6/91 D 91 ✓

COTTON RESEARCH & DEVELOPMENT CORPORATION

RESEARCH AND DEVELOPMENT GRANT: PROJECT CAE1C

"IMPROVING IRRIGATION EFFICIENCY THROUGH REMOTE SENSING"

FINAL REPORT

Original Project Objectives

The main aim of this project was to develop a low–cost multispectral airborne video imaging system (referred to as MAVIS) for detecting and monitoring spatial and temporal variations in the vigour of irrigated cotton crops caused by moisture related and other forms of stress.

A related objective was to develop standard procedures to acquire, to analyse crop canopy spectral response with the aid of digital image processing, and to calibrate video imagery using traditional agronomic and field measurements for more effective management of water and other crop inputs.

The ultimate goal was to assess the feasibility of establishing a commercial fee–for–service operation to monitor and manage crops using digital analysis of airborne video imagery.

Summary of Methodology and Modifications

The initial focus of the project was irrigation scheduling although it became necessary to broaden the scope of the investigation to other forms of stress due to disruption of field trials by unseasonal rainfall during the first season and delays in access to most of the capital funds which precluded the purchase of a thermal infrared imaging radiometer until the second half of the investigation.

An extensive literature review to evaluate equipment configuration alternatives was followed in early 1989 by visits to video and image processing equipment suppliers in several Australian capital cities and a visit to the United States to inspect several experimental video based remote sensing systems and liaise with relevant remote sensing specialists.

During the ensuing 1989/90 and 1990/1 irrigation seasons a three phase crop monitoring program was implemented involving image acquisition (the aircraft phase), image processing (the laboratory phase) and ground truthing (the field phase). In general, components for the MAVIS image acquisition system were purchased using project funding, computer hardware and software for image processing was provided by the University of Canberra while instruments for ground truthing – including field radiometer, neutron probe and equipment for a range of agronomic measurements – were obtained on loan as required.

The initial MAVIS image acquisition system was constructed using off–the–shelf video and electronic components and comprised a linked array of three remotely controlled high resolution monochrome CCD video cameras each band pass filtered to a separate spectral wavelength in the visible and near IR. Manual camera settings were maintained to ensure spectral comparability of imagery obtained at different times and wide angle lenses were used so that swath width would encompass row lengths of normal com–

mercial fields. Video imagery can be viewed in real time on one of two video display screens during flight or stored for subsequent review and image processing. The image recording system comprises linked SVHS portable VCR recorders with integrated time code generator for simultaneous frame numbering to enable subsequent retrieval of comparable frames belonging to each spectral band.

To enable comparable frames over target scenes to be extracted from each video cassette tape in the laboratory a video controller board was installed in a personal computer and a linking batch file written to precisely trigger a framegrabber board so that selected imagery could be converted from analog into digital image files. An additional batch file was written to reformat video data so that digital image processing could be conducted using commercially available software on an IBM compatible personal computer.

Comprehensive tables were prepared containing details of changes in spatial resolution, swath width and image motion effects for a range of flying heights, focal length settings and aircraft speeds during image acquisition.

Repetitive video imagery of two trial fields was subsequently obtained in three broad visible and near infrared spectral bands during the 1989/90 irrigation season to simulate the Landsat Multi Spectral Scanner. It took eight out of fifteen flights to select the best combination of flight parameters and equipment settings for production of acceptable airborne video imagery. Trials were designed to assess whether it was possible to spectrally separate weeds from cotton, crop varietal and potential yield differences, contrasting tillage techniques used in seedbed preparation and differences in rates of nitrogen and water use. Agronomic data – including plant height, node details and yield estimates based on fruit and boll counts – were collected to ensure that ground sampling reflected the full range of spectral classes derived from early season image classification maps.

Analysis of portable spectroradiometer observations obtained in association with field trials during 1989/90 showed that differences in spectral reflectance due to canopy development and plant maturity during the season were greater than those attributable to temporary changes in canopy geometry and reduced leaf turgor for water stressed plants. However, short term changes in near infrared reflectivity were found to be a particularly useful indicator of the need to irrigate while a reversal in the relative strength of green band spectral response for cotton versus grey clay soils showed emphasised the need for cautious interpretation with respect to time during the season. These observations were used to guide the selection of narrow band green, red and near infrared filters for image acquisition during 1990/1.

Several other changes were made to the MAVIS system prior to the 1990/1 irrigation season. The pod which was initially used to mount video cameras under the belly of the light aircraft was replaced with a baseplate assembly within a specially modified co–pilot door for more rapid system deployment and improved access to and alignment of cameras. A high resolution thermal infrared imaging radiometer with video recorder was added to facilitate remote measurement of temperatures within a user defined range. Recording facilities were re–housed in a customised dust–proof case which is mounted on seat rails in place of the co–pilot's seat.

