A MULTI-TEMPORAL & MULTI-ANGULAR STUDY OF HYPERSPECTRAL DATA RELATED TO THE BIOPHYSICAL PROPERTIES OF COTTON CROPS & SOIL CHARACTERISTICS, NSW, AUSTRALIA.

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ABSTRACT

This interim research report is intended to highlight key elements of the larger CHRIS-based experiment in the absence of reliable field-based cotton targets resulting from widespread drought across Eastern Australia. The results primarily reflect a predominance of glasshouse trial results in addition to elements of early CHRIS, HyMap, and field-related results.

Keywords: ESA, CHRIS, hyperspectral, cotton, multi-temporal, multi-scale, vegetation indices, vegetation mapping.

1. INTRODUCTION

Growers are challenged to access current and precise information about their crops in the field. Therefore, information about crop conditions and landscape variability during the growing season is a crucial factor. Remote sensing has become one of main tools for agricultural applications, especially for crop monitoring during the growth cycle applying vegetation specific indices as indicators (Clevers and Jongschaap, 2003). Remote sensing techniques mostly applies reflectance data obtained either by satellite or aircraft to provide relatively low cost spatially distributed data on plant growth at large scales. Improving the spectral information of vegetation through remote sensing platforms was perceived as the key to a more direct means of identifying surface cover types (Goetz, 1992; Merton and Cochrane, 1995). In order to detect plant growth condition and vigour, the underlying principle is that plant canopy with varying nutrient levels reflect differently in specific wavelength (Mutanga *et al.* 2003). Therefore, remote sensing data, especially high spectral resolution data, can be used to detect canopy reflectance in specific wavelength in which represent the plant 'stress' status.

Therefore this study aims to monitor the spectral variations in agricultural practices as a function of multi-scale changes over time. Scale-dependency will be assessed at leaf, canopy, and landscape scales. Like most hyperspectral studies, the irregularly spaced intervals between image and field dataset acquisition (coincident or not) adds to the complexity of any undertaking of this magnitude. Furthermore, this study aims to investigate selected aspects of

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the relationship between the BRDF of the various lab, field, aerial, and orbital spectrometers, particularly between pointable devices such as CHRIS and the lab/field goniometer spectrometer (Figure 3).

This study focuses on the hyperspectral imaging and mapping of a single species across a large homogeneous area. The aim of this study is the use of high spectral resolution data to discriminate of spectral variation of single crop at leaf, canopy, and orbital scales. Through this analysis, two main goals will be assessed; 1) the variation spectra can be used to predict vegetation health and vigour, 2) the possibility the use spectral variation relate to nutrient deficiency in the field.

Advanced technology in remote sensing enables to discriminate crop condition such as vigour, stress, health, maturity and yield by analysing vegetation indices in small range of spectral reflectance captured by the sensor, change detection, crop and sensor geometry and other aspects of analysis. The calculation of multi-temporal hysteresis data from even a single vegetation species can provide an opportunity to examine the suitability of measuring temporal spectral trajectories as ecologically meaningful data associated with changing vegetation growth, phenology, stress, and productivity.

This interim research report is intended to highlight key elements of the larger CHRIS-based experiment in the absence of reliable field-based cotton targets resulting from widespread drought across Eastern Australia.

2. STUDY SITES

The main study site located at “Colly” Central, forms a remote hub of an agricultural business owned by Iffley Cotton Field, Tywnam Pty. Ltd. who regionally operate large commercial cropping stations predominantly growing cotton, sunflowers, and winter wheat. The Colly farm is centred at 29°36’South, 148°51’East, and is located about 40 kilometres east of the remote small town of Collarenebri in the North West region of New South Wales, Australia (Figure 1). The research site is a large commercial enterprise with a history of remote sensing research, an existing multispectral-based yield prediction model, and excellent records of past yields and other agronomic measures. Five fields were selected in the Colly area ranging between 42 to 257ha. Agronomic data was made available across the time period of our research, and included records of plantings, irrigation rates, fertilisation history, and crop yields.

