QUANTIFYING HAIL DAMAGE FOR CROP LOSS ASSESSMENT: TECHNIQUES USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS

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Abstract

Hail damage results in losses of approximately 3% of total broad-acre crop production every year across the Darling Downs region of Queensland. Current practices of hail damage assessment are both time and labour intensive. The use of remote sensing and geographic information systems can provide alternative techniques for the assessment of crop hail damage. Remote sensing is currently providing valuable data for precision agriculture and land-use / land-cover mapping but rarely has it been used for insurance and loss calculation. Results have indicated the usefulness of Landsat 7 ETM+ imagery in the calculation of area and quantum of damage for loss adjusting purposes.

Depending upon the analysis techniques used, an average accuracy of 5% to 30% difference was established from that observed in the field. It was identified that the Normalised Difference Vegetation Index (NDVI) had the strongest correlation to defoliation followed closely by the Tasselled Cap Transformation (Greenness), while the Modified Soil Adjusted Vegetation Index (MSAVI2) showed unexpected low accuracies. Higher accuracies were obtained from the introduction of a reduced boundary to reduce the impact of mixed pixels, with the 2-pixel boundary, resulting in the highest accuracies.

1. Introduction

Hail damage results in losses of approximately 3% of total broad-acre crop production every year across the Darling Downs region of Queensland. Current practices of hail damage assessment are both time and labour intensive. The use of remote sensing and geographic information systems can provide alternative techniques for the assessment of crop hail damage. This project focuses specifically on hail damage claims on broad-acre grain sorghum on the central Darling Downs, Queensland. In coordination with Freemans Toowoomba and the University of Southern Queensland, the general objective of this project is to assess the capability and utility of satellite imagery for crop loss adjustment and to develop techniques that aim to analyse the extent and degree of loss from hail. The use of remote sensing in agriculture is not a new concept. In fact, it has been used for many decades and is providing valuable information for precision agriculture and land-use mapping. However, the use of this technology is rarely being used in the insurance industry for agricultural loss calculation.

Specifically, the study aims to:
(a) determine the best spectral band combinations for discriminating and mapping crop damage from hail;
(b) assess if the parameters *area damaged* and *quantum* damaged to the crop could be quantified using satellite imagery; and
(c) validate the techniques developed in this study to other claims data.

2. Literature Review

2.1 Understanding Crop Canopies

In order to analyse the relationship of spectral variability and vegetation patterns, it is important to understand the characteristics and properties of individual leaves and plants. This is best understood by examining leaf structure in relatively fine detail (Campbell, 1996).

Chlorophyll molecules do not absorb sunlight equally due to the photosynthesis process strongly absorbing blue and red light. It has been identified that factors, such as nutrient levels, the presence of disease and pests and environmental conditions can have an impact on chlorophyll type and quantity and hence the reflectance patterns because leaves lacking chlorophyll are highly reflective in the visible spectrum (Erickson, 2000). In contrast to the visible region, near infrared is not influenced by the leaf pigmentation but the mesophyll tissue structure within the leaf (Lillesand and Kiefer, 1994). Consequently, changes in reflectance can be reveal changes in vegetation vigour, disturbance and presence of hail damage.

Knowledge of spectral behaviour of individual leaves is important in explaining spectral characteristics of leaves, however it does not fully explain reflectance from areas of complete vegetation cover (Campbell, 1996). This can be attributed to a magnitude of issues including variances in leaf size, orientation, shape and coverage of the ground surface. Canopies generally consist of multiple layers of leaves from which canopy reflectance is a combination of leaf reflectance and shadow. Knipling (1970) has identified as much as 7% in the visible region and 15% in the infrared region decrease in reflectance between individual leaves and canopy.