Multispectral imagery from two different flying altitudes and flight directions was obtained over a single field of commercial cotton as a result of 36 separate flights during the 1990/1 season. An irrigation trial, comprising randomised blocked replicates of three contrasting watering strategies, was maintained by sustaining differences in the timing of irrigation – early, normal and late – for each treatment throughout the season. In association with each flight, a range of instrumental ground measurements and agronomic observations – including – eight channel radiometer measurements, neutron probe soil moisture measurements, crop and air temperature and humidity measurements, leaf area estimates, fruit counts, plant height assessments and plant mappings – were made at observational plots defined within each of the nine treatment strips to enable ground and video based measurements of spectral response to be compared and correlated with seasonal and diurnal variations in crop and soil conditions. An array of seventeen well distributed ground control points was installed and surveyed so that video imagery in different spectral bands could be co-registered to a planimetrically correct reference and to ensure that spectral response values and ground observations within observational plots could be compared for exactly the same locations.

The inclusion of the thermal infrared imaging radiometer into the MAVIS image acquisition system during the second season necessitated the addition of separate computer hardware and software to convert resulting imagery from analog into digital format, analyse inherent patterns, extract temperature measurements and produce hard copy inkjet products of selected scenes.

Results of the Research as Measured Against Project Objectives

The broad aims of the project were realised in that a low cost multispectral airborne video imaging system was successfully designed, constructed and deployed by a team of remote sensing scientists and used to monitor meaningful spatial and temporal changes in irrigated cotton under controlled, experimental conditions.

Digital analysis of imagery acquired during the project, in association with ground data, clearly showed that computer based image processing, rather than visual interpretation of multispectral airborne video imagery, greatly enhances the capacity for discrimination of a range of differences in the status and vigour of irrigated cotton crops.

The important task of preparing video imagery for digital processing presented the project team with a major dilemma. Because a separate camera was used for each of four spectral bands it could not be assumed that comparable frames of video imagery were acquired in co-registered form. Differences in the field of view, imaging mechanism and spatial resolution meant that thermal imagery had to be processed and interpreted separately. The use of micropositioning devices and video mixers to align optical axes could not overcome differences in image geometry or ground areas covered by the remaining three cameras, caused by separate lens/filter assemblies and different performance characteristics of sensors and electronics components within each camera. Band to band misalignment commonly amounted to 3% or 45m compared to a swath width of 1500m from a flight altitude of 2,100 metres above ground level.

Visible and near infrared bands for all imagery acquired during the project were rectified through registration and resampling to facilitate band to band comparisons and enable ground observation points to be accurately located on video imagery.

Two contrasting approaches to image processing were adopted. Imagery acquired during 1989/90 was processed as co-registered multi-spectral data whereas imagery acquired during 1990/1 was processed in single channel mode for more rapid product delivery and interpretation.

Quite small differences in crop status were able to be discriminated within trial fields using digital classification of co-registered multispectral imagery for selected dates during the first season of the project. Cotton varieties were most easily separated using imagery obtained earlier in the season while reliable indicators of differences in potential yield were obtained from imagery acquired after canopy closure but before the onset of senescence. Differences in nitrogen application rate, contrasting seedbed preparation techniques and (nutgrass) weed infestation were found to be less susceptible to date of image acquisition, although higher levels of accuracy and improved discrimination was achieved for all parameters if the raw multispectral data was transformed into either a vegetation index or principal component image set prior to computer based image classification.

However, the resulting benefits of increased discrimination had to be weighed against the problems associated with obtaining, processing and interpreting co-registered multispectral imagery. These problems include: the difficulty of establishing adequate ground control for each video image; the time involved in producing co-registered imagery by resampling all spectral bands to a common projection for each scene; the technical expertise required to transform raw channel spectral data into either a vegetation index or principal components channel prior to classification and accuracy assessment based on comparisons with ground observations; and the confusion caused by producing too many classes for a crop manager to cope with.

Consequently, a single channel image processing and interpretation mode was adopted for more rapid product delivery to enable interpretation to focus on spatial and temporal patterns within irrigated cotton during the second season.

Spectral transects across individual video images consistently revealed elevated digital response values from the canopy (up to 10% above expected levels) in visible and near infrared bands on the opposite side of each image with respect to the position of the sun. This phenomena was found to be due to a combination of halation from bending of the sun's rays around the plane prior to illuminating the ground in the vicinity of the no-shadow spot (a well known but not a visually imposing phenomena with aerial photography), heliotrophic changes in leaf angle, the large field of view of video cameras used to obtain a reasonable swath width of imagery at moderate flying altitudes and high sun angles at preferred flying times which ensure that affected areas fall within the field of view. Its effect is less pronounced on sloping ground, over heterogeneous soil/crop conditions, under conditions of high canopy closure for narrow rows with N-S orientation and through close attention to flight planning. It was concluded that imagery acquired over the same fields, within an hour of the same time of day, from a similar altitude and flight direction, may be compared for the purpose of change detection. Further research is being undertaken as part of a Master's dissertation to develop a computer algorithm to remove this solar effect through digital subtraction prior to subsequent image processing.