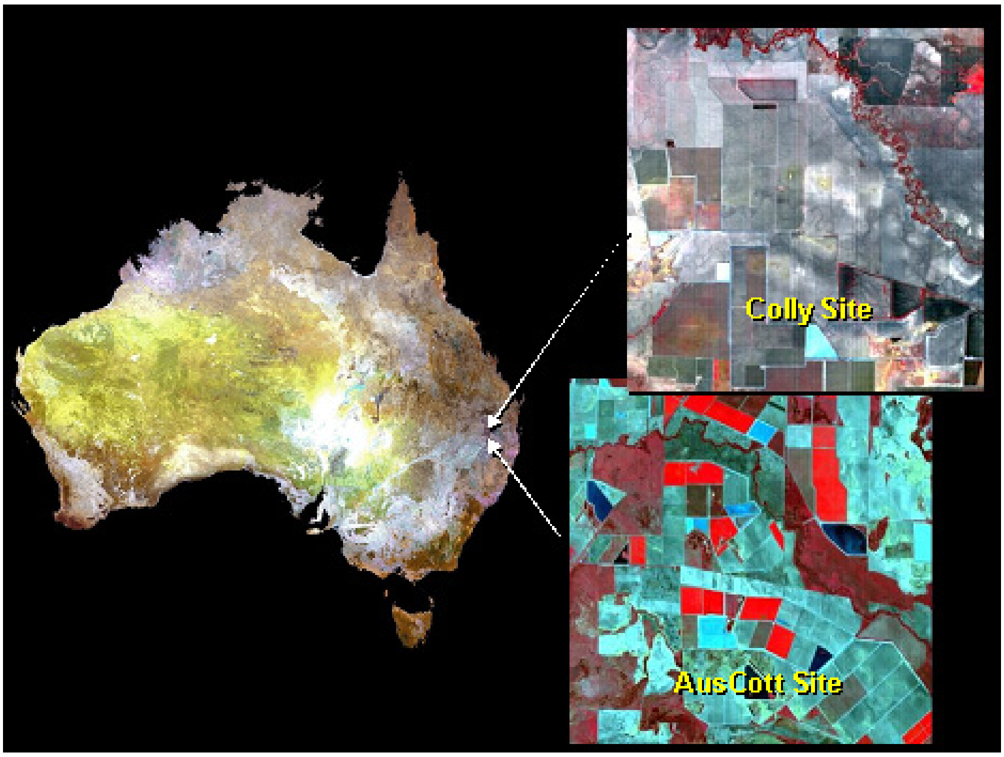


Figure 1 CHRIS Images of the Australian Study Sites.

Note: The primary cotton research site is Colly Cotton (29.66°S, 148.85°E), with AusCott (lat/long ??) as the secondary site.

3. DATASETS

The following schematic (Figure 2) shows the three core areas of data; *1.* remotely sensed imagery, *2.* lab/glasshouse BRDF experiments, and *3.* field derived soil and goniometer measurements. As this is an interim CHRIS report, aspects of relevant image and lab-based analysis will be emphasised.

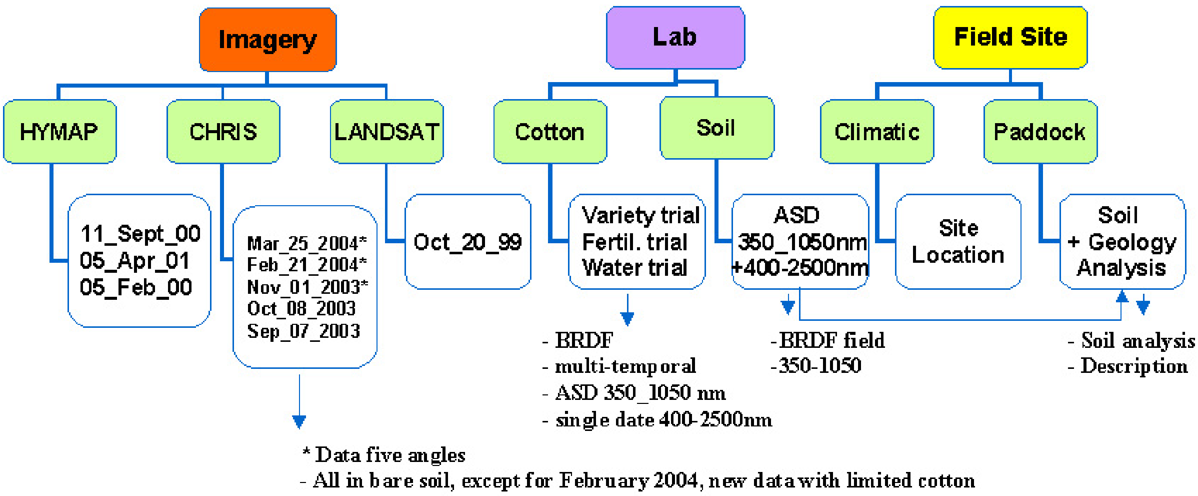


Figure 2. Schematic Diagram of Image, Lab, and Field Site Datasets.

Field and remotely sensed datasets (*refer* Figure 3) include *1.* & *2.* Lab/Field ASD HH spectrometer (512 bands; 281 – 1088nm) mounted to the hemispherical goniometer, *3.* HyMap (Cocks *et al*., 1998) aerial hyperspectral imaging system (126 bands; 400 – 2500nm), *4.* CHRIS (*Mode 1*; 62 bands; 405 – 1035nm), *5.* Landsat (std. mode; 7 bands). HyMap imagery of this study site area was acquired in 5 Feb 2000 (maturity), 11 Sept 2000 (emergent growth), 5 Apr 2001 (late maturity/senescence). Accurate field spectral data was not obtained coincident with HyMap data scans all runs were collected as opportunistic acquisitions prior to the formation of this CHRIS research initiative, however ancillary data related to cotton growth and yield and other agronomic variables were recorded.

