Preliminary investigating into the effectiveness of remote sensing and GIS for identifying Yellow Canopy Syndrome (YCS) in Sugarcane.

Compiled by Dr Andrew James Robson.

Abstract

The preliminary evaluation of remote sensing and GIS for identifying YCS symptomatic crops produced varied results. Although both a principal component analysis and an ANOVA of Worldview 2 data produced significant outcomes, large disparities in the sample size of YCS symptomatic and non-symptomatic crops as well as the qualitative nature of confirming YCS, proved to be major issues. The hyperspectral reflectance measurements of third leaf samples from YCS symptomatic and non-symptomatic sugarcane plants identified some spectral separation between 520- 640 nm, 1400 – 1850 nm and 1950 - 2400 nm, but the root mean square error (RMSE) following a partial least squares discriminant analysis (PLSDA) was poor. The GIS analysis of Herbert mill data for 2010- 2013 identified little influence of YCS on the distribution of CCS at the block level, with the average regional CCS increasing over those years. The 2014 season should provide further evidence of this with a greater number of crops being confirmed with YCS symptoms. Finally, a comparison of average crop GNDVI and yield values for the Burdekin and Herbert, identified 2013 to be atypical to the previous years 2010- 2012. This result indicated that the conversion of crop vigour (presented as GNDVI) to yield was poor, a result most likely attributed season weather variability. This finding indicates that YCS may be a physiological response to this seasonal variability or alternatively be contributing to the reduced conversion to yield.

Executive Summary.

The following report evaluates the capacity of remote sensing and GIS for distinguishing Yellow Canopy Syndrome (YCS) from non-symptomatic crops and to determine whether the presence of YCS influences CCS at the regional scale.

The spatial distribution of YCS symptomatic crops within the Herbert appeared to originate in the southern region in 2013 (n= 70) and then extend sporadically throughout the entire region during 2014 (n= 495). For the Burdekin a similar spread of positive crops was identified, with a substantial increase during the 2014 season (n= 39) to March 2014 (n= 246), with the eastern side of the region exhibiting a greater increase in symptomatic crops. This result may be associated with the on ground assessment of crops, with areas such as Home Hill, Ayr and Brandon being under more scrutiny in 2014 than other regions such as the Majors creek.

The preliminary evaluation of Worldview 2 and SPOT5 imagery failed to identify any consistent association between reduced crop vigour, presented as a classified Greenness Normalised Difference Vegetation Index (GNDVI), and the presence of YCS. A principal component analysis of Worldview 2 data identified 98% of the spectral variation in differentiating YCS and non YCS blocks, with NIR (770 – 895 nm) and Mid NIR (860–1040 nm) being the most influential bands. The NIR region provides an insight into the plant's internal structure, including the interfaces of cell walls with air, protoplasm or chloroplasts, starch and cellulose, whilst the Mid NIR region can indicate changes in the plant's chemical constituents i.e. carbon, hydrogen, nitrogen, oxygen, starch, cellulose, water, lignin etc. An additional analysis of variance (ANOVA) of the Worldview 2 data found significant differences between the positive to negative crops across most spectral bands, but the correlations were poor. Interestingly, the ANOVA, PCA and partial least squares discriminant analysis (PLS-DA) of the Worldview 2 spectra identified a narrower range of spectral data for YCS symptomatic crops compared to those symptom free. This was initially attributed to the unequal sample size (894 negative compared to 42 positive). However, this also occurred with the hyperspectral third leaf samples. It is suggested that more intensive statistical analysis such as as 'relative frequency analysis' or 'support vector machine' be used to separate the incidence of YCS from crop variety or class. Also the allocation of GPS centroids to each positive YCS crop along with the inclusion of an elevation layer will provide a spatial dimension to better understand the spatial distribution and spread of YCS.

To determine if spectral wavelengths more specific to YCS could be identified, a field spectrometer was used to measure third leaf samples from symptomatic and nonsymptomatic plants. Although no specific wavelengths were identified, the spectra demonstrated some separation between 520 - 640 nm, 1400 – 1850 nm and 1950 – 2400 nm. Unfortunately the airborne hyperspectral data captured in December 2013 over positive and negative symptomatic crops within the Burdekin had not been received prior to the submission of this report. Additional time would be required to analyse this data. Similarly, by having only one comparative hyperspectral data set from the field spectrometer severely limits the scientific rigour of this analysis. It is suggested that if this research was to be repeated more sample locations would be required, including multiple varieties and crop classes. If narrow wavebands specific to YCS symptoms were identified then there would be an opportunity to develop a low cost sensor to undertake non- invasive screening of commercial crops and breeding stock.

To identify if YCS was influencing CCS at the regional level, a GIS analysis was undertaken using CCS block data (2010- 2013) from the Herbert growing region. The initial investigations of the spatial and temporal distribution of CCS indicated little influence from YCS. The distribution of CCS at the block level for the 4 year period was relatively consistent without any major shift to the negative, although only 70 crops were identified to be YCS symptomatic in 2013. The mean CCS displayed an incremental increase over the 4 year period from 12.57 (2010), 12.68 (2011), 13.5 (2012) to 14.0 (2013). With the incidence of YCS greatly increasing during the 2014 season, it would be recommended that a similar evaluation of CCS data be undertaken following the 2014 harvest.

Finally, a comparison of exponential trend lines produced from the correlation between individual crop GNDVI and yield, across three growing regions: Burdekin, Herbert and Bundaberg, identified a potential anomaly in the 2013 harvest season compared to previous years. The trend line produced from the 2013 harvest season for the Herbert and the Burdekin regions displayed a horizontal shift indicating that the overall crop development/

crop vigour in 2013 was similar to previous years but the conversion of biomass (assumed by GNDVI) to yield was poor. When compared to monthly weather data for the

corresponding years, reduced rainfall between the December to February growing period as well as higher average temperatures and radiation were identified as possible drivers. A comparative trend line shift was not identified in the Bundaberg growing region. This finding may indicate that the 2013 season for the Herbert and Burdekin was atypical to the previous 3 years and that YCS may in fact be a physiological response, particularly as it was not expressed in the Bundaberg region.

1. Brief introduction of YCS.

In recent years, a number of Australian cane growing regions have exhibited a yellowing of cane plants that has been termed 'Yellow Canopy Syndrome' or YCS. It has predominantly been identified in the tropical northern regions of the Herbert and Burdekin and as yet to be seen on large scale in the southern regions. Although the driver of this syndrome has yet to be determined, it presence has been associated with a yellowing of the lower leaves that can extend to the entire stalk, a more malleable stalk and root death. Figure 1, identifies the initial stages of YCS with one half of a lower leaf turning yellow. Figure 2 identifies the later progression of symptoms with the majority of the plant displaying a yellowing.

Figure 1. Lower sugarcane leaf from the Burdekin region exhibiting a yellow and green division along the mid rib associated with YCS.

Figure 2. (left) A non-symptomatic cane crop and (right) a general yellowing of the lower cane leaves associated with YCS.

In terms of productivity, YCS has been suggested to decrease CCS content and tonnes of cane per hectare. The suspected root death in particular can have serious implications to the germination/ plant density of ratoon crops with stools more likely to be pulled from the ground during the mechanical harvest of the crop. Although these implications to productivity are still being researched, the threat to the industry is still high. As such an initial evaluation of remote sensing/ GIS was conducted to identify if YCS affected plants could be distinguished from healthy plants using both multispectral and hyperspectral technologies; As well as to form a stronger understanding of the spatial influence of YCS on plant vigour, yield and CCS.

1.1. General introduction to remote sensing technologies and spectral properties of leaves.

Remote sensing in in its broadest terms refers to measuring something without physically touching it and predominantly includes satellite and airborne imagery, as well as field spectroscopy and active sensors (i.e. Greenseeker). In terms of the imagery specifics these sensors can provide a range of spatial (i.e. area covered by each pixel) and spectral resolutions (i.e. multispectral, hyperspectral). Multispectral refers to a limited number of spectral bands (i.e. 4 or less) with large band widths, whilst hyperspectral has many spectral bands with narrow band widths and is generally continuous data. Remote sensing technologies are well proven for the capacity to identify the health and vigour of vegetation as they provide not only a measure of the visible characteristics of a plant but also the internal constituent composition of the plant structures.

The reflectance properties of a healthy green leaf can be seen in Figure 3. The visible part of the spectrum exhibits low reflectance, with a peak at 550 nm (green) resulting from two chlorophyll absorption bands at 450 nm (blue) and 650 nm (red) (Rao et al. 1998, Curran et al. 2001). The transition from low reflectance in the visible spectral region to the high reflectance in the near infrared (NIR) is known as the red –edge which shifts to the left in response to plant stress. The NIR region (700-1300 nm) provides an insight into the plant's internal structure, including the interfaces of cell walls with air, protoplasm or chloroplasts with any forms of desiccation affecting this region. Changes in the plant's chemical constituents i.e. carbon, hydrogen, nitrogen, oxygen, starch, cellulose, water, lignin etc. can be identified via changes in the Mid Near infrared (1300-2500 nm) (Nilsson, 1995 and Curran et al. 2001).

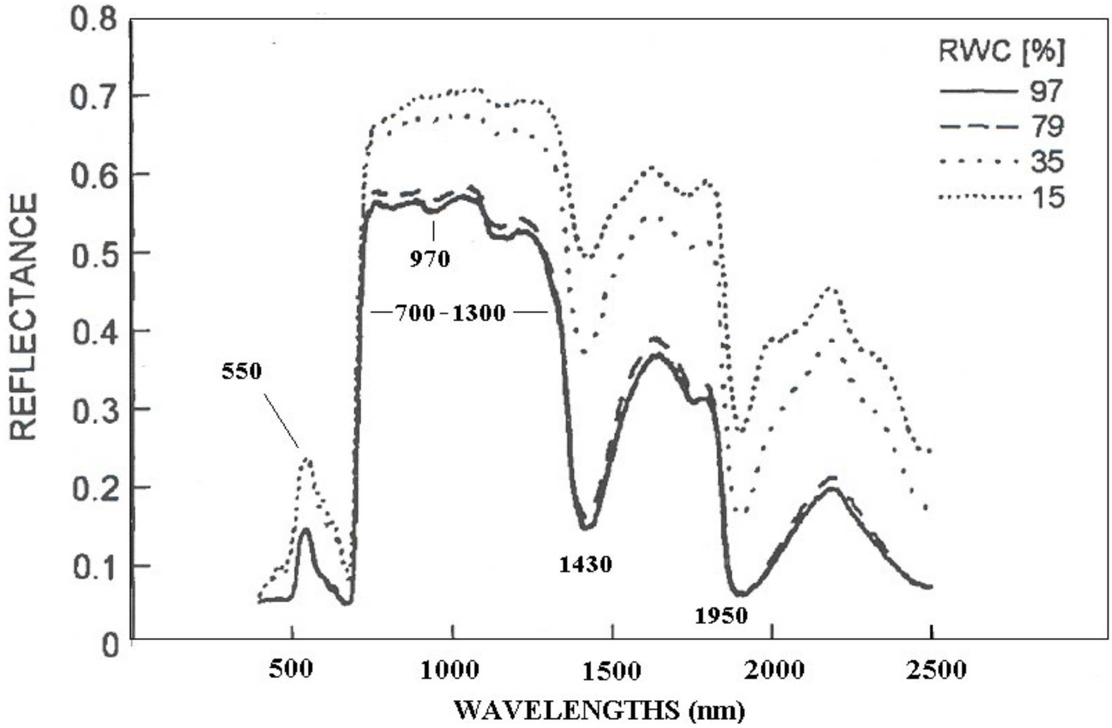


Figure 3. Spectral reflectance of leaves under progressive desiccation from a Relative Water Content (RWC) of 97% to 15%. Figure sourced from Penuelas and Inoue (1999).

Although Figure 3 identifies the influence of waters stress on the overall reflectance properties of a leaf, the influence of plant disease is similar with an increased reflectance (reduced absorption) within the visible blue and red spectral regions i.e. those associated with chlorophyll pigments. This explains symptomatic chlorotic yellowing that occurs with some diseases. Reflectance within the NIR region decreases with the incidence of plant stress/ disease as the internal cell structures of the leaf i.e. the spongy mesophyll and cell walls, degrade.

By understanding the spectral characteristics of a healthy leaf and the changes that may occur from stress, it is hypothesised that YCS could be determined spectrally. This may be via the reflectance properties within the visual spectral region i.e. with the leaf yellowing as well as by changes in the NIR and MIR region in the event that YCS affects the internal constituents of the cane.

1.2. Previous Remote sensing research on Plant disease.

Previous research has shown that the spectral characteristics of growing leaves can be used to distinguish a number of plant pathogens from a number of crop species, including sclerotinia stem rot in soybeans (Dudka et al. 1998); Potato Yellow Vein Virus (PYVV) (Chavez et al. 2009); Tomato Spotted Wilt Virus (TSWV) (Everitt et al. 1997) and aflatoxin (Robson, 2007) in Peanut. To remain specific to sugarcane, the following focuses on research undertaken on Orange Rust (*Puccinia kuehnii*) disease (Apan et al. 2004) and Sugarcane yellow leaf virus (SCYLV) (Grisham et al. 2010).

Orange rust is a fungal disease that presents with orange leaf pustules that increase water loss, hence increasing the rate of water stress. It is more prevalent around summer/ autumn. Apan et al. (2004) derived a number of Disease water stress indices (DWSI) from hyperspectral Hyperion data that effectively identified rust affected areas. These included the spectral ratios DWSI1= R800/R1660, DWSI2= R1660/R550, DWSI5= (R800+R550)/(R1660+R680) as the highest separability of spectra was identified at 550nm, 680nm, 750- 880 nm and 1660- 2200nm.