Diurnal changes in energy from the canopy of irrigated cotton were assessed by comparing imagery acquired at several different times during the day on a number of occasions. The mean, standard deviation and range of spectral response in each band was found to reach a minimum around sunrise and sunset, when the landscape achieves thermal equilibrium, and to peak within an hour after solar noon, suggesting this is the best time to reveal within and between field variations in irrigated cotton when soil and canopy temperatures reach a maximum and crops experience a diurnal maximum in the level of moisture stress.

Video imagery in the red band was found to be particularly useful in diagnosing soil variability before crop canopies begin to close.

Near infrared band spectral reflectance was found to be highly positively correlated with and closely follow seasonal changes in leaf area index (LAI), % ground cover and plant height. By way of comparison, red band reflectance exhibited a high early season negative correlation while a poor association was observed with visible green or thermal infrared spectral response. Near infrared response was particularly sensitive to different watering strategies, with higher reflectivity exhibited by crops which were consistently irrigated well before root zone moisture levels were exhausted.

Atmospheric attenuation was found to be relatively unimportant, being only one of a range of factors giving rise to band specific differences in spectral response between airborne imagery and groundbased measurements of % reflectance and temperature. Highest levels of agreement between airborne and ground based observations were obtained in the near infrared band.
On balance, near infrared imagery was found to provide an excellent basis for mapping between-field and within-field variability in plant architecture/canopy characteristics and ensuring that representative plant stands were selected for ground based assessment of potential yield and monitoring of insect pressure. Because of its high spatial resolu-

tion, near infrared airborne video imagery revealed a consistent pattern of significantly reduced plant vigour for rows of cotton affected by soil compaction due to wheel tracking. Red band spectral response differences were far less pronounced, higher reflectivity being associated with wheel tracking, whereas no significant difference in green reflectance could be detected between wheel track versus non wheel track rows.

Actual soil moisture deficits or root zone moisture levels were not able to be determined accurately using spectral reflectance values or canopy temperatures since many other factors – including time of day, strength of incoming energy, air temperature, humidity and susceptibility to waterlogging – were all found to influence signal strength arriving at the camera. Crop canopy temperatures recorded with the thermal infrared camera were found to rise with increasing soil moisture depletion regardless of irrigation strategy. However, the temperature difference for the same irrigation treatment of a single crop was typically less than 5 degrees C between a saturated versus a fully depleted root zone soil moisture profile. Consequently, it was concluded that decisions regarding the actual time and total amount of water to apply could not be based on spectral response as recorded on airborne video imagery. However, differences in airborne video signal strength, particularly in the thermal infrared band, were found to be consistent with relative variations in root zone moisture status. Thermal infrared imagery was found to be suitable on any one day to rank and prioritize fields, bays and sets of individual rows according to relative soil moisture status. Repetitive acquisition of thermal imagery during the latter half of an irrigation cycle also enabled the critical time for a field to be pin–pointed after which additional spatial variability which characterises increasing moisture stress would result in undesirable differences in management during the rest of the season.

Routine image based crop assessments were based on differences between the actual versus expected spectral response having regard to the stage of crop maturity, and diagnostic patterns of within field variability.

Adoption and Implementation of Results

A crop monitoring program covering 5,000 hectares of irrigated cotton on 12 separate holdings owned by 9 different co–operators in two adjacent valleys (Gwydir and Namoi) was planned for the 1991/2 season to evaluate whether image acquisition, processing and interpretation procedures developed during the experimental phase of this project could be utilised on an operational cost recovery basis.

An initial post emergence mid November 1991 flight was undertaken to obtain soil dominated reference imagery. The initial flying schedule, ranging from two flights per week between mid December 1991 and mid March 1992 for several holdings to a single mid season flight for others, was truncated after three flights to enable teething problems to be resolved.

A fixed flight path, commencing mid morning at Narrabri and finishing early afternoon at Collarenebri, was adopted so that imagery for each co–operator was obtained under the same set of illumination conditions.

Video imagery in four spectral bands from each flight was displayed separately on a computer monitor in the laboratory so that frames covering fields of co–operators could be selected, converted from analog form into a digital computer file and reformatted. Image processing was accomplished in unregistered, single band mode using micro–BRIAN and Thermotechnics software to obtain statistics of crop canopy spectral reflectance and temperature prior to density slicing each image using a standard seven colour system. Differences in crop vigour were annotated and depicted on paper products using a colour ink jet plotter.