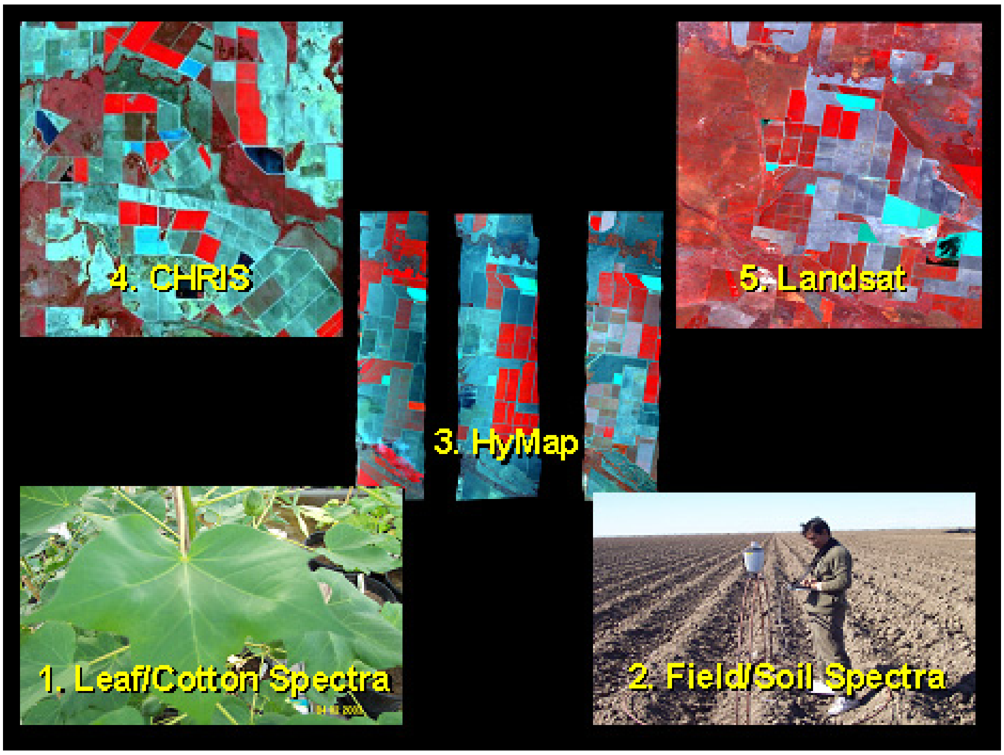


Figure 3 Multi-scale Research Datasets.

Note: Spectra/imagery obtained at the: leaf-scale(1), field-scale(2), aerial-scale(3), & orbital scale(4 & 5).

To gain an estimate of cotton growth variability and yields (Table 1) versus remotely sensed spectral measures, a laboratory trial based on fertility rate was conducted in a series of glasshouse experiments across the same growing period in the 2002/2003 season.

Table 1. Total cotton selected field area of subset image of Iffley farm, ROI and yield for 1999/2000 Growing season

Fields No.	Area (ha)	Area (%)	ROI Calc (ha)	Yield (bales/ha)
302	240	(28.17)	215.92	10.403
303	252	(29.58)	235.92	11.243
307	237	(27.82)	217.59	12.182
323	81	(9.51)	72.14	8.303
325	42	(4.93)	37.31	7.907
Total Area	852	(100.01) 0)	778.88	

Source (in part) : Iffley Farm, Tynam Pty. Ltd (2003) *unpublished.*

Only selected fields were planted with cotton during 1999/2000 growing season (early phase of drought event), therefore, only five cotton fields were selected as focus of analysis. Field numbers included 302, 303, 307, 323, and 325, with total area 852ha (*refer* Figure 4). Region Of Interest (ROI) where defined within each of these fields, representing 90.8% of the original area (*refer* Table 1).

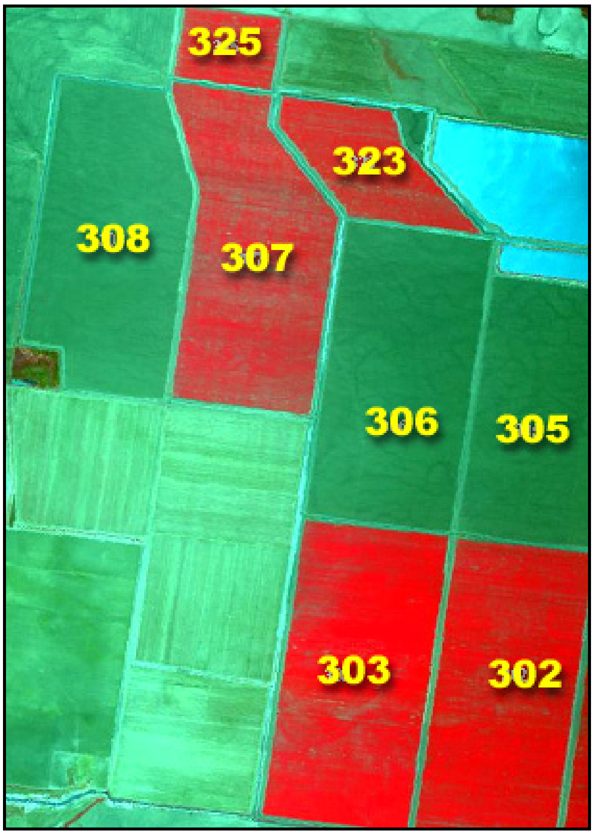


Figure 4. Colly Cotton Field Study Sites.
Note: Field numbers 302, 303, 307, 323, and 325 where used to define spectral ROI's.