SCYLV presents as a yellowing of the canopy where younger leaves display a yellowing of the lower surface of the midrib and the upper surface remains green or develops a yellow, reddish or pink discolouration. Grisham et al. (2010) identified the presence of SCYLV could be predicted at an accuracy of 64% following a discriminant function analysis of airborne hyperspectral data. The predictive capacity was however influenced by different cultivars and by sampling date. The significant spectral bands identified to differentiate SCYLV from healthy plants were 400– 500 nm, 500- 590 nm, 590- 650 nm, and 740- 850 nm, which were consistent with a reduction of the leaf pigments violaxanthin, β- carotene, neoxanthin and chlorophyll *a.* SCYLV was identified to reduce yield, and cause an increase in BRIX, including starch within the leaves.

2. Objectives of this study:

a) Investigate whether YCS symptomatic sugarcane could be spectrally identified using multispectral and hyperspectral data.

b) To identify the influence of YCS on the temporal and spatial distribution of crop and regional vigour (GNDVI) using remote sensing and GIS.

c) To identify the influence of YCS on the temporal and spatial distribution of crop CCS within the Herbert over a 4 year period (2010- 2013).

3. Methodology and Materials.

3.1. Study locations.

The sites chosen for this initial study included the Burdekin and Herbert growing regions, as both presented YCS symptomatic crops. Bundaberg, a non-symptomatic region, was also included to provide a comparative analysis of regional production and imagery values.

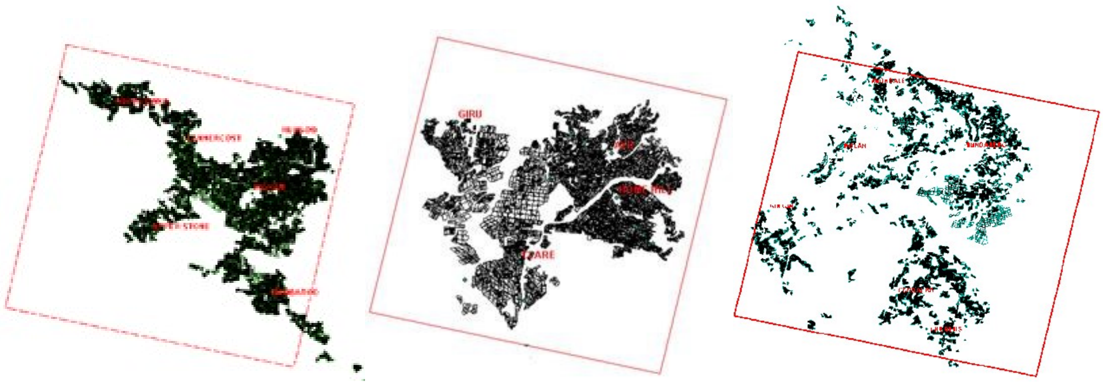


Figure 4. Crop boundary files of sugarcane crops within the Herbert, Burdekin and Bundaberg/ Isis growing regions. SPOT5 image coverage area (3600km^2) highlighted in red.

For the hyperspectral analysis and field sampling, a 100km^2 area was selected within the Burdekin region (Figure 5). This represented the extent of a Worldview 2 image (outlined in blue) and encompassed both symptomatic (yellow polygons) and non –symptomatic crops (cyan polygons). The 3 smaller transects (~22 km^2) (black outline) define the coverage areas of the airborne hyperspectral imagery. Additionally two individual crops (red polygons), one displaying YCS symptoms (4.5 ha) and one not (7.4 ha), were selected for on ground spectral measurements. To eliminate possible influences from cultivar, age etc. both crops were KQ228, 1st Ratoon and were early plant.

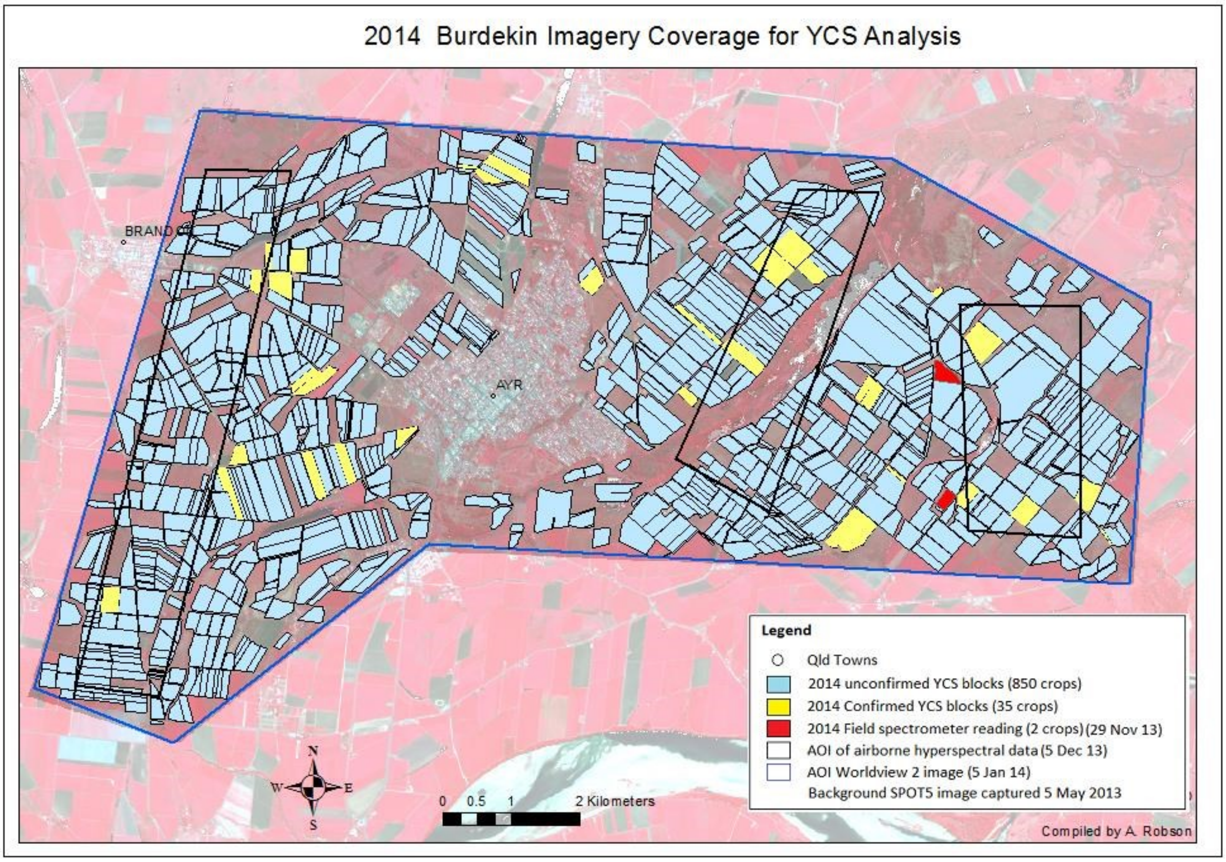


Figure 5. Burdekin region. Areas being covered by the airborne hyperspectral sensor highlighted in black, with confirmed YCS crops in yellow. The crops highlighted in blue indicate YCS negative crops. The two red polygons indicate the crops (1 positive YCS and 1 negative) sampled for hyperspectral analysis.

3.2. Data used for this initial study.

As this preliminary study did not include a budget for multispectral or hyperspectral images, all imagery used was funded by Sugar Research Australia (SRA) projects DPI021 and DPI025.

- The 2013 and 2014 YCS positive crop GIS layers were provided by Sugar Research Australia (SRA), Herbert Cane Productivity Service Ltd (HCPSL) and Burdekin Productivity Service (BPS) following on ground regional inspections within the Burdekin (September 2013 and March 2014) and Herbert (August 2013 and May 2014) growing regions. The dates indicate when the files were created and is assumed to correlate closely to when the surveys were undertaken.
- Worldview2 satellite image (50cm spatial resolution; 8 spectral bands: (coastal blue = 440- 450 nm; blue = 450 – 510 nm; green = 510 – 580 nm; yellow = 585 – 625 nm; red = 630 – 690 nm; Red- edge = 705 – 745 nm; NIR (Near-Infrared1) = 770 – 895 nm; MIR (Near infrared2) = 860–1040 nm).
- SPOT5 satellite image (10m spatial resolution; 4 spectral bands: Green (500-590 nm), Red (610- 680 nm), Near infrared (790- 890 nm), and Mid Infrared (1580- 1750 nm).
- Hyperspectral Airborne imagery was captured by Airborne Research Australia (ARA) and included two sensors: SPECIM EAGLE (400- 100nm) and SPECIM HAWK. The Eagle instrument has 252 bands ranging from 400.7 nm – 999.2 nm with a swath width of 965 pixels. The Hawk instrument has 241 bands ranging from 993.1 nm – 2497.4 nm with a swath width of 296 pixels.
- Hyperspectral field data was acquired using an Analytical Spectral Devices (ASD) field spectrometer 350-2500 nm (2nm increments).
- GIS Mill data layers provided for the Herbert (provided by the Herbert Cane Productivity Service Ltd; Mike Sefton); Burdekin (Wilmar: Greg Wieden) and Bundaberg (Bundaberg Sugar Ltd: Gavin Lerch, Allan Pitt).
- Weather data sourced from the SILO database.

3.3. Imagery type and acquisition date:

- *Burdekin*: Worldview2 captured 29 January 2014; SPOT5 (14 May 2010, 22 April 2011, 16 May 2012, 5 May 2013, 29 December 2013 and 8 May 2014); Hyperspectral Airborne captured December 2014 (data still not received).
- *Burdekin*: Field based hyperspectral data collected December 2014.
- *Herbert*: SPOT5 imagery (5 May 2011, 4 April 2012, 25 May 2013)

- *Bundaberg*: SPOT5 (10 May 2010, 27 March 2011, 1 April 2012, 25 April 2013)

3.4. Sampling Methodologies and data analysis:

Field spectroscopy: Samples were collected early in the growing season (i.e. end of November), in the hope that YCS could be better differentiated from the normal leaf senescence associated with maturation. During the maturation process the chlorophyll degrades, hence also resulting in leaf yellowing.

Ideally field spectrometer reading should be collected within the field so as to reduce any degradation of the sample constituents. Unfortunately due to cloudy weather on the day of sampling the in-field spectrometer readings could not be taken in the crop. As a contingency 10 3rd leaf samples were collected from 5 replicate locations within the YCS symptomatic crop and 5 in the symptom free crop. All samples were refrigerated between field collection and being spectrally measured. Following a protocol adopted for 3rd leaf nitrogen sampling, only the mid-section of the leaf blades were used with the mid ribs removed. Samples were placed in sampling mount attached to an LI800 Integrating sphere.

The reflectance data was initially inspected to identify any obvious anomalies with any suspect spectra removed. The water absorption bands (1350- 1420 nm, 1760- 1965 nm and 2450- 2500 nm) were removed as they were major sources of inconsistency and noise. For the partial least squares discriminant analysis (PLS-DA) and principal component analysis (PCA) the data was smoothed with a Savitzky- Golay second order polynomial before a number of pre-processing methods were applied, including a first and second derivation. Unfortunately due to time constraints of this preliminary study only one sampling event was undertaken. For a comprehensive evaluation many more sample locations, including multiple varieties etc. should be undertaken.

Satellite imagery: All imagery was top of atmosphere (TOA) corrected and orthorectified before analysis. For the derivation of vigour maps, the mill GIS boundary layers (converted to GDA 94) were used to subset the imagery to ensure all spectral data was specific to cane only. Each sub-setted image was converted into a Greenness Normalised Difference Vegetation Index (GNDVI) layer. GNDVI ((NIR - Green)/ (NIR + Green)) provides a strong indication of plant structure/ vigour as well as chlorophyll content but has been found to saturate less than the commonly used NDVI. An unsupervised classification was applied to the GNDVI layers to derive an 8 class colour ramped map.

To determine the if YCS was influencing crop reflectance and yield at the block and regional scale, the exponential trend lines derived from the correlation between GNDVI and TCH between 2010 – 2013 were compared. This comparison was undertaken using YCS symptomatic locations i.e. the Herbert and Burdekin as well as the symptom free region of Bundaberg. SILO weather data was also sourced to investigate if seasonal climate variability was also influencing the trend lines.

In an attempt to statistically define YCS blocks from those symptom free, the 2014 Burdekin mill data specific to the 100km^2 area of interest (Figure 5) was used to subset the Worldview 2 image captured 29 January 2014. The software StarSpan GUI, was used to extract the 8 band spectral information. This data was analysed using a partial least squares discriminant analysis (PLS-DA) similar to the method stated for field spectroscopy data, as well as with a principal component analysis (PCA) and an analysis of variance (ANOVA).

GIS analysis: To identify if YCS was decreasing CCS at the regional scale, Herbert mill data including the harvest results for 2010, 2011, 2012 and 2013 were overlayed into ArcGIS. Using the spatial statistics the average regional CCS, standard deviation and distribution of CCS per block was identified. Using the Quantile 'Natural break' classification those crops that exhibited a CCS lower than 8 were identified and maps defining the distribution were created.

4. Results.

4.1 Distribution of YCS blocks in the Burdekin and Herbert:

The GIS layers identifying the confirmed YCS blocks from the Burdekin (provided September 2013 and March 2014) and Herbert (August 2013 and May 2014) regions were overlayed into a GIS to identify if there was any obvious spatial pattern in their distribution.