2.2 Vegetation Indices and Transformations

The influence of leaf structure and vegetative canopy is well researched across the electromagnetic spectrum. Similarly, the use of vegetation indices for the measure of vegetative vigour and biomass are well accepted in the remote sensing community. The NDVI (Normalised Difference Vegetation Index) is the most common vegetation index used in remote sensing. It utilises the correlation between red and infrared radiation by manipulating the digital number values of different bands (ERDAS, 1999). The NDVI is defined as:

$$\text{NDVI} \quad = \quad \frac{IR - R}{IR + R} \quad \text{Where IR = near infrared reflectance}$$
R = red reflectance

The NDVI exploits the fact that green vegetation has a non-linear inverse relationship in the red region and a non-linear direct relationship in the near-infrared region between the amount of green biomass (Tucker, 1979). The MSAVI2 (Second Modified Soil Adjusted Vegetation Index) is self-adjusting and attempts to account for differences in soil background. The MSAVI2 is described as:

$$\text{MSAVI2} = \frac{1}{2}\left(2(NIR+1)-\sqrt{(2\times NIR+1)^2-8(NIR-R)}\right)$$

Where: NIR = near infrared reflectance
R = red reflectance

The Tasselled Cap Transformation is a linear transformation using all six Landsat bands (excluding TM6 thermal infrared) to identify three main features:

- *Brightness* – a weighted sum of all the bands and is greatly influenced by the direction of the principle variation in soil reflectance;
- *Greenness* – strongly related to the amount of green vegetation and biomass and leaf area index present in the scene. It is a contrast between the near infrared and visible bands; and
- *Wetness* – which is strongly related to soil and canopy moisture.

2.3 Crop Loss Assessment

Hail damage results in about 3% of crop production every year on the Darling Downs. Traditional crop loss assessment is well documented and follows a highly researched scientific procedure. Generally, the stage of growth and the degree of damage to the plant determine yield loss predictions. Defoliation affects the plants ability to effectively photosynthesis because of the loss in leaf area causing the plant to become stressed. Research has identified that the amount of defoliation is positively related to the ability for a plant to recover (Shipiro and Peterson, 1986). These stresses cause physiological changes that alter the optical and thermal properties of plants and leaves, which cause changes in canopy geometry and reflectance (see Figure 1). It has been identified that the percentage defoliation is more accurate when estimated 7-10 days after the storm (Erickson, 2000). Therefore, it was assumed that the image capture window would be 10-14 days after the hail event, significant time to allow the plant to be succumbed to stress and lasting 14-28 days. After this time, the plants have started to physically recover.

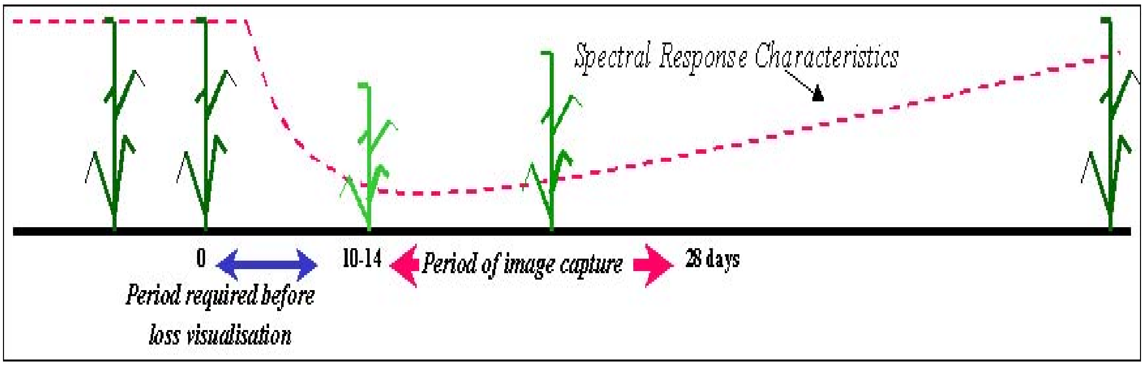


Figure 1: Spectral behaviour of sorghum before during and after a hail damage

Limitations have been identified to exist with the current system of loss assessment. The main disadvantages are outlined below:

- It is difficult to provide accurate and reliable analysis (uses 'science of estimation');
- Variations between assessors can exist;
- It is often difficult to view the entire area due to size or access constraints;
- It can be difficult to gain access to the property due to uncontrollable factors;
- It is difficult to ensure the availability of concerned parties;
- Long distances to claim areas consume both time and money;
- High costs of travel;
- Assembly and deployment of logistics could be difficult; and
- Overpayment and underpayment of claims.

