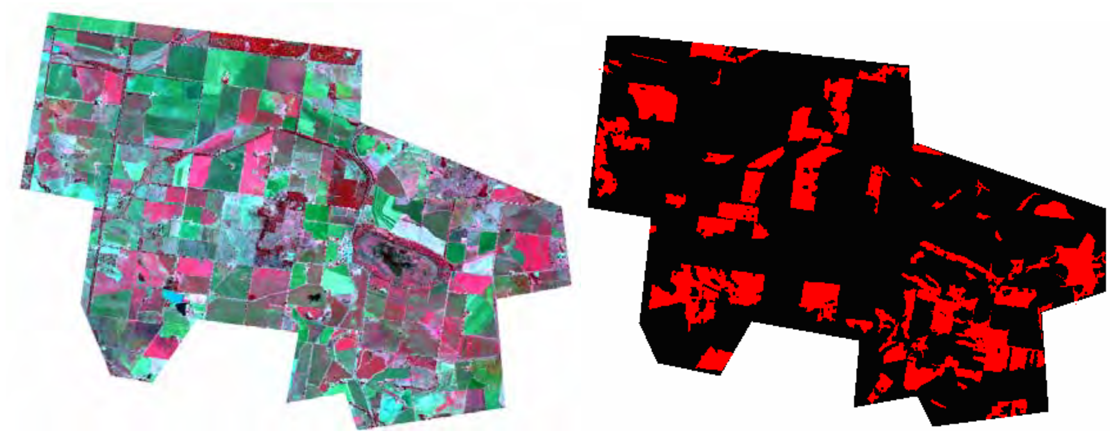


Figure 3. A four year (2004-2007) classified NDVI comparison of a rainfed paddock near the South Burnett township of Wooroolin. The pink circle indicates a large region of low vigour that only occurred within the 2006 maize crop and was later identified to be a result of erosion.

Although this low vigour event was the result of erosion and therefore would have been visually obvious to the grower, this technology can provide an exact estimate of the area affected, allowing for decisions such as the feasibility of re- planting to be determined. Similarly positive results have also been identified following foliar disease outbreaks, pest invasion, salinity and even lightening strikes (Robson, 2007).

Regional prediction of peanut cropping area and yield forecasting

Within the rainfed regions of intensive peanut cropping areas of Australia, the peanut canopy displays equal or greater IR reflectance than most other crops in the later stages of the growing season, owing to its lack of maturity related senescence, unlike that displayed by other summer crops (Figure 4a). This feature means that late season acquired images, particularly through the peanut pod-filling stage, can be used to distinguish peanut from surrounding crops and therefore used to accurately measure the total cropping area. This is demonstrated in Figure 4b where a spectral angle mapper (SAM) supervised classification technique applied to the 2004 Wooroolin multi-spectral image highlights (in red) only those pixels that have NDVI values consistent with those predetermined to be representative of peanut crops.



a. b.

Figure 4. (a) False colour image acquired 11 April 2004, of the intensive peanut cropping region near the township of Wooroolin; the bright pink paddocks indicate peanut crops with high IR reflectance. (b) Resultant SAM classification showing peanut crops as red and all other land cover as black.

From the resultant SAM classification, an estimate of total peanut cropping area within the extent ($64km^2$) of this image was 2747.1ha. When multiplied by an average pod yield of 4.3t/ha, based on yield samples from the six crops sampled during the 2003-04 peanut season, the total peanut production for this region was estimated at 11,923 tonnes of peanuts. Although this estimate does suffer some inaccuracy due to some mis-classified pixels and the use of an average yield value, it does provide a more accurate estimate of total yield compared to currently available methods. This prediction may be improved with more specific classification software, as well the replacement of the averaged yield value with values that more accurately represent the spatial variability of each crop.

From ground samples collected from the 2004 to the 2007, peanut crops at 8 separate dryland locations and encompassing five peanut varieties, (cvs. Streeton, VB-97, NC7, Conder and Deakin), a highly significant correlation was identified between pod yield and the corresponding NDVI value for each sample location (Figure 5).

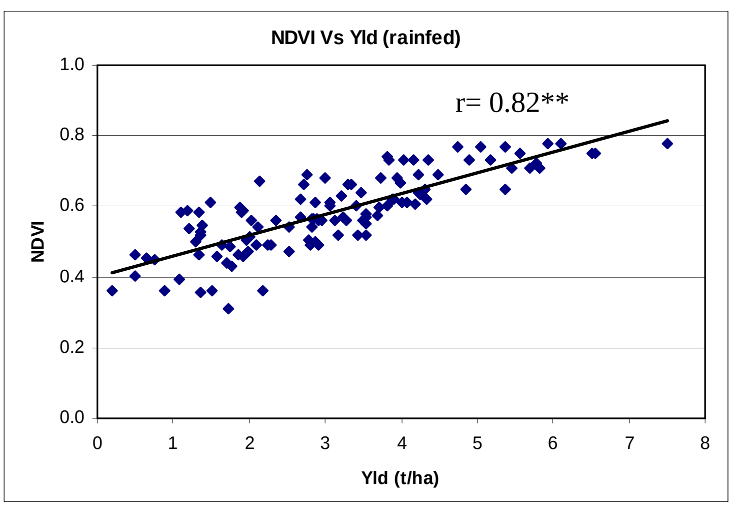


Figure 5. Correlation between 115 ground sampling points encompassing 5 varieties across 8 locations and four growing seasons, and the corresponding NDVI value for each sample point. (** = P≤ 0.01).

This high correlation when combined with the cropping area predictions may enable more accurate regional and even national yield estimates from satellite imagery to be developed. On a regional scale yield forecasts up to 8 weeks prior to harvest could allow better decisions to be made regarding issues such as likely supply, staffing requirements and import needs, while on a national and international scale this application could enable government agencies to establish estimates of likely surpluses or deficits and form food reserve estimates which could ultimately influence decisions relating to trade and emergency aid.

CONCLUSION

The results presented in this paper indicate a number of possible applications that remote sensing and subsequent image analysis offers to the peanut industry as well as other cropping systems. Such applications include: the accurate prediction of pod maturity and yield variability across individual crops, as well as a cost analysis of possible lost production from under performing areas; a total production estimate for an intensive cropping area; the identification of a paddocks inherent spatial variability of crop growth, and the in- season identification of irrigation inefficiencies, and other limiting constraints such as foliar diseases. This information has been well received by peanut growers, agronomists and agribusiness representatives.

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