Although the program was overly ambitious it highlighted the following issues to be addressed before undertaking any further operational monitoring using the MAVIS system:

* Image degradation, caused by solar reflection from the soil and crop canopy, was considerably worse than that encountered during the experimental phase of the project.

* The large number of high resolution images in four spectral bands covering a small area and the associated tasks of displaying video imagery, selecting individual frames for conversion into digital format, image processing and generating hard copy ink jet products indicated that an image acquisition, processing and interpretation schedule involving more than one flight every two weeks for monitoring even a modest acreage was impractical. The development of low cost yet suitable image processing software for conventional PC computer hardware will facilitate faster image processing using multiple units.

* Closer attention to system deployment, including more flexible flight schedules and improved routing to avoid changes in weather between and during each flight, more selective coverage to target only those crops within the second half of an irrigation cycle.

* A more efficient system for delivering hard copy and digital products.

* Better training to enable landholders and field agronomists to interpret spectral reflectance strength and patterning from remotely sensed digital imagery and verify interpretations using field observations.

The MAVIS system was conceived to overcome problems associated with infrequent revisit capability, slow turn-around and the high cost of remotely sensed imagery from commercial earth resources observation satellites and high resolution airborne scanners. Some of the constraints of image acquisition for agriculture using the MAVIS system versus commercial satellites have been overcome with the production of FARM IMAGES since January 1992. A FARM IMAGE consists of a customised low cost, large scale image subset covering any agricultural enterprise for a selected date and band combination to highlight features nominated by the landholder. This product was development and is supplied by AgRecon, a remote sensing company established by the University of Canberra, under an exclusive contract with the Australian Centre for Remote Sensing.

Publications and Presentations

Three papers and four presentations have been prepared in association with the project describing flight planning considerations for acquiring imagery, image processing routines for enhancing within-field variations in crop canopy spectral response and the interpretations of different forms of crop stress in resulting imagery, as follows:

Button, B J and Cull, P O (1990) An Airborne Video Remote Sensing System for Operational Management of Irrigated Crops, 5th Biennial Australasian Remote Sensing Conference, Perth, 8 pp.

Cull, P O (1991) Monitoring and Optimising Water Use in Crop Production, Remote Sensing Symposium in association with National Agricultural and Resources Outlook Conference, Canberra, pp 23-6.

Button, B J and Cull, P O (1991) Airborne Video Sensing: A New Approach to Monitoring Cotton, The Australian Cottongrower Vol 12 No 2 pp 36-47.

Workshop on Remote Sensing in the Forestry Industry - Sponsored by Bureau of Rural Resources, Canberra, March 1990.

Workshop on Remote Sensing and Field Agronomy – Sponsored by Bureau of Rural Resources, Canberra, June 1990.

Workshop on Remote Sensing in Agriculture – Sponsored by Department of Primary Industries and Energy, Perth, October 1990.

What Colour is Your Cotton?: New Approaches to Crop Monitoring. Invited presentation to Industry Conference on Cotton: Staying in it for the Long Haul, Moree, February 1991.

One Masters dissertation has been successfully completed with a further three in preparation, as follows:

Hodgson, L G (1991) Cotton Crop Condition Assessment Using Aerial Video Imagery (successfully completed).

Roth, G (to be submitted mid 1992) Airborne Video Imagery – A Potential Tool for Monitoring Irrigated Cotton.

Malouf, C P (planned for submission end 1992) An Evaluation of Thermal Video Imagery for Detecting Temperature Changes in Cotton Crop Canopies as an Indicator of Moisture Induced Stress.

Tickle, P (for submission during 1993) Using Airborne Video Remote Sensing to Estimate Crop Growth Parameters.

Additional Information

Additional information relating to this project can be obtained from:

Dr Brian J Button
Senior Lecturer in Applied Science
University of Canberra
PO Box 1
BELCONNEN ACT 2616
Phone 06 201 2565

Abstract

A multispectral airborne video imaging system (MAVIS) was constructed, trialled and deployed to acquire remotely sensed imagery for improved irrigation scheduling, detection and monitoring of various forms of stress in irrigated cotton crops. Image acquisition, processing and interpretation procedures developed during two years of experimental work were assessed during a subsequent crop monitoring exercise. A range of issues were identified which require resolution before the MAVIS system can be regarded as having commercial potential.

Acknowledgement of Support

This project was funded by matching grants from the Land and Water Resources Research and Development Corporation and the Cotton Research and Development Corporation. In kind support was provided by the University of Canberra and National Mutual Rural Enterprises.