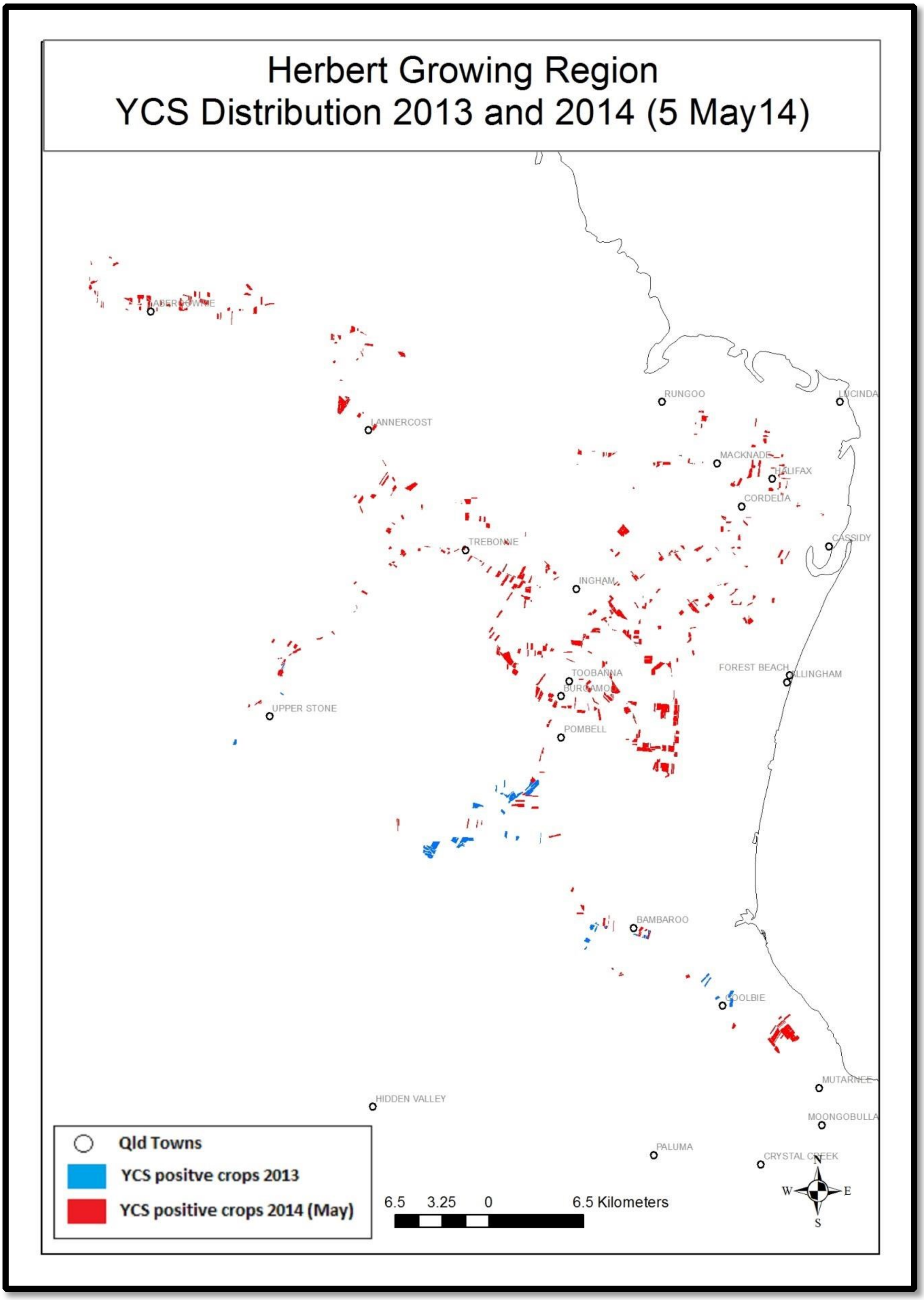


Figure 6. Distribution of YCS blocks identified by field assessments of the Herbert 2013 and (blue polygons) and 2014 (red polygons).

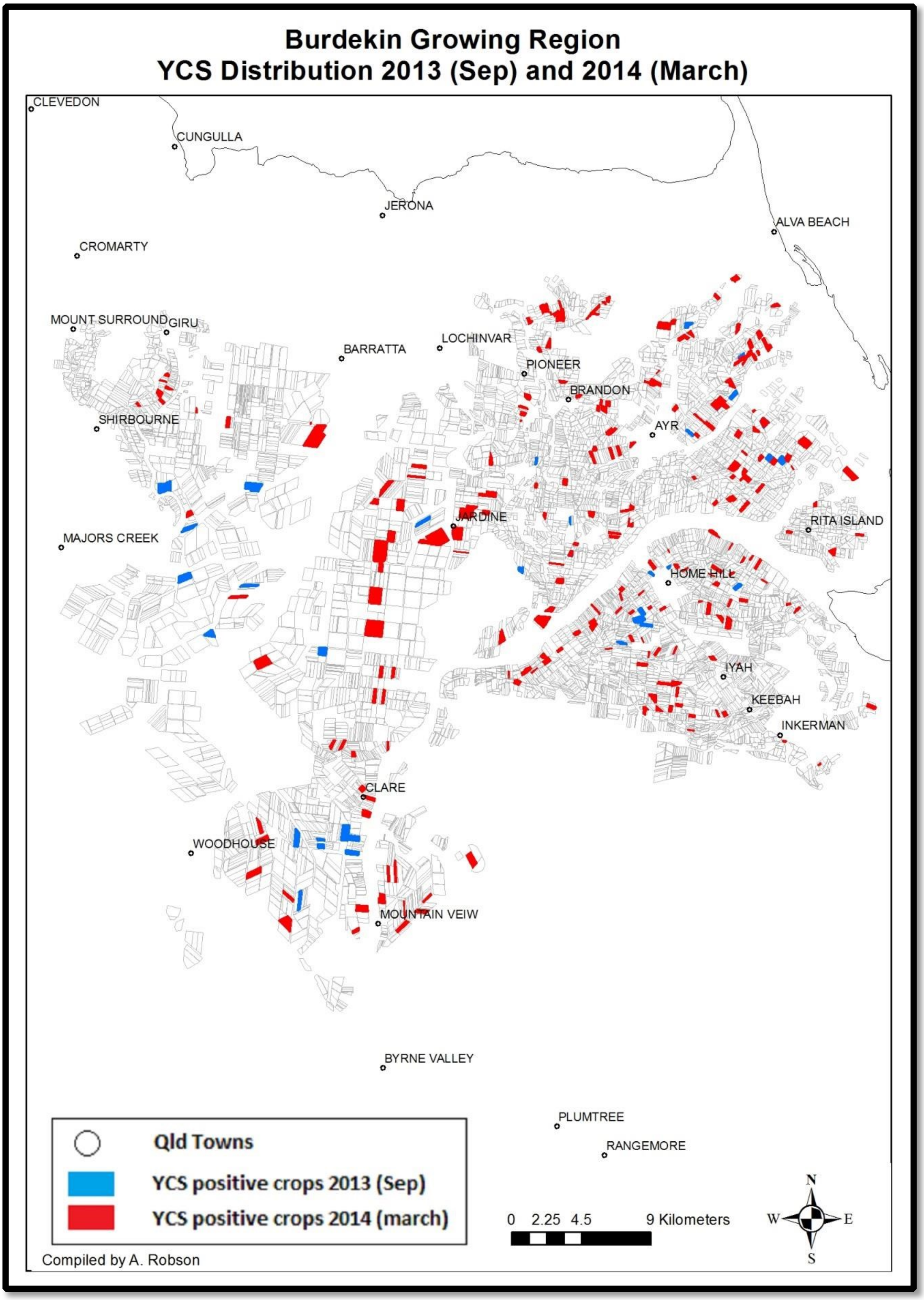


Figure 7. Distribution of YCS blocks identified by field assessments of the Burdekin during the early 2014 season (September 2013) (blue polygons) and March 2014 (red polygons).

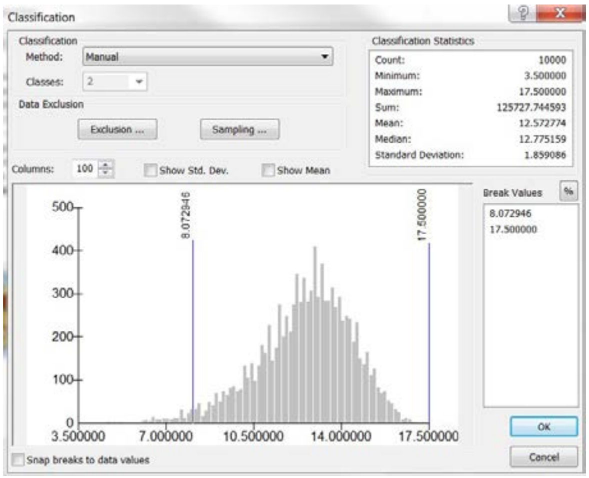
For the Herbert there appeared to be an initial clustering of symptomatic crops occurring within the southern growing region, near Pombell (blue polygon Figure 6). This may indicate a starting point for YCS in the Herbert region or alternatively represent where field inspections were most prevalent. For the Burdekin (Figures 7) there is some spatial segregation in the distribution of YCS confirmed crops, with a much higher prevalence on the eastern side. This subregion displayed some increase in YCS positive samples between the two inspection times, whilst the western sub region exhibited some decline. This result may be related to the actual spread of symptomatic crops or possibly be associated with the on ground assessment of crops, with areas such as Home hill, Ayr and Brandon being under more scrutiny in 2014 than the mid-western region near Majors creek.

Both regions present an obvious increase in symptomatic crops from 2013 to 2014. However, to determine if this increase and prevalence of YCS is associated with crop variety or class further statistics would be required. This may include the allocation of GPS centroids to each positively identified crop along with the inclusion of an elevation layer to create a spatial dimension. An intensive statistical methodology known as 'relative frequency analysis' or 'support vector machines' is currently being developed for the interrogation of mill layers in terms of yield distribution and its correlation to satellite derived vegetation indices and may have direct application here.

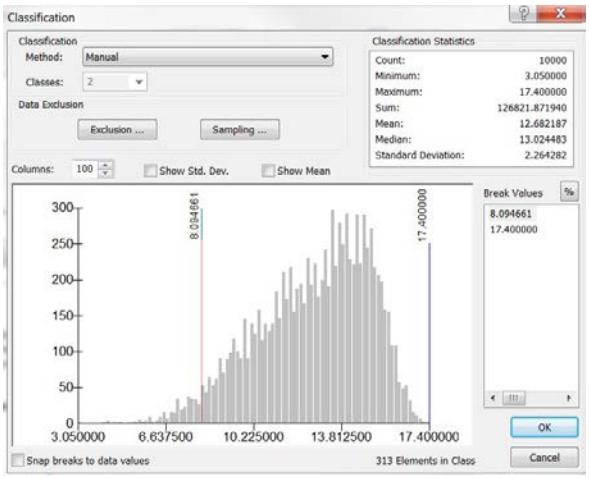
4.2. Investigating the relationship between YCS and CCS (Herbert 2010- 2013)

Initial investigations of the spatial and temporal distribution of CCS within the Herbert growing region between 2010 and 2013 indicated little influence from YCS. At the regional level the distribution of CCS was relatively consistent and provided little evidence of a broad scale reduction or a shift to low CCS (Figure 8). Although only 70 crops were identified to be symptomatic in 2013. The mean CCS increased over the 4 year period from 12.57 (2010), 12.68 (2011), 13.5 (2012) to 14.0 (2013). The spatial distribution of crops with a mill reportable CCS less than 8 between the 2010- 2013 period, again identified little influence from YCS (Figure 9). 2010 and 2011 had more crops with a CCS less than 8 compared to 2012 and 2013. This is most likely the result of seasonal weather variability.

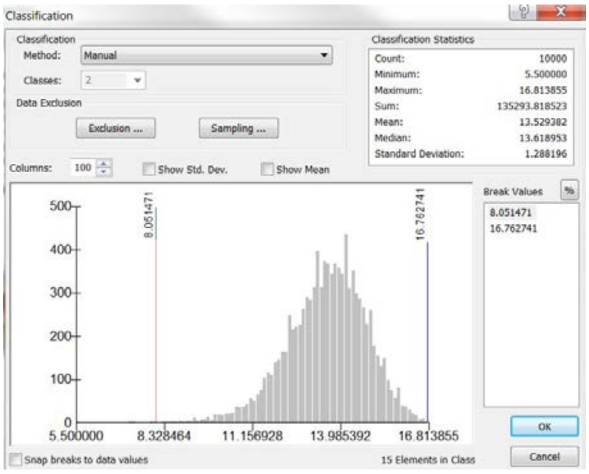
However harvest results from 2014 may show a greater influence due to more crops expressing YCS symptoms.



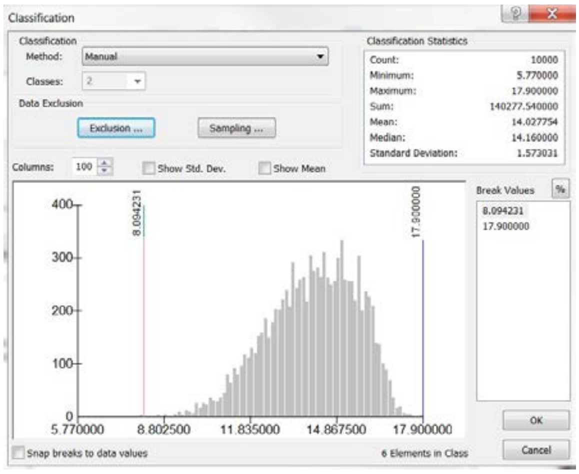
2010



2011



2012



2013

Figure 8 : Distribution and frequency of crop level CCS in the Herbert Region from 2010-2013.