There is a need for a more reliable, effective, up-to-date technique for use within the loss adjusting industry for assessing hail damage. Remote sensing and GIS are techniques potentially useful in processing crop damage for loss adjustment. The following benefits are expected through the use of remote sensing and GIS:

- potentially scientifically more accurately;
- minimal variations between assessments;
- potentially improves efficiency;
- potential cost savings;
- potential for expansion into other crops and insurable phenomena; and
- ability to assess entire fields.

3. Research Design

3.1 Study Area

The study area was chosen due to the magnitude of claims and large amounts of destruction within a small spatial area thus allowing the capture of many claims within a single image. Freemans Toowoomba acknowledged the potential of using this particular hail storm to further their investigations into the usefulness of remote sensing and GIS in the analysis of hail damage. The area is located in southeast Queensland, Australia.

It has been identified that many variables impact upon the spectral behaviour of objects. Therefore, in the development of analytical techniques for determining defoliation due to hail, it is important to minimise a number of variable factors involved. In establishing the plot, the following selection criteria was considered:

- consistent soil type;
- minimal topological variations;
- same variety of sorghum;
- same maturity of sorghum;
- same cropping practices;
- same cropping history of field; and
- a continuum of damage across a field.

3.2 Data Acquisition and Image Processing

The use of SPOT and Landsat are very common throughout the world. However, due to the unavailability of SPOT imagery during the acquisition window (See Figure 1**),** Landsat 7 ETM+ was acquired for the 17 January 2000. The Digital Cadastral Database (DCDB) was used as a tool for locating and delimitating property boundaries, as it is often difficult to determine which fields belong to which properties. While the image processing goal was to evaluate the use of this imagery in calculating quantity and severity of defoliation in sorghum using the Landsat 7 ETM+ imagery. The GIS provided the environment, where the imagery could be displayed, processed and analysed using ERDAS® Imagine 8.4.

Heads-up digitising was used to identify and extract three factors. Firstly, the individual fields which have sustained damage, a representative area of undamaged sorghum equivalent to that of the damaged field before the hail event and finally a representative area of totally (100%) damaged sorghum. In addition, three techniques were than applied:

- a Normalised Difference Vegetation Index (NDVI);
- a Tasselled Cap Transformation (Greenness); and
- a Modified Soil Adjusted Vegetation Index (MSAVI2).

Mixed pixels in agriculture scenes are very common because of current farming practices being adopted. A mixed pixel is a pixel that contains radiation reflection by more than one type of object. In 1997, studies by Erickson (2000) experienced mixed pixel problems while trying to assess damage in maize, however the impact of such problems was not documented. Identifying the best boundary best indicates defoliation and pure pixels. This study adopted 3 boundaries for assessment:

- Perimeter – using the real field boundary;
- 1-Pixel – field boundary is buffered in by 1 pixel; and
- 2-pixel – field boundary is buffered in by 2 pixels.

Finally, a rescale operation, which stretched the minimum and maximum values to a set specified range. The specified range adopted was from 1 to 100. This new data range is a measure of vegetation foliation where 1 equals 100% damage vegetation and 100 is 0% damaged vegetation. This can be easily converted to defoliation by the following equation:

$$\text{Defoliation} = 100 - \text{Rescale Value.}$$

4. Results

4.1 Defoliation Calculation

Previous studies have recognised the usefulness of remote sensing in monitoring vegetation biomass. As expected, visual image interpretation of hail damage using Landsat 7 ETM+ imagery (3,4,5 – blue, green and red, respectively) allowed for the best discrimination between defoliation levels. The spectral response curves of healthy vegetation illustrated the expected vegetation patterns of low reflectance in the near infrared regions. Within the visible spectrum, increases in defoliation resulted in higher spectral responses, while in the near infrared bands, lower radiation was observed. From analysis of these spectral curves, it is evident that incremental relationships exist between the radiance levels and damage to the plant.

