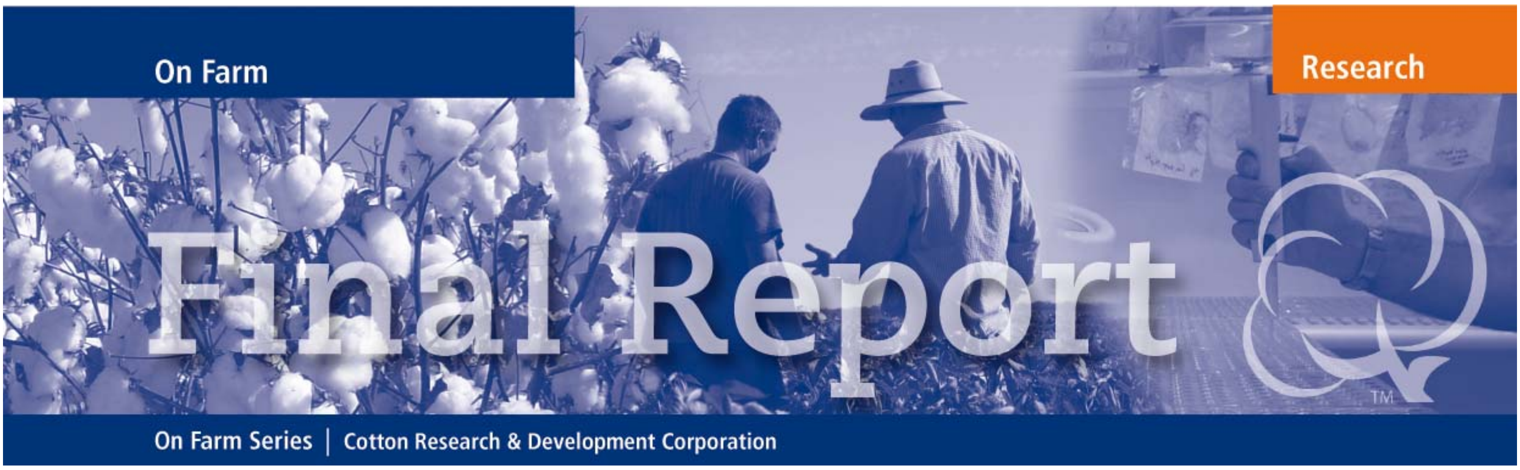

Part 1 - Summary Details

CRDC Project Number: **NEC11**

Project Title: Optimising irrigation scheduling with the use of continuous 'real time' plant monitoring sensors

Project Commencement Date: 1 Oct 2005 **Project Completion Date:** 30 Sept 2008

CRDC Program: Farming Systems

Part 2 – Contact Details

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Part 3 – Final Report

Background

Increases in crop water use efficiency have been found possible through greater precision in irrigation scheduling and the use of irrigated crop management strategies such as regulated deficit and deficit irrigation. However, limitations exist in the use of soil moisture sensors and/or the water balance approach method of irrigation scheduling. A key limitation with using either of these approaches for irrigation scheduling is that they only measure and/or estimate soil bulk moisture and do not provide a measure of actual plant water status. Crop growth and response to irrigation is a function of plant water status and depends on soil water status, evaporative demand, the rate of water flow through the plant and the corresponding hydraulic flow resistance between the bulk soil and the appropriate plant tissue. It is therefore prudent to investigate the use of plant based measurements as a basis for irrigation scheduling.

A wide range of plant monitoring sensors (PMS) are now commercially available. These sensors enable continual 'real-time' measurements of a variety of crop parameters including stem growth, fruit growth, leaf temperature, sap flow, infrared cameras and auxanometers. The use of PMS may enable a greater level of insight into the 'real time' water status in relation to moisture deficit. However, there is little information available demonstrating the potential to use PMS instruments for commercial irrigation scheduling of cotton and the threshold values required to initiate irrigation applications under different crop/cultivar/environmental conditions. Hence, there is a need to assess the benefits of various PMS instruments for scheduling and where appropriate, identify threshold values for initiating irrigation applications in cotton.

This project supported a post-doctoral position at the NCEA. The Post Doc linked with a number of cotton related irrigation research projects at the NCEA and focused on better integration of our understanding of cotton agronomy and physiology with irrigation engineering and systems research.