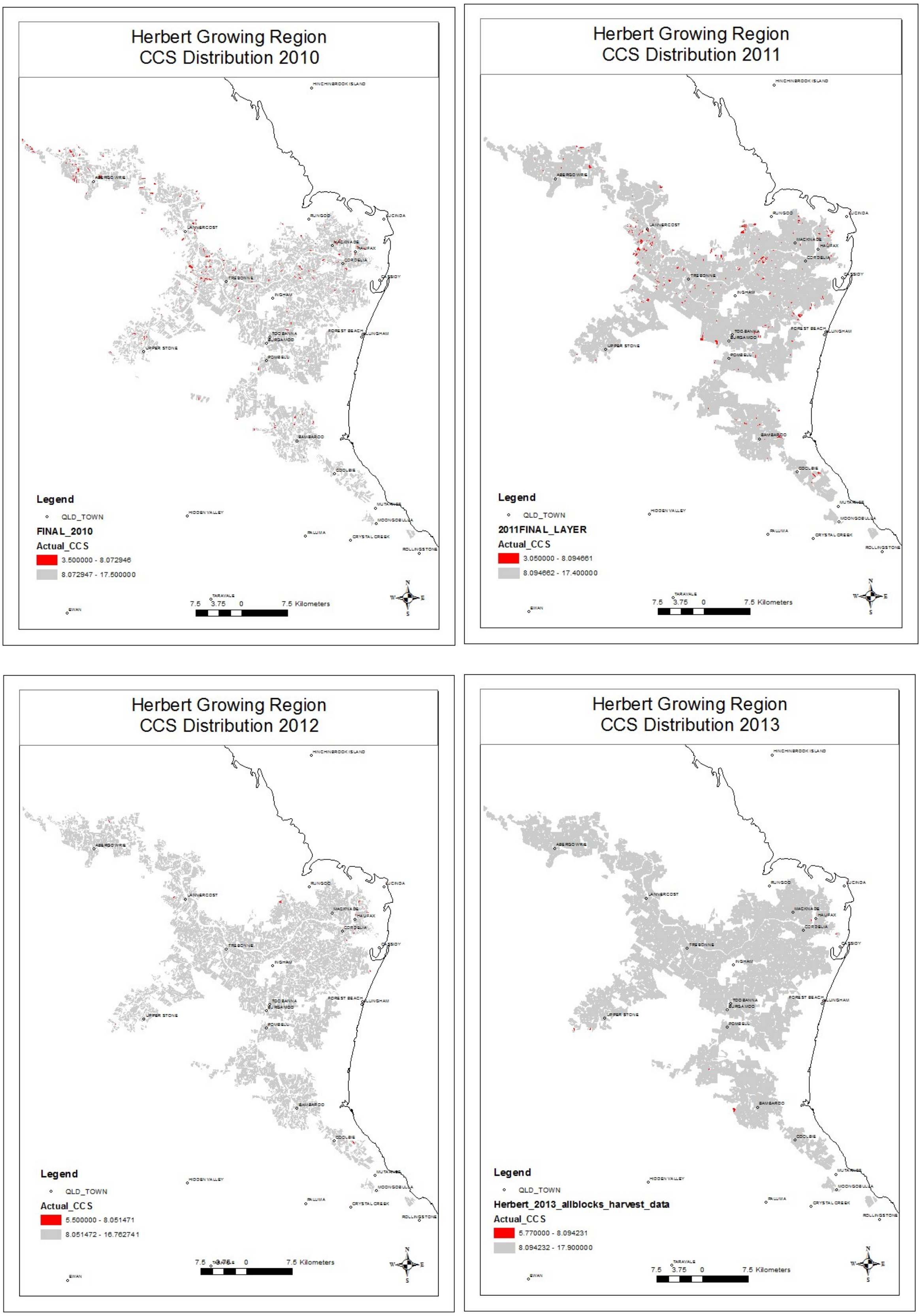


Figure 9 : Spatial distribution of crop level CCS in the Herebrt Region from 2010- 2013.

4.3. Satellite imagery to identify YCS blocks.

A number of imagery platforms offering varied spatial and spectral resolutions were investigated to determine if satellite imagery could diffierentiate YCS symptomatic crops from those un affected. SPOT5 imagery was captured over the Burdekin (29 December 2013 and 8 May 2014) and the Herbert (25 May 2013), whilst a high resolution 8 band Worldview 2 image was captured over a 100km^2 region in the Burdekin (29 Jan 2014). The initial evaluation comparing crop vigour (as classified GNDVI layers) failed to identify any consistent trend between YCS symptomatic crops and reduced crop vigour. This can be seen in Figure 10, that displays the August 2013 GIS layer of symptomatic YCS crops overlayed onto a classified GNDVI image (captured 25 May 2013) for a sub region of the Herbert. The influence of YCS failed to produce a constant reduction in GNDVI but rather a range of GNDVI classes from low (yellow) to high (magenta). A similar trend was identified in the Burdekin 29 December image and September 2013 GIS layer (Figure 11) and 8 May 2014 image and March 2014 layer (Figure 12).

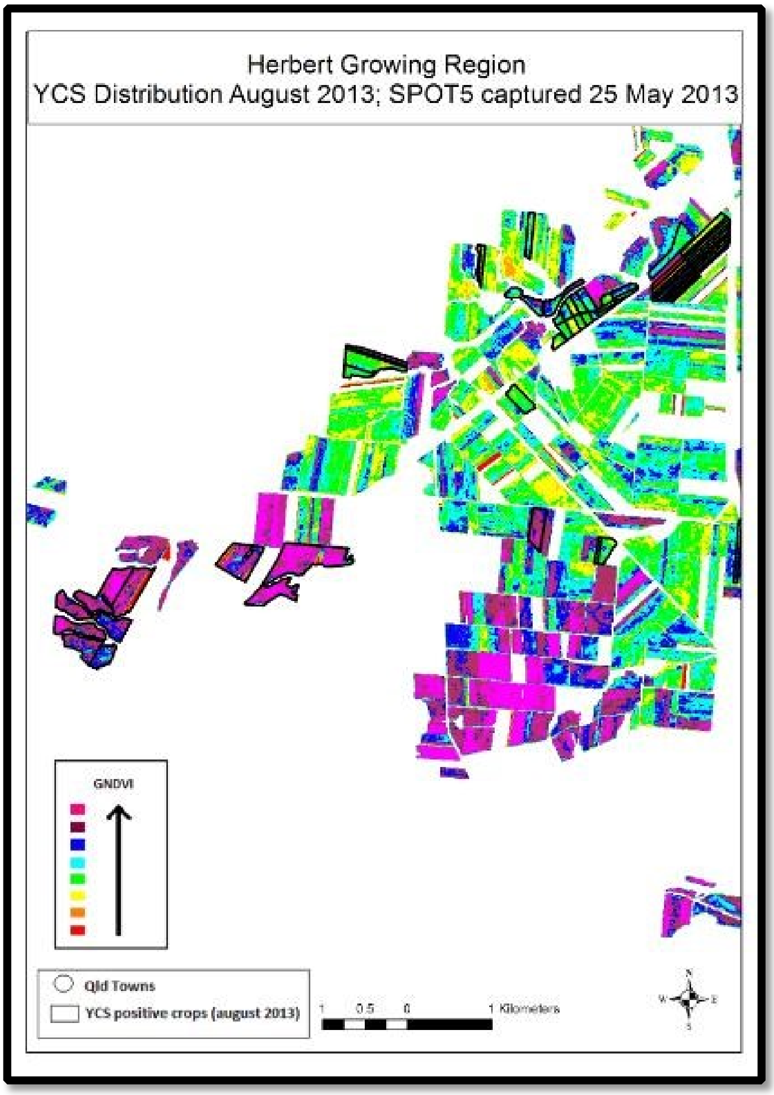


Figure 10. August 2013 GIS layer of symptomatic YCS crops overlayed onto a classified GNDVI image (captured 25 May 2013) for a sub region of the Herbert.

Unfortunately a SPOT5 image was not yet acquired over the Herbert region for the 2014 season. This image would have provided additional evidence on whether harvester damage, expressed as low GNDVI was more prevalent following YCS symptomatic crops. For the Burdekin a similar comparison between YCS block identified in the September 2013 GIS layer and the December 2013 image failed to show a consistent reduction in plant vigour. This questions claims that YCS symptomatic crops in general were more prone to mechanical harvester damage due to dead roots and weakened stools. Conversely, the majority of crops displayed high vigor (magenta and maroon), which supports observations made by HCPSL (pers com. Mike Sefton) that the 2013 season saw record levels of stalk tillering, possibly the result of YCS. High levels of tillering will present as high GNDVI.

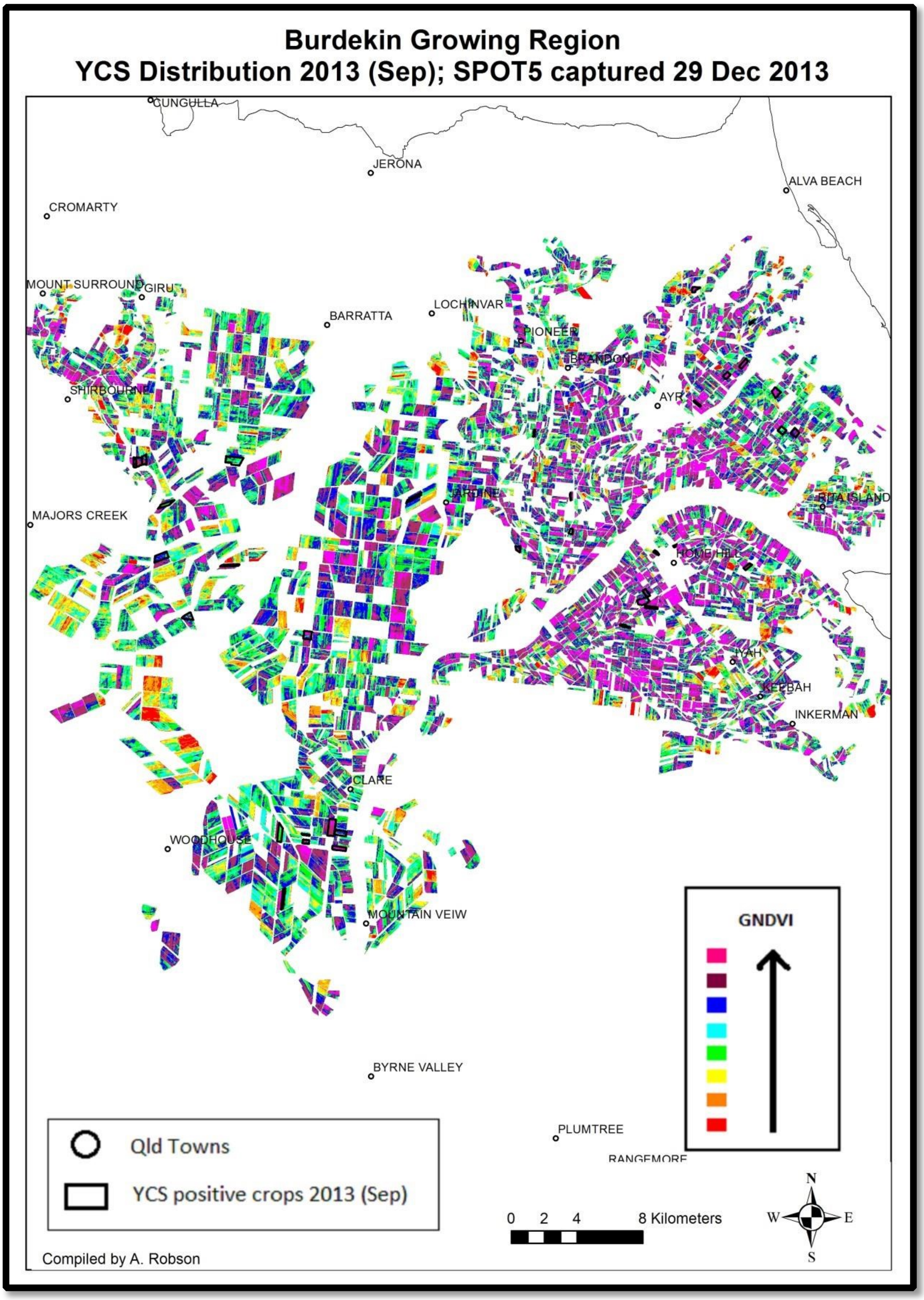


Figure 11. September 2013 GIS layer of symptomatic YCS crops overlayed onto a classified

GNDVI image (captured 29 December 2013) for the Burdekin region.