Table 1 shows the defoliation levels calculated by these three techniques, while Table 2 identifies the differences observed between the defoliation levels calculated and the assessed defoliation. Figure 2 is an example of the colour thematic maps produced from the rescaled techniques. Notice the differences in defoliation classification between the three boundaries where blue indicates minimal damage and green – light to moderate and red as severely damaged.

Table 1- Calculated Defoliation Levels for the NDVI, Tasselled Cap Greenness and MSAVI Techniques

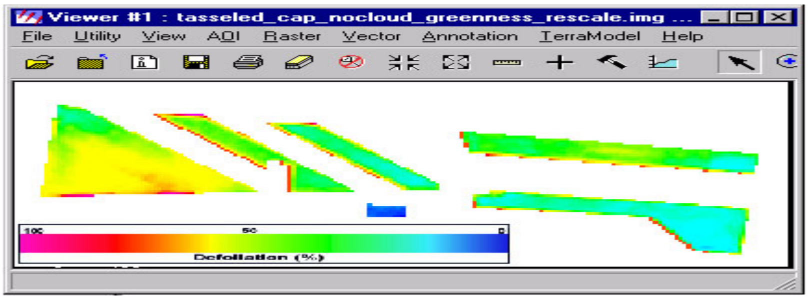
SUMMARY OF RESULTS										
Paddock	***Percentage defoliation***	***Perimeter***	***1 pixel***	***2 pixel***	***Perimeter***	***1 pixel***	***2 pixel***	***Perimeter***	***1 pixel***	***2 pixel***
	Observed	**NDVI**			**TC Greenness**			**MSAVI**		
1.00	***77.00***	58.77	59.74	**70.37**	55.45	60.51	**71.47**	46.42	47.94	**62.52**
2.00	***45.00***	40.10	35.92	**36.00**	41.05	40.18	**42.78**	29.44	25.73	**27.71**
3.00	***52.00***	50.81	45.76	**50.87**	49.48	47.24	**53.36**	38.63	33.83	**41.29**
4.00	***45.00***	41.98	40.03	**44.03**	42.57	43.73	**49.48**	30.37	28.86	**34.93**
5.00	***20.00***	31.71	27.88	**27.51**	32.58	31.37	**33.49**	22.17	19.05	**20.43**

Table 2 - Differences observed between the calculated defoliation levels and the observed defoliation.

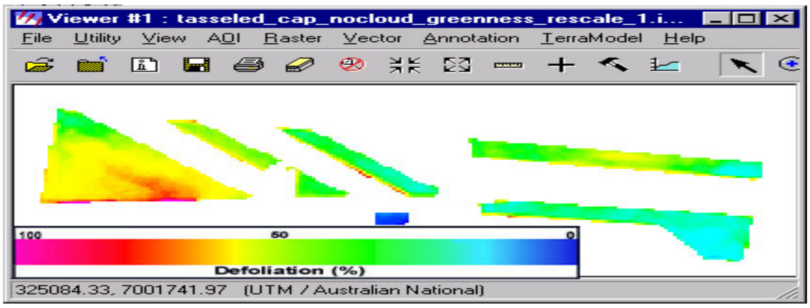
SUMMARY OF DIFFERENCE FROM OBSERVED										
Paddock	***Percentage defoliation***	***Perimeter***	***1 pixel***	***2 pixel***	***Perimeter***	***1 pixel***	***2 pixel***	***Perimeter***	***1 pixel***	***2 pixel***
	Observed	**NDVI**			**TC Greenness**			**MSAVI**		
DIFFERENCE										
1.00	77.00	-18.23	-17.26	**-6.63**	-21.55	-16.49	**-5.53**	-30.58	-29.06	**-14.48**
2.00	45.00	-4.90	-9.08	**-9.00**	-3.95	-4.82	**-2.22**	-15.56	-19.27	**-17.29**
3.00	52.00	-1.19	-6.24	**-1.13**	-2.52	-4.76	**1.36**	-13.37	-18.17	**-10.71**
4.00	45.00	-3.02	-4.97	**-0.97**	-2.43	-1.27	**4.48**	-14.63	-16.14	**-10.07**
5.00	20.00	11.71	7.88	**7.51**	12.58	11.37	**13.49**	2.17	-0.95	**0.43**
Average		7.81	9.09	**5.05**	8.61	7.74	**5.42**	15.26	16.72	**10.60**