3.1 CHRIS DATASET CHARACTERISTICS

A common point in each look angle image (+55°, +36°, 0°, -36, -55°) is useful to assess the degree of pointing accuracy that the CHRIS sensor achieves across the acquisition. Figure 5 (Colly site) and Figure 6 (AusCott site) show strong pointing error drift across the look angle datasets. In one acquisition (Colly +55°) the exact location fell somewhere off the study site area. This pointing drift creates difficulties when mapping across the datasets effectively reducing the spatial extent of coincident coverage. The derivation of ROI's from these spatially reduced datasets in this instance becomes problematic, especially when only 5% of pixels are common to all the 5 view angle datasets.

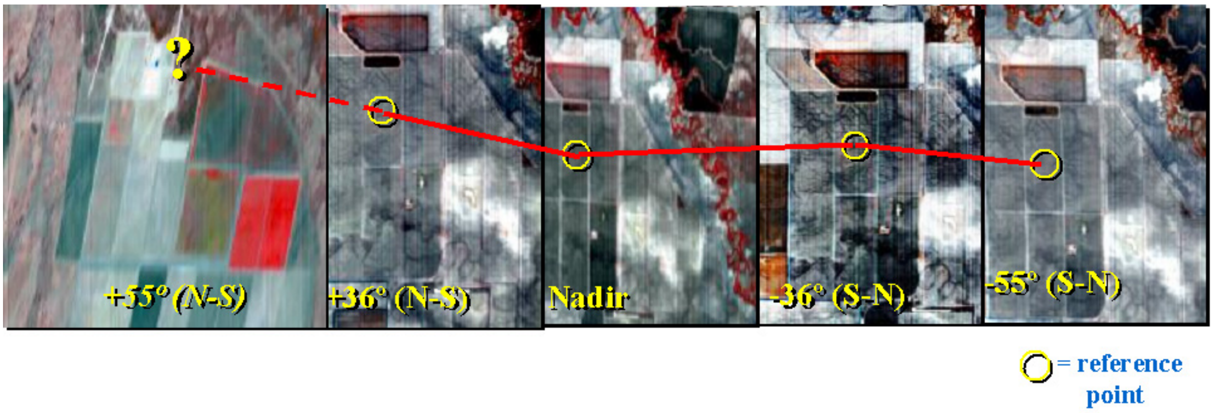


Figure 5. CHRIS Colly Dataset Look Angles (November 2003).
Note: Common reference points are marked as yellow circles.

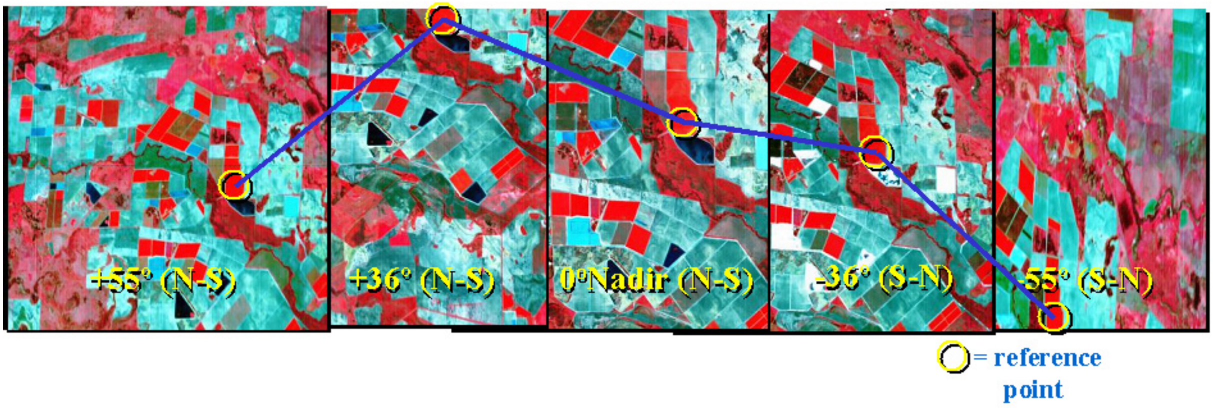
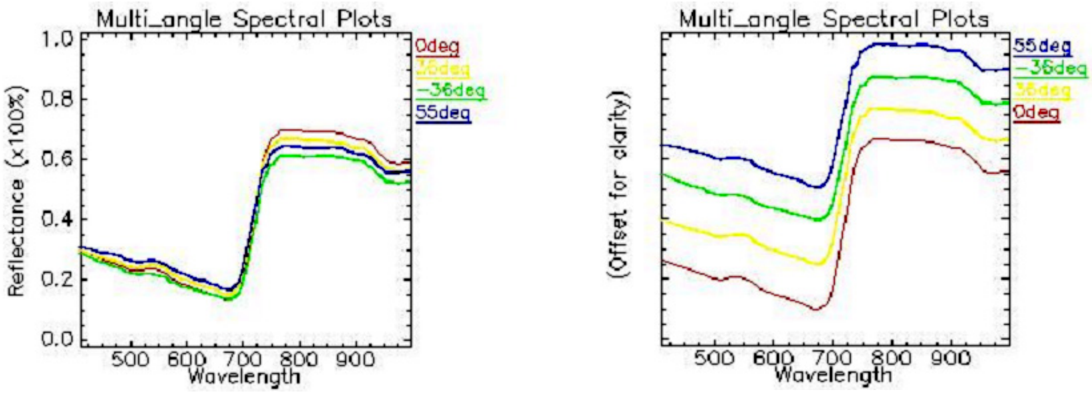


Figure 6. CHRIS AusCott Dataset Look Angles (March 2004).
Note: Common reference points are marked as yellow circles.