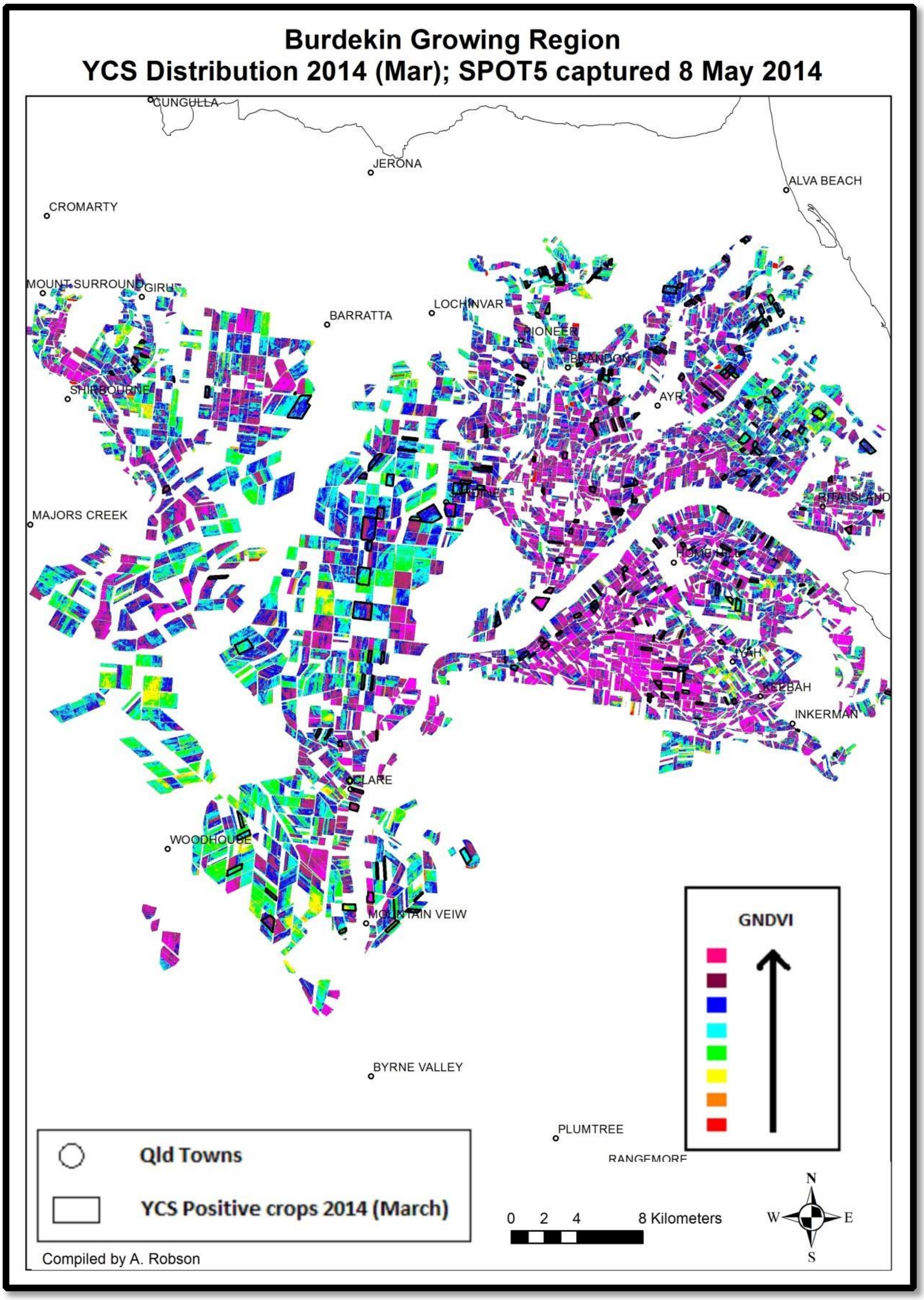


Figure 12. March 2014 GIS layer of symptomatic YCS crops overlayed onto a classified GNDVI image (captured 8 May 2014) for the Burdekin region.

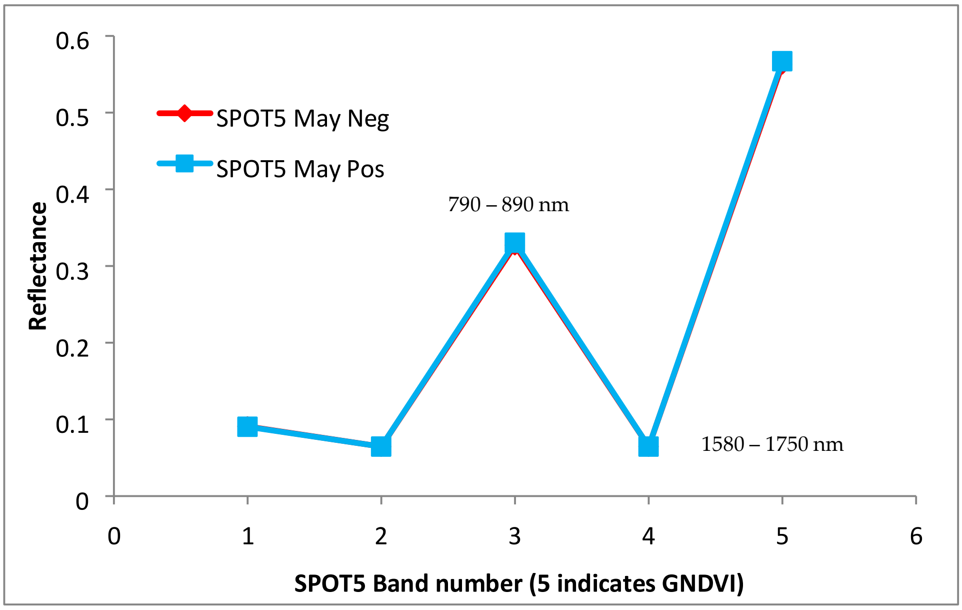


Figure 13. Averaged spectra from the four SPOT5 bands and GNDVI of YCS symptomatic (n= 216) and non- symptomatic crops (n= 8665) extracted from an image captured May 2014.

The extraction of average spectral values from each SPOT 5 spectral band and derived GNDVI for both YCS symptomatic and non-symptomatic crops identified a lack of separation (Figure 13). This result is likely to be the result of the averaging process and large disparity in sample numbers. It is suggested that more intensive statistical analysis such as those mentioned previously i.e. 'relative frequency analysis' or 'support vector machines' be used to determine if the incidence of YCS is associated with crop variety or class.

From the Worldview 2 image captured over the Burdekin on the 29 January 2014, a similar lack of separation between the YCS positive (n= 35) and YCS negative crops (n= 850) could be seen (Figure 14). This again could be the result of the averaging process and large disparity in sample numbers.

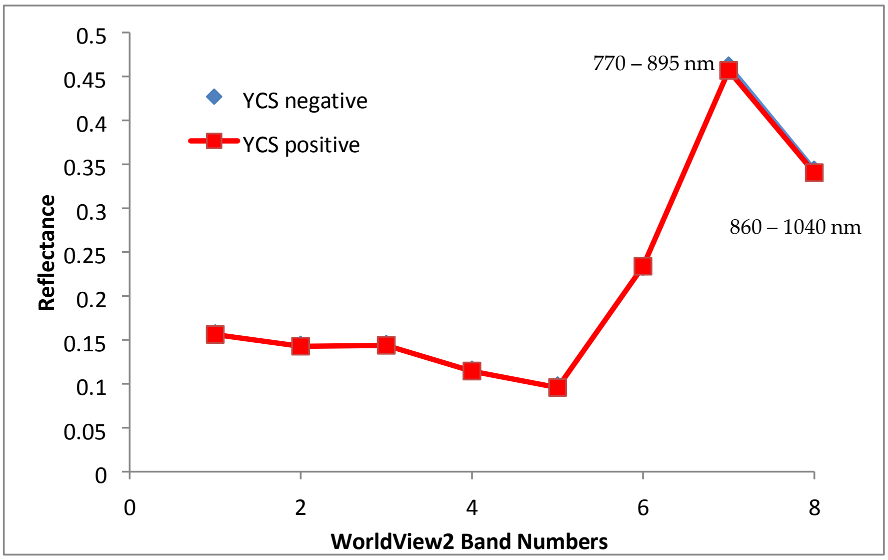


Figure 14. Average reflectance from YCS -ve blocks (n= 894) and YCS +ve (n= 42) extracted from Worldview2 image captured 29 January 2014.

In an attempt to differentiate the YCS positive and negative crops, an analysis of variance (ANOVA) was undertaken on the reflectance data from all Worldview 2 bands as well as a number of derived vegetation indices. The results were similar for majority of the analyses and generally indicated that the large disparity in sample size was limiting the ability to spectrally discriminate between the YCS symptomatic and non- symptomatic samples. As displayed in the results of the Red-edge band, the wide range of reflectance values including many outliers produced by YCS non-symptomatic crops, greatly influenced the distribution of sample points (Figure 15 and 16).

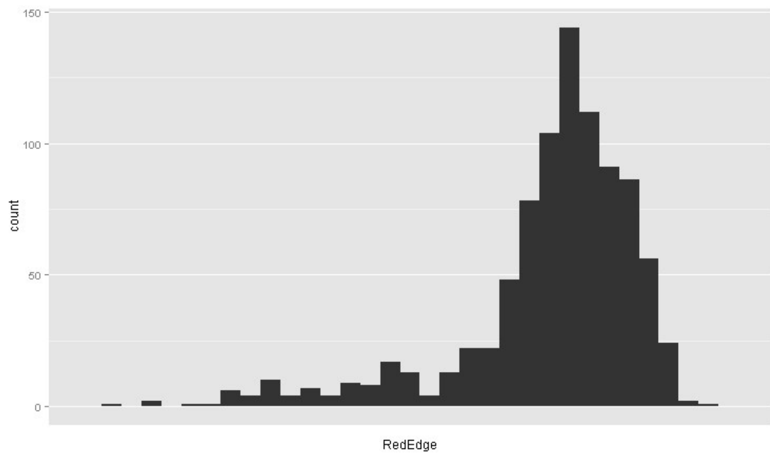


Figure 15. Distribution of average crop Red-edge reflectance values.

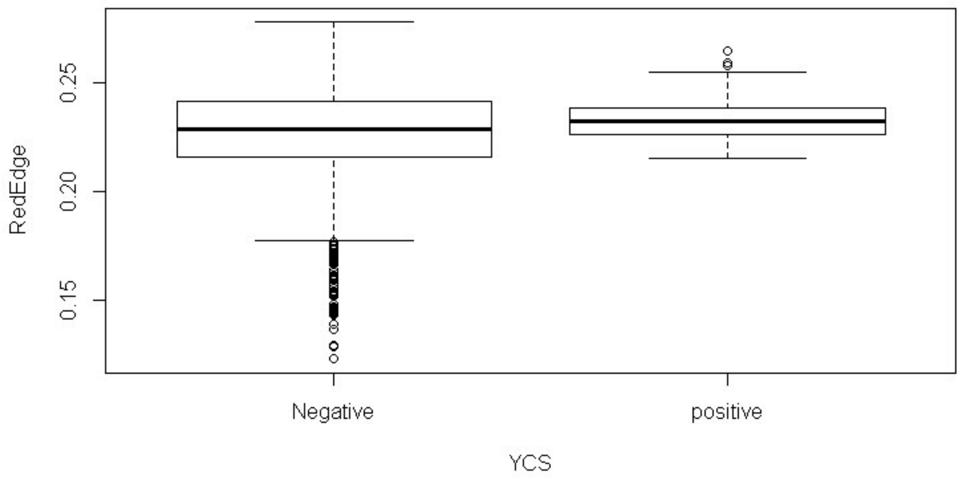


Figure 16. Box plot identifying the red- edge spectral reflectance of YCS symptomatic (+ve) and non-symptomatic (-ve) crops.

The ANOVA of the Red-edge data resulted in an F value of 5.185 and a p- value of 0.023* which rejected the null hypothesis that there was no difference between YCS symptomatic and non- symptomatic crops. Although encouraging additional statistical analysis is required to understand and then possibly account for the factors influencing the large data spread.

A principal component analysis (PCA) and partial least squares discriminant analysis (PLS-DA) was also undertaken on the 8 band Worldview2 data in an attempt to further differentiate the symptomatic crops from the non- symptomatic. A number of positive outliers were removed, resulting in around 98% of the spectral variation being explained by the first two factors, NIR (90%) and Mid NIR (8%) (Figure 17). The lack of clustering of YCS negative and positive samples does raise concerns. This is supported by the PLS-DA result (Figure 18) which also fails to segregate the two treatments and produces a poor correlation R= 0.04: RMSEC 0.2.

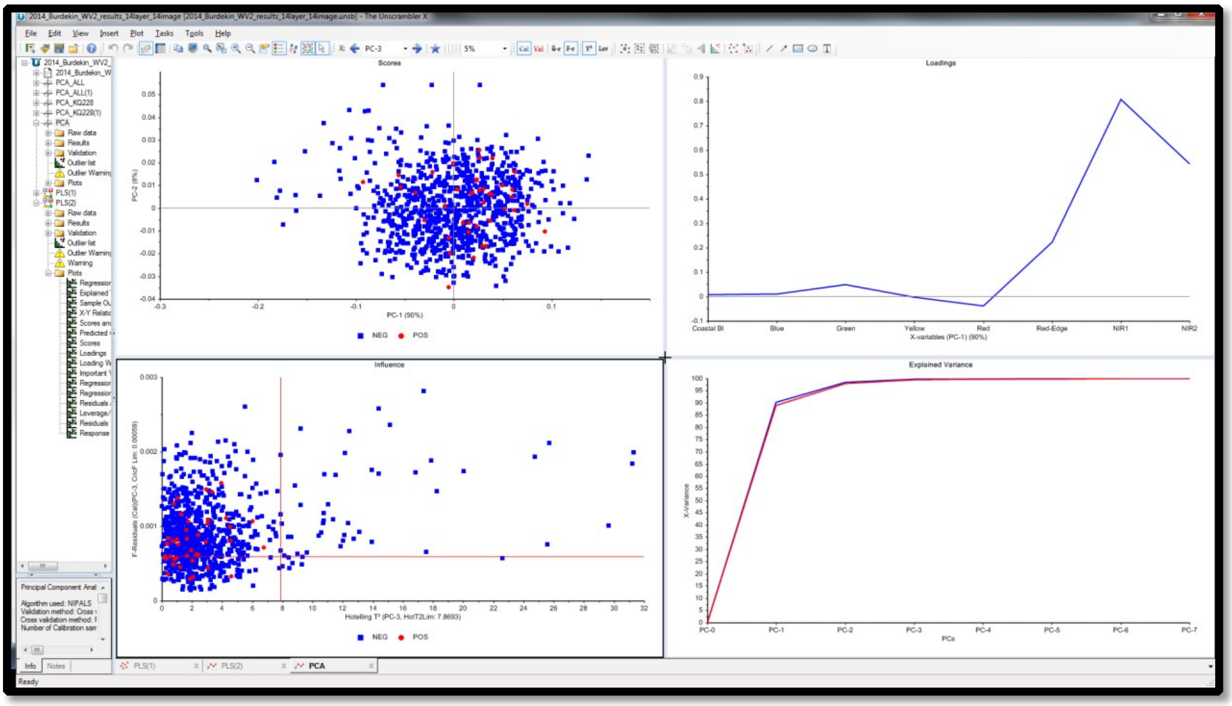


Figure 17. Principal Component Analysis (PCA) of YCS positive (red) (n= 35) and negative (blue) (n= 850) cane blocks with the average cane block reflectance data measured by the 8 band Worldview 2 satellite.