It was observed that some correlation does exist between the calculated Normalised Difference Vegetation Index and the assessed defoliation, with average differences of 7.61 for the perimeter boundary, 9.09% for 1-pixel boundary and 5.05% for the 2-pixel boundary. Higher accuracies occurred in the fields 3 and 4 with differences of 1.13% and 0.97%, respectively, using the 2-pixel boundary. Larger differences can be identified within fields 1, 2 and 5, with an average of 10.24% difference across all boundaries. This difference inflates another 1.30% to 11.54 % when only fields 1 and 5 are taken into account. Excluding these two fields as outliers, the average differences obtained by the NDVI are within 3.04%, 6.76% and 3.70% respectively for the perimeter, 1-pixel and 2-pixel boundaries.

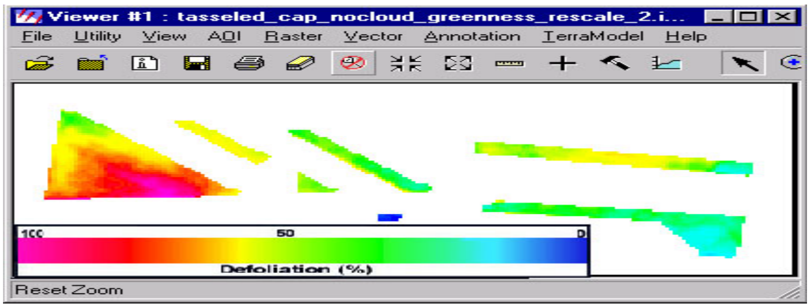
The results of the Tasselled Cap Transformation Greenness were observed to be on average between 8.61%, 7.74% and 5.42% different for the 3 boundaries respectively. Accuracies observed in Fields 2 and 3 using the 2-pixel boundary are high within 2.22% and 1.36% correspondingly. However, the smallest difference in defoliation occurred in Field 4 using the 1-pixel boundary at 1.27%. Excluding the large differences observed in Fields 1 and 5, the average differences reduced by 5.64%, 4.77% and 2.56% for the perimeter, 1-pixel and 2-pixel boundaries respectively to 2.97%, 3.62% and 2.86% differences. Figure 2 shows colour thematic maps of defoliation observed using the Tasselled Cap Transformation Greenness technique across all three boundaries.



(a) Perimeter Boundary



(b) 1-Pixel Boundary



(c) 2-Pixel Boundary

Figure 2: Colour Thematic Map of rescaled Tasselled Cap Greenness

The Modified Soil-Adjusted Vegetation Index produced varied results. On average, differences in defoliation of 15.26% for the perimeter, 16.72% for 1-pixel and 10.60% for 2-pixel boundaries have been observed. These results are quite large when compared to that of the NDVI and the Tasselled Cap Greenness. However, within field 5 using a 2-pixel boundary, the MSAVI has recorded the lowest difference of all the techniques at 0.43%. Unfortunately, many large differences exist across the remainder of the fields.