Objectives

The overall aim of this project was to evaluate the potential to use plant monitoring sensors for irrigation scheduling and improve industry knowledge on the physiological responses of cotton to imposed soil moisture deficits. The specific project objectives were to:

1) Review and evaluate the use of PMS under field conditions as an alternative tool for irrigation scheduling.
2) Collect field data using PMS for a range of different irrigation application systems for both conventional and Bollgard varieties.
3) Correlate PMS field data to changes in soil moisture, climatic conditions and plant physiological growth to produce PMS ‘threshold values’ for re-irrigation.
4) Evaluate PMS tools and strategies for commercial application in precision irrigation scheduling.

Methods

This project involved:

(a) Reviewing plant based sensors for irrigation scheduling (see Attachment 5)

(b) Conducting field trials (in each of three years) to evaluate the utility of specific plant based sensors for irrigation scheduling and identify potential threshold levels of initiating irrigation applications (See Attachments 1, 2 and 3).

(c) Conducting an analysis of spatial variability in cotton yields within surface irrigated fields (see Attachment 4), and

(d) Contributing to extension activities and publications to disseminate project outcomes (see Attachment 6)

Results and Outcomes

(a) Reviewing plant based sensors for irrigation scheduling

A grower guide to plant based sensing for irrigation scheduling document has been finalised (Attachment 5). This document was written in a style which complements the existing National Program for Sustainable Irrigation publication "Soil water monitoring: an information package" (Charlesworth, 2005) and to appeal beyond the cotton industry. Staff from both the CRC Irrigation Futures and Queensland Department of Primary Industries (Horticulture) have since expressed an interest in both extending the range of sensors covered and adding grower case studies to a revised version of the document prior to widespread publication. NPSI are currently assessing an application to cover the costs of professional desktop editing of the document and associated printing/publication costs.

(b) Evaluation of plant based sensors for irrigation scheduling

Field trials to assess the performance of plant based sensors for irrigation scheduling were conducted at sites across the Darling Downs in each season of the project. Full details of these project results are provided in Attachments 1, 2 and 3. However, the key results from each trial as follows:

2005/06 trial – The main commercial sensor assessed during this season was the Stem Micro-Variation (Diameter) sensor by Phytech Pty Ltd. Daily contractual amplitude (DCA) measurements were found to be well correlated to measurements of soil moisture (R^2 = 83%) and plant water status (R^2 = 74%) obtained using other commercial scheduling tools. This suggested that stem diameter sensors could be used for scheduling and that the development of 'threshold levels' for irrigation scheduling based on these correlations would be achievable. However, differences in DCA between irrigation treatments was noted suggesting that (a) further work would be required to adequately define the 'threshold levels', and (b) inter-season variation in soil moisture and climatic conditions may affect the reliable use of stem diameter sensors for irrigation scheduling due to differing levels of crop conditioning (i.e. response to crop stress earlier in the season).

2006/07 trial - This trial evaluated both the use of stem diameter sensors and hyperspectral sensing within an irrigated cotton crop. The SDS data was obtained across a several crop varieties and irrigation management strategies but no significant relationships were identified between daily contractual amplitude and leaf water potential. This work suggests that it may be difficult to identify a single threshold trigger for irrigation based on daily contractual amplitude. Hyperspectral data was also obtained on three growing dates and related to leaf water potential data. Correlation analyses between the hyperspectral data and leaf water potential demonstrated that many of the reflectance bands used to predict water stress in other crops were ineffective for cotton. However, a multivariate step-wise regression using up to five bands within the 422 to 980 nm range was found to explain between 54 and 65% of the variation in leaf water potential. This suggests that it may be possible to develop a low-cost radiometric sensor for the non-destructive sensing of crop water stress in cotton.