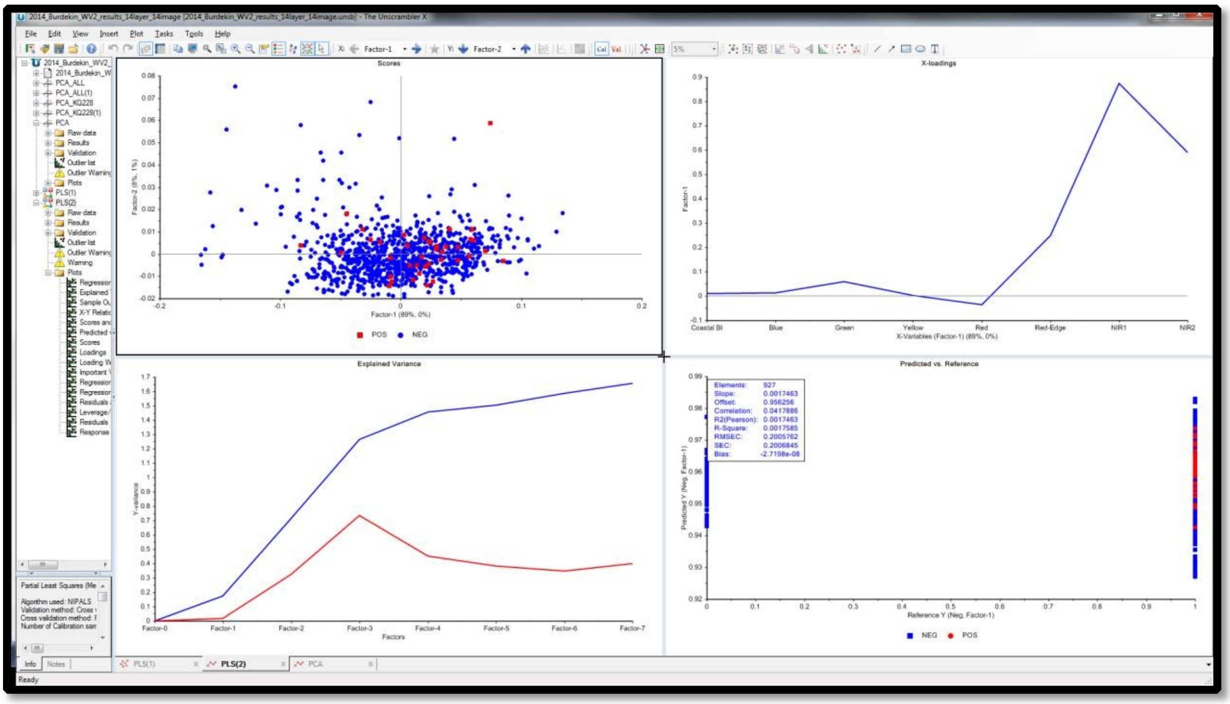


Figure 18. PLS-DA of YCS positive (red) (n= 35) and negative (blue) (n= 850) cane blocks with the average cane block reflectance data measured by the 8 band Worldview 2 satellite.

4.4. Hyperspectral analysis of YCS

The hyperspectral measurement of 3rd leaf samples from both YCS symptomatic and non-symptomatic crops provided some evidence that YCS could be spectrally identified.

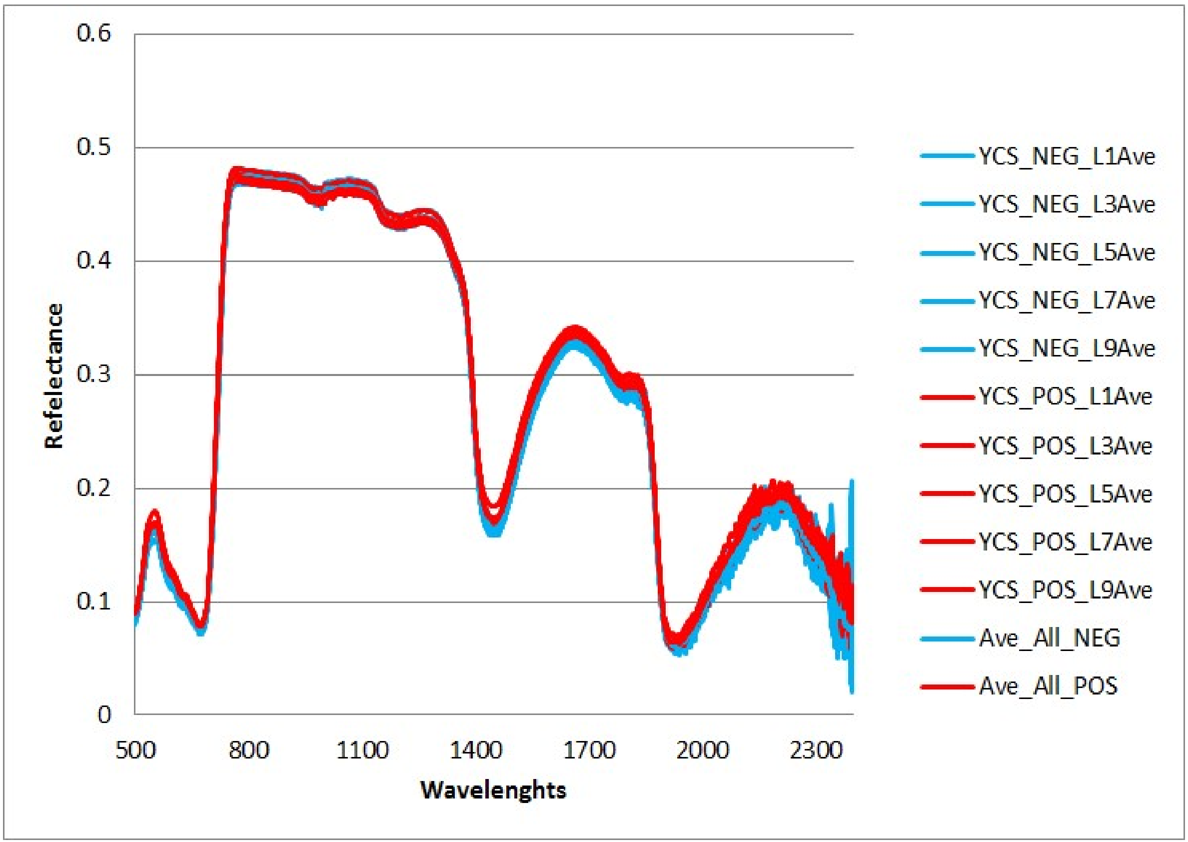
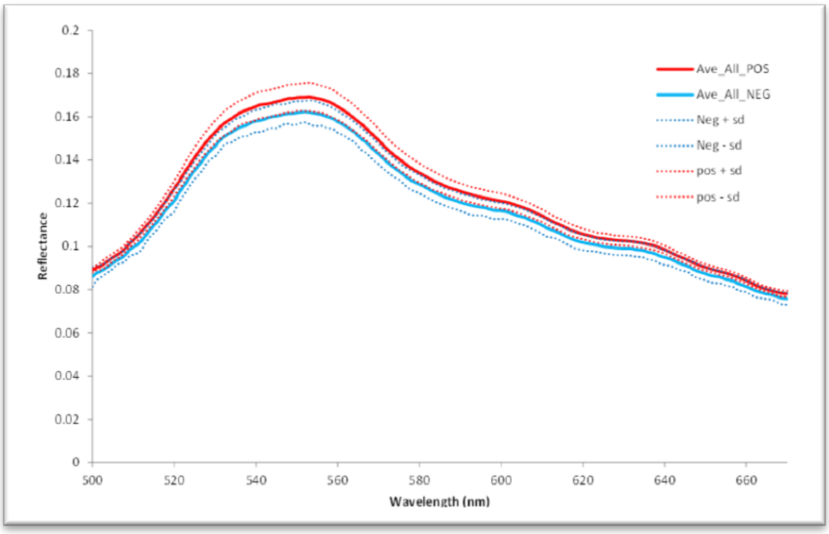
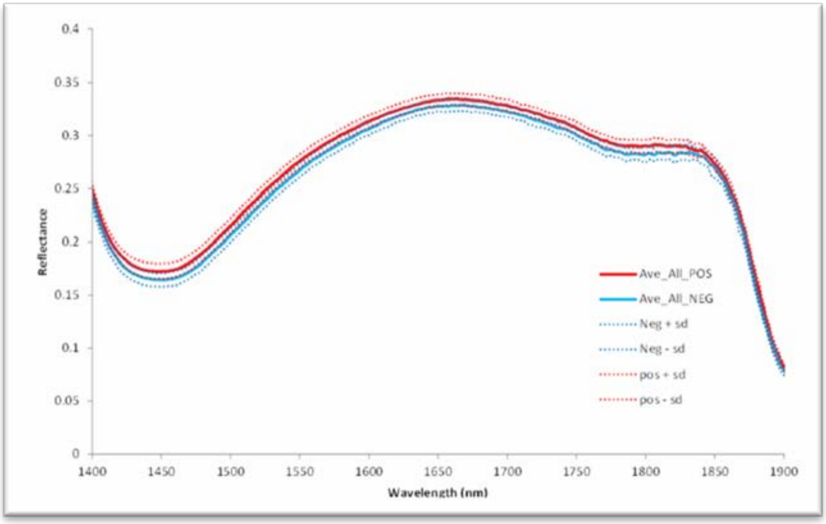


Figure 19. Reflectance data (350 – 2500 nm) measured from third leaf samples of YCS positive (red) (n= 74) and negative (blue) (n= 54) plants.





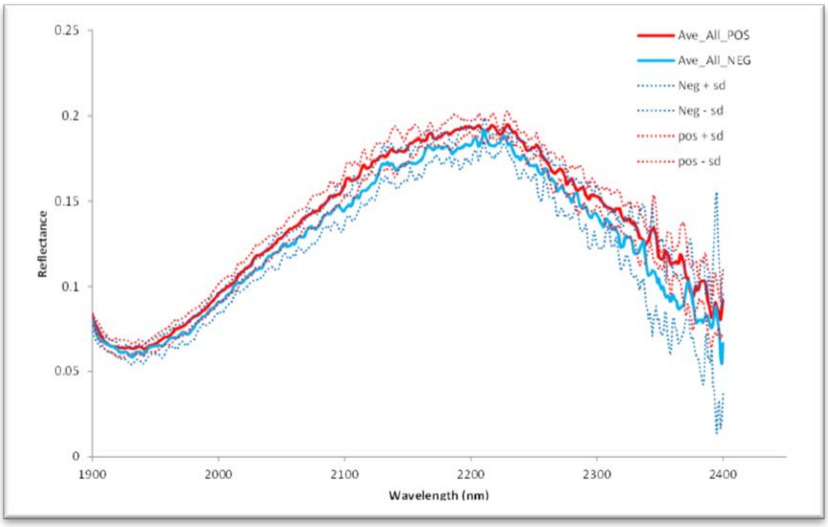


Figure 20. Reflectance data 520- 640 nm (a); 1400 – 1850 nm (b) and 1950 - 2400 nm (c) from third leaf samples of YCS positive (red) (n= 74) and negative (blue) (n= 54) plants.

The main spectral regions that displayed some segregation were 520- 640 nm (visible green - red); 1400 – 1850 nm and 1950 - 2400 nm (Mid NIR) (Figure 20). Variation in the Mid Near infrared spectral region (1300-2500 nm) indicates changes in the plant's chemical constituents i.e. carbon, hydrogen, nitrogen, oxygen, starch, cellulose, water, lignin etc. (Nilsson, 1995 and Curran et al. 2000). Apan et al 2004, identified similar wavelengths in the spectral differentiation of Orange Rust as well as a higher reflectance in the Mid NIR from rust affected samples.

Interestingly the NIR region (700-1300 nm) displayed little separation, which may support the similar lack of segregation identified from the satellite imagery.