A **B**

Figure 7. CHRIS multi-angle spectral plots of cotton.
Note: Spectra (A) and stacked spectra (B) are derived from the 25 March 2004 CHRIS dataset.

4. GLASSHOUSE EXPERIMENT

Glasshouse trials growing five varieties of cotton were carried out during September 2002 until April 2003. The five varieties of cotton plant (Sicot 189, Siokra V16, Delta Diamond, Delta Pearl, and Delta Opal) were grown under four types of soil fertilization. The standard watering rate during this trial was at rate of 455mm/growing season, equivalent to rainfall rate at Colly Cotton research site. Soils substrate consist of three components; river sand, organic-rich soil, and clay-rich soil were used in this experiment. Cotton grown in Australia is dominated by cracking self-mulching clay, sandy soil, found mostly on flood plains (Cotton Australia, 2001). Clay soil also contains many of the nutrients required by cotton plants. The specific soil structure of a blend of rich-organic matter and clay was designed to replicate the analogous soil structure of Colly Cotton site research site. Potted glasshouse soils were also mixed with varying quantities of standard agricultural fertilizer specifically for productivity trials (Table 2).

Table 2. Category and Composition of Soils.

Soil Name	Symbol	Sand:Black Soil:Clay Soil
Low	S0	60:20:20
Moderate	S1	40:30:30
Fertile	S2	20:40:40 + standard fertilizer
Very fertile	S3	20:40:40+ standard fertilizer + micronutrient

Note: Standard fertilizer = 1 gram/pot, Micronutrient = 20 mg/pot. Replicating std. field agricultural application rates.

A randomized block design was applied for the cotton growing experiments. However, the result of analysis of variance for each single treatment is not presented here. The ASD FieldSpec HandHeld spectroradiometer (ASD , 1999) was used to collect the spectral data to detect the spectral differences among different fertilization and watering rates from the 5 different cotton crop varieties. The ASD HH has a wavelength range of 325 to 1075nm with a Full Width Half Maximum (FWHM) of 1.6nm, acquiring 512 contiguous channel bands with a selectable foreoptic viewing angle of 1, 10, or 25 degrees.

A goniometer was constructed to measure plant hemispherical reflectance as a function of Bidirectional Reflectance Distribution Function (BRDF) (Figure 8B). The goniometer comprises a horizontal azimuth hemisphere bisected by a vertical zenith track along which the spectrometer is moved at angular increments. The construction was designed measure azimuth and zenith spectra of the plant or soil as a complete 3-*D* hemisphere.

The spectroradiometer was elevated one meter above the foliage to acquire of cotton spectra. A 10° spectroradiometer foreoptic was used to create a Field of View (FOV) area 240.46cm² (*refer* Equation 1 & Equation 2).

$$r = h^* \tan\left(\frac{\alpha}{2} * \frac{\pi}{180}\right)$$

Equation 1. Radius Calculation

$$A = \pi * r^2$$

Equation 2. FOV Area Calculation

where: r is the radius of field of view, h height of equipment to the target, α is angle of view of the spectraradiometer, and A is total area field of view to the target.

Spectral measurements of cotton were replicated 10 times per plot, and the spectroradimeter was configured to average 25 samples per single spectrum. Samples were acquired throughout the growing season.

A.

B.

C.

D.

Figure 8 Site location and glasshouse experiment.
Note : *A.* Ploughed Colly cotton field with remnant cotton lint, *B.* lab/field goniometer *C.* cotton grown at different watering rates, *D.* cotton grown at different soil fertility rates.

5. VEGETATION INDICES

Derived broad-band vegetation indices (VIs) have been widely used to quantify crop variables such as wet biomass, leaf area index, plant height, and productivity (Thenkabail, Smith and De Pauw, 2004). Variation of these crop variables may occur due to climate, soils, cultivars, management practices as well as technological input. Studies (*e.g.*, Blackburn, 1998; Sibayama and Akiyama, 1991; Elvidge and Mouat, 1989) has shown that narrow waveband (hyperspectral) indices could provide additional information in quantifying biophysical characteristic of agricultural crops.

This paper present the derived spectrally dataset limited to representative spectra curve of the four classes; very fertile, fertile, medium and low nutrient content of soil to calculate VI's of cotton. Calculation of spectral values were focused on six aspects of indices; red-edge ratio (Gitelson and Merzylak, 1996), CAI index (Oppelt and Mauser, 2001a and b), NDVI (Tucker, 1979), and NVI values (Takebe *et al*., 1990, Bausch and Duke, 1996). The index of Gitelson and Merzylak (1996) shown in Equation 3 was modified using 752nm and 690nm instead of 750nm and 700nm originally defined. 752nm is the maximum reflectance at near infrared region and 690nm is the maximum absorption of red spectrum region. The red-edge productivity of a plant can be assessed as the ratio between 752nm and 690nm can show:

$$Red\_edge\ ratio = \frac{R_{752}}{R_{690}}$$

Equation 3.

where: R_{752} reflectance (%) value at 752nm, R_{690} reflectance (%) value at 690nm.