2007/08 trial - This field trial collected multispectral satellite imagery, field radiometric spectroscopy and NDVI data under commercial conditions on two sites to evaluate their ability to identify (a) spatial variability in cotton crop stress at the field level and (b) crop stress thresholds appropriate for irrigation scheduling. Correlation analysis of specific radiometric wavelengths and leaf water potential measurements were also undertaken. The active sensor technology (i.e. NDVI) was able to identify varietal differences and varying yield responses under all climatic conditions encountered. However ground rig speed, distance above the canopy and data point positioning information is critical for mapping and comparison with other data sources. The passive sensors (i.e. satellite or handheld radiometric) were found to be hampered by poor atmospheric conditions and high variability in localised sunlight intensity. Operational difficulties associated with plant material handling and LWP measurement techniques in the field made it difficult to obtain reliable plant stress data sets suitable for identifying relationships with the remotely sensed data. Daily time constraints (11am-2pm) associated with the use of the radiometric sensor limit the number of leaf samples that can be assessed and subsequently used for correlation with spectral data. Hence, this work was unable to identify significant correlations between a range of commonly used radiometric “water bands” < 1075 nm and LWP. Limited availability of the hyperspectral sensor also prohibited evaluating the relationships between the longer radiometric wavelengths (1100-2500 nm) and LWP.

(c) Analysis of infield spatial variability of cotton yields

This analysis collated commercial yield monitor data from 150 fields across five cotton growing regions in Queensland collected during the 2004/05 and 2005/06 seasons. Significant differences in cotton yields were observed between the head ditch and tail drain end of most fields across all regions. However, the nature of the difference between each end of the field varied greatly between individual sites with a maximum difference of 3.7 bales/ha (i.e. yield at tail drain end higher than head ditch end) to a minimum of -1.8 bales/ha (i.e. yield at tail drain end lower than head ditch end). A substantial proportion of these differences appear to be related to irrigation design and/or management practices. In approximately ⅓ of the fields evaluated, there was a 0.5 bales/ha higher yield at the tail drain end compared to the head ditch end. There was no significant difference in the trends observed between the regions but the average difference ranged from 0.4 bales/ha for the Emerald region to approximately -0.2 bales/ha in the Goondiwindi and Mungindi regions.

(d) Contributing to extension activities and publications

This project was worked closely with the extension staff associated with the QDPI&F Rural Water Use Efficiency team members in Queensland. In particular, the project has had good industry exposure through collaboration on field work activities with Ms Jenelle Hare (QDPI&F, Dalby). A field day was conducted at the 2006/07 trial site for growers and consultants. The 2006/07 trial site also hosted a field walk for visiting Chinese agricultural scientists and was visited by the Cotton CRC Management team. This field trial data was also published online in QDPI&F newsletters. Components of the broader project activities have also been publicised via presentations to the cotton conference, industry field days and via CRC Irrigation Futures forums. It is intended that the grower guide to plant based sensing document will be formally published in the near future.

Conclusion

This project has evaluated a potential to use various plant based sensing technologies for irrigation scheduling of cotton. Key messages arising from this research include:

- Visual analysis of the daily contractual amplitude (DCA) measured using stem diameter sensors can be useful to understand temporal changes in crop stress.
- DCA was found to be well correlated with soil moisture deficit and leaf water potential for a single crop. However, it was not possible to identify threshold levels of DCA which could be

used for scheduling irrigation of cotton across varieties and under different irrigated conditions. Hence, there would appear to be only marginal benefits associated with using stem diameter sensors in addition to existing soil moisture measurements.

- Radiometric sensing of cotton plants using commonly accepted wavelength/bands used for other crops is not useful in predicting leaf water potential.
- It may be possible to use up to five spectral bands (between 422 and 980 nm) to predict leaf water potential in cotton.
- Ground-rig NDVI sensors are able to identify varietal differences and varying yield within fields but NDVI was not significantly related to leaf water potential.
- There was no evidence that satellite (Quickbird) derived radiometric data could be sensibly used for irrigation scheduling.
- Significant infield spatial yield variability exists in surface irrigated fields which appears to be related to the irrigation design and/or management.
- There is no evidence arising from this project to support widespread adoption of plant based sensors in the cotton industry at this point in time.