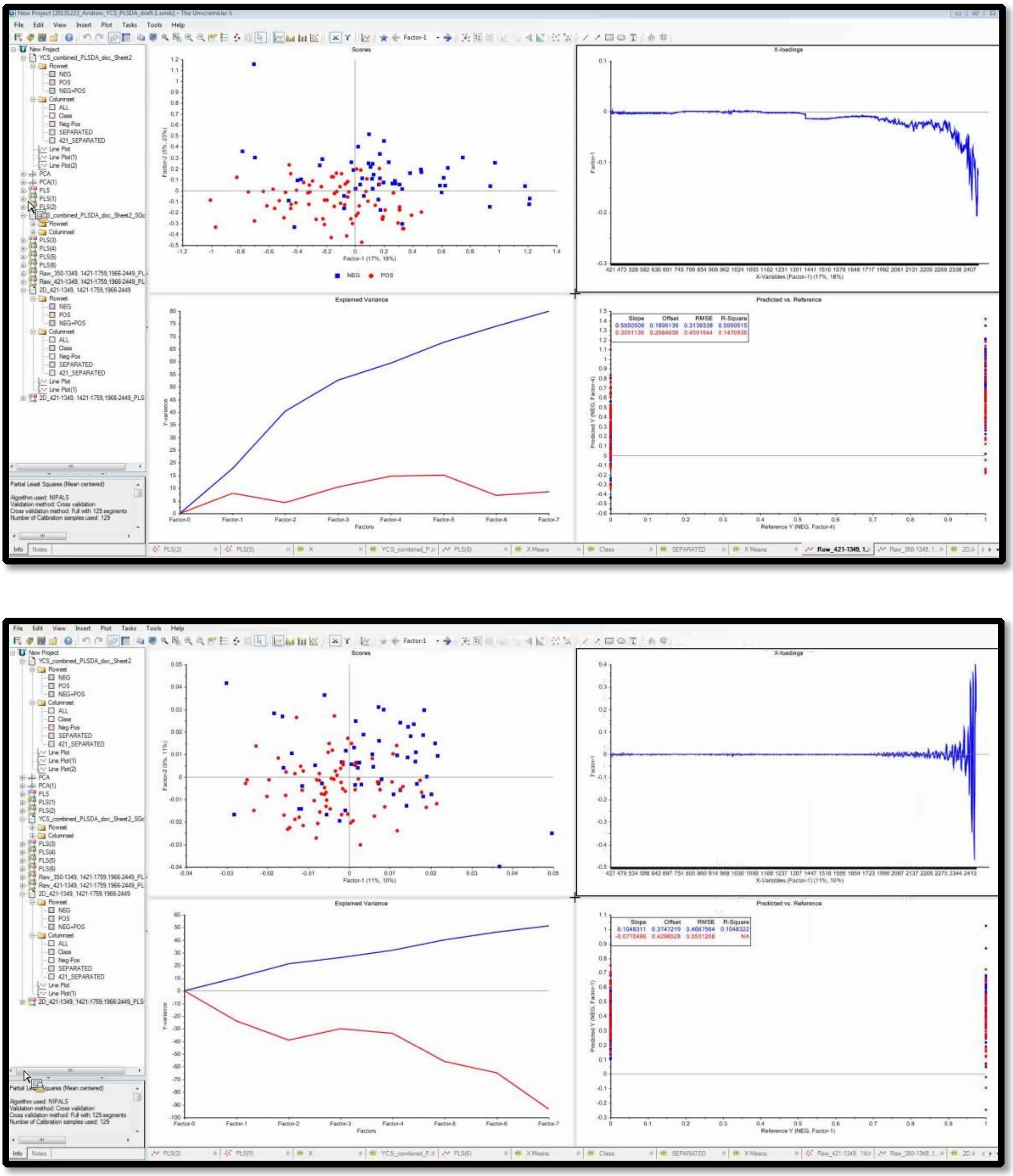


Figure 21. Partial least Squares discriminant analysis (PLS-DA) of raw data (top) and second derivative (PLS-DA) (lower) of hyperspectral data of 3rd leaf samples from symptomatic (red markers) and non- symptomatic (blue markers) YCS stalks. A number of spurious negative samples have been removed.

Partial Least Squares Discriminant Function Analysis (PLS-DA) of both raw and second derivative data from YCS positive (blue) and negative (red) third leaf samples did exhibit some separation of YCS (Figure 21). The PLS-DA of the raw spectra in particular identified a greater explanation of variance in the spectral region above 1400 nm, whilst the second derivative identified greater variability above 1900 nm. The prediction accuracy of YCS positive samples for both the raw data (root mean square error (RMSE = 0.459) and the second derivative data (RMSE = 0.553) were poor.

By having only one comparative data set severely limits the scientific rigour of this analysis. The fact that Figure 20 demonstrates some separation is highly encouraging. It is suggested that this research be repeated with the inclusion of more sample locations with additional varieties and crop classes. Another potential issue is the classification of YCS symptomatic plants is purely qualitative. It is very possible that samples classified as Negative, were affected by YCS but were yet to display symptoms. Similarly the symptomatic plants may have been affected by other constraints that expressed similar yellowing symptoms to YCS. Finally the use of only the 3rd leaf may limit the capacity for this technology to identify constituents affected by the disease. It has been stated the YCS predominantly affects the lower leaves and the malleability of the stalk. It is advised that if this research was to be repeated that spectral measurements be taking above the canopy, within the field, so that the spectral information was not limited to only one leaf. It is hoped that the airborne hyperspectral imagery will address some of these issues but as yet has not been made available form Airborne research Australia.

4.5. Comparing annual relationship between average block yield, GNDVI and weather data for a number of Australian cane growing regions.

A comparison of trend lines produced from the correlation between average crop GNDVI and yield, grown across three growing regions: Burdekin (Figure 26), Herbert (Figure 24) and Bundaberg (Figure 22), between 2010- 2013 identified a potential anomaly in the 2013 harvest season. The exponential trend lines produced from the 2013 harvest season were lower for the Herbert and the Burdekin than that observed in previous years. It appears that for 2013, crop vigour (GNDVI) was similar to previous years but the conversion to yield was poor. A similar result was not identified in the Bundaberg growing region. A visual assessment of the monthly weather data for the corresponding years for the Burdekin (Figure 27) and the Herbert (Figure 25) identified reduced rainfall between the December to February as well as higher average temperatures and radiation as possible drivers. The Bundaberg region (Figure 23) also experienced the higher temperatures but unlike the Burdekin and Herbert, received extremely high rainfall in December 2012, an event that may have protected the crops from possible heat stress.

Bundaberg

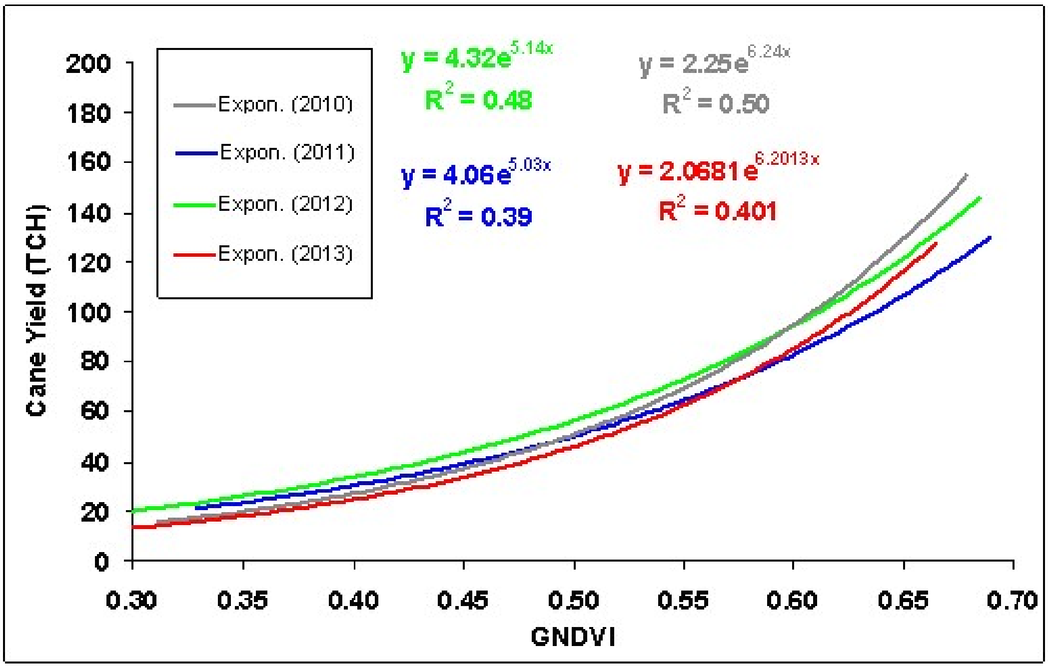


Figure 22. Exponential trend lines derived from average crop GNDVI and average crop yields for the Bundaberg (2010- 2013).

Season	GNDVI	Actual Yld (TCH)	Image capture
2009/10	0.567	81.8	10-May-10
2010/11	0.567	73.3	27-Mar-11
2011/12	0.584	88.9	1-Apr-12
2012/13	0.560	71.8	25-Apr-13

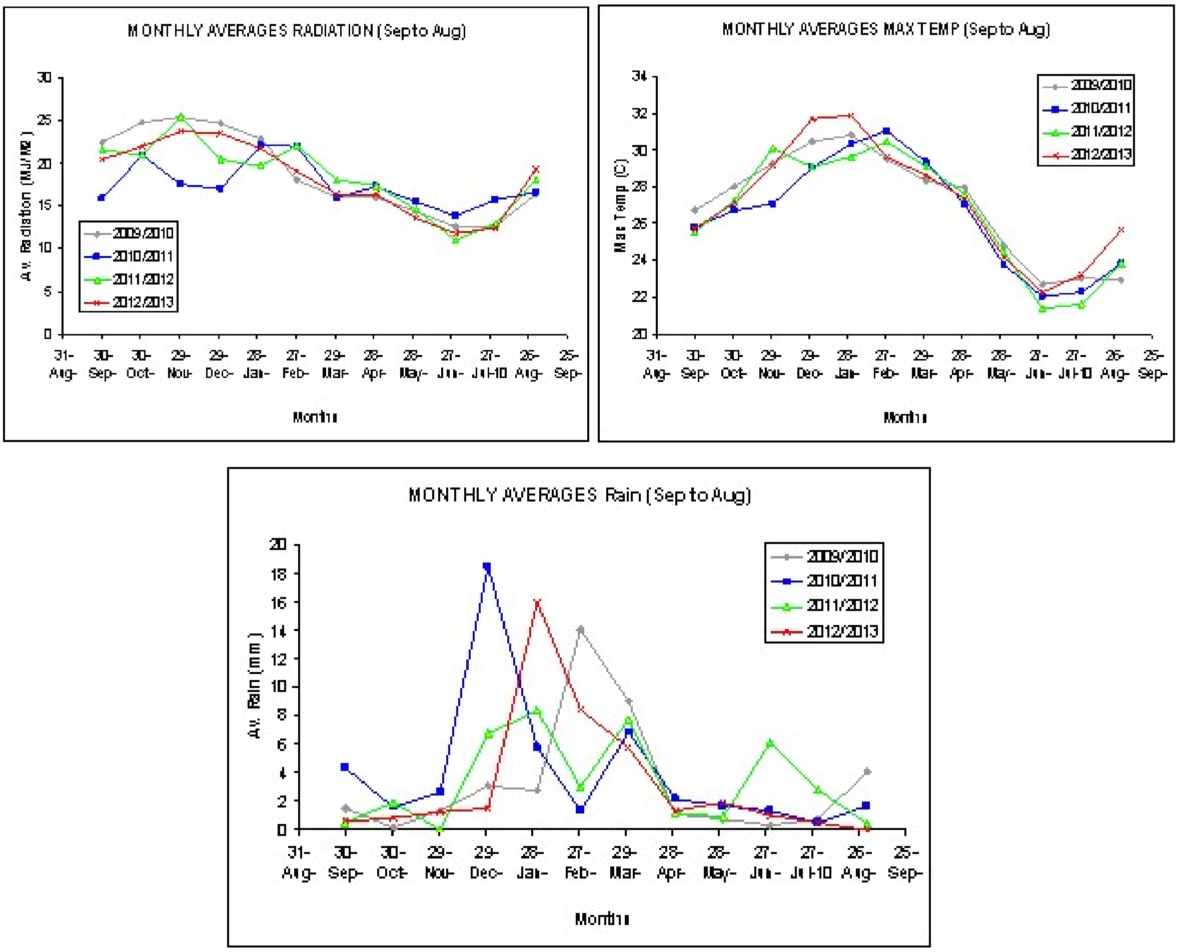


Figure 23. Comparison of monthly radiation, Max temperature and Rainfall for the Bundaberg region between August and September 2009/10, 2010/11, 2011/12 and 2012/13.