4.2 Area Calculation

As remote sensing imagery is essentially a snap shot (or photograph) of the earth's surface, it can provide an accurate portrayal of the field, which can be used for area calculation. Figure 3 represents the area calculations observed for the five fields on the property from three different sources: the claim form (obtained from Freemans Toowoomba), the farmer, and ERDAS ® area calculations (based on pixel area). It can be seen from this chart that within some fields (for example Fields 2 and 3), the areas calculated are quite close. However, large variations did exist within fields 1 and 4.

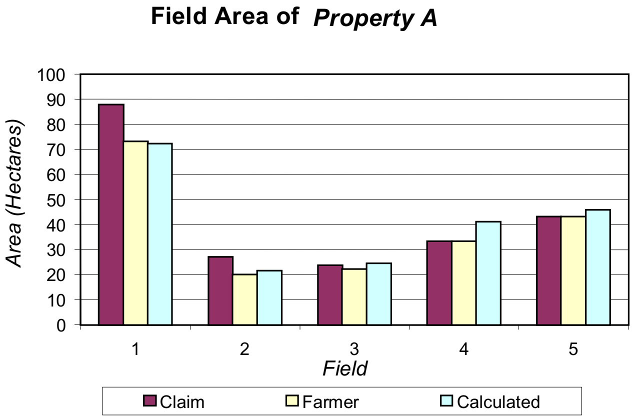


Figure 3 - Area calculations from three different sources

5. Discussion

5.1 Understanding variations between the boundaries within each technique

The impact of mixed pixels and the edge effect on field assessment is a very important consideration. Furthermore, when the different boundaries are compared it can be seen that the use of buffering boundaries has alleviated the effects of mixed pixels. Additionally, as mixed pixels are represented as a factor of the vegetation within the assessment field and the soil with the fallow field beside it, the outcome is decreased digital number values. These values are then assessed as damaged pixels, when in fact their defoliation is less, thus drawing the average defoliation down and the frequency of severe defoliation up. However, on average, the reduction in the boundary has resulted in greater defoliation rates in the field, even though the mixed pixels are shown as having a larger defoliation rate than what would be expected due to the rescaling. This effect is because those areas of mixed pixels have resulted in smaller values than those of the 100% damaged regions when the techniques were applied. This effect changes the minimum value from that of the known 100% damaged to another value when rescaling hence falsifying the defoliation levels.

5.2 Understanding variations between assessed defoliation and calculate defoliation

Accurate information is important within the loss adjusting industry. Therefore, in order to successfully integrate remote sensing and GIS techniques, the difference between the assessed and calculated defoliation must be as small as possible. Due to incomplete field data the accuracy assessment has been derived from the average defoliation found by each technique against the average defoliation observed by the assessor. Large variations exist between those observed by the assessor and those calculated by each technique investigated. It has been estimated that low vegetation cover, soil characteristics and variations, infield variability, cropping history and practices, atmospheric conditions, inaccurate assessment and mixed pixels, all impact on the accuracies of the techniques developed, although variations are not limited to these.

Infield variability is probably the most influential contributor to differences in assessment as variations are common within the fields that have not been affected by hail. These variations may be influenced by many factors which combine to determine plant health, vigour and regeneration capabilities. The impacts of infield variability on hail assessment can be overcome from the incorporation of multi-temporal analysis both prior and post of the hail event, however this increases the cost of analysis as additional imagery is required. However, this project has assumed that infield variability is minimal, as it alleviates the need for additional imagery.

The impact of atmospheric conditions on satellite imagery is greatest within the shorter wavelengths where atmospheric scattering is common. While scattering decreases within the red and near infrared regions used in the calculation of NDVI and MSAVI, the impact of atmospheric conditions on these techniques are minimal. However, the Tasselled Cap Transformation uses calculated coefficients, which are applied to each band of Landsat imagery, and consequently such conditions may impact upon the accuracy of the calculations and the reliability of analysis.