The Chlorophyll Absorptions Integral (CAI) index derives the chlorophyll content by measuring the area between a straight line connecting two points of the red-edge and the curve of the red-edge itself. Therefore, it is an approach based on a spectral envelope (continuum) measurement (Oppelt and Mauser, 2001a & b). To conform to the spectral bands of the ASD spectroradiometer, the CAI was modified in the following equation (*see* Equation 4 and 5)

$$mCAI = A - \int_{R552}^{R752} f$$

Equation 4

where: A = area of the trapeze between R_{552} and R_{752}, f = reflectance curve.

Therefore, the *mCAI* value can be calculated as follow:

$$mCAI = \frac{(R_{552} + R_{752})}{2} * (752–552) – \text{sum} \sum_{R552}^{R752} R * 1.579$$

Equation 5

The modified CAI (mCAI) calculates the area above the spectral curve between 552nm (green peak) and 752nm and the index, with 1.579nm is the FWHM of the spectraradiometer. The mathematic approach is to calculate the area of the trapezoid (A) between 552nm and 752nm and subtract it with the integral of the spectral curve between the same spectral values. This calculated index also can be used to estimate the vigour and health of cotton plant under different fertilization rates.

The ratio of to be constant at the level regardless of the differences in chlorophyll concentrations, and defined a chlorophyll absorption ratio index (CARI, Kim et al 1994). To estimate the variation within the 550nm and 770nm reflectance range, the chlorophyll absorption band at 670 nm can be used to predict the Chlorophyll Absorption Ratio Index (CARI) ratio variations, therefore:

$$CARI = CAR \frac{R_{700}}{R_{670}}$$

$$CAR = |(a \times 670 + R_{670} + b)|/(a^2 + 1)^{0.5}$$

$$a = (R_{700} - R_{550})/150 \text{ and } b = R_{550} - (a \times 550)$$

Equation 6

The Photochemical Reflectance Index is calculated based on the normalised ratio of reflectance between R_{528} and R_{567}. These two wavelengths define regions of biochemical absorption and therefore capable of measuring photosynthetic down-regulation (Gamon, *et. al*. 1995)

$$PRI = \frac{R_{528} - R_{567}}{R_{528} + R_{567}}$$

Equation 7

6. INTERIM RESULTS AND DISCUSSION

Table 5. Calculated values of Red_egde, CAI, NDVI, NDI, CARI and PRI. shows the fertile and very fertile soil condition gives the higher value for all indices calculated, except for PRI value. Low soil fertility produces lower values for given indices calculated, while the red-edge, CAI and the CARI of healthy plants show high index values. Interestingly, in this vegetation index calculation the values on NDVI and PRI among the soil fertility conditions give almost the same values; 0.99 to 1.00 and -0.08 to -0.11, respectively. It is assumed that the NDVI value calculated is not appreciably different amongst soil conditions due in part to plant “greenness” in emergent growth.

Generally, reflectance curves highlight a significant difference among cotton growth conditions. High fertility plants exhibit higher reflectance especially in the NIR compare to that of low fertility samples. Additionally, the “green peak” at 552nm is clearly more apparent compared to those of lower fertility. These trends were highlighted when applying the four vegetation indices; red-edge, CAI, NDI and CARI. Higher values at the red-edge, CAI and CARI indicate higher plant vigour for both fertile and very fertile soil conditions. Interestingly, Red-edge, CAI, NDI, and CARI all exhibit lower values for lower fertility trials, however NDVI and PRI are exceptions to this trend. The cotton trials generated valuable spectral library data for application to lab, field, and satellite data.

Variation in VIs has shown that soil condition influences the crop biophysical performance during growing season in addition to the spectral characteristics. Similar trends were reported by Thenkabail *et al*. (2004) as cotton leaves changed visible spectral properties from green to light green due to some soil backgrounds that effect the reflectance such as soil moisture (Dabrowska_Zeilinska, Inoue, Gruszczynska, Kowalik, and Stankiewicz, 2001), particle size (Dathe, Eins, Niemeyer, and Gerold, 2001), and nutrient content (Palacios-Orueta, Pinzón Ustin, and Roberts 1999).

Table 3. Leaf Scale Mean & Std. Deviation of Indices

	So (low)		S1(medium)		S2 (fertile)		S3(very Fertile)	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
RVSI	-2.253	1.775	-3.753	2.850	-5.013	2.202	-6.943	2.855
Red_edge Ratio	3.057	1.124	4.294	0.546	5.065	1.696	6.042	2.105
NDVI	0.471	0.153	0.614	0.042	0.649	0.078	0.695	0.082
RNVI	2.116	0.520	2.219	0.289	2.472	0.769	2.949	0.607
CARI	28.381	26.319	43.124	30.002	55.982	41.873	52.090	29.599
PRI	-0.203	0.137	-0.214	0.060	-0.058	0.176	-0.102	0.070
WI	1.017	0.060	0.981	0.031	0.956	0.021	0.953	0.018
NPCI	0.104	0.324	0.064	0.306	0.051	0.248	0.006	0.271

Table 4. Variation in Vegetation Index Values CHRIS Dataset (Nov'03)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
RVSI	-0.02379	-0.04801	-0.02607	-0.01619	-0.02502	-0.02124
SR	1.855329	2.778927	1.897708	1.559155	1.730547	1.839076
NDVI	0.299555	0.470749	0.309799	0.218492	0.267546	0.295546
RNVI	1.694012	2.038898	1.660468	1.471129	1.649593	1.735462
PRI	-0.01198	-0.03166	-0.00027	-0.00619	-0.01172	-0.02025
WI	0.949135	0.945022	0.972169	0.971461	0.999029	0.978073
NPCI	-0.03289	-0.12683	-0.08576	-0.04171	-0.02451	-0.01708

Table 5. Calculated values of Red_egde, CAI, NDVI, NDI, CARI and PRI.