Herbert

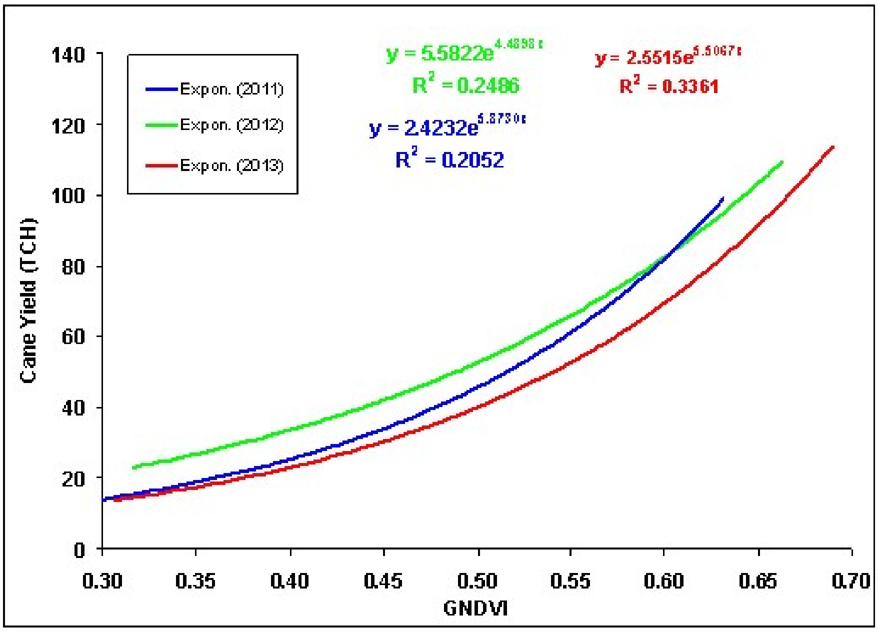
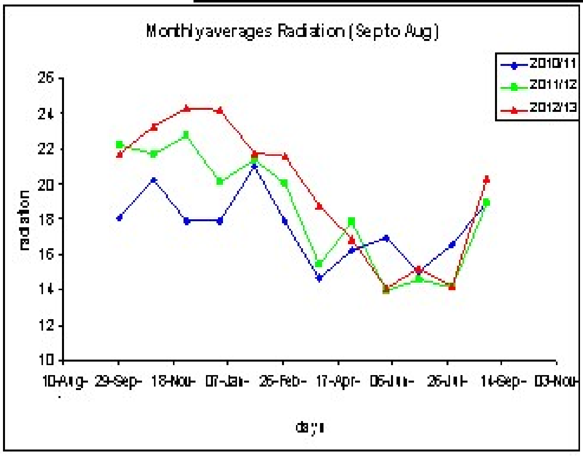
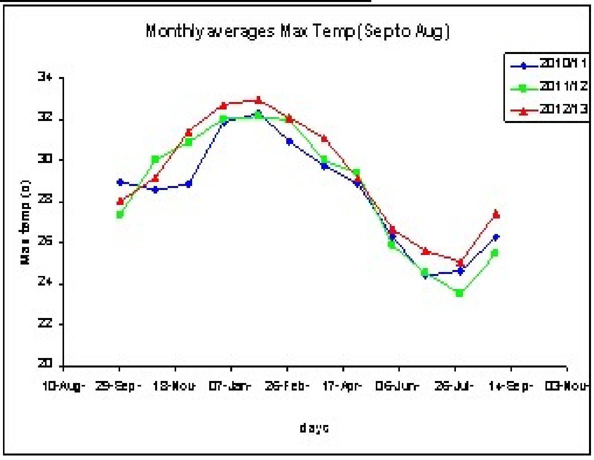


Figure 24. Exponential trend lines derived from average crop GNDVI and average crop yields for the Herbert (2011- 2013).

	Av GNDVI	Av Act Yield(TCH)	image capture
2011	0.489839101	55.6	5-May-11
2012	0.559306008	72.0	4-Apr-12
2013	0.601065164	74.4	25-May-13





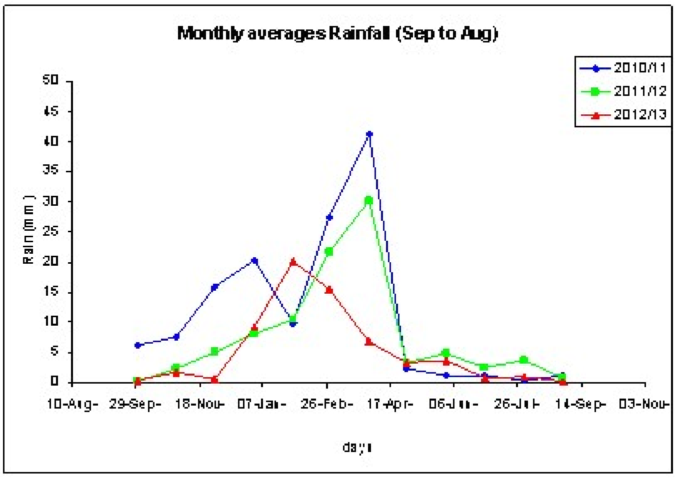


Figure 25. Comparison of monthly radiation, Max temperature and Rainfall for the Herbert region between August and September 2010/11. 2011/12 and 2012/13.

Burdekin

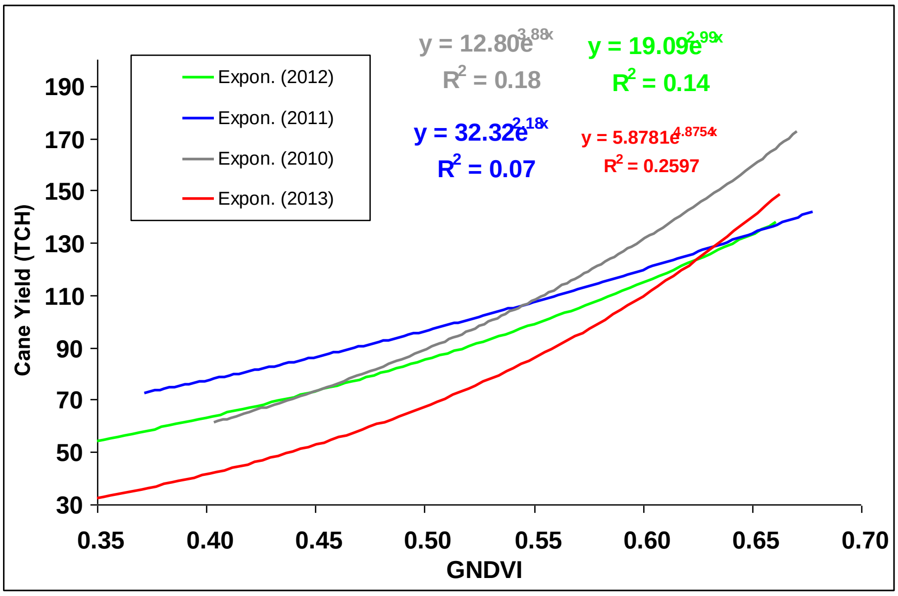


Figure 26. Exponential trend lines derived from average crop GNDVI and average crop yields for the Burdekin (2010- 2013).

	av GNDVI	Act. Av TCH	image capture time
2010	0.591864364	129.6	14-May-10
2011	0.574438435	120	22-Apr-11
2012	0.560017453	106	16-May-12
2013	0.580168759	105	5-May-13

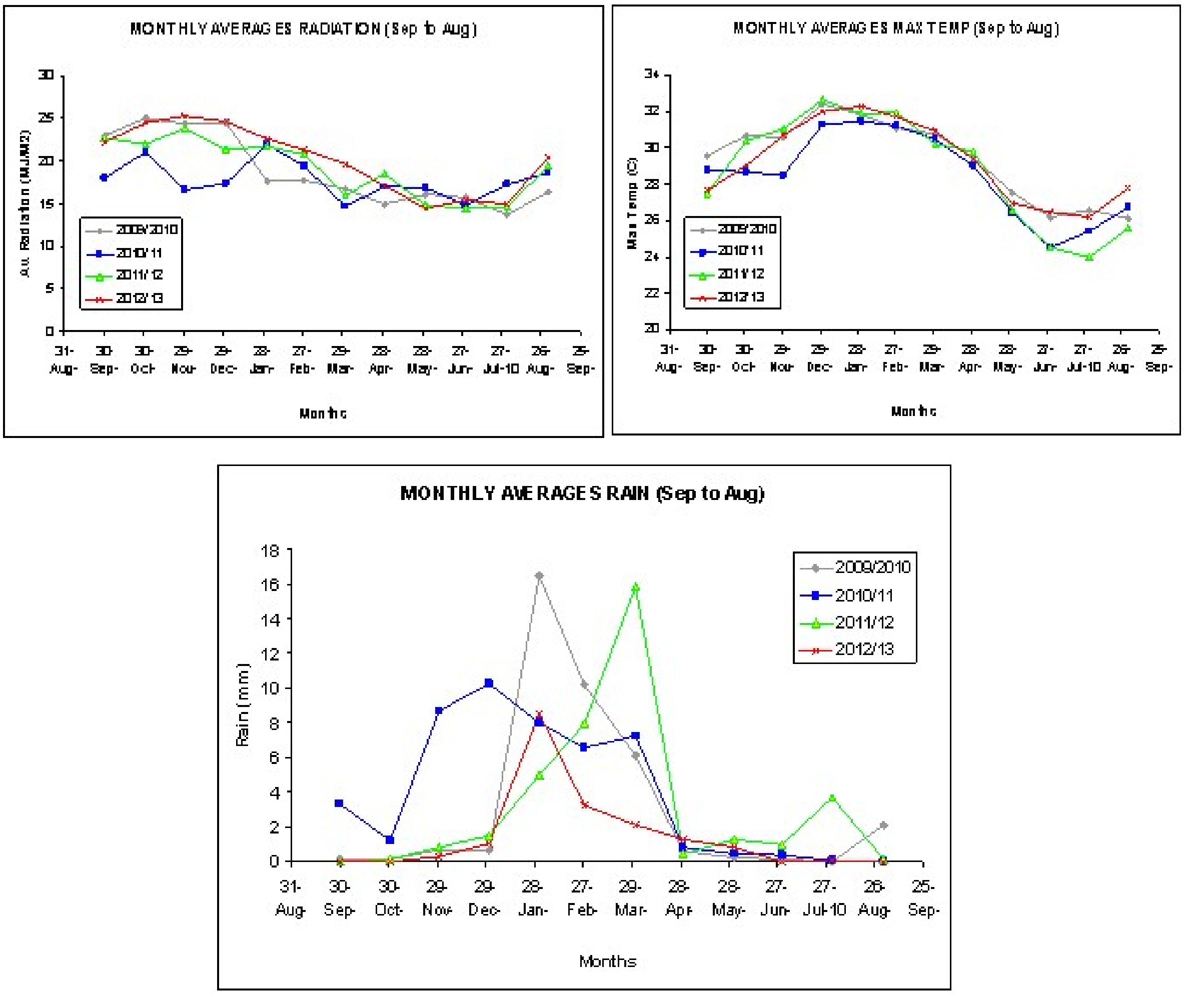


Figure 27. Comparison of monthly radiation, Max temperature and Rainfall for the Burdekin region between August and September 2009/10, 2010/11. 2011/12 and 2012/13.

This result raises the issue whether Yellow Canopy Syndrome (YCS) is a physiological symptom of the 2013 atypical season (when compared to 2010, 2011 and 2012) or is it contributing to the reduced conversion of biomass (assumed from GNDVI) to yield.

5. Conclusion.

A large amount of hyperspectral and multispectral data as well as mill layers and ground based information has been collected for this study and it is suggested a thorough statistical analysis be undertaken. An intensive statistical methodology known as 'relative frequency analysis' or 'support vector machines' could be used to determine if the incidence of YCS is associated with crop variety or class, or through the allocation of GPS centroids to each positive YCS crop along with the inclusion of an elevation layer provide a spatial dimension. Unfortunately the airborne hyperspectral data captured in December 2013 had not been received prior to the submission of this report so additional time would be required to analyse this data. Similarly, by having only one comparative hyperspectral data set severely limits the scientific rigour of this analysis. The fact that figure demonstrates some separation is highly encouraging. It is suggested that if this research was to be repeated more sample locations would be required, including multiple varieties and crop classes.

6. Acknowledgements:

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7. References:

Apan, A., Held, A., and Phinn, S., and Markley, J. (2004) Detecting sugar cane " Orange rust" disease using EO-1 Hyperion hyperspectral Imagery. *International Journal of Remote Sensing,* **25**(2):489-498.

Chavez, P., Zorgastua, P., Chuquillanqui, C., Salazar, L. F., Mares, V., and Quiroz, R. (2009). Assessing Potato Yellow Virus (PYVV) infection using remotely sensed data. International journal of Pest Management, 55:3, 251-256.

Curran, P.J., Dungan, J.L., and Peterson, D.L. (2001). Estimating foliar biochemical concentration of leaves with reflectance spectrometry testing the Kokaly and Clark methodologies. Remote Sensing of Environment, **76**:349-359.

Dudka, M. Langton, S. Shuler, R. Kurle, J. and Grau, G.R. (1998) Use of Digital imagery to evaluate disease incidence and yield loss caused by Sclerotinia stem rot of Soybeans. International conference on precision agriculture St Paul, MN.

Everitt, J.H., Escobar, D.E., Alaniz, M.A., and Davis, M.R. (1997). Remote sensing to detect Tomato Spotted Wilt Virus and other problems in peanuts. In *Proc. 16th Biennial Workshop Videography and Colour Photography in Resource Assesment. American Society of Photogrammetry and remote Sensing*, Bethesdy, Maryland. 460-465.

Grisham, M.P., Johnson, R. M., and Zimba, P.V. (2010). Detecting Sugarcane yellow leaf virus infection in asymptomatic leaves with hyperspectral remote sensing and associated leaf pigment changes. Journal of Virological Methods, 167. 140-145.

Nilsson, H.E. (1995). Remote sensing and image analysis in plant pathology. Canadian Journal of Plant Pathology, **17**:154-166.

Penuelas, J and Inoue, Y. (1999). Reflectance indices indicative of changes in water and pigment contents of peanut and wheat leaves. Photosynthetica, **36**(3):355-360.

Rao, T.V.R., Filho, J.F., and Silva, L.C. (1998). Development of vegetation indices to estimate the biomass and leaf area of an irrigated peanut crop. *Presented at the 1998 ASAE Annual International Meeting*, Orlando, Florida July 12- 16th. Paper no 982190.

Andrew Robson, Chris Abbott, David Lamb and Rob Bramley (2012). Developing sugar cane yield algorithms from satellite imagery. Proceedings of the Australian Society of Sugar Cane Technologists. 34th Conference, Cairns, Qld. 1- 4 May 2012.

A.J. Robson, Remote sensing applications for the determination of yield, maturity and aflatoxin contamination in Peanut. Ph.D. Thesis, the University of Queensland (2007).