Many techniques exist for the estimation of vegetation biomass and vigour. As only three techniques have been adopted in this study, it is possible that the NDVI, MSAVI and Tasselled Cap Transformation may not accurately correlate to foliation/ defoliation levels in vegetation due to unknown factors. On the other extent it is also possible that the assessor is incorrect in their prediction of defoliation thus loss assessment is a ‘science of estimation’ which relies on human knowledge and judgement. Additionally, the assessor does not analyse the entire field, but instead visits multiple plots in the field from which an average defoliation for the field is calculated.

5.3 Understanding variations area calculations

It is common in the crop insurance industry for errors to occur. This can happen when incorrect estimates are provided by the insured and/or used by the assessor. Area can either be an over-estimation or under-estimation of the total area within the fields, thus, resulting in implications in quantum of loss calculations. Additionally, it is common, for the insured to record smaller acreages on the application form, as the smaller the area insured, the smaller the premiums required for the insurance. Similarly, it is also common for the insured to over estimate the area of damage in order to receive more compensation after a hail event.

Incomplete records have made it impossible to assess the accuracy of area calculated at specific defoliation levels within the field. The claim only identifies total area affected within the property and as the entire property has sustained hail damage, it is impossible to assess the accuracy of remote sensing in calculating the area affected by hail. However, the accuracy of remote sensing and GIS is reliant: firstly, on the spatial resolution of the data and secondly on the ability for the user to accurately digitise around the fields in question. The fields included in this study are quite small, some less than 20 hectares. Therefore as the pixel size 625m^2 (25 x 25m), the inclusion and exclusion of each additional pixel in digitising results in one-sixteenth of a hectare change, which on a small spatial area is quite large.

6. Conclusions

The current practices of hail damage assessment has some limitations, the use of remote sensing and GIS can provide alternative and complementary techniques for the assessment of broad-acre hail damage. Analysis of satellite imagery has concluded that identifiable spectral variances exist between healthy vegetation and damaged sorghum, the most pronounced variance occurs in the red and near infrared regions of the electromagnetic spectrum. Results have indicated that remote sensing is useful for analysing defoliation to an average accuracy of 5% to 30% difference from that observed in the field, depending upon the technique and boundary used.

It was identified that the methods of NDVI and Tasselled Cap Transformation (Greenness) are better defined in calculating the defoliation though many implications exist that explain the variations that have existed. However, it is difficult to precisely predict defoliation rates based on limited assessment information on the claims reports, historical events and the inability to validate data using field survey and analysis. Hence, further investigation is required for checking and verification of such techniques in accurately estimating the defoliation rates incurred. On average, it is clear that the 2-pixel boundary is more accurate than other methods of defoliation calculation, and this has been identified as being related to mixed pixels. Area calculation is relatively accurate, but is dependant on the spatial resolution of the imagery and the accuracy of digitising by the user.

References

Campbell, J.B., 1996, *Introduction to Remote Sensing*, 2nd Edition, The Guilford Press, New York.

ERDAS, 1999, *ERDAS Field Guide*, 5th Edition, ERDAS inc., Georgia.

Erickson, B.J., 2000, *Using Remote Sensing to Assess Stand Loss and Defoliation in Maize*.

Knipling, E.B., 1970, ‘Physical and Physiological Basis for the Reflectance of Visible and Near Infrared Radiation from Vegetation’, *Remote Sensing of Environment*, In Campbell, J.B., 1996. *Introduction to Remote Sensing,* 2nd Edition, The Guilford Press, New York.

Lillesand, T.M. and Kiefer, R.W., 1994, *Remote Sensing and Image Interpretation*, 3rd Edition, John Wiley and Sons.

Shipiro, C.A. and Peterson, T.A., 1986, *Sorghum Yield Loss Due to Hail Damage.*

Tucker, C.J., 1979. ‘Red and Photographic Infrared Linear Combinations for Monitoring Vegetation’, *Remote Sensing of Environment,* Vol. 8, Elsevier, North Holland Inc..

Webb, T., (T.Webb@bom.gov.au), 15 June 2001, Re: Request for Information – Hail Storm on 2 January 2000 at 4-5pm, email to Owen Chandler (q9921993@mail.connect.usq.edu.au).