	Low	Medium	Fertile	Very Fertile
Red-edge	1.59	2.95	6.33	6.20
CAI/1000	0.51	2.15	4.47	4.60
NDVI	0.99	1.00	1.00	1.00
NVI	2.04	2.38	3.52	2.69
CARI	6.89	28.20	65.49	84.88
PRI	-0.09	-0.11	-0.08	-0.10

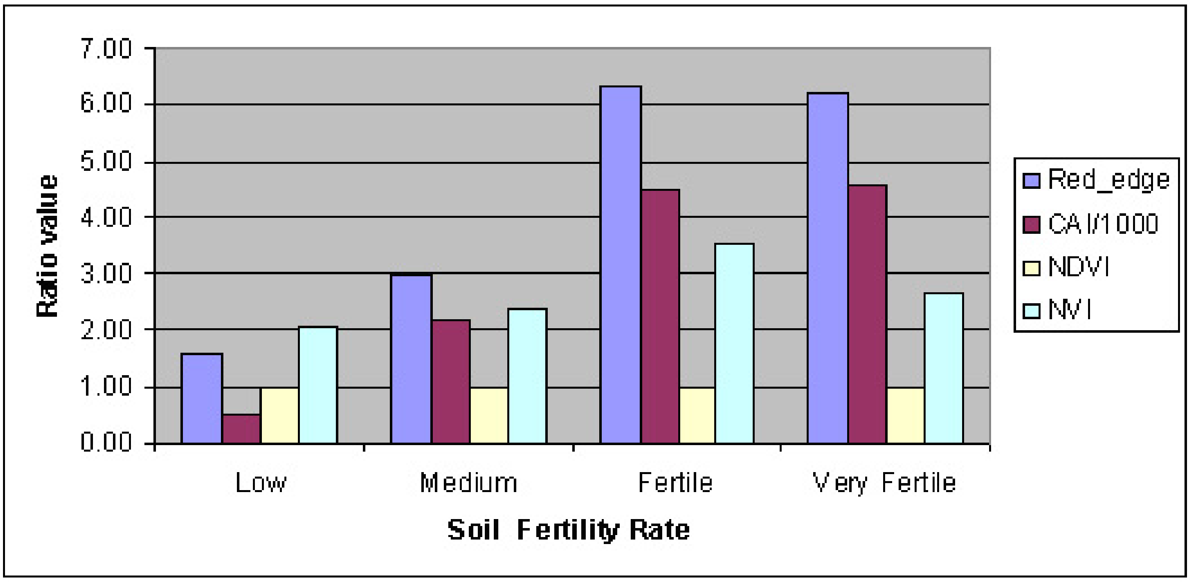


Figure 9. Graph of Spectral Vegetation Indices (Red-edge, CAI, NDVI, and NVI) as a Function of Soil Fertility.

The measured production and estimated production per hectare of cotton is shown in table 3. It shows that variation in soil fertility give significant in production.

Table 6. Production of Cotton at Varying Soil Condition

	Yield (g/pot)	Estimated yield (kg/ha)		Bale/ha		Bale/ha	
		9 pl/m	12 pl/m	9 pl/m	70% est.	12pl /ha	70% est.
Low	10.68	865.08	1537.92	3.81	2.67	6.77	4.74
Medium	15.59	1262.79	2244.96	5.56	3.89	9.89	6.92
Fertile	43.35	3511.35	6242.40	15.47	10.83	27.50	19.25
Very Fert.	52.20	4228.20	7516.80	18.63	13.04	33.11	23.18

Note: Pl = plants.

Considering the presented results of the first data in the laboratory, the authors will intensify the field experiments in the field during 2003/2004 growing season. Additionally, multi-temporal air borne; HyMap and space borne; CHRIS/PROBA hyperspectral data analysis will be evaluated against the laboratory and the field measurements. The results will be used to develop a method of spatial variation of soil fertility in the field based on spectral indices calculation.

7. REFERENCES

Asner, G. P. (1998) Biophysical and biochemical sources of variability in canopy reflectance, *Remote Sensing of Environment*, 63, 234-253.

Bausch, W. C. and Duke, H. R. (1996). Remote sensing of plant nitrogen status in corn. *Transactions of the ASAE*, 39(5): 1869-1875.

Blackburn, G. A (1998) Spectral indices for estimating photosysthesic pigment concentrations test using tree leaves, *International Journal of Remote Sensing* , 19(4) :657-675.