Extension Outputs

Publications

White, S.C. and Raine, S.R. (2006). Field evaluation of plant monitoring sensors (PMS): Macquarie Downs 2005/06. National Centre for Engineering in Agriculture, USQ, Toowoomba. 20pp. (Attachment 1)

White, S.C. and Raine, S.R. (2007). Field trial report (2006/07). Optimising irrigation scheduling with the use of continuous real time plant monitoring sensors. NCEA Publication 1001574/7/1. National Centre for Engineering in Agriculture, USQ, Toowoomba. 12pp. (Attachment 2)

McHugh, A.D., Boughton, B., Eberhard, J., McKeering, L.M., Robson A.R. and Raine, S.R. (2008). Evaluating the relationships between plant based measurements and remotely sensed data for irrigation scheduling of cotton. National Centre for Engineering in Agriculture Publication 1001574/8, USQ, Toowoomba. (Attachment 3)

White, S.C. and Raine, S.R. (2008). Infield spatial variability of surface irrigated cotton yields. National Centre for Engineering in Agriculture Publication 1001574/9, USQ, Toowoomba. (Attachment 4)

White, S.C. and Raine, S.R. (2008). A grower guide to plant based sensing for irrigation scheduling. Publication 1001574/6. National Centre for Engineering in Agriculture, USQ, Toowoomba. 52pp. (Attachment 5)

Online resources

"Irrigation by cotton variety demonstration"
http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/30_8649_ENA_HTML.htm

"Improved furrow irrigation performance - is it an improvement?"
http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/26_9822_ENA_HTML.htm

Presentations

White, S.C. (2005). Plant sensing for precision irrigation. Where are we headed? Cotton Precision Ag Forum.

White, S.C. (2006). The use of stem diameter sensors for irrigation scheduling in cotton. Product, Production, Profit – Progressing our Natural Advantage. 13th National Cotton Conference, Gold Coast.

White, S.C. (2006). Plant monitoring sensors (PMS) for irrigation scheduling in cotton. Summer Zone Workshop, CRC Irrigation Futures.

White, S.C. and S.R. Raine (2007). Spatial variability in cotton yield due to irrigation non-uniformity. Toolkits for Profitability Workshop, CRC Irrigation Futures, Toowoomba

Raine, S.R. and J.P. Foley (2008). Scheduling and other tactics to improve irrigated water use efficiency. GRDC Update, Dalby.

Part 4 – Final Report Executive Summary

Increases in crop water use efficiency have been found achieved through greater precision in irrigation scheduling and the use of irrigated crop management strategies such as regulated deficit and deficit irrigation. However, limitations exist in the use of soil moisture sensors and/or the water balance approach method of irrigation scheduling. A key limitation with using either of these approaches for irrigation scheduling is that they do not provide a measure of actual plant water status. Crop growth and response to irrigation is a function of plant water status and depends on soil water status, evaporative demand, the rate of water flow through the plant and the corresponding hydraulic flow resistance between the bulk soil and the appropriate plant tissue. Hence, this project investigated the potential to use plant based measurements for commercial irrigation scheduling of cotton.

The first year (2005/06) of this project evaluated the potential to use stem diameter sensors for irrigation scheduling in cotton under a lateral move machine near Leyburn. While the first season results were encouraging, the second season (2006/07) conducted on furrow irrigation at Nandi across a range of irrigation schedules and three crop varieties found weaker relationships (i.e the technique lacks robustness). There was also significant plant to plant variation in sensor responses. The key recommendation from this work is that stem diameter sensors can be used to identify plant stress responses associated with irrigation. However, their benefits over traditional irrigation scheduling technologies are marginal and these sensors will continue to have limited application as an irrigation scheduling and assessment tool in cotton unless appropriate threshold levels can be identified which take into account varietal differences and crop conditioning.

During 2006/07, the project evaluated the relationships between hyperspectral canopy reflectance data and that of plant status and identified band widths correlated to plant water status when measured during a normal commercial irrigation cycle. The 2007/08 trial used two sites (Pampas and Cecil Plains) to evaluate remote methods of plant based sensing (i.e. satellite imagery and ground-based NDVI) and to test the robustness of the relationships between the hyperspectral bandwidth data to changes in crop water status. The active sensor technology (i.e. NDVI) was able to identify varietal differences and varying yield responses under all climatic conditions encountered. However ground rig speed and sensor distance above the canopy was found to be critical. The passive sensors (i.e. satellite or handheld radiometric) were found to be hampered by poor atmospheric conditions and high variability in localised sunlight intensity. No significant relationships were identified between leaf water potential and either the NDVI or hyperspectral data.

Other outputs include an analysis of historical yield monitor data across five cotton regions to identify field scale trends in spatial variability. A grower guide to plant based sensing for irrigation scheduling has also been produced.

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