Clevers, J.P.G.W and Jongschaap, R. (2003). Imaging spectrometry fro agricultural application in van der Meer, F.D and de Jong, S. M. (ed.) *Imaging Spectrometry : Basic Principle and Prospective Application*s, Kluwer Academic Publisers; pp157-200

Dabrowska_Zeilinska, K., Inoue Y., Gruszczynska, M., Kowalik, W. and Stankiewicz, K., (2001). Various approaches for soil moisture estimates using remote sensing, IGARSS Conference, Sydney

Dathe, A. Eins, S. Niemeyer, J. and Gerold, G. (2001) The surface fractal dimention of soil-pore interface as measured by image analysis. Geoderma Vol 103: 203-229. Elsivier Science Inc, New York.

Elms, M.K. and Green, C. J., (1997). Spatial variability of yield in irrigated cotton. In: Dugger, P., Richter, D.A. (Eds.), Proceedings Beltwide Cotton Conference, 6–10 January 1997, New Orleans, LA. National Cotton Council of America, Memphis, TN, pp. 598–600.

Elvidge, C. D and Mouat, D. A (1989) Analysis of green vegetation detection limits in 1989 AVIRIS data, in Proceeding of the International Symposium of Remote Sensing of Environment, 7th Thematic Conference-Remote Sensing for Exploration Geology, Calgary, Canada.

Elvidge, C.D. (1990). Visible and near infrared reflectance characteristics of dry plant materials. *International Journal of Remote Sensing* 11:1775-1795

Gamon, J.A., Roberts, D.A., and Green, R.O. (1995). Evaluation of photochemical reflectance index in AVIRIS imagery, In *Summaries of the Fifth Annual JPL Airborne Earth Science Workshop, Vol 1. AVIRIS Worksho*p (Ed R.O Green), January 23-26, 1995. NASA Jet Propulsion Laboratory Publication 95-1, vol.1, p55-58

Gitelson, A., and Merzlyak, M.N. (1996), Detection of red-edge position and chlorophyll content by reflectance measurements near 700 nm, *Journal of Plant Physiology*, 148, pp.501-508.

Goetz, A. F. H. (1991), Imaging spectrometry for studying earth, air, fire and water. *EARSeL Advances in Remote Sensing* 1, pp.3-15.

Kim, M.S., Doughtry, C.S.T., Chappelle, E. W., and McMurtrey, J.E. 1994. The use high spectral resolution bands for estimating absorbed photo synthetically active radiation (APAR). In: *Proc. ISPRS'94 Val d'Isere*, France 17-21 January 1994 (pp299-306)

Moran, M. S., Inoue, Y. and Barnes, E.M. (1997). Opportunities and limitations for image-based remote sensing in precision crop management. *Remote Sensing of Environment*, 61: 319-346

Mutanga, O., Skidmore, A.K., and van Wieren, S. (2003). Discriminating tropical grass (Cenchrus cilaris) canopies grown under different nitrogen treatment using spectroradiometry. *ISPRS Journal Photogrammetry and Remote Sensing, 57(3): 256-272.*

Oppelt, N. and Mauser, W. (2001a): The chlorophyll content of maize (Zea mays) derived with the Airborne Imaging Spectrometer. AVIS. *8th International Symposium "Physical Measurements and Signatures in Remote Sensing*", 8-12 January, Aussois, France, pp.407–412.

Oppelt, N. and Mauser, W. (2001b): Derivation of the chlorophyll content of maize. *International Workshop on Spectroscopy Application in Precision Farming*, 16–18 January, Freising, Germany, pp.52–56.

Palacios-Orueta, A., Pinzón J. E. Ustin, S.L., and Roberts, Dar A. (1999). Remote Sensing of Soils in Santa Monica Mountains : II Hierarchical Foreground and Background Analysis. *Journal of Remote Sensing Environment.* Vol. 68:131-151. Elsivier Science Inc, New York

Palacios-Orueta, A., Pinzón J. E. Ustin, S.L., and Roberts, Dar A. (1999). Remote Sensing of Soils in Santa Monica Mountains : II Hierarchical Foreground and Background Analysis. *Journal of Remote Sensing Environment.* Vol. 68:131-151. Elsivier Science Inc, New York

Perry, J. R. and L. F. Lautenschlager. (1984). Functional equivalence of spectral vegetation indices. *Remote Sensing of Environment*, 14: 169-182.

Senay, G. B., Ward, A.D. Lyon, J.G, Fausey, N.R and Nokes, S.E.. (1998) Manipulation of high spatial resolution aircraft remote sensing data for use in site-specific farming. *Transactions of the ASAE*, 41(2): 489-495.

Sibayama, M. and Akiyama, T (1991), Estimating grain yield of maturing rice canopies using high spectral resolution reflectance measurement, *Remote Sensing of Environment,* 36: 45-53

Takebe, M.,. Yoneyama, T., Inada, K. and Murakami. T. 1990. Spectral reflectance ratio of rice canopy for estimating crop nitrogen status. *Plant and Soil*, 122: 295-297.

Thenkabail, P. S., Smith, R. B and De Pauw (2004) Hyperspectral Vegetation Indices for Determining Agricultural Crop Characteristics available at: http://www.yale.edu/ceo/Project/swap/Project/hyper.html last retrieval 20 March 2004

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8: